STANDARD

DNVGL-ST-F101 Edition October 2017

Submarine pipeline systems

DNV GL AS

FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

This document supersedes the October 2013 edition of DNV-OS-F101.

Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

Changes October 2017

• Sec.1 Introduction

— Rigid risers have been excluded and will be covered in the next revision of DNVGL-ST-F201. This affects several places.
— Requirements to technology qualification of new technologies.
— Defect has been defined

• Sec.4 Design – loads

— Minor editorial changes and updates
— Previous section 4G400 and 5C500 have been merged into [4.7.4] and updated.

• Sec.5 Design – limit state criteria

— Minor editorial changes and updates
— [5.2.1] has been re-organised except for mitre bend angle that has been reduced from three to two degrees.
— [5.2.2] has been modified. More guidance is given in general (see also Table 8-1 and [8.7.1]). Some specific requirements for replacing the system pressure test (old table 5-1) has been removed.
— [5.3.2] The format has been modified slightly. The resistance safety factor, γ_{sc}, has now got an additional index for the relevant limit state. The reason is that the number of γ_{sc}'s are increasing. This also implies that γ_{ε} has become $\gamma_{sc,dc}$.
— [5.4] Name of some limit states and headings have been modified to make it consistent with Table 5-7.
— [5.4.6.8] The criterion has been re-formulated (but is identical) except for the pressure term modified in line with Safebuck JIP.
— [5.4.8] Requirements to fracture and fatigue have been updated and are stated in [5.4.8]. For recommended practice on how to perform this, new revision of DNV GL-RP-F108 is pointed to. Appendix A is removed.
— [5.4.8] The term sensitive welds has been introduced.
— [5.6.1] References to other standards have been updated.
— [5.8.2] New. From installation JIP.

• Sec.7 Construction – linepipe

— Changes and modifications to the following:
  — Steel making and plate rolling essential variables [7.1.8]
  — Hydrogen content [7.2.3.3]
  — Hydrostatic testing [7.5.1]
— Subsection [7.1], [7.2], [7.5], [7.6]. Added clarifications and more requirements to coiled line pipe
— [7.4] Requirements to explosion welded clad plates added

— [7.7] Requirements to dimensions and geometrical measurements have been updated based on a specific workshop with the industry. Further, a minimum diameter of 60 mm has been specified. Dimensional requirements to smaller pipes have been modified and harmonized with common coil tubing pipes

— [7.9.2] Supp. F; Guidance note to DWTT added, acknowledging challenges with inverse fracture for high toughness materials and supporting a similar statement in API RP 5L3.

— [7.9.3] Supp. P; Has been modified.

— [7.9.5] Supp. U; Modified to include both approaches to achieve Suffix U; retrospective documentation and as part of production testing. Restructuring of content to better clarify requirements.

• Sec.8 Construction - components and pipeline assemblies

— Restructuring of content to better clarify requirements.
— Table 8-1 has been modified.
— DNVGL-RP-0034 is acknowledged as an alternative material specification for forged CMn steel.

• Sec.12 Documentation

— Some requirements to documentation in other sections have been moved to this section. A reference to DNVGL-RP-O101 is also included.

• Sec. 13 Commentary (informative)

— [13.6] Roadmap for use of this standard with pipe-in-pipe systems based on workshop series JIP-

• App.A Fracture limit state of girth welds

— Empty - moved to new revision of DNVGL-RP-F108.

• App.B Mechanical testing and corrosion testing

Minor changes and modifications, e.g. to the following:

— References to DNVGL-RP-F108 added
— Reference to BS 8571 for SENT added
— Clarifications to all-weld tensile testing.

• App.C Welding

In general only minor updates on reference standards and some changes to clarify paragraphs.

— [C.3.4.5] Batch testing modified to be sampled in same positions as WPQ
— [C.4.8.7] Maximum heat input variation for multiple pieces more clarified
— [D.2.1.5] Added requirement for heat input range to be stated on WPS
— [C.8.1.13] Maximum interpass temperature for welding of solid CRA and in root and hot pass for lined/clad carbon steel increased to 1500C.

• App.D Non-destructive testing

— [D.7] Fully revised requirements for pipe body inspection (usually applicable for plate mills for SAWL).
— [D.8.13] Added requirement to use 2 angles in AUT setup for inspection of longitudinal imperfections.

• App.E Automated ultrasonic girth weld testing

— [E.2] Added requirement to evaluate impact on sensitivity of long seam weld
— [E.2] Added requirement for inspection of CRA welds and materials
— [E.2] Added requirement for monitoring wall thickness upon AUT inspection of SMLS pipe girth welds.
— [E.2] Accommodate for use of adaptive focal laws
— [E.2] Added requirement to include SDH reflector for TOFD in reference block
— [E.5] Revised acceptance criteria for porosity, Table E-1
— [E.5] Added workmanship acceptance criteria for fatigue sensitive welds
— [E.8] Added generalised requirements to number of imperfections within scope of AUT qualification
— [E.8] Reduced requirements to CCW scanning of defective welds in AUT qualification, now 1 weld is required.
— [E.8] Added requirement to demonstrate stability upon repeated inspection in AUT validation.

• App.F Requirements for shore crossing and onshore sections

— Updated on land fall, now referred to as shore crossing based on the Crossway JIP by Atteris

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.

Acknowledgements

The present revision of DNVGL-ST-F101 is mainly reflecting feed-back from experience by several companies that are hereby acknowledged. The comments improved the quality and content of this standard significantly and the effort spent by the commenting companies is impressive and hereby acknowledged.

This revision includes results from the following JIP's sponsored by the listed companies. Their contribution is hereby acknowledged.

Installation JIP

The following companies, listed in alphabetical order, are acknowledged for their contributions to the JIP

ABB	HHI	NOV	Technip
Allseas	JFE Steel	Petrobras	Tideway Offshore Solutions
Bureau Veritas	KW/Petrofac	Saipem	VBMS
EMAS	McDermott	Statoil	WoodGroup Kenny
Heermea Marine Contractors	Nexans	Subsea7	Woodside

Pipe-in-pipe workshop series JIP

The following companies, listed in alphabetical order, are acknowledged for their contributions to the JIP

Genesis	ITP	Shell	Technip
HMC	Petrobras	Subsea7	Vision oil and gas
Intecsea	Saipem	T.D. Williamson	Wood Group Kenny

Crossway JIP performed by Atteris.

Safebuck JIP peformed by Atkins.

Changes - current

CONTENTS

Contents

SECTION 1 INTRODUCTION

1.1 General

This standard gives criteria and recommendations on concept development, design, construction, operation and abandonment of submarine pipeline systems.

1.2 Objectives

The objectives of this standard are to:

— ensure that the concept development, design, construction, operation and abandonment of pipeline systems are conducted with due regard to public safety and the protection of the environment
— provide an internationally acceptable standard of safety for submarine pipeline systems by defining minimum requirements for concept development, design, construction, operation and abandonment
— serve as a technical reference document in contractual matters between purchaser and contractor
— provide requirements for designers, purchaser, and contractors.

1.3 Scope

This standard provides guidance and requirements to concept development, design, construction, operation and abandonment of pipeline systems.

The standard includes guidance and criteria to:

— design basis (survey, environmental data, soil sampling)
— design criteria (layout, LRFD format and functional)
— material selection and corrosion control
— line pipe
— components
— coating
— offshore construction and pre-commissioning
— operation and abandonment
— material testing
— welding
— non-destructive testing (NDT).

The focus is on structural integrity of the pipeline.

1.4 Application

Tha applicability of this standard is given in Table 1-1. The standard shall be applied in its entirety.

Table 1-1 Applicability of standard

General	
Application	Pipeline systems in the petroleum and natural gas industries. For submarine pipeline systems that have extraordinary consequences, the quantification of consequences by the three safety classes provided in this standard may be insufficient, and higher safety classes may be required.[1]
Phases	Concept development, design, construction, operation and abandonment.
Pipeline types	Single rigid metallic pipeline systems, pipeline bundles of the piggyback type and pipeline bundles within an outer pipe[2].
	Pipe-in-pipe.
	Risers and compliant risers are covered by DNVGL-ST-F201*Dynamic risers*.
Extent/battery limits	
Pressure and flow	Pipeline system in such a way that the fluid transportation and pressure in the submarine pipeline system is well defined and controlled [3].
Concept development, design, construction, operation and abandonment	Submarine pipeline system[4].
Geometry and configuration	
Dimensions	No limitation except that pipe outside diameters shall be above 60 mm. (Explicit criteria for local buckling, combined loading are only given for straight pipes with $15 < D/t_2 < 45$.)
Configurations	Tee's, wye's, PLEM or PLET, spools which are integrated part of the pipeline.
Water depth	No limitation, see [5.1.2.1].
Loads	
Pressure	No limitation.
Temperature	No limitation. Material properties need to be documented for relevant temperatures in line with [5.3.3].
Global deformations	No limitation.
Line pipe Material	
General	See [7.1.2.1]. C-Mn steel line pipe is generally conforming to ISO 3183 Annex J but with modifications and amendments (245-555). Material grade limited to, including, X80 (DNVGL 555). CRA line pipe with specific requirements to 22Cr and 25Cr steel and 13Cr martensitic steel. Clad and lined line pipe. Supplementary requirements for sour service, fracture arrest properties, plastic deformation, dimensional tolerances and high utilization.

Components	Bends, fittings, flanges, valves, mechanical connectors, CP insulating joints, anchor flange, buckle arrestor, pig traps, clamps and couplings.
Design	See [5.6].
Material and manufacture	See Sec.8.
Fluids	
Categories	See Table 2-1. CO_2 pipelines are in general covered by this standard in line with ISO 13623. The following aspects needs special attention for CO_2 pipelines: — material selection — corrosion and sour service evaluations — operation. For these aspects, see DNVGL-RP-F104.
Sour service	Generally conforming to ISO 15156.
Installation	
Method	See Sec.10. S-lay, J-lay, towing and laying methods introducing plastic deformations. Installation requirements for protective and anchoring structures are also included.
1) Example of extra ordinary consequences may be pristine environment and exploration in arctic climate. 2) Umbilicals intended for control of subsea installations are not included in this standard. Individual pipes, within an umbilical, made of materials applicable to this standard, may be designed according to this standard. 3) Different parts of the pipeline system may be designed to different standards or recommended practices. It is important to identify differences between these at an early stage and assess these. Examples of conflicting requirements are; pressure definitions and system test pressure requirements. 4) The operator may apply this standard on sub-sets of the limits of this standard. Typical example of excluded items is smaller diameter piping such as kicker lines and designs these to e.g. ISO 15649.	

1.5 Alternative methods and procedures

In case alternative methods and procedures to those specified in this standard are used, it shall be demonstrated that the obtained safety level is equivalent to the one specified herein, see [2.3.5]. Such alternative methods shall be formally and rigorously justified and accepted by all relevant contracting parties.

Technologies that are not covered by existing, validated requirements, and where failure poses risk to life, property or the environment, or presents financial risk, shall be qualified. Recommended practice on technology qualification are given in DNVGL-RP-A203.

1.6 Structure of standard

This standard is based on limit state design. This implies that the same design criteria apply to both construction/installation and operation. All structural criteria are therefore given in Sec.5.

The standard is organised as follows:

- This section contains the objectives and scope of the standard. It further introduces essential concepts, definitions and abbreviations.
- Sec.2 contains the fundamental safety philosophy and design principles. It introduces the safety class methodology and normal classification of safety classes. It gives overall requirements to systematic

review or QRA. How this will affect the different phases is further described in subsections [X.1.3], where X indicates section, in the different sections.

— Sec.3 contains requirements to concept development, establishment of design premises, with system design principles, pipeline safety and control system, and collection of environmental data.
— Sec.4 defines the design loads to be applied in Sec.5. It includes classification of loads into functional loads (including pressure), environmental loads, interference loads and accidental loads. Finally, it defines design cases with associated characteristic values and combinations.
— Sec.5 contains requirements to pipeline layout, system test and mill test. It contains description of the design (LRFD) format and characterisation of material strength for straight pipes and supports. Design criteria for the different limit states for all phases; installation, as-laid, commissioning and operation, are given.
— Sec.6 contains materials engineering and includes material selection, material specification (including required supplementary requirement to the line pipe specification), welding and corrosion control.
— Sec.7 contains requirements to line pipe. The requirements to C-Mn steels are based on ISO 3183. The section also includes requirements to CRAs and lined/clad pipe.
— Sec.8 contains requirements to materials, manufacture and fabrication of components and assemblies. Structural requirements to these components are given in [5.6].
— Sec.9 contains requirements to corrosion protection and weight coating.
— Sec.10 contains requirements to offshore construction including installation, pre- and post-intervention and pre-commissioning.
— Sec.11 contains requirements to operation including commissioning, integrity management, repair, re-qualification, de-commissioning and abandonment of the submarine pipeline system.
— Sec.12 contains requirements to documentation for the submarine pipeline system from concept development to abandonment.
— Sec.13 is an informative section which discusses several aspects of the standard.

The appendices are a compulsory part of the standard.

— App.A is empty. The content on ECA from previous revision is now reflected in the updated DNVGL-RP-F108.
— App.B details the requirements to materials testing including mechanical and corrosion testing as well as chemical analysis.
— App.C contains requirements to welding including qualification of welding procedures and construction welding.
— App.D contains requirements to Non-Destructive Testing (NDT) except Automated Ultrasonic Testing (AUT) of girth welds.
— App.E contains requirements to AUT of girth welds.
— App.F contains selected requirements to shore crossing and onshore parts of the submarine pipeline system.

Additional requirements or modified requirements compared to the stated ISO standards are denoted by AR or MR by the end of the paragraph. This applies to [7.2] and [9.3].

Modified requirements compared to the stated ISO standards are given in this standard by stating the ISO paragraph number in brackets prior to the modified requirements. This applies to Sec.8.

Guidance notes provide additional information, clarification or examples to the paragraph in order to increase the understanding of the requirement. Guidance notes do not contain requirements.

1.7 References

1.7.1 General

The following standards include provisions which, through reference in the text, constitute provisions of this standard.

References are either defined as normative or informative. Normative references in this document are indispensable for its application. Informative references provide additional information intended to assist the understanding or use of the document.

Guidance note:

Normative references are typically referred to as "testing shall be performed in accordance with ISO xxx", while informative references are typically referred to as "testing may be performed in accordance with ISO xxx or ISO yyyy", or "recommended practice on xx is given in DNVGL-RP-Fxxx".

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In case of conflict between this standard and referenced DNV GL standards or recommended practices, the standard or recommended practice with the latest edition date shall prevail.

The latest valid edition of each of the DNV GL reference documents applies.

Guidance note:

Any conflict is intended to be removed in next revision of that document.

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This standard is intended to comply with the ISO standard 13623: *Petroleum and natural gas industries - Pipeline transportation systems*, specifying functional requirements for offshore pipelines and risers.

Guidance note:

The following deviations to ISO 13623 standard are intentional:

- This standard allows higher utilisation for fluid category A and C pipelines. This standard is in compliance with ISO 16708.
- For design life less than 33 years, a more severe environmental load is specified in this standard, in agreement with ISO 16708.
- applying the supplementary requirements U, for increased utilisation, this standard allows 4% higher pressure containment utilisation than ISO 13623.
- the equivalent stress criterion in ISO 13623 may, under some conditions allow higher utilisation than this standard.
- requirements to system pressure test (pressure test) are less stringent.
- minor differences may appear depending on how the pipeline has been defined in safety classes, ISO 13623 does not use the concept of safety classes.

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The requirements to C-Mn steel line pipe of this standard are intended to comply with the ISO standard 3183 Annex J limited to, including, X80 (DNVGL 555), but with modifications and amendments.

Guidance note:

The latest revision of the DNV GL publications may be found in the publication list at the DNV GL website www.dnvgl.com.

Amendments and corrections to the DNV GL publications are published on www.dnvgl.com when relevant. These shall be considered as mandatory part of the above standards and recommended practices.

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1.7.2 DNV GL service specifications

The latest revision of the following documents applies.

Table 1-2 DNV GL service specifications

Document code	*Title*
DNVGL-SE-0160	Technology qualification management and verification
DNVGL-SE-0475 Sec.1	Certification and verification of pipelines
DNVGL-SE-0476	Offshore riser systems

1.7.3 DNV GL Standards

The following documents contain provisions which, through reference in this text, constitute provisions of this offshore standard. The latest revision of the following document applies.

Table 1-3 DNV GL standards

Document code	*Title*
DNVGL-OS-A101	Safety principles and arrangements
DNVGL-OS-C101	Design of offshore steel structures, general - LRFD method
DNVGL-OS-E201	Oil and gas processing systems
DNVGL-OS-E301	Position mooring
DNVGl-ST-C501	Composite components
DNVGL-ST-F201	Dynamic risers
DNVGL-ST-N001	Marine operations and marine warranty

1.7.4 DNV GL recommended practices

The latest revision of the following documents applies.

Table 1-4 DNV GL recommended practices

Document code	*Title*
DNVGL-RP-A203 Sec.1	Technology qualification
DNVGL-RP-B401	Cathodic protection design
DNVGL-RP-C203	Fatigue design of offshore steel structures
DNVGL-RP-C205	Environmental conditions and environmental loads
DNVGL-RP-C211	Structural reliability analysis
DNVGL-RP-C212	Offshore soil mechanics and geotechnical engineering
DNVGL-RP-F101	Corroded pipelines

Document code	*Title*
DNVGL-RP-F102	Pipeline field joint coating and field repair of line pipe coating
DNVGL-RP-F103	Cathodic protection of submarine pipelines
DNVGL-RP-F105	Free spanning pipelines
DNVGL-RP-F106	Factory applied pipeline coatings for corrosion control
DNVGL-RP-F107	Risk assessment of pipeline protection
DNVGL-RP-F108	Assessment of flaws in pipeline and riser girth welds
DNVGL-RP-F109	On-bottom stability design of submarine pipelines
DNVGL-RP-F110	Global buckling of submarine pipelines
DNVGL-RP-F111	Interference between trawl gear and pipelines
DNVGL-RP-F112	Design of duplex stainless steel subsea equipment exposed to cathodic protection
DNVGL-RP-F113 Sec.1	Pipeline subsea repair
DNVGL-RP-F114	Pipe-soil interaction for submarine pipelines
DNVGL-RP-F115	Pre-commissioning of pipelines
DNVGL-RP-F116	Integrity management of submarine pipeline systems
DNVGL-RP-F118	Pipe girth weld automated ultrasonic testing system qualification and project specific procedure validation
DNVGL-RP-F204	Riser fatigue
DNVGL-RP-J202	Design and operation or carbon dioxide pipelines
DNVGL-RP-N101 Sec.1	Risk management in marine and subsea operations
DNVGL-RP-N103	Modelling and analyses of marine operations
DNVGL-RP-O101 Sec.1	Technical documentation for subsea projects
DNVGL-RP-O501	Managing sand production and erosion
DNVGL-RP-0034	Steel forgings for subsea applications

1.7.5 DNV GL other publications

The latest revision of the following documents applies.

Table 1-5 DNV GL other publications

Document code	*Title*
DNVGL-RU-HSLC	Rules for classification: High speed and light craft
DNVGL-CG-0051	Non-destructive testing

1.7.6 Other references

Table 1-6 Other references

Document code	*Title*
API RP 5L1	Recommended Practice for Railroad transportation of Line Pipe
API RP 5L2	Recommended Practice for Internal Coating of Line Pipe for Non-corrosive Gas Transmission Service
API RP 5L3	Recommended Practice for Conducting Drop-Weight Tear Tests on Line Pipe
API RP 5LW	Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels
API RP 17N	Subsea Production System Reliability and Technical Risk Management
API RP 2201	Safe Hot Tapping Practices in the Petroleum & Petrochemical Industries
API Spec 6A	Specification for Wellhead and Christmas Tree Equipment
API Spec 6FA	Specification for Fire Test for Valves
API 5LD	Specification for CRA Clad or Lined Steel Pipe
ASME B16.9	Factory-Made Wrought Buttwelding Fittings
ASME B31.3	Process Piping
ASME B31.4	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
ASME B31.8	Gas Transmission and Distribution Systems
ASME BPVC-V	Boiler and Pressure Vessel Code Section V - Non-destructive Examination
ASME BPVC-VIII-1	Boiler and Pressure Vessel Code Section VIII - Div. 1 - Rules for Construction of Pressure Vessels
ASME BPVC-VIII-2	Boiler and Pressure Vessel Code Section VIII - Div. 2 - Rules for Construction of Pressure Vessels - Alternative Rules
ASNT	American Society for Nondestructive Testing. Central Certification Program (ACCP).
ASTM A 961	Standard Specification for Common Requirements for Steel Flanges, Forged Fittings, Valves, and Parts for Piping Applications
ASTM A264	Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate
ASTM A370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A388	Standard Practice for Ultrasonic Examination of Steel Forgings
ASTM A577	Standard specification for Ultrasonic Angle-Beam Examination of Steel Plates
ASTM A578	Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications
ASTM A609	Standard Practice for Castings, Carbon, Low Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof
ASTM A956	Standard Test Method for Leeb Hardness Testing of Steel Products
ASTM A1038	Standard Test Method for Portable Hardness Testing by the Ultrasonic Contact Impedance Method
ASTM C33	Standards specification for concrete aggregates

Document code	*Title*
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM E110	Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers
ASTM E 165	Standard Practice for Liquid Penetrant Examination for General Industry
ASTM E 280	Standard Reference Radiographs for Heavy-Walled (4 1/2 to 12-in. (114 to 305-mm)) Steel Castings
ASTM E 309	Standard Practice for Eddy-Current Examination of Steel Tubular products Using Magnetic Saturation
ASTM E 317	Standard Practice for Evaluating Performance Characteristics of Pulse-Echo Testing Instruments and Systems Without the Use of Electronic Measurement Instruments
ASTM E 426	Standard Practice for Electromagnetic (Eddy Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys
ASTM E 709	Standard Guide for Magnetic Particle Examination
ASTM E 797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
ASTM E1212	Standard Practice for Quality Management Systems for Non-destructive Testing Agencies
ASTM E1417	Standard Practice for Liquid Penetrant Examination
ASTM E1444	Standard Practice for Magnetic Particle Examination
ASTM E1820	Standard Test Method for Measurement of Fracture Toughness
ASTM G 48	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
AWS C5.3	Recommended Practices for Air Carbon Arc Gouging and Cutting
BS 7488	Fracture mechanics toughness tests. Method for determination of KIc, critical CTOD and critical J values of metallic materials
BS 8571	Method of test for determination of fracture toughness in metallic materials using single edge notched tension (SENT) specimens
BS 7910	Guide to methods for assessing the acceptability of flaws in metallic structures
BSI BS 7910	Guide to methods for assessing the acceptability of flaws in metallic structures
BSI PD 5500	Specification for unfired fusion welded pressure vessels
EN 1591-1	Flanges and their joints - Design rules for gasketed circular flange connections - Part 1: Calculation
EN 1998	Eurocode 8: Design of structures for earthquake resistance
EN 10204	Metallic products - Types of inspection documents
EN 12668	Non destructive testing - Characterisation and verification of ultrasonic examination equipment- All parts
EN 13445-3	Unfired pressure vessels - Part 3: Design
EN ISO 9606-1	Qualification testing of welders - Fusion welding - Part 1: Steels
EN ISO 14175	Welding consumables - Gases and gas mixtures for fusion welding and allied processes

Document code	*Title*
IEC 61511	Functional safety - Safety Instrumented Systems for the Process Industry Sector
IMCA M140	Specification for DP capability plots
IMO Res. A.1047 (27)	Principles of safe manning
IMO MSC/Circ.645	Guidelines for Vessels with Dynamic Positioning Systems
ISO 148-1	Metallic materials – Charpy pendulum impact test - Part 1: Test method
ISO 377	Metallic materials - Charpy pendulum impact test
ISO 2400	Welds in steel – Reference block for the calibration of equipment for ultrasonic examination
ISO 3183	Petroleum and natural gas industries - Steel pipe for pipeline transportation systems
ISO 3452	Non-destructive testing – Penetrant testing – All parts
ISO 3690	Welding and allied processes – Determination of hydrogen content in arc weld metal
ISO 3834-2	Quality requirements for fusion welding of metallic materials – Part 2: Comprehensive quality requirements
ISO 4063	Welding and allied processes – Nomenclature of processes and reference numbers
ISO 4126	Safety devices for protection against excessive pressure
ISO 4136	Destructive tests on welds in metallic materials – Transverse tensile test
ISO 5173	Destructive tests on welds in metallic materials – Bend tests
ISO 5178	Destructive tests on welds in metallic materials – Longitudinal tensile test on weld metal in fusion welded joints
ISO 5817	Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections
ISO 6507	Metallic materials – Vickers hardness test
ISO 6847	Welding consumables - Deposition of a weld metal pad for chemical analysis
ISO 6892	Metallic materials – Tensile testing
ISO 6947	Welding and allied processes – Welding positions
ISO 7005-1	Pipe flanges - Part 1: Steel flanges for industrial and general service piping systems
ISO 7539	Corrosion of metals and alloys - Stress corrosion testing
ISO 7963	Non-destructive testing – Ultrasonic testing – Specification for calibration block No. 2
ISO 8501-1	Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness – Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
ISO 9000	Quality management systems – Fundamentals and vocabulary
ISO 9001	Quality management systems – Requirements
ISO 9606-1	Qualification testing of welders - Fusion welding - Part 1: Steels
ISO 9712	Non-destructive testing – Qualification and certification of NDT personnel

Document code	*Title*
ISO/TR 9769	Steel and iron – Review of available methods of analysis
ISO 9934	Non-destructive testing – Magnetic particle testing – All parts
ISO 10375	Non-destructive testing – Ultrasonic inspection – Characterization of search unit and sound field
ISO 10474	Steel and steel products - Inspection documents
ISO 10893	Non-destructive testing of steel tubes – All parts
ISO 11484	Steel products – Employer's qualification system for non-destructive testing (NDT) personnel
ISO 12135	Metallic materials - Unified method of test for determination of quasistatic fracture toughness
ISO 12715	Non-destructive testing -- Ultrasonic testing -- Reference blocks and test procedures for the characterization of contact probe sound beams
ISO/TS 12747	Petroleum and natural gas industries – Pipeline transportation systems – Recommended practice for pipeline life extension
ISO 13623	Petroleum and natural gas industries – Pipeline transportation systems
ISO 13847	Petroleum and natural gas industries – Pipeline transportation systems – Welding of pipelines
ISO 14284	Steel and iron – Sampling and preparation of samples for the determination of chemical composition
ISO 14723	Petroleum and natural gas industries - Pipeline transportation systems - Subsea pipeline valves
ISO 14731	Welding coordination – Tasks and responsibilities
ISO 14732	Welding personnel -- Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials
ISO 15156	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - All parts
ISO 15589	Petroleum and natural gas industries – Cathodic protection of pipeline transportation systems – All parts
ISO 15590	Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems - All parts
ISO 15614-1	Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys
ISO 15618-2	Qualification testing of welders for underwater welding – Part 2: Diver-welders and welding operators for hyperbaric dry welding
ISO 15649	Petroleum and natural gas industries – Piping
ISO 15653	Metallic materials, Method of test for the determination of quasistatic fracture toughness of welds
ISO 15741	Paints and varnishes - Friction-reducing coatings for the interior of on-and offshore steel pipelines for non-corrosive gases
ISO 16708	Petroleum and natural gas industries – Pipeline transportation systems – Reliability-based limit state methods

Document code	*Title*
ISO 16828	Non-destructive testing - Ultrasonic testing - Time-of-flight diffraction technique as a method for detection and sizing of discontinuities
ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories
ISO 17636	Non-destructive testing of welds – Radiographic testing
ISO 17637	Non-destructive testing of welds – Visual testing of fusion-welded joints
ISO 17638	Non-destructive testing of welds – Magnetic particle testing
ISO 17640	Non-destructive testing of welds – Ultrasonic testing – Techniques, testing levels, and assessment
ISO 17643	Non-destructive testing of welds – Eddy current testing of welds by complex-plane analysis
ISO 19232	Non-destructive testing – Image quality of radiographs
ISO 19901-2	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 2: Seismic design procedures and criteria
ISO 21457	Petroleum, petrochemical and natural gas industries — Materials selection and corrosion control for oil and gas production systems
ISO 21809	Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – All parts
ISO 22825	Non-destructive testing of welds – Ultrasonic testing – Testing of welds in austenitic steels and nickel-based alloys
MSS SP-55	Quality standard for steel castings for valves, flanges, and fittings and other piping components - Visual method for evaluation of surface irregularities
MSS SP-75	High-Strength, Wrought, Butt-Welding Fittings
NACE TM0177	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments
NACE TM0284	Standard Test Method - Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking
NORDTEST	NT Technical Report 394 (Guidelines for NDE Reliability Determination and Description, Approved 1998-04).
NORSOK L-005	Compact flanged connections
NORSOK N-006	Assessment of structural integrity for existing offshore load-bearing structures
NORSOK U-009	Life extension for subsea systems
NORSOK Y-002	Life extension for transportation systems
NS 477	Welding inspectors - Tasks, education and certification

1.8 Definitions

1.8.1 Verbal forms

Table 1-7 Definitions of verbal forms

Term	*Definition*
shall	verbal form used to indicate requirements strictly to be followed in order to conform to the document
should	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required
may	verbal form used to indicate a course of action permissible within the limits of the document
agreement, by agreement	unless otherwise indicated, this means agreed in writing between manufacturer/contractor and purchaser

1.8.2 Terms

Table 1-8 Definitions of terms

Term	*Definition*
abandonment	the activities associated with taking a pipeline permanently out of operation An abandoned pipeline cannot be returned to operation. Depending on the legislation this may require cover or removal.
accidental loads	a load with an annual frequency less than 10^{-2}, see [5.4.10]
accumulated plastic strain	the sum of plastic strain increments, irrespective of sign and direction Strain increments shall be calculated from after the line pipe manufacturing.
additional requirements	requirements that applies to this standard, additional to other referred standards
as-built survey	a survey of the installed and completed pipeline system that is performed to verify that the completed installation work meets the specified requirements and documents deviations from the original design, if any
as-laid survey	a survey performed either by continuous touchdown point monitoring or by a dedicated vessel during installation of the pipeline
assemblies, in-line	pipeline components, see Table 1-1, buckle and fracture arrestors, PLEMs and PLETs which are integrated part of the pipeline and connected or welded to the pipeline during installation
assemblies, pipeline	risers, pipe strings (for reeling or towing), spools which are welded onshore, see [8.6].
annual probability	the probability of an event to occur in the period of one year
atmospheric zone	the part of the pipeline system above the splash zone
buckling, global	buckling mode which involves a substantial length of the pipeline, usually several pipe joints and not gross deformations of the cross-section; upheaval buckling is an example thereof, see [5.4.7]

Term	*Definition*
buckling, local	buckling mode confined to a short length of the pipeline causing gross changes of the cross-section; collapse, localised wall wrinkling and kinking are examples thereof, see [5.4.3]
characteristic load *(L_c)*	the reference value of a load to be used in the determination of load effects The characteristic load is normally based upon a defined fractile in the upper end of the distribution function for load, see [4.7].
characteristic resistance *(R_c)*	the reference value of structural strength to be used in the determination of the design strength The characteristic resistance is normally based upon a defined fractile in the lower end of the distribution function for resistance, see [5.3.2].
clad pipe (C)	pipe with internal (corrosion resistant) liner where the bond between (line pipe) backing steel and cladding material is metallurgical
clamp	circumferential structural element, split into two or more parts Examples; connecting two hubs in a mechanical connector or two pipe half-shells for repair purpose.
code break	a point or cross section on the pipeline where one set of specifications apply on one side and another set on the other side
coiled tubing	continuously-milled tubular product manufactured in lengths that require spooling onto a take-up reel, during the primary milling or manufacturing process
commissioning	activities associated with the initial filling of the pipeline system with the fluid to be transported, part of operational phase
commissioning, De -	activities associated with taking the pipeline temporarily out of service
commissioning, Pre -	activities after tie-in/connection and prior to commissioning including system pressure testing, de-watering, cleaning and drying
concept development phase	the concept development phase will typically include both business evaluations, collecting of data and technical early phase considerations
condition load effect factor (γ_C)	a load effect factor included in the design load effect to account for specific load conditions, see Table 4-5
connector	mechanical device used to connect adjacent components in the pipeline system to create a structural joint resisting applied loads and preventing leakage Examples: threaded types, including (i) one male fitting (pin), one female fitting (integral box) and seal ring(s), or (ii) two pins, a coupling and seals sea ring(s); flanged types, including two flanges, bolts and gasket/seal ring; clamped hub types, including hubs, clamps, bolts and seal ring(s); dog-type connectors.
construction phase	the construction phase will typically include manufacture, fabrication and installation activities Manufacture activities will typically include manufacture of line pipe and corrosion protection and weight coating. Fabrication activities will typically include fabrication of pipeline components and assemblies. Installation activities will typical include pre- and post intervention work, transportation, installation, tie-in and pre-commissioning.
contractor	a party contractually appointed by the purchaser to fulfil all, or any of, the activities associated with design, construction and operation

Term	*Definition*
corrosion allowance (t_{corr})	extra wall thickness added during design to compensate for any reduction in wall thickness by corrosion (internally/externally) during operation, see [6.4.2]
corrosion control	all relevant measures for corrosion protection, as well as the inspection and monitoring of corrosion, see [6.4.1]
corrosion protection	use of corrosion resistant materials, corrosion allowance and various techniques for corrosion mitigation, see [6.4.1]
coupling	mechanical device to connect two bare pipes to create a structural joint resisting applied loads and preventing leakage
design	all related engineering to design the pipeline including both structural as well as material and corrosion
design case	characterisation of different load categories, see [4.1.5]
defect	for welds a defect is defined as a flaw which is deemed to be unacceptable, for instance by virtue of its size exceeding a specified acceptance criteria (which may be based on workmanship or ECA) All flaws that exceeds the flaw acceptance criteria shall be defined as defects and repaired.
design life	the initially planned time period from initial installation or use until abandonment of the equipment or system. The original design life may be extended after a re-qualification
design premises	a set of project specific design data and functional requirements which are not specified or which are left open in the standard to be prepared prior to the design phase
design phase	the design phase will typically be split into FEED-phase, basic design and detail design. For each design phase, the same design tasks are repeated but in more and more specific and detailed level
dynamic riser	production risers tied back to floating structures (ISO 13628-1)
element	a structural element in an assembly, e.g. outer and inner pipe, bulkhead of a pipe-in-pipe system
engineering critical assessment (ECA)	fracture mechanics assessment of the acceptability of flaws in metallic materials
erosion	material loss due to repeated impact of sand particles or liquid droplets
fabrication	activities related to the assembly of objects with a defined purpose in a pipeline system
fabrication factor (α_{fab})	factor on the material strength in order to compensate for material strength reduction (in hoop direction) from cold forming during manufacturing of line pipe, see Table 5-5
fabricator	the party performing the fabrication
failure	an event affecting a component or system and causing one or both of the following effects: — loss of component or system function; or — deterioration of functional capability to such an extent that the safety of the installation, personnel or environment is significantly reduced
fatigue	cyclic loading causing degradation of the material

Term	*Definition*
fittings	elbows, caps, tees, single or multiple extruded headers, reducers and transition sections
flange	collar at the end of a pipe usually provided with holes in the pipe axial direction for bolts to permit other objects to be attached to it
flaw	a feature that has been detected by NDT, often caused by welding such as porosity, lack of fusion etc. The size of a flaw may be an input to a fracture mechanics assessment (ECA) to determine its acceptability. Alternatively, assessments may be carried out to determine a maximum allowable flaw size for sentencing purposes (basis for UT/AUT acceptance criteria).
fluid categorisation	categorisation of the transported fluid according to hazard potential as defined in Table 2-1
fractile	the p-fractile (or percentile) and the corresponding fractile value x_p is defined as: $$F(x_p) = p$$ F is the distribution function for x_p
hub	the parts in a mechanical connector joined by a clamp
hydrogen induced cracking (HIC)	internal cracking of rolled materials due to a build-up of hydrogen pressure in micro-voids (Related terms: stepwise cracking)
hydrogen induced stress cracking (HISC)	cracking that results from the presence of hydrogen in a metal while subjected to tensile stresses (residual and/or applied) The source of hydrogen may be welding, corrosion, cathodic protection, electroplating or some other electrochemical process. Crack growth proceeds by a hydrogen embrittlement mechanism at the crack tip, i.e. the bulk material is not necessarily embrittled by hydrogen. HISC by corrosion in presence of hydrogen sulphide is referred to as Sulphide Stress Cracking (SSC).
hydrostatic test	in some standards or recommended practices used for the mill pressure test. In this standard referred to as hydrostatic (i.e. with water) pressure test in general
inner pipe	the inner pipe in a pipe-in-pipe system The purpose of this pipe is to convey the product.
inspection	activities such as measuring, examination, weighing testing, gauging one or more characteristics of a product or service and comparing the results with specified requirements to determine conformity
installation (activity)	the operations related to installing the equipment, pipeline or structure, e.g. pipeline laying, tie-in, piling of structure etc.
installation (object)	see offshore installation
installation manual (IM)	a document prepared by the contractor to describe and demonstrate that the installation method and equipment used by the contractor will meet the specified requirements and that the results can be verified
integrity	see pipeline integrity

Term	*Definition*
jointer	two lengths of pipe welded together by the manufacturer to build up one complete (≈40’) pipe joint
limit state	a state beyond which the structure no longer satisfies the requirements The following limit states categories are of relevance for pipeline systems: — serviceability limit state (SLS): A condition which, if exceeded, renders the pipeline unsuitable for normal operations. Exceedance of a serviceability limit state category shall be evaluated as an accidental limit state. — ultimate limit state (ULS): A condition which, if exceeded, compromises the integrity of the pipeline. — fatigue limit state (FLS): An ULS condition accounting for accumulated cyclic load effects. — accidental limit state (ALS): An ULS due to accidental (in-frequent) loads.
line pipe	a welded or seamless pipe, available with ends plain, bevelled, grooved, cold expanded, flanged, or threaded; principally used to convey gas, oil or water
lined pipe (L)	pipe with internal (corrosion resistant) liner where the bond between (line pipe) backing steel and liner material is mechanical
load	any action causing stress, strain, deformation, displacement, motion, etc. to the equipment or system
load categories	functional load, environmental load, interference load or accidental load, see [4.1]
load effect	effect of a single load or combination of loads on the equipment or system, such as stress, strain, deformation, displacement, motion, etc.
load effect combinations	see [4.7.3]
load effect factor (γ_F, γ_E, γ_A)	the partial safety factor by which the characteristic load effect is multiplied to obtain the design load effect, see [4.7.3]
load scenarios	scenarios which shall be evaluated, see [4.1]
location class	a geographic area of pipeline system, see Table 2-2
lot	components of the same size and from the same heat, the same heat treatment batch
manufacture	making of articles or materials, often in large volumes In relation to pipelines, refers to activities for the production of line pipe, anodes and other components and application of coating, performed under contracts from one or more contractors.
manufacturer	the party who is contracted to be responsible for planning, execution and documentation of manufacturing
manufacturing procedure specification (MPS)	a manual prepared by the manufacturer to demonstrate how the specified properties may be achieved and verified through the proposed manufacturing route
material resistance factor (γ_m)	partial safety factor transforming a characteristic resistance to a lower fractile resistance, see Table 5-1
material strength factor (α_u)	factor for determination of the characteristic material strength reflecting the confidence in the yield stress see Table 5-3

Term	*Definition*
mill pressure test	the hydrostatic strength test performed at the mill, see [5.2.2] and [D.2.1.5]
minimum wall thickness	the specified non-corroded pipe wall thickness of a pipe minus the manufacturing tolerance
nominal failure probability	a probability of structural failure due to natural uncertainties as reflected in structural reliability analyses Gross errors are not included, see [2.3.5]
nominal outside diameter	the specified outside diameter
nominal pipe wall thickness	the specified non-corroded pipe wall thickness of a pipe
nominal strain	the total engineering strain not accounting for local strain concentration factors
nominal plastic strain	the nominal strain minus the linear strain derived from the stress-strain curve, see Table 1-8
notch	used in connection with fracture toughness testing and consists of the machined notched plus the fatigue pre-crack
offshore installation (object)	general term for mobile and fixed structures, including facilities, which are intended for exploration, drilling, production, processing or storage of hydrocarbons or other related activities/fluids The term includes installations intended for accommodation of personnel engaged in these activities. Offshore installation covers subsea installations and pipelines. The term does not cover traditional shuttle tankers, supply boats and other support vessels which are not directly engaged in the activities described above.
operation, incidental	conditions which that are not part of normal operation of the equipment or system In relation to pipeline systems, incidental conditions may lead to incidental pressures, e.g. pressure surges due to sudden closing of valves, or failure of the pipeline control system and activation of the pipeline safety system.
operation, normal	conditions that arise from the intended use and application of equipment or system, including associated condition and integrity monitoring, maintenance, repairs etc. In relation to pipelines, this should include steady flow conditions over the full range of flow rates, as well as possible packing and shut-in conditions where these occur as part of routine operation
operation phase	the operation phase starts with the commissioning, filling the pipeline with the intended fluid. The operation phase will include inspection and maintenance activities In addition, the operation phase may also include modifications, re-qualifications and de-commissioning.
operator (pipeline)	the party ultimately responsible for concept development, design, construction and operation of the pipeline system The operator may change between phases
ovality	the deviation of the line pipe perimeter from a circle This can be stated as ovalisation (%), or as local out of roundness, e.g. flattening, (mm).

Term	Definition
outer pipe	the outer pipe in a pipe-in-pipe system The main purpose of this pipe is to protect the annulus, keep it dry and not expose it to excessive pressure
ovalisation	the deviation of the perimeter from a circle. This has the form of an elliptic cross-section
parameter operating envelop	limitations of the operating parameters in the pipeline control system that will ensure that the parameter control envelope is not exceeded with an acceptable reliability This includes all relevant parameters and links between these including minimum values if relevant. This will first be established in the concept phase (mainly based on hydraulic analyses), extended in the design phase and re-assessed in the operation phase.
parameter safety envelop	limitations of the operating parameters in the pipeline safety system that will ensure that the parameter safety envelope is not exceeded with an acceptable reliability This will first be established in the concept phase (mainly based on hydraulic analyses), extended in the design phase and re-assessed in the operation phase.
partial safety factor	a factor by which the characteristic value of a variable is modified to give the design value (i.e. a load effect, condition load effect, material resistance or safety class resistance factor), see [5.3]
pipe, high frequency welded (HFW)	pipe manufactured by forming from strip and with one longitudinal seam formed by welding without the addition of filler metal The longitudinal seam is generated by high frequency current applied by induction or conduction.
pipe, seamless (SMLS)	pipe manufactured in a hot forming process resulting in a tubular product without a welded seam The hot forming may be followed by sizing or cold finishing to obtain the required dimensions.
pipe, submerged arc-welded	longitudinal or helical (SAWL or SAWH): Pipe manufactured by forming from strip or plate, and with one longitudinal (SAWL) or helical (SAWH) seam formed by the submerged arc process with at least one pass made on the inside and one pass from the outside of the pipe
pipeline components	any items which are integral parts of the submarine pipeline system such as bends, fittings, flanges, valves, mechanical connectors, CP isolation joints, anchor flanges, buckle and fracture arrestors, pig traps, repair clamps and repair couplings (see Sec.8)
pipeline control system	the basic process control system that ensures that the operating parameters are within the operating parameter envelop
pipeline integrity	pipeline integrity is the ability of the submarine pipeline system to operate safely and withstand the loads imposed during the pipeline lifecycle
pipeline integrity management	the pipeline integrity management process is the combined process of threat identification, risk assessments, planning, monitoring, inspection, maintenance etc. to maintain pipeline integrity

Term	*Definition*
pipeline safety system	the system as per in IEC 61511 that ensures that the operating parameters are within the safety parameter envelop The safety parameters can be, but are not limited to, flow, internal pressure, temperature or composition
pipeline system	pipeline with compressor or pump stations, pipeline control stations, metering, tankage, supervisory control and data acquisition system (SCADA), safety systems, corrosion protection systems, and any other equipment, facility or building used in the transportation of fluids See also submarine pipeline system.
pipeline walking	accumulation of incremental axial displacement of pipeline due to start-up and shut-down
positioning/heading keeping	maintaining a desired position/heading within the normal execution of the control system and environmental conditions
position/heading reference system	all hardware, software and sensors that supply information and or corrections necessary to give positioning/heading reference
pressure test	see system pressure test
pressure, collapse (p_c)	characteristic resistance against external over-pressure, see [5.4.4]
pressure, design (p_d)	in relation to pipelines, this is the maximum internal pressure during normal operation, referred to the same reference elevation as the incidental pressure, see Table 1-8 and [3.4.2]
pressure, hydro- or hydrostatic test	see pressure, mill test

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>pressure, incidental (p_{inc})</td><td>in relation to pipelines, this is the maximum internal pressure the pipeline or pipeline section is designed to withstand during any incidental operating situation, referred to a specified reference elevation, see Table 1-8 and [3.4.2]

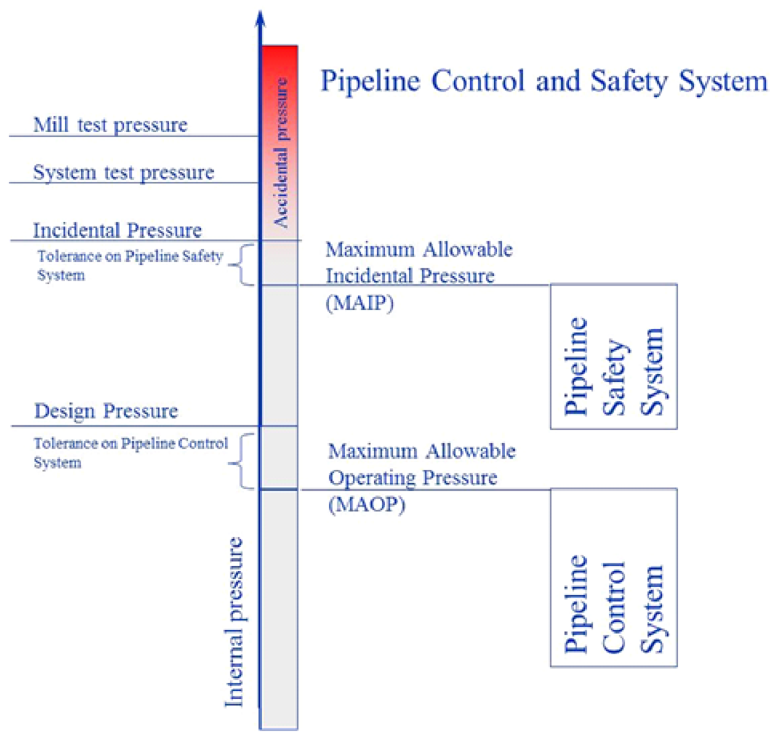

Figure 1-1 Pressure definitions</td></tr>
<tr><td>pressure, initiation</td><td>the external over-pressure required to initiate a propagating buckle from an existing local buckle or dent (100-year value), see [5.4.5]</td></tr>
<tr><td>pressure, local; local design, local incidental or local test</td><td>in relation to pipelines, this is the internal pressure at any point in the pipeline system or pipeline section for the corresponding design pressure, incidental pressure or test pressure adjusted for the column weight, see [4.2.2]</td></tr>
<tr><td>pressure, maximum allowable incidental (MAIP)</td><td>in relation to pipelines, this is the maximum pressure at which the pipeline system shall be operated during incidental (i.e. transient) operation
The maximum allowable incidental pressure is defined as the maximum incidental pressure less the positive tolerance of the pipeline safety system, see Table 1-8 and [3.4.2].</td></tr>
<tr><td>pressure, maximum allowable operating (MAOP)</td><td>in relation to pipelines, this is the maximum pressure at which the pipeline system shall be operated during normal operation
The maximum allowable operating pressure is defined as the design pressure less the positive tolerance of the pipeline control system (PCS), see Table 1-8 and [3.4.2].</td></tr>
</table>

Term	*Definition*
pressure, mill test (p_h)	the test pressure applied to pipe joints and pipe components upon completion of manufacture and fabrication, see [5.2.2]
pressure, propagating (p_{pr})	the lowest pressure required for a propagating buckle to continue to propagate, see [5.4.5]
pressure, shut-in	the maximum pressure that can be attained at the wellhead during closure of valves closest to the wellhead (wellhead isolation) This implies that pressure transients due to valve closing shall be included.
pressure, system test (p_{test})	in relation to pipelines, this is the internal pressure applied to the pipeline or pipeline section during testing on completion of installation work to test the pipeline system for tightness (normally performed as hydrostatic testing), see [5.2.2]
pressure, test	see pressure, system test
progressive failure	some pipeline concepts may have some structural redundancy, e.g. failure of one barrier may lead to functional consequences but not to consequences of the environment For such concepts, the first failure may lead to a second failure that then may lead to severe consequences, i.e. progressive failures. This will be typical for pipe-in-pipe systems.
pup piece	an extra line pipe piece added to a component in order to build up a certain overall length, typically for construction and/or fabrication purpose
purchaser	the owner or another party acting on his behalf, who is responsible for procuring materials, components or services intended for the design, construction or modification of an installation or a pipeline
quality assurance (QA)	planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality (The quality assurance actions of an organisation is described in a quality manual stating the quality policy and containing the necessary procedures and instructions for planning and performing the required actions).
quality control (QC)	the internal systems and practices (including direct inspection and materials testing), used by manufacturers to ensure that their products meet the required standards and specifications
quality plan (QP)	the document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, project or contract A quality plan usually makes reference to the part of the quality manual (e.g. procedures and work instructions) applicable to the specific case.
ratcheting	accumulated deformation during cyclic loading, especially for diameter increase, see [5.4.13] Does not include so called pipeline walking.
reliability	the probability that a component or system will perform its required function without failure, under stated conditions of operation and maintenance and during a specified time interval
re-qualification	the re-assessment of a design due to modified design premises and/or sustained damage

Term	*Definition*
resistance	the capability of a structure, or part of a structure, to resist load effects, see [5.3.2]
riser	a riser is defined as the connecting piping or flexible pipe between a submarine pipeline on the seabed and installations above water The riser extends to the above sea emergency isolation point between the import/export line and the installation facilities, i.e. riser ESD valve.
riser support/clamp	a structure which is intended to keep the riser in place
riser system	a riser system is considered to comprise riser, its supports, all integrated pipeline components, and corrosion protection system
risk	the qualitative or quantitative likelihood of an accidental or unplanned event occurring, considered in conjunction with the potential consequences of such a failure In quantitative terms, risk is the quantified probability of a defined failure mode times its quantified consequence.
safety class (SC)	in relation to pipelines; a concept adopted to classify the significance of the pipeline system with respect to the consequences of failure, see [2.3.4]
safety class resistance factor (γ_{SC})	partial safety factor which transforms the lower fractile resistance to a design resistance reflecting the safety class, see Table 5-2
single event	straining in one direction.
specified minimum tensile strength (SMTS)	the minimum tensile strength specified by this standard For supplementary requirement U, this corresponds to a statistical value equal to or lower than the mean minus three standard deviations.
specified minimum yield stress (SMYS)	the minimum yield stress specified by this standard For supplementary requirement U, this corresponds to a statistical value equal to or lower than the mean minus two standard deviations.
splash zone	external surfaces of a structure or pipeline that are periodically in and out of the water by the influence of waves and tides
spool	a pipe section which is used to connect a pipeline to another subsea structure (e.g. manifold, PLET, tee) or riser

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>stress-strain curve</td><td>

a uni-axial material characterisation, see Table 1-8

This may be given based on engineering stress-strain or true stress-strain dependent on if the reduction in cross sectional area is included in the force-to-stress conversion.

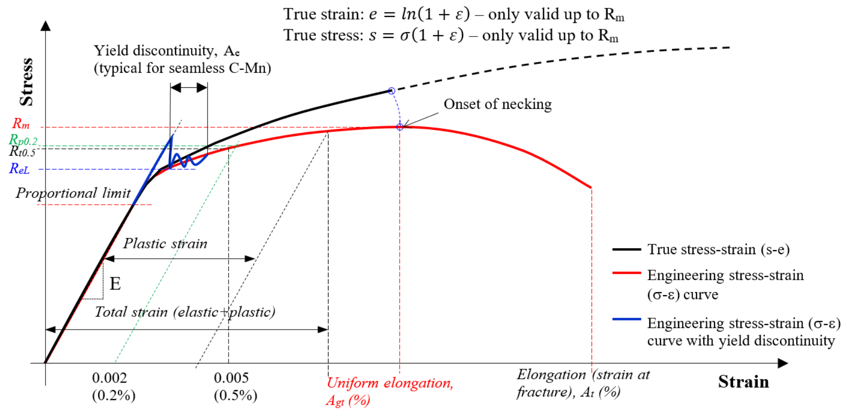

Figure 1-2 Stress-strain curve and definitions

</td></tr>
<tr><td>submarine pipeline</td><td>

a submarine pipeline is defined as the part of a submarine pipeline system which, except for pipeline risers is located below the water surface at maximum tid

The pipeline may, be resting wholly or intermittently on, or buried below, the seabed.

</td></tr>
<tr><td>submarine pipeline system</td><td>

a submarine pipeline system extends to the first weld beyond:

— the first valve, flange or connection above water on platform or floater
— the connection point to the subsea installation (i.e. piping manifolds are not included)
— the first onshore valve, flange, connection or insulation joint, unless otherwise specified by the on-shore legislation

The component above (valve, flange, connection, insulation joint) includes any pup pieces, i.e. the submarine pipeline system extends to the weld beyond the pup piece.

</td></tr>
<tr><td>submerged zone</td><td>the part of the pipeline system or installation below the splash zone, including buried parts</td></tr>
<tr><td>supplementary requirements</td><td>requirements for material properties of line pipe that are extra to the additional requirements to ISO and that are intended to apply to pipe used for specific applications</td></tr>
<tr><td>system effects</td><td>system effects are relevant in cases where many pipe sections are subjected to an invariant loading condition, and potential structural failure may occur in connection with the lowest structural resistance among the pipe sections, see [4.7.3]</td></tr>
<tr><td>system pressure test</td><td>final test of the complete pipeline system, see [5.2.2]</td></tr>
</table>

Term	*Definition*
target nominal failure probability	a nominal acceptable probability of structural failure Gross errors are not included, see [2.3.5]
technology qualification	the process of providing the evidence that technology will function within specified limits with an acceptable level of confidence
temperature, design, minimum	the lowest possible temperature profile to which the component or system may be exposed to during installation and operation (100-year value) This may be applied locally, see [4.2.1.6].
temperature, design, maximum	the highest possible temperature profile to which the equipment or system may be exposed to during installation and operation (100-year value)
temperature, operation	representative temperature profile(s) during operation
test unit	a prescribed quantity of pipe that is made to the specified outer diameter and specified wall thickness, by the same pipe-manufacturing process, from the same heat, and under the same pipe-manufacturing conditions
threats	an indication of impending danger or harm to the pipeline system
tide	see [3.3.4]
ultimate tensile strength (UTS)	the measured ultimate tensile strength
verification	an examination to confirm that an activity, a product or a service is in accordance with specified requirements
weld, strip/plate end	weld that joins strip or plate joins together
work	all activities to be performed within relevant contract(s) issued by owner, operator, contractor or manufacturer
yield stress (YS)	the measured yield tensile stress
100-year load effect	the load effect that has a probability of being exceeded within one year equal to 10^{-2}

1.8.3 Abbreviations

Table 1-9 Abbreviations

Abbreviation	*Description*
ALS	accidental limit state
AR	additional requirement to the stated ISO standard
API	American Petroleum Institute
APS	application procedure specification
ASD	allowable stress design
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AUT	automated ultrasonic testing

Abbreviation	*Description*
BM	base material
BS	british standard
CE	carbon equivalent
C-Mn	carbon manganese
CMOD	crack mouth opening displacement
CP	cathodic protection
CRA	corrosion resistant alloy
CTOD	crack tip opening displacement
CVN	charpy v-notch
DAC	distance amplitude correction
DC	displacement controlled
DFI	design, fabrication and installation
DGS	distance gain-size
DP	dynamic positioning
DWTT	drop weight tear testing
EBW	electron beam welded
EC	eddy current testing
ECA	engineering critical assessment
EDI	electronic data interchange
EMS	electro magnetic stirring
ERW	electric resistance welding
ESD	emergency shut down
FBH	flat bottom hole
FEED	front end engineering design
FJC	field joint coating
FLS	fatigue limit state
FMEA	failure mode effect analysis
FTA	flowline termination assembly
G-FCAW	gas-flux core arc welding
GMAW	gas metal arc welding
HAT	highest astronomical tide
HAZ	heat affected zone
HAZOP	hazard and operability study

Abbreviation	*Description*
HFW	high frequency welding
HIPPS	high integrity pressure protection system
HIC	hydrogen induced cracking
HISC	hydrogen induced stress cracking
ID	internal diameter
ILTA	in-line tea assembly
IM	installation manual
IMCA	international marine contractor’s association
ISO	international organization for standardization
ITP	inspection and testing plan
JCO	pipe fabrication process for welded pipes
JCOE	pipe fabrication process for welded pipes, expanded
J-R curve	plot of resistance to stable crack growth for establishing crack extension
KV	charpy value
KVL	charpy value in pipe longitudinal direction
KVT	charpy value in pipe transversal direction
L	load effect
LAT	lowest astronomic tide
LC	load controlled
LBW	laser beam welded
LBZ	local brittle zones
LRFD	load and resistance factor design
M/A	martensitic/austenite
MAIP	maximum allowable incidental pressure
MAOP	maximum allowable operating pressure
MDS	material data sheet
MPQT	manufacturing procedure qualification test
MPS	manufacturing procedure specification
MR	modified requirement to the stated ISO standard
MSA	manufacturing survey arrangement
MT	magnetic particle testing
MWP	multiple welding process
N	normalised

Abbreviation	*Description*
NACE	national association of corrosion engineers
NDT	non-destructive testing
OHTC	overall heat transfer coefficient
P	production
PCS	pipeline control system
PFD	probability of failure on demand
PIM	pipeline integrity management
PiP	pipe-in-pipe
PPT	pre-production trial
PRE	pitting resistance equivalent
PRL	primary reference level
PSS	pipeline safety system
PT	penetrant testing
PTFE	poly tetra flour ethylene
PVC	pressure vessel codes
PWHT	post weld heat treatment
pWPS	preliminary welding procedure specification
PQT	procedure qualification trial
Q	qualification
QA	quality assurance
QC	quality control
QP	quality plan
QRA	quantitative risk assessment
QT	quenched and tempered
ROV	remotely operated vehicle
RT	radiographic testing
SAWH	submerged arc-welding helical
SAWL	submerged arc-welding longitudinal
SC	safety class
SCF	stress concentration factor
SCR	steel catenary riser
SENB	single edge notched bend fracture mechanics specimen
SENT	single edge notched tension fracture mechanics specimen

Abbreviation	*Description*
SFC	steel forging class
SLS	serviceability limit state
SMAW	shielded metal arc welding
SMLS	seamless pipe
SMTS	specified minimum tensile strength
SMYS	specified minimum yield stress
SN	stress versus number of cycles to failure
SNCF	strain concentration factor
SRA	structural reliability analysis
SSC	sulphide stress cracking
ST	surface testing
TCM	two curve method
TMCP	thermo-mechanical controlled process
TOFD	time of flight diffraction
TRB	three roll bending
UEL	uniform elongation length, see Table 6-1
ULS	ultimate limit state
UO	pipe fabrication process for welded pipes
UOE	pipe fabrication process for welded pipes, expanded
UT	ultrasonic testing
UTS	ultimate tensile strength
VT	visual testing
WM	weld metal
WAT	wax appearance temperature
WPQT	welding procedure qualification test
WPS	welding procedure specification
YS	yield stress

1.8.4 Symbols – latin characters

a	crack depth
A	cross-sectional area
A_e	pipe external cross-sectional area
A_i	pipe internal cross-sectional area

A_s	pipe steel cross-sectional area
B	specimen width
D	nominal outside diameter
D_{fat}	Miner's sum
DFF	design fatigue factor, see Equation (5.36)
D_i	$D-2t_{nom}$ nominal internal diameter
D_{max}	greatest measured inside or outside diameter
D_{min}	smallest measured inside or outside diameter
E	Young's modulus
f_{cb}	minimum of f_y and $f_u/1.15$, see Equation (5.9)
f_u	tensile strength to be used in design, see Equation (5.5)
$f_{u,temp}$	derating on tensile stress to be used in design, see Equation (5.5)
f_y	yield stress to be used in design, see Equation (5.4)
$f_{y,temp}$	derating on yield stress to be used in design, see Equation (5.4)
g	gravity acceleration
H	residual lay tension, see Equation (4.10)
h_{bead}	height of weld bead including misalignment, see e.g. Table D-4
h_l	elevation at pressure point, see Equation (4.1)
H_p	permanent plastic dent depth
h_{ref}	elevation at pressure reference level, see Equation (4.1)
H_s	significant wave height
ID	nominal inside diameter
k	number of stress blocks
L	characteristic load effect
M	moment
N	axial force in pipe wall (true force) (tension is positive) or Number of load effect cycles
n_i	number of stress blocks
N_i	number of stress cycles to failure at constant amplitude
O	ovality,
p_b	pressure containment resistance, see Equation (5.8)
p_c	characteristic collapse pressure, see Equation (5.11)
p_d	design pressure
P_{Di}	(i'th) damaging event, see Equation (5.38)
p_e	external pressure
p_{el}	elastic collapse pressure, see Equation (5.12)
p_f	failure probability

$p_{f,T}$	target nominal failure probability, see Table 2-5
p_i	characteristic internal pressure
p_{inc}	incidental pressure
p_{init}	initiation pressure
p_{ld}	local design pressure
p_{li}	local incidental pressure, see Equation (4.1)
p_{lt}	local test pressure (system test), see Equation (4.2)
p_{mpt}	mill test pressure, see [7.5.1]
p_p	plastic collapse pressure, see Equation (5.13)
p_{pr}	propagating pressure, see Equation (5.16)
$p_{pr,A}$	propagating buckle capacity of infinite buckle arrestor
p_t	system test pressure, see Equation (4.2) and Equation (5.1)
p_x	crossover pressure, see Equation (5.18)
R	global bending radius of pipe, Reaction force or Resistance
R_m	tensile strength
R_{px}	strength equivalent to a permanent elongation of x% (actual stress)
R_{tx}	strength equivalent to a total elongation of x% (actual stress)
S	effective axial force (tension is positive)
t_c	characteristic thickness to be replaced by t_1 or t_2 as relevant, see Table 5-5
T	temperature
t, t_{nom}	nominal wall thickness of pipe (un-corroded)
T_0	testing temperature
t_1, t_2	pipe wall thickness, see Table 5-5
t_{corr}	corrosion allowance, see Table 5-5
$T_c/T_{c'}$	contingency time for operation/ceasing operation, see [4.3.6] and Figure 4-1
t_{fab}	fabrication thickness tolerance, see Table 7-18
$t_{m,min}$	measured minimum thickness
T_{max}	maximum design temperature, see [4.2.1]
T_{min}	minimum design temperature, see [4.2.1]
T_{pop}	planned operational period, see [4.3.6]
$T_R/T_{R'}$	reference period for operation/ceasing operation, see [4.3.6] and Figure 4-1
T_{Safe}	planned time to cease operation, see [4.3.6] and Figure 4-1
T_{WF}	time between generated weather forecasts, see [4.3.6] and Figure 4-1
W	section modulus or specimen thickness
W_{sub}	submerged weight

1.8.5 Symbols – greek characters

α	thermal expansion coefficient
α_c	characteristic flow stress ratio, see Equation (5.22)
α_{fab}	fabrication factor, see Table 5-4
α_{gw}	girth weld factor (strain resistance), see Equation (5.31)
α_h	$\left(\frac{R_{t0,5}}{R_m}\right)_{max}$ strain hardening
α_{mpt}	mill pressure test factor, see Table 5-8
α_p	pressure factor used in combined loading criteria, see Equation (5.19)
α_{pm}	plastic moment reduction factor for point loads, see Equation (5.25)
α_{spt}	system pressure test factor, see Table 5-8
α_U	material strength factor, see Table 5-3
β	factor used in combined loading criteria, see Equation (5.24)
ε	strain
ε_c	characteristic bending strain resistance, see Equation (5.30)
ε_f	accumulated plastic strain resistance
$\varepsilon_{l.nom}$	total nominal longitudinal strain
ε_p	plastic strain
ε_r	residual strain range
γ_A	load effect factor for accidental load, see Table 4-4
γ_c	condition load effect factor, see Table 4-5
γ_E	load effect factor for environmental load, see Table 4-4
γ_F	load effect factor for functional load, see Table 4-4
γ_{inc}	incidental to design pressure ratio, see Table 3-1
γ_m	material resistance factor, see Table 5-1
γ_{rot}	safety factor for residual strain
$\gamma_{SC,i}$	safety class resistance factor for limit state i (PB, LB, DC), see Table 5-2
η	usage factor
κ	curvature
ν	Poisson's ratio
μ	friction coefficient
ρ_{cont}	density pipeline content
ρ_t	density pipeline content during system pressure test

σ	standard deviation of a variable (e.g. thickness)
σ_e	equivalent stress, Von Mises, see Equation (5.45)
σ_h	hoop stress, see Equation (5.46)
σ_l	longitudinal/axial stress, see Equation (5.47)
τ_{lh}	tangential shear stress

1.8.6 Subscripts

A	accidental load
BA	buckle arrestor
c	characteristic resistance
d	design value
E	environmental load
e	external
el	elastic
F	functional load
h	circumferential direction (hoop direction)
H	circumferential direction (hoop direction)
i	internal
L	axial (longitudinal) direction
M	moment
mpt	mill pressure test
p	plastic
R	radial direction
Rd	design resistance (i.e. including partial resistance factors)
s	steel
S	SLS
Sd	design load (i.e. including load effect factors)
spt	system pressure test
U	ULS
X	crossover (buckle arrestors)

SECTION 2 SAFETY PHILOSOPHY

2.1 General

2.1.1 Objective

2.1.1.1 This section presents the overall safety philosophy that shall be applied in the concept development, design, construction, operation and abandonment of pipelines.

2.1.2 Application

2.1.2.1 This section applies to all submarine pipeline systems which shall be built and operated in accordance with this standard.

2.1.2.2 The integrity of a submarine pipeline system shall be ensured through all phases, from initial concept through to final de-commissioning, see Figure 2-1. Two integrity stages are defined:

— establish integrity in the concept development, design and construction phases; and
— maintain integrity in the operations phase.

2.1.2.3 This section also provides guidance for extension of this standard in terms of new criteria, etc.

2.2 Safety philosophy structure

2.2.1 General

2.2.1.1 The integrity of the submarine pipeline system is ensured through a safety philosophy integrating different parts as illustrated in Figure 2-2.

2.2.1.2 The overall safety principles and the arrangement of safety systems shall be in accordance with DNVGL-OS-A101 and DNVGL-OS-E201. See also [3.4].

2.2.2 Safety objective

2.2.2.1 An overall safety objective shall be established, planned and implemented, covering all phases from conceptual development until abandonment.

Guidance note:

Most companies have a policy regarding human aspects, environment and financial issues. These are typically on an overall level, but may be followed by more detailed objectives and requirements in specific areas. These policies should be used as a basis for defining the safety objective for a specific pipeline system. Typical statements may be:

— The impact on the environment shall be reduced to as far as reasonably possible.

— No releases will be accepted during operation of the pipeline system.

— There shall be no serious accidents or loss of life during the construction period.

— The pipeline installation shall not, under any circumstances impose any threat to fishing gear.

— Diverless installation and maintenance.

Statements such as those above may have implications for all or individual phases only. They are typically more relevant for the work execution (i.e. how the contractor executes his job) and specific design solutions (e.g. burial or no burial). Having defined the safety objective, it can be a point of discussion as to whether this is being accomplished in the actual project. It is therefore recommended that the overall safety objective be followed up by more specific, measurable requirements.

If no policy is available, or if it is difficult to define the safety objective, one could also start with a risk assessment. The risk assessment could identify all hazards and their consequences, and then enable back-extrapolation to define acceptance criteria and areas that need to be followed up more closely.

The structural failure probability is reflected in the choice of three safety classes (see [2.2.4]). The choice of safety class should also include consideration of the expressed safety objective.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Concept		Design		Construction							Operation				
Business development	Concept development	Basic design	Detail design	Linepipe	Components and assemblies	Corrosion protection and weight coating	Pre-intervention	Installation	Post-intervention	Pre-commissioning	Commissioning	Integrity management	Inspection and repair	Re-qualification	Abandonment
2* & 3		4, 5 & 6		7	8	9	10				11				
Establish Integrity											Maintain Integrity				

Numbers in the figure refers to section number in this standard.

Figure 2-1 Integrity assurance activities during the pipeline system phases

Figure 2-2 Safety philosophy structure

2.2.3 Systematic review of risks

2.2.3.1 A systematic review shall be carried out at all phases to identify and evaluate threats, the consequences of single failures and series of failures in the pipeline system, such that necessary remedial measures can be taken. The extent of the review or analysis shall reflect the criticality of the pipeline system, the criticality of a planned operation, and previous experience with similar systems or operations. The uncertainty in the applied risk review model itself shall also be qualified.

Guidance note:

A methodology for such a systematic review is quantitative risk analysis (QRA). This may provide an estimation of the overall risk to human health and safety, environment and assets and comprises:

- hazard identification
- assessment of probabilities of failure events
- accident developments
- consequence and risk assessment.

The scope of the systematic review should comprise the entire pipeline system, and not just the submarine pipeline system.

It should be noted that legislation in some countries requires risk analysis to be performed, at least at an overall level to identify critical scenarios that might jeopardise the safety and reliability of a pipeline system. Other methodologies for identification of potential hazards are failure mode and effect analysis (FMEA) and hazard and operability studies (HAZOP). Concrete guidance on critical aspects are given in the individual sections, typically in [X.1.3] where X indicates section.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.2.3.2 Special attention shall be given to sections close to installations or shore approaches where there is frequent human activity and thus a greater likelihood and consequence of damage to the pipeline. This also includes areas where pipelines are installed parallel to existing pipelines and pipeline crossings.

2.2.4 Design criteria principles

2.2.4.1 Safety of the pipeline system is ensured by use of a safety class methodology. The pipeline system is classified into one or more safety classes based on failure consequences, normally given by the content and location. For each safety class, a set of partial safety factors is assigned to each limit state.

2.2.5 Quality assurance

2.2.5.1 The safety format requires that gross errors (human errors) shall be controlled by requirements for organisation of the work, competence of persons performing the work, verification of the design, and quality assurance during all relevant phases.

2.2.5.2 It is assumed that the operator of a pipeline system has established a quality objective. The operator shall, in both internal and external quality related aspects, seek to achieve the quality level of products and services intended in the quality objective. Further, the operator shall provide assurance that intended quality is being, or will be, achieved.

2.2.5.3 Documented quality systems shall be applied by operators and other parties (e.g. design contractors, manufactures, fabricators and installation contractors) to ensure that products, processes and services will be in compliance with the requirements. Effective implementation of quality systems shall be documented.

2.2.5.4 Repeated occurrence of non-conformities reflecting systematic deviations from procedures and/or inadequate workmanship shall initiate:

— investigation into the causes of the non-conformities
— reassessment of the quality system
— corrective action to establish possible acceptability of products
— preventative action to prevent re-occurrence of similar non-conformities.

Guidance note:

ISO 9000 gives guidance on the selection and use of quality systems.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.2.5.5 Quality surveillance in the construction phase shall be performed by the operator or an inspectorate nominated by the operator. The extent of quality surveillance shall be sufficient to establish that specified requirements are fulfilled and that the intended quality level is maintained.

2.2.5.6 To ensure safety during operations phase, an integrity management system in accordance with [11.3] shall be established and maintained.

2.2.6 Health, safety and environment

2.2.6.1 The concept development, design, construction, operation and abandonment of the pipeline system shall be conducted in compliance with national legislation and company policy with respect to health, safety and environmental aspects.

2.2.6.2 The selection of materials and processes shall be conducted with due regard to the safety of the public and employees and to the protection of the environment.

2.3 Risk basis for design

2.3.1 General

2.3.1.1 The design format is based upon a limit state and partial safety factor methodology, also called load and resistance factor design format (LRFD). The load and resistance factors depend on the safety class, which characterizes the consequences of failure.

2.3.2 Categorisation of fluids

2.3.2.1 Fluids to be transported by the pipeline system shall be categorised according to their hazard potential as given by Table 2-1.

Guidance note:

It is recommended to categorize CO_2 pipelines as more severe by category E unless long operational experience exist by the operator of CO_2 pipeline of similar composition and operated in similar manner. Recommended practice for pipelines conveying CO_2 is given in DNVGL-RP-F104.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 2-1 Categorisation of fluids

Category	*Description*
A	Typical non-flammable water-based fluids.
B	Flammable and/or toxic fluids which are liquids at ambient temperature and atmospheric pressure conditions. Typical examples are oil and petroleum products. Methanol is an example of a flammable and toxic fluid.
C	Non-flammable fluids which are non-toxic gases at ambient temperature and atmospheric pressure conditions. Typical examples are nitrogen, carbon dioxide, argon and air.
D	Non-toxic, single-phase natural gas.
E	Flammable and/or toxic fluids which are gases at ambient temperature and atmospheric pressure conditions and which are conveyed as gases and/or liquids. Typical examples would be hydrogen, natural gas (not otherwise covered under category D), ethane, ethylene, liquefied petroleum gas (such as propane and butane), natural gas liquids, ammonia, and chlorine.

2.3.2.2 Gases or liquids not specifically identified in Table 2-1 should be classified in the category containing fluids most similar in hazard potential to those quoted. If the fluid category is not clear, the most hazardous category shall be assumed.

2.3.3 Location classes

2.3.3.1 The pipeline system shall be classified into location classes as defined in Table 2-2.

Table 2-2 Classification of location

Location	*Definition*
1	The area where no frequent human activity is anticipated along the pipeline route.
2	The part of the pipeline/riser in the near platform (manned) area or in areas with frequent human activity. The extent of location class 2 should be based on appropriate risk analyses. If no such analyses are performed a minimum horizontal distance of 500 m shall be adopted.

2.3.4 Safety classes

2.3.4.1 Pipeline design shall be based on potential failure consequence. This is implicit by the concept of safety class. The safety class may vary for different phases and locations. The safety classes are defined in Table 2-3.

Table 2-3 Classification of safety classes

Safety class	*Definition*
Low	Where failure implies insignificant risk of human injury and minor environmental and economic consequences.
Medium	Where failure implies low risk of human injury, minor environmental pollution or high economic or political consequences.
High	Classification for operating conditions where failure implies risk of human injury, significant environmental pollution or very high economic or political consequences.

2.3.4.2 The partial safety factors related to the safety class are given in [5.3.2].

2.3.4.3 For normal use, the safety classes in Table 2-4 apply:

Table 2-4 Normal classification of safety classes [1)]

Phase	*Fluid category A, C*		*Fluid category B, D and E*	
	Location class		*Location class*	
	1	2	1	2
Temporary[2,3]	Low	Low	-	-
Operational	Low	Medium	Medium	High

1)	Other classifications may exist depending on the conditions and criticality of failure the pipeline. For pipelines where some consequences are more severe than normal, i.e. when the table above does not apply, the selection of a higher safety class shall also consider the implication, on the total gained safety. If the total safety increase is marginal, the selection of a higher safety class may not be justified.
2)	Installation until pre-commissioning (temporary phase) should be classified as safety class Low.
3)	For safety classification of temporary phases after commissioning, special consideration shall be made to the consequences of failure, i.e. giving a higher safety class than Low.

2.3.5 Reliability analysis

2.3.5.1 As an alternative to the specific LRFD (and ASD) format, a recognised structural reliability analysis (SRA) based design method may be applied provided that:

— the method complies with DNVGL-RP-C211
— the approach is demonstrated to provide adequate safety for familiar cases, as indicated by this standard.

Reliability based limit state design shall not be used to replace the safety factors for pressure containment criterion in Sec.5 with the exception of accidental pressure. Accidental limit states shall be designed based on SRA in line with [5.4.10] ensuring that the overall nominal failure probability complies with the nominal failure probability target values in this sub-section.

2.3.5.2 Suitably competent and qualified personnel shall perform the structural reliability analysis, and extension into new areas of application shall be supported by technical verification.

2.3.5.3 As far as possible, nominal target failure probability levels shall be calibrated against identical or similar pipeline designs that are known to have adequate safety on the basis of this standard. If this is not feasible, the nominal target failure probability level shall be based on the failure type and safety class as given in Table 2-5.

Guidance note:

It can be seen as a contradiction that this standard requires a target failure probability one to two orders of magnitude lower for pressure containment compared to the other limit states/failure modes. The question is really - How to determine acceptable target failure probabilities for offshore pipelines?

In order to calibrate proper partial safety factors for all limit states, some backward-engineering on target failure probabilities were performed, see [13.4]. By applying structural reliability analysis on known pipeline designs using known statistical distribution for the most important stochastic variables, the implicit target probabilities were established for the different limit states. In this way the target values were established based on an experienced failure rate that was perceived as acceptable to all stakeholders including the society at large. The work revealed failure probabilities for pressure containment (hoop stress) one to two orders of magnitude lower than for the other failure modes. This is the main reason for the differences seen in the recent version of the standard.

The target failure probabilities may also be seen from a practical point of view. The experienced failures for any structures could be categorised into gross errors also including the unexpected and unknown and failures due to natural variance (structural reliability). Looking into historical failure rates for offshore pipelines the gross errors dominate. Then one may argue that the target probability of failure used in structural reliability analyses do not matter that much. However, the target failure of probability with respect to pressure containment is in some sense in a special position as it is determining the pipe wall thickness. Being stricter on the target failure probability increases the wall thickness and thus indirectly the robustness towards other failure modes and at least some gross errors. Relaxing the target failure probability would reduce the robustness and, thus, the expected failure rate with respect to several failure rates would most likely increase.

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Guidance note:

Local factors and associated consequences may be e.g. shipping lanes.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 2-5 Nominal annual target failure probabilities per pipeline vs. safety classes[5)]

Limit state category	*Limit state*	*Safety classes*			
		Low	*Medium*	*High*	*Very high*[4)]
SLS	All	10^{-2}	10^{-3}	10^{-3}	10^{-4}
ULS ALS	Pressure containment[1)]	10^{-4} to 10^{-5}	10^{-5} to 10^{-6}	10^{-6} to 10^{-7}	10^{-7} to 10^{-8}
ULS FLS[2)] ALS[3)]	All other	10^{-3}	10^{-4}	10^{-5}	10^{-6}

1) The failure probability for the pressure containment (wall thickness design) is one to two order of magnitudes lower than the general ULS criterion given in this table, in accordance with industry practice and reflected by the ISO requirements.
2) The failure probability will effectively be governed by the last year in operation or prior to inspection depending on the adopted inspection philosophy.
3) Nominal target failure probabilities can alternatively be one order of magnitude less (e.g. 10^{-4} per pipeline to 10^{-5} per km) for any running km if the consequences are local and caused by local factors.
4) See Table F-2.
5) The target shall be interpret as probability that a failure occurs in the period of one year.

SECTION 3 CONCEPT AND DESIGN PREMISE DEVELOPMENT

3.1 General

3.1.1 Objective

3.1.1.1 This section identifies and provides a basis for definition of relevant field development characteristics. Further, key issues required for design, construction, operation, and abandonment of the submarine pipeline system are identified.

3.1.2 Application

3.1.2.1 This section applies to submarine pipeline systems which shall be built according to this standard.

3.1.2.2 The design premises outlined in this section should be developed during the conceptual phase and reviewed and updated when found necessary.

3.1.3 Systematic review

3.1.3.1 The overall requirement to systematic review in Sec.2 shall be reflected in the concept evaluation.

3.1.3.2 Threats identified may typically have impacts on cost, schedule and performance, and may include:

— scope changes (flow characteristics, throughputs, maturity of technical solutions)
— market factors and prices (material, equipment, contractors)
— severe weather conditions (delays to marine operations due to limiting weather conditions)
— contractor availability and performance (cost, construction delays, quality)
— supply and quality of material (delays, performance)
— availability and cost of financing (delays, commercial feasibility)
— constructability (limited access for installation vessels, simultaneous operations with other installation activities, vessel capacity and deck space)
— novel technology.

3.1.3.3 Threat identification for the society/safety report

— environmental impact
— impact on other industries
— safety of life.

3.1.3.4 Threats identification on the pipeline may include:

— environment
— third party activities
— geo-hazards
— flow constraints.

3.1.3.5 Impacts of the identified threats on operation of the submarine pipeline system shall be evaluated.

3.2 Concept development

3.2.1 Concept development

3.2.1.1 When selecting the submarine pipeline system concept all aspects related to design, construction, operation and abandonment shall be considered. Due account should be given to identification of potential aspects which can stop the concept from being realised:

— long lead effects of early stage decisions (e.g. choice of material grade may affect manufacturing aspects of line pipe, choice of diameter may give restrictions to installation methods etc.)
— life cycle evaluations (e.g. maintenance activities etc.)
— installation aspects for remote areas (e.g. non-availability of major installation equipment or services and weather issues).

3.2.1.2 Data and description of field development and general arrangement of the pipeline system shall be established.

3.2.1.3 The data and description should include the following, as applicable:

— safety objective
— environmental objective
— location, inlet and outlet conditions
— pipeline system description with general arrangement and battery limits
— functional requirements including field development restrictions, e.g., safety barriers and subsea valves
— installation, repair and replacement of pipeline elements, valves, actuators and fittings
— project plans and schedule, including planned period of the year for installation
— design life including specification for start of design life, e.g. final commissioning, installation etc.
— data of product to be transported including possible changes during the pipeline system's design life
— transport capacity and flow assurance
— pipeline safety system requirements including process system layout and incidental to design pressure ratio evaluations
— pipeline sizing data
— attention to possible code breaks in the pipeline system
— geometrical restrictions such as specifications of constant internal diameter, requirement for fittings, valves, flanges and the use of flexible pipe or risers
— relevant pigging scenarios (inspection and cleaning)
— pigging fluids to be used and handling of pigging fluids in both ends of pipeline including impact on process systems
— pigging requirements such as bend radius, pipe ovality and distances between various fittings affecting design for pigging applications
— sand production
— second and third party activities
— restricted access for installation or other activities due to presence of ice.

3.2.1.4 An execution plan should be developed, including the following topics:

— general information, including project organisation, scope of work, interfaces and project development phases
— contacts with purchaser, authorities, third party, engineering, verification and construction contractors
— legal aspects, e.g. insurance, contracts, area planning, requirements to vessels.

3.2.1.5 The design and planning for the submarine pipeline system should cover all development phases including construction, operation and abandonment.

3.3 Design premise

3.3.1 Hydraulic analyses and flow assurance

3.3.1.1 Hydraulic analyses of the pipeline systems should be performed to determine the required diameter and pressure to meet the transport capacity requirement.

3.3.1.2 A parameter safety envelope (e.g. pressure, temperature, content composition) shall be determined. The hydraulics of the pipeline system should be analysed to demonstrate that the pipeline system can safely transport the fluids within this parameter safety envelope. This shall include identification of constraints and requirements for its operation. This analysis should cover steady-state and transient operating conditions. The parameter safety envelope shall also include minimum values if applicable.

Guidance note:

Examples of constraints and operational requirements are allowances for pressure surges, prevention of blockage such as caused by the formation of hydrates and wax deposition, measures to prevent unacceptable pressure losses from higher viscosities at lower operation temperatures, measures for the control of liquid slug volumes in multi-phase fluid transport, flow regime for internal corrosion control erosional velocities and avoidance of slack line operations. It includes requirements to insulation, maximum shut-down times, requirements for heating etc. as well as description of pressure designing cases (e.g. preservation cases with methanol) with associated temperatures.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:

Examples of this may be minimum required pressures for pipeline systems that not are designed for the fully external over pressure.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.3.1.3 The hydraulics of the pipeline system shall be analysed to demonstrate that the pipeline control system and pipeline safety system meet its requirement during start-up, normal operation, shut-down (e.g. closing of valves) and all foreseen non-intended scenarios. This shall also include determination of required incidental to design pressure ratio.

3.3.1.4 The hydraulic analyses shall be used to determine the characteristic high design temperature profile based on conservative insulation values reflecting the variation in insulation properties of coatings and surrounding seawater, soil and gravel.

3.3.1.5 The hydraulic analyses shall be used to determine the characteristic low design temperature. Benefit of specifying low temperatures locally due to e.g. opening of valves is allowed and shall be documented e.g. by hydraulic analyses.

3.3.2 Environmental condition

3.3.2.1 Environmental phenomena that might impair proper functioning of the system or cause a reduction of the reliability and safety of the system shall be considered, including:

— wind
— tide
— waves
— internal waves and other effects due to differences in water density
— current

— ice
— earthquake
— geotechnical conditions
— geomorphology processes
— temperature
— marine growth (fouling).

3.3.2.2 Recommended practice for principles and methodologies for establishing environmental conditions and loads is given in DNVGL-RP-C205.

3.3.3 Collection of environmental data

3.3.3.1 The environmental data shall be representative for the geographical areas in which the pipeline system shall be installed. If sufficient data are not available for the geographical location in question, conservative estimates based on data from other relevant locations may be used.

3.3.3.2 Statistical data shall be utilised to describe environmental parameters of a random nature (e.g. wind, waves). The parameters shall be derived in a statistically valid manner using recognised methods.

3.3.3.3 For the assessment of environmental conditions along the pipeline route, the pipeline may be divided into a number of sections, each of which is characterised by a given water depth, bottom topography and other factors affecting the environmental conditions.

3.3.3.4 The environmental data to be used in the design of the submarine pipeline system which is connected to an offshore structure or routed near an offshore structure are in principle the same as the environmental data used in the design of the offshore structure.

3.3.4 Environmental data

3.3.4.1 The estimated maximum tide shall include both highest astronomic tide and positive storm surge. Minimum tide estimates should be based upon the lowest astronomic tide and possible negative storm surge.

3.3.4.2 All relevant sources to current shall be considered. This may include tidal current, wind induced current, storm surge current, density induced current or other possible phenomena. For near-shore regions, long-shore current due to wave breaking shall be considered. Variations in magnitude with respect to direction and water depth shall be considered when relevant.

3.3.4.3 In areas where ice may develop or where ice bergs may pass or where the soil may freeze sufficient statistics shall be established in order to enable calculations of relevant loads.

3.3.4.4 Air and sea temperature statistics shall be provided giving representative high and low design values.

3.3.4.5 Marine growth on pipeline systems shall be considered, taking into account both biological and other environmental phenomena relevant for the location.

3.3.5 Pipeline route

3.3.5.1 The pipeline route shall be selected with due regard to safety of the public and personnel, protection of the environment, and the probability of damage to the pipeline or other facilities. Agreement with relevant parties should be sought as early as possible. Factors to take into consideration shall, at minimum, include the following:

— Environment

  — archaeological sites
  — exposure to environmental loads
  — areas of natural conservation interest such as oyster beds and coral reefs
  — marine parks
  — turbidity flows.

— Seabed characteristics

  — uneven seabed
  — unstable seabed
  — seabed geotechnical properties (hard spots, soft sediment and sediment transport)
  — subsidence
  — seismic activity.

— Facilities

  — offshore installations
  — subsea structures and well heads
  — existing pipelines and cables
  — obstructions
  — coastal protection works.

— Third party activities

  — ship traffic
  — fishing activity
  — dumping areas for waste, ammunition, etc.
  — mining activities
  — military exercise areas.

— Shore crossing

  — local constraints
  — 3rd party requirements
  — environmentally sensitive areas
  — vicinity to people
  — limited construction period.

3.3.5.2 Expected future marine operations and anticipated developments in the vicinity of the pipeline shall be considered when selecting the pipeline route.

3.3.5.3 In-line assemblies should not be located on the curved route sections of the pipeline.

Guidance note:

It is preferred to have a sagbend length of straight section after a curve before the in-line assembly because of potential rotation.

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3.3.5.4 Pipeline ends should be designed with a reasonable straight length ahead of the target boxes. Curvatures near pipeline ends should be designed with due regard to end terminations, lay method, lay direction and existing/planned infrastructure.

3.3.6 Route survey

3.3.6.1 Surveys shall be carried out along the total length of the planned pipeline route to provide sufficient data for design and construction related activities.

3.3.6.2 The survey corridor shall have sufficient width to define an installation and pipeline corridor which will ensure safe installation and operation of the pipeline.

3.3.6.3 The required survey accuracy may vary along the proposed route. Obstructions, highly varied seabed topography, or unusually or hazardous sub-surface conditions may dictate more detailed investigations. The survey accuracy shall be sufficient for performing the design, construction and operation activities in a safe manner.

3.3.6.4 Investigations to identify possible conflicts with existing and planned installations and possible wrecks and obstructions shall be performed. Examples of such installations include other submarine pipelines, and power and communication cables.

3.3.6.5 The results of surveys shall be presented on accurate route maps and alignments, scale commensurate with required use. The location of the pipeline and related facilities, together with seabed properties, anomalies and all relevant pipeline attributes shall be shown. Reference seawater elevation shall be defined.

3.3.6.6 Additional route surveys may be required at shore crossings to determine:

— nearshore and onshore geology, bathymetry and topography specific to the coastal environment
— environmental conditions caused by adjacent coastal features
— pipeline route alignment and vertical profile to achieve pipeline stability and protection, and minimise impact on environmental, archaeological sites, people and existing facilities and operations
— the shore crossings construction method, by open-cut trench and cover, horizontal directional drilling, tunnelling or jetty structure, or a combination of these

3.3.6.7 All topographical features which may influence the stability and installation or influence seabed intervention of the pipeline shall be covered by the route survey, including:

— obstructions in the form of rock outcrops, large boulders, pock marks, etc., that could necessitate remedial, levelling or removal operations to be carried out prior to pipeline installation
— topographical features that contain potentially unstable slopes, sand waves, pock marks or significant depressions, valley or channelling and erosion in the form of scour patterns or material deposits.

3.3.6.8 Areas where there is evidence of increased geological activity or significant historic events that if re-occurring may impact the pipeline, additional geohazard studies should be performed. Such studies may include:

— extended geophysical survey
— mud volcanoes or pockmark activity
— seismic hazard
— seismic fault displacements
— possibility of soil slope failure
— mudflow characteristics
— mudflow impact on pipelines.

3.3.7 Seabed properties

3.3.7.1 Geotechnical characteristics necessary for evaluating the effects of relevant loading conditions shall be determined for the seabed deposits, including possible unstable deposits in the vicinity of the pipeline. For guidance on geotechnical investigation for pipelines, see DNVGL-RP-C212.

3.3.7.2 Geotechnical properties may be obtained from generally available geological information, results from seismic surveys, seabed bathymetry surveys, and geotechnical in-situ tests and laboratory tests on sampled soil. Supplementary information may be obtained from visual surveys or special tests, as e.g. pipe penetration tests.

3.3.7.3 Soil parameters of main importance for the pipeline response are:

— particle size distribution
— strength parameters (intact and remoulded undrained shear strength for cohesive soils, and angle of internal friction for non-cohesive soils); and
— relevant deformation characteristics.

These parameters should preferably be determined from adequate laboratory tests or from interpretation of in-situ tests. In addition, classification and index tests should be considered, such as:

— unit weight
— water content
— liquid and plastic limit
— soil mineralogy and chemistry
— other relevant tests.

3.3.7.4 Rock parameters of main importance for pipeline response are:

— rock type and minerology
— rock strength and variability in rock strength with depth below seabed
— rock erodibility (e.g. potential for catastrophic cliff erosion)
— karst features.

3.3.7.5 It is primarily the characteristics of the upper layer of the seabed that determine the response of the pipeline resting on the seabed. For situations where the top layer comprises a soil, the determination of soil parameters for these very shallow soils may be relatively more uncertain than for deeper soils. Also the variations of the top soil between soil testing locations and between tested locations and non-tested locations add to the uncertainty. Soil parameters used in the design may therefore need to be defined with upper bound, best estimate and lower bound limits valid within defined areas or sections of the route. The characteristic value(s) of the soil parameter(s) used in the design shall be in line with the selected design philosophy accounting for these uncertainties.

Guidance note:

The upper layer may be slurry with a very low strength. In these cases emphasis should also be made to the soil layer underneath.

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3.3.7.6 Since the distance between geotechnical testing locations is often much longer than the length of the pipeline involved in a particular design situation, one will in such circumstances have to assume that the geotechnical characteristics for the designs situation is the worst of high and low estimates obtained from relevant available geotechnical investigation data related to the entire route or to a defined section of the route.

3.3.7.7 In areas where the seabed material may be subjected to erosion, special studies of the current and wave conditions near the bottom including boundary layer effects may be required for the on-bottom stability calculations of pipelines and the assessment of pipeline spans.

3.3.7.8 Additional investigation of the seabed material may be required to evaluate specific scenarios, as for example:

— challenges with respect to excavation and burial operations
— the probability of the forming of frees-pans caused by scouring during the operational phase
— the probability of pipeline self-burial occurring during the operational phase
— challenges with respect to pipeline crossings

— challenges with the settlement of the pipeline system and/or the protection structure at the valve/tee locations
— possibilities of mud slides or liquefaction as the result of repeated loading
— implications for external corrosion.

3.3.7.9 Recommended practice on pipe-soil interaction and geotechnical surveys is given in DNVGL-RP-F114.

3.4 System design principles

3.4.1 System integrity

3.4.1.1 The pipeline system shall be designed, constructed and operated in such a manner that:

— the specified transport capacity is fulfilled and the flow assured.
— the defined safety objective is fulfilled and the resistance against loads during planned operational conditions is sufficient.
— the safety margin against accidental loads or unplanned operational conditions is sufficient.
— system layout, including needs for different valves etc., meets the requirements imposed by the systematic review of the process control.

3.4.1.2 Pipelines in C-Mn steel for potentially corrosive fluids of categories B, D and E (see [2.3]) should be designed for inspection pigging. In cases where the pipeline design does not allow inspection pigging, an analysis shall be carried out in accordance with recognised procedures to document that the risk of failure leading to a leak is acceptable. For corrosive fluids of other categories the benefit of inspection pigging on operational reliability shall be evaluated.

3.4.1.3 The need for in-line cleaning and/or inspection, involving the presence of appropriate pig launcher/ receiver should be determined in the design phase.

3.4.1.4 The possibility of changes in the type or composition of fluid to be transported during the lifetime of the pipeline system shall be assessed in the design phase.

3.4.1.5 Any re-qualification deemed necessary due to changes in the design conditions shall take place in accordance with provisions set out in Sec.11.

3.4.2 Pipeline control and safety system

3.4.2.1 The incidental pressure is defined as having an annual probability of exceedance less than 10^{-2} (a probability of being exceeded within a year). If the pressure probability density function does not have a monotonic decay beyond 10^{-2} the pressure exceeding the incidental pressure shall be checked as accidental loads in compliance with [5.4.10].

Guidance note:

Examples of pressure probability density distributions are given in Figure 3-1. An example of a pipeline system with a two peak distribution may be a pipeline system protected by a HIPP system.

The 100-year value, the incidental pressure (see mark in Figure 3-1), will be used for normal design for both two peak distributions and single peak distributions. For two peak distributions the second peak pressure shall also be checked for accidental limit state in accordance with [5.4.10] (see pressure of 1200 in Figure 3-1).

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Guidance note:

When the submarine pipeline system is connected to another system with different pressure definition the pressure values may be different in order to comply with the requirements of this sub-section, i.e. the design pressure may be different in two connected systems. The conversion between the two system definitions will often then be based on that the incidental pressures are equal.

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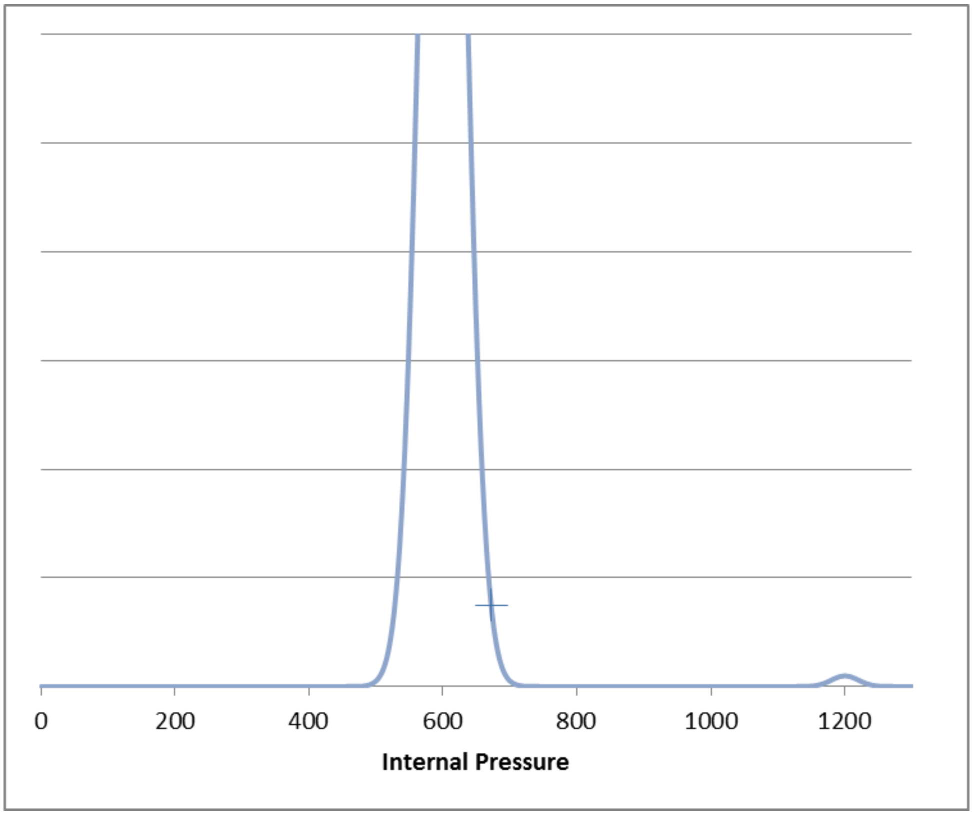

Figure 3-1 Pressure distribution function with two peak distribution

3.4.2.2 The submarine pipeline system shall have a specified incidental pressure or be split into different sections with different specified incidental pressures. These should all be defined at a defined reference elevation.

3.4.2.3 To fulfil the requirements in [3.4.2.1] and [3.4.2.2] a pipeline protection system may be required. This comprises the pipeline control system (PCS) and pipeline safety system (PSS).

Guidance note:

An example of situations where a pipeline control and safety system may not be required is if full shut-in pressure including dynamic effects, is used as incidental pressure.

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3.4.2.4 The purpose of the PCS is to maintain the operating parameters within the operating envelope during normal operation e.g. to ensure that the local design pressure is not exceeded at any point in the submarine pipeline system. The PCS should operate automatically. Due account shall be given to the tolerances of the PCS and its associated instrumentation, see Table 1-8. Hence, the maximum allowable operating pressure (MAOP) is equal to the design pressure minus the PCS operating tolerance.

3.4.2.5 The PCS could be included as a risk reducing measure provided that this system is independent of PSS and further complies with the following:

— The PCS is not included as a part of the demand rate defined for the PSS
— Failure of an automatic PCS shall not affect the alarm system needed for human intervention.
— The risk reduction factor taken shall be smaller than 10 unless the PCS is built in accordance with safety system standards, e.g., IEC61511. The assessment of risk reduction factor and evidence to support the assessment shall be made according to the requirements in IEC61511.
— Risk reduction from human intervention, in addition to PCS, assumes that actions are based upon information from systems independent of PCS and PSS. The total risk reduction factor resulting from Human Intervention and the PCS shall be less than 100.

3.4.2.6 The purpose of the PSS is to protect the submarine pipeline system by limiting the operating parameters within the parameter safety envelope during incidental operation, e.g. to ensure that the local incidental pressure is not exceeded at any point in the pipeline system in the event of failure of the PCS. The PSS shall operate automatically. Due account shall be given to the tolerances of the PSS. Hence, the maximum allowable incidental pressure is equal to the incidental pressure minus the PSS operating tolerance.

3.4.2.7 The PCS is a basic process control system as defined by IEC 61511. The Pipeline Safety shall comply with the requirements of IEC 61511. PSSs required with a probability of failure on demand of less than 10^{-3} shall consist of two independent systems.

The requirements for the level of risk reduction to be provided by the PSS, the SIL Level shall be derived according to the requirements of [5.4.10] and not from a risk assessment. Figure B-6 provides further guidance.

3.4.2.8 The PSS may consist of pressure relief devices (ISO 4126) and/or safety instrumented systems, see IEC 61511. Pressure relief valves are considered fulfilling requirements to the PSS if these are designed and maintained to relieve the required discharge capacity at a pressure not exceeding the maximum allowable incidental pressure.

3.4.2.9 A design pressure may be defined for each incidental pressure. The incidental to design pressure ratio shall be selected such that the pipeline control and safety system meet the requirements in [3.4.2.1] and [3.4.2.2]. Typical and minimum incidental to design ratios are given in Table 3-1. When design pressure is used for structural design purpose, this shall be minimum 91% of the incidental pressure.

Guidance note:

This standard use incidental pressure in all limit states. Other referenced standards or recommended practices (e.g. for components) may use design pressure instead. For such applications, the design pressure shall be the higher of p_{li}/γ_{inc} and $0.91 \cdot p_{li}$.

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Table 3-1 Incidental to design pressure ratios, γ_{inc}

Condition or pipeline system	γ_{inc}
Typical pipeline system	1.10
Minimum, except for below	1.05
When design pressure is equal to full shut-in pressure including dynamic effects	1.00

3.4.3 External corrosion control

3.4.3.1 For the selection and detailed design of external corrosion control, the following conditions relating to the environment shall be defined, in addition to those mentioned in [3.3.2.1]:

— exposure conditions, e.g. burial, rock dumping, etc.
— sea water and soil resistivity.

3.4.3.2 Other conditions affecting external corrosion which shall be defined are:

— temperature profiles (e.g. average, characteristic high design) along the pipeline and through the pipe wall thickness
— pipeline fabrication and installation procedures
— requirements for mechanical protection, submerged weight and thermal insulation during operation
— design life
— selected coating and cathodic protection system.

3.4.3.3 Special attention should be given to the shore crossing zone and interaction with relevant cathodic protection system for onshore vs. offshore pipeline sections.

3.4.3.4 The impact from third party activities on the external pipeline condition, as mentioned in [3.3.5.1] should be considered.

3.4.4 Internal construction conditions

3.4.4.1 A description of the internal pipeline conditions during the construction phase shall be prepared (this includes storage, construction, installation, pressure testing and commissioning). The duration of exposure to sea water or humid air, and the need for using inhibitors or other measures to control corrosion shall be considered.

3.4.5 Internal corrosion control

3.4.5.1 In order to assess the need for internal corrosion control, including corrosion allowance and provision for inspection and monitoring, the following conditions shall be defined:

— operating temperature/pressure profiles along the pipeline including expected variations during the design life
— flow velocity and flow regime
— fluid composition (initial and anticipated variations during the design life) with emphasis on potentially corrosive components (e.g. hydrogen sulphide, carbon dioxide, water content and expected content of dissolved salts in produced fluids, residual oxygen and active chlorine in sea water)
— chemical additions and provisions for periodic cleaning
— provision for inspection of corrosion damage and expected capabilities of inspection tools (i.e. detection limits and sizing capabilities for relevant forms of corrosion damage)
— the possibility of erosion by any solid particles in the fluid shall be considered. Recommended practice for erosive wear in piping systems is given in DNVGL-RP-O501 Sec.3.

SECTION 4 DESIGN - LOADS

4.1 General

4.1.1 Objective

4.1.1.1 This section defines the loads to be checked by the limit states in Sec.5. This includes:

— load scenarios
— categorisation of loads
— design load effects
— characteristic load
— load effect factor combinations
— load effect calculations.

4.1.2 Application

4.1.2.1 This section applies to all parts of the submarine pipeline system.

4.1.3 Systematic review

4.1.3.1 The overall requirement to systematic review in Sec.2 implies for this section that a review of loads based on their uncertainty and importance for the different limit states shall be performed.

4.1.4 Load scenarios

4.1.4.1 All loads and forced displacements which may influence the pipeline shall be taken into account. For each cross section or part of the system to be considered and for each possible mode of failure to be analysed, all relevant combinations of loads which may act simultaneously shall be considered.

4.1.4.2 The most unfavourable load scenario for all relevant phases and conditions shall be considered. Typical scenarios to be covered in the design are:

— transportation
— installation
— as laid
— water filled
— system pressure test
— operation
— shut-down.

4.1.5 Categorisation of loads

4.1.5.1 The objective of the categorisation of loads into the different load categories is to relate the load effect to the associated uncertainties.

4.1.5.2 Unless the load is categorised as accidental it shall be categorised as:

— functional load,
— environmental load or

— interference load.

The load categories are described in [4.2], [4.3] and [4.5] below. Construction loads shall be categorised into the above loads and are described in [4.4]. Accidental loads are described in [4.6].

4.2 Functional loads

4.2.1 General

4.2.1.1 Loads arising from the physical existence of the pipeline system and its intended use shall be classified as functional loads.

4.2.1.2 Effects from the following phenomena are the minimum to be considered when establishing functional loads:

— weight
— reactions from installation vessel (tensioners, straightener, stinger/rollers)
— external hydrostatic pressure
— static hydrodynamic forces during installation
— reactions from soil in sag bend
— internal pressure
— temperature of contents
— pre-stressing
— reactions from components (flanges, clamps etc.)
— permanent deformation of supporting structure
— cover (e.g. soil, rock, mattresses, culverts)
— reaction from seabed (friction and rotational stiffness)
— permanent deformations due to subsidence of ground, both vertical and horizontal
— permanent deformations due to frost heave
— changed axial friction due to freezing
— possible loads due to ice interference, e.g. bulb growth around buried pipelines near fixed points (in-line valves/tees, fixed plants etc.), drifting ice etc.
— loads induced by pigging operations.

4.2.1.3 The weight shall include weight of pipe, buoyancy, contents, coating, anodes, marine growth and all attachments to the pipe.

4.2.1.4 End cap forces due to pressure shall be considered, as well as any transient pressure effects during normal operation (e.g. due to closure of valves).

4.2.1.5 Temperature due to internal fluid and external environmental shall be determined and corresponding temperature profiles for the following scenarios:

— the maximum and minimum design (100-year return values) temperature during operation
— representative temperatures during operation
— representative temperatures during installation, as-laid, water filled and system pressure test.

Guidance note:

The temperature is normally determined for the pipe steel (to be used for structural purpose) but may also be required for anodes, coating etc.

The selection of design or operational temperature is given by Table 4-3.

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4.2.1.6 Local minimum temperature profiles, which may be caused by e.g. sudden shut-downs, may be applied. This will typically be relevant to defined components and sections of the pipeline (e.g. spots around valves).

4.2.1.7 Fluctuations in temperature shall be taken into account when checking fatigue strength.

4.2.1.8 For expansion analyses, the temperature difference relative to laying shall be considered. The temperature profile shall be applied.

4.2.1.9 Pre-stressing, such as permanent curvature or a permanent elongation introduced during installation, shall be taken into account if the capacity to carry other loads is affected by the pre-stressing. Pretension forces induced by bolts in flanges, connectors and riser supports and other permanent attachments, shall be classified as functional loads.

4.2.1.10 The soil pressure acting on buried pipelines shall be taken into account if significant.

4.2.2 Pressure loads

4.2.2.1 The following internal pressures shall be defined at a certain defined reference level; system test pressure, operating pressure (if relevant), design pressure (if applicable), and incidental pressure, see [3.4.2] for definitions and Table 1-8. These pressures are summarised in Table 4-1.

Guidance note:

The incidental pressure is defined in terms of exceedance probability within a year. The ratio between the incidental pressure and the design pressure, see Table 3-1, is determined by the accuracy and speed of the pipeline safety system. When the pressure source is given (e.g. well head shut-in pressure) this may constitute the selection of the incidental pressure. The design pressure can then be established based on the pipeline safety system. When transport capacity requirement constitutes the design premise this may give the design pressure and the incidental pressure can then be established based on the pipeline safety system.

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Table 4-1 Pressure terms

Pressure	*Abbreviations*	*Symbol*	*Description*
Mill test	-	P_h	Hydrostatic test pressure at the mill, see [7.5].
System test	-	P_t	The pressure to which the complete submarine pipeline system is tested to prior to commissioning, see [5.2.2].
Incidental	-	P_{inc}	Maximum pressure (100-year value) the submarine pipeline system is designed to withstand, see [3.4.2].
Maximum allowable incidental	MAIP	-	Maximum allowable incidental pressure is equal to the incidental pressure minus the pipeline safety system (PSS) operating tolerance.
Design	-	P_D	The maximum pressure during normal operation that the pipeline control system (PCS) allows.
Maximum allowable operating	MAOP	-	Maximum allowable operating pressure is equal to the design pressure minus the pipeline control system (PCS) operating tolerance, and is hence the upper limit of the pipeline control system.

4.2.2.2 The local pressure is the internal pressure at a specific point based on the reference pressure adjusted for the fluid column weight due to the difference in elevation. It can be expressed as:

$$p_{li} = p_{inc} - \rho_{cont} \cdot g \cdot \left(h_l - h_{ref}\right) \tag{4.1}$$

$$p_{lt} = p_t - \rho_t \cdot g \cdot \left(h_l - h_{ref}\right) \tag{4.2}$$

$$p_{inc} = p_d \cdot \gamma_{inc} \tag{4.3}$$

where:

p_{li} = the local incidental pressure
p_{inc} = the incidental reference pressure at the reference elevation
ρ_{cont} = the density of the relevant content of the pipeline
g = the gravity
h_{ref} = the elevation of the reference point (positive upwards)
h_l = the elevation of the local pressure point (positive upwards)
p_{lt} = the local system test pressure
p_t = the system test reference pressure at the reference elevation
ρ_t = the density of the relevant test medium of the pipeline
p_d = the design pressure at the pressure reference elevation
γ_{inc} = the incidental to design pressure ratio.

4.2.2.3 In cases where external pressure increases the capacity, the external pressure shall not be taken as higher than the water pressure at the considered location corresponding to low astronomic tide including possible negative storm surge.

4.2.2.4 In cases where the external pressure decreases the capacity, the external pressure shall not be taken as less than the water pressure at the considered location corresponding to high astronomic tide including storm surge.

4.3 Environmental loads

4.3.1 General

4.3.1.1 Environmental loads are defined as those loads on the pipeline system which are caused by the surrounding environment, and that are not otherwise classified as functional or accidental loads.

4.3.1.2 Recommended practice for calculation of characteristic environmental loads is given in DNVGL-RP-C205.

4.3.2 Wind loads

4.3.2.1 Wind loads shall be determined using recognised theoretical principles. Alternatively, direct application of data from adequate tests may be used.

4.3.2.2 The possibility of vibrations and instability due to wind induced cyclic loads shall be considered (e.g. vortex shedding).

4.3.3 Hydrodynamic loads

4.3.3.1 Hydrodynamic loads are defined as flow-induced loads caused by the relative motion between the pipe and the surrounding water.

4.3.3.2 All relevant sources for hydrodynamic loads shall be considered. This may include waves, current, and relative pipe motions and indirect forces e.g. caused by vessel motions.

4.3.3.3 The following hydrodynamic loads shall be considered:

— drag and lift forces which are in phase with the absolute or relative water particle velocity
— inertia forces which are in phase with the absolute or relative water particle acceleration
— flow-induced cyclic loads due to vortex shedding, galloping and other instability phenomena
— buoyancy variations due to wave action.

Guidance note:

Research into the hydrodynamic coefficients for open bundles and piggy-back lines indicates that the equivalent diameter approach may be nonconservative, and a system specific computational fluid dynamics (CFD) analysis may be required to have a robust design.

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4.3.3.4 The applied wave theory shall be capable of describing the wave kinematics at the particular water depth in question including surf zones hydrodynamics where applicable. The suitability of the selected theory shall be demonstrated and documented.

4.3.3.5 The current-induced drag and lift forces on the submarine pipeline system shall be determined and combined with the wave-induced forces using recognised theories for wave- current interaction. A vector combination of the current and wave-induced water particle velocities may be used, however, calculation of the total particle velocities and accelerations based upon more exact theories on wave-current interaction is preferable.

4.3.3.6 Data from model testing or acknowledged industry practice may be used in the determination of the relevant hydrodynamic coefficients.

4.3.3.7 Consideration shall be given to wave direction, short crested waves, wave refraction and shoaling, shielding and reflecting effects.

4.3.3.8 Variations in current velocity magnitude and direction as a function of water depth shall be considered.

4.3.3.9 Where parts of the pipeline system are positioned adjacent to other structural parts, possible effects due to disturbance of the flow field shall be considered when determining the wave and/or current actions. Such effects may cause an increased or reduced velocity, or dynamic excitation by vortices being shed from the adjacent structural parts.

4.3.3.10 If parts of the submarine pipeline system are built up of a number of closely spaced pipes, then interaction and solidification effects shall be taken into account when determining the mass and drag coefficients for each individual pipe or for the whole bundle of pipes. If sufficient data is not available, large-scale model tests may be required.

4.3.3.11 For pipelines on or close to a fixed boundary (e.g. pipeline spans), lift forces perpendicular to the axis of the pipe and perpendicular to the velocity vector shall be taken into account (possible vortex induced vibrations).

4.3.3.12 In connection with vortex shedding-induced transverse vibrations, potential increase in drag coefficient shall be taken into account.

4.3.3.13 Possible increased waves and current loads due to presence of Tee's, Y's or other attachments shall be considered.

4.3.3.14 The increased loads from marine growth shall be considered as follows:

— Increased drag/lift area due to the marine growth
— Increased pipe surface roughness and resulting increase in drag coefficient and reduced lift coefficient
— Any beneficial effect of the marine growth should be ignored in stability analyses

4.3.3.15 Tide loads shall be considered when the water depth is a significant parameter, e.g. for the establishment of wave actions, pipe lay operation particularly near shore approaches/landfalls, etc.

4.3.4 Ice loads

4.3.4.1 In areas where ice may develop or drift, the possibility of ice loads on the pipeline system shall be considered.

Guidance note:

Ice loads may be due to ice frozen on the pipeline system itself, or partly due to floating ice, or combination of these two.

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4.3.4.2 The possibility of ice scouring and impacts from drifting ice shall be considered for shore approaches and areas where ice may interfere with the seabed and the submarine pipeline system.

4.3.4.3 Increased hydrodynamic loading due to presence of ice shall be considered.

4.3.4.4 In case of ice frozen to parts of the submarine pipeline system or vessels, (e.g. due to sea spray) the following forces shall be considered:

— weight of the ice
— impact forces due to thaw of the ice
— forces due to expansion of the ice
— increased wind, waves and current forces due to increased exposed area.

4.3.4.5 Forces from floating ice shall be calculated according to recognised theory. Due attention shall be paid to the mechanical properties of the ice, contact area, shape of structure, direction of ice movements, etc. The oscillating nature of the ice forces (built-up of lateral force and fracture of moving ice) shall be taken into account. When forces due to lateral ice motion will govern structural dimensions, model testing of the ice-structure interaction may be required.

4.3.5 Earthquake

4.3.5.1 Load imposed by earthquake, either directly or indirectly (e.g. due to failure of pipeline gravel supports), shall be classified as accidental or environmental loads, depending on the probability of earthquake occurrence in line with accidental loads in [4.6].

4.3.6 Characteristic environmental load effects

4.3.6.1 The characteristic environmental load and the corresponding load effect depend on if the scenario can be classified as:

— a weather restricted condition, or
— an unrestricted condition (temporary condition or permanent condition).

Figure 4-1outlines the procedure for assessing environmental loads.

For a weather restricted operation, the environmental load is the minimum of the determined Operation limit (OP_{LIM}) The operation limit may be defined by maximum allowed structural response (e.g. local buckling in the sag bend), anchor handling capability, safe working conditions on deck, assistance system or any limitations identified in HAZOP. In case operation limits are stricter for ceasing the operation than for normal laying this should be evaluated in detail. The operation limit is then dependent on vessels and equipment used.

For a non-weather restricted operations the environmental load is based on environmental statistics and therefore independent on vessel and equipment.

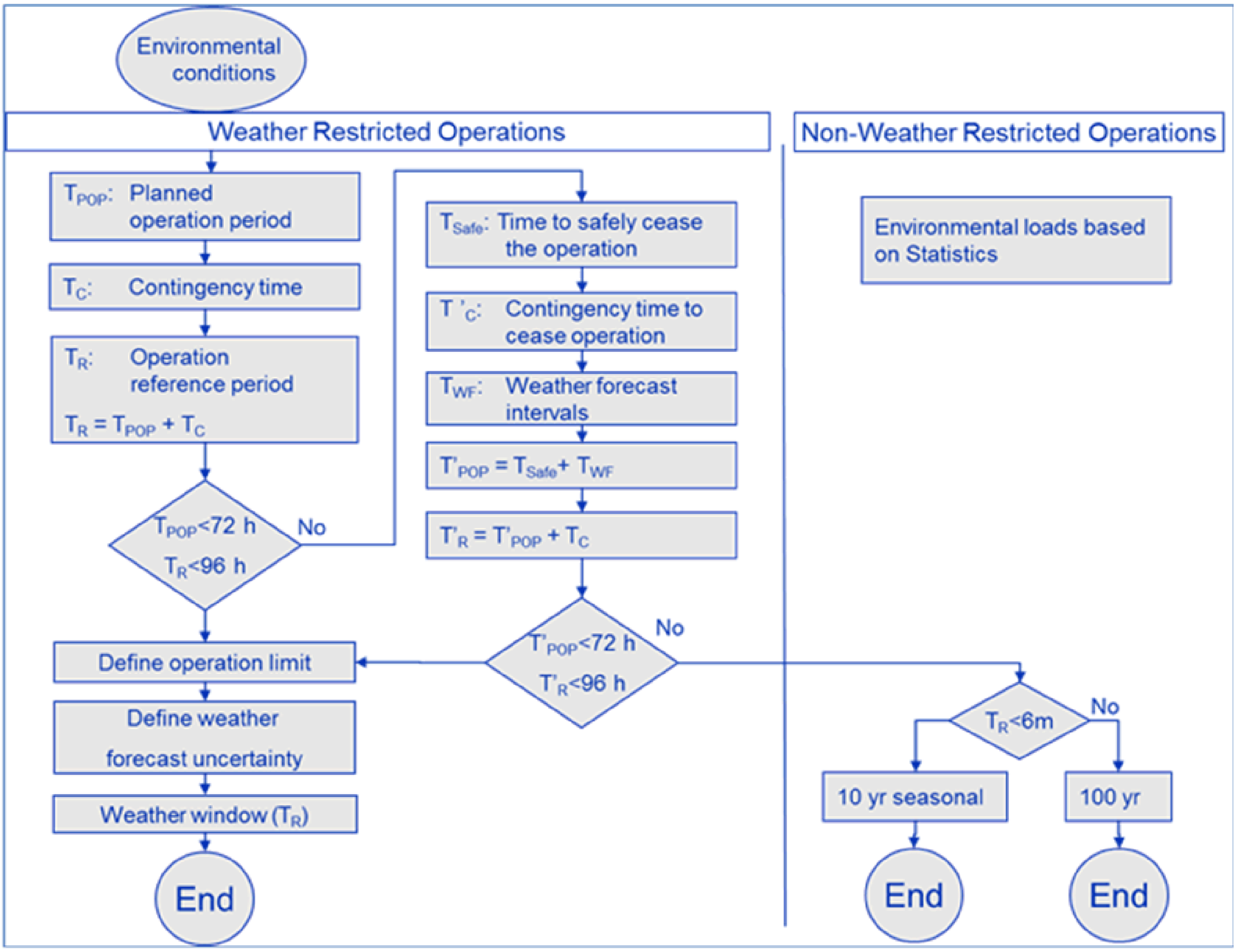

Figure 4-1 Determination of characteristic environmental load

4.3.6.2 Weather restricted operations may start-up based upon reliable weather forecast less than the operation limit. Uncertainty in the weather forecast for the operational period shall be considered.

Guidance note:

For weather restricted operations and example of how to account for the uncertainty in weather forecast reference is made to DNVGL-ST-N001.

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4.3.6.3 Operations with a reference period (T_R) less than 96 hours and a planned operation period (T_{POP}) less than 72 hours can be defined as weather restricted. The operation reference period (T_R) is the planned operation period (T_{POP}) including contingency time, (T_C).

4.3.6.4 An operation can be defined as weather restricted operation even if the planned operation time exceeds 72 hours provided that the operation can be interrupted and put into a safe condition within the maximum allowable period for a weather restricted operation. The reference period for such operations is defined as the planned operation period for ceasing the operation, (T'_{POP}), including the contingency time for ceasing the operation (T'_C). The planned operation period for ceasing the operations is defined as the time to safely cease the operation (T_{Safe}) and the weather forecast intervals (T_{WF}).

4.3.6.5 An operation can be defined as a temporary condition if the duration is less than 6 months unless defined as weather restricted conditions. The environmental load effect for temporary conditions shall be taken as the 10-year return period for the actual season.

Guidance note:

Conditions exceeding 6 months but no longer than 12 months may occasionally be defined as temporary conditions.

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4.3.6.6 Conditions not defined as weather restricted conditions or temporary conditions shall be defined as permanent conditions. The environmental load effect for permanent conditions shall be taken as the 100-year return period.

4.3.6.7 When considering the environmental design load the most unfavourable relevant combination, position and direction of simultaneously acting environmental loads shall be used in documenting the integrity of the submarine pipeline system. Functional loads (see [4.2]), interference loads (see [4.5]) and accidental loads (see [4.6]) shall be combined with the environmental loads as appropriate, see Table 4-3.

4.3.6.8 The characteristic environmental load effect for installation, L_E, is defined as the most probable largest load effect for a given seastate and appropriate current and wind conditions given by:

$$F(L_E) = 1 - \frac{1}{N} \tag{4.4}$$

where:

$F(L_E)$ is the cumulative distribution function of L_E, and N is the number of load effect cycles in a sea-state of a duration not less than 3 hours.

4.3.6.9 The most critical load effect combination for the relevant return period shall be used. When the correlations among the different environmental load components (i.e. wind, wave, current or ice) are unknown the characteristic combined environmental loads in Table 4-2 may be used.

Table 4-2 Combinations of characteristic environmental loads in terms of return period [1)]

Wind	*Waves*	*Current*	*Ice*	*Earthquake*
Permanent condition				
100-year	100-year	10-year		
10-year	10-year	100-year		
10-year	10-year	10-year	100-year	
10-year	10-year	10-year		100-year[2)]
Temporary condition				
10-year	10-year	1-year		
1-year	1-year	10-year		

1-year	1-year	1-year	10-year	
1-year	1-year	1-year		10-year[2)]

1) This is in compliance with ISO 16708, but in conflict with ISO 13623 in case the design life is less than 33 years.
2) Special attention shall be given to potential waves or current induces by earthquakes.

4.4 Construction loads

4.4.1 General

4.4.1.1 Loads which arise as a result of the construction and operation of the submarine pipeline system shall be classified into functional and environmental loads.

4.4.1.2 Construction loads include:

— stacking of pipes
— pipe transportation loads
— handling of pipe and pipe sections, e.g. lifting of pipe, pipe joints, pipe strings and pipe spools, and reeling of pipe strings
— static and dynamic installation loads
— pull-in at landfalls, tie-ins, trenching etc.
— pressure testing
— commissioning activities, e.g. increase in pressure differential due to vacuum drying
— dynamic loads from pre-commissioning activities, e.g. flooding and de-watering with pigs.

4.4.1.3 Inertia loads due to sudden water filling, excessive deformation in overbend and sagbend, and forces due to operation errors or failures in equipment that could cause or aggravate critical conditions shall be considered, see [10.1.3].

Guidance note:

The design criteria for such considerations will depend on the likelihood of the scenario. In case the likelihood is less than once in hundred years, it can be considered as an accidental limit state and be checked in accordance with [5.4.10], else a normal ULS check apply.

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4.4.1.4 For construction loads imposed by geometrical tolerances, extreme tolerances may be taken as mean ± 3 standard deviations of the combined tolerances.

4.5 Interference loads

4.5.1 General

4.5.1.1 Loads which are imposed on the pipeline system from 3rd party activities shall be classified as interference loads. Typical interference loads include trawl interference, anchoring, vessel impacts and dropped objects.

4.5.1.2 The requirement for designing the submarine pipeline system for interference loads shall be determined based upon interference frequency studies and assessment of the potential damage. If the probability of occurrence is less than 10^{-2} within a year the load shall be classified as accidental load, see [4.6].

4.5.1.3 The trawling loads can be divided in accordance with the three crossing phases:

— Trawl impact, i.e. the initial impact from the trawl board or beam which may cause local dents on the pipe or damage to the coating.
— Over-trawling, often referred to as pull-over, i.e. the second phase caused by the wire and trawl board or beam sliding over the pipe. This will usually give a more global response of the pipeline.
— Hooking, i.e. the trawl board is stuck under the pipe and in extreme cases, forces as large as the breaking strength of the trawl wire are applied to the pipeline.

Each of the three types of trawling loads shall be classified as an ULS or an ALS dependent on their frequency. Hooking becomes then often an accidental load.

4.5.1.4 Recommended practice for calculations of trawl interference loads is given in DNVGL-RP-F111 Sec.4.

4.5.1.5 The trawl impact energy shall be determined considering, as a minimum:

— the trawl gear mass and velocity
— the effective added mass and velocity.

The impact energy shall be used to determine the required testing energy for testing for the coating and possible denting of the pipeline wall thickness. In case piggy-back lines these shall also have adequate safety against trawl impacts.

4.5.1.6 Other 3rd party interference loads shall be calculated using recognised methods.

4.6 Accidental loads

4.6.1 General

4.6.1.1 Loads which are imposed on a pipeline system under abnormal and unplanned conditions and with a probability of occurrence less than 10^{-2} within a year shall be classified as accidental loads.

4.6.1.2 Typical accidental loads can be caused by:

— extreme wave and current loads
— vessel impact or other drifting items (collision, grounding, sinking, iceberg)
— dropped objects
— infrequent internal over pressure (e.g. in case of malfunction of HIPPS)
— seabed movement and/or mud slides
— explosion
— fire and heat flux
— accidental water filling due to wet buckle
— operational malfunction
— dragging anchors.

4.6.1.3 Recommended practice for size and frequency of accidental loads is given in DNVGL-RP-F107.

4.7 Design load effects

4.7.1 General

4.7.1.1 A load effect is the resulting cross-sectional loads arising as response to applied loads (e.g. weight, pressure, drag).

4.7.1.2 The magnitude of a time variant load effect to be used in a limit state criterion is defined by its probability of being exceeded, the characteristic load effect.

4.7.2 Characteristic load

4.7.2.1 The characteristic load effect is a quantified load effect to be used in the design load effect calculation. The characteristic load for time invariant loads is the nominal (average) load. The characteristic load for time variant loads is given in [4.3.6].

4.7.2.2 The characteristic load effect is composed of contributions of functional, environmental and interference load effects.

4.7.2.3 For non-weather restricted operations, the characteristic load shall be the most critical 100-year load effect

Guidance note:

The 100-year load effect implies a probability of exceedance less than 10^{-2} within a year.

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4.7.2.4 The most critical 100-year load effect is normally governed by extreme functional, extreme environmental, extreme interference or accidental load effect. Unless special evaluation is carried out to identify the most critical 100-year load effect, the characteristic load effects in Table 4-3 shall be used.

4.7.2.5 In addition to the characteristic loads defined above, the fatigue load case shall also be checked, see Table 4-3.

Table 4-3 Characteristic loads

Extreme Load	*Load effect factor combination* 1)	*Functional load*	*Environmental load*	*Interference load*	*Accidental load*
Functional load effect	a, b	100-year 2)	1-year	Associated	NA
Environmental load effect	a, b	Associated 3)	100-year 4)	Associated	NA
Interference load effect	b	Associated 3)	Associated	UB	NA
Fatigue load effect 5)	c	Associated	Associated	Associated	NA
Accidental load effect	d	Associated	Associated	Associated	BE

Characteristic load definition:

— n-year: most probable maximum in n years
— UB: upper bound
— BE: best estimate.

1) The referred load effect factor combinations are given in Table 4-4.
2) This will normally be equivalent to an internal pressure equal to the local incidental pressure combined with expected associated values of other functional loads.
3) This will normally be equivalent to an internal pressure and temperature not less than the operating pressure and the operating temperature profiles.
4) As defined in Table 4-2.
5) The fatigue load cases are;
   a) cyclic functional loading (start-up and shut-down, pressure and temperature cycles shall be represented),
   b) random environmental load (e.g. wave and current spectra, conservative pressure and temperature for the fatigue damage shall be used) and
   c) repeated interference loading (conservative pressure and temperature for the fatigue damage shall be used)

4.7.3 Design load effect

4.7.3.1 Each limit state, see [5.4], shall be checked for the design load effect.

4.7.3.2 The design load effect can generally be expressed in the following format:

$$L_{Sd} = L_F \cdot \gamma_F \cdot \gamma_c + L_E \cdot \gamma_E + L_I \cdot \gamma_F \cdot \gamma_c + L_A \cdot \gamma_A \cdot \gamma_c \qquad (4.5)$$

In specific forms, this corresponds to:

$$M_{Sd} = M_F \cdot \gamma_F \cdot \gamma_c + M_E \cdot \gamma_E + M_I \cdot \gamma_F \cdot \gamma_c + M_A \cdot \gamma_A \cdot \gamma_c \qquad (4.6)$$

$$\varepsilon_{Sd} = \varepsilon_F \cdot \gamma_F \cdot \gamma_c + \varepsilon_E \cdot \gamma_E + \varepsilon_I \cdot \gamma_F \cdot \gamma_c + \varepsilon_A \cdot \gamma_A \cdot \gamma_c \qquad (4.7)$$

$$S_{Sd} = S_F \cdot \gamma_F \cdot \gamma_c + S_E \cdot \gamma_E + S_I \cdot \gamma_F \cdot \gamma_c + S_A \cdot \gamma_A \cdot \gamma_c \qquad (4.8)$$

Guidance note:
The load combinations to the left are referred to explicitly in the limit state criteria, e.g. Equation (5.19).

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4.7.3.3 The design load effect shall be calculated for the characteristic load (see [4.7.2]) for all relevant load effect combinations and corresponding load effect factors in Table 4-4.

Guidance note:

The partial safety factors in this standard have been determined by structural reliability methods to a pre-defined failure probability. Structural reliability calculations differentiate between single joint failures (local checks) and series system failures (system effects).

These two kinds of scenarios are expressed as two different load effect combinations:

a) shall only be considered for scenarios where system effects are present

b) for local scenarios and shall always be considered.

When system effects are present, the pipeline will fail at its weakest point. Hence, the likely load shall be combined with the extreme low resistance. Applied to pipelines system effect can be expressed as the weakest link principle (where the chain gets weaker the longer the chain is). This is characterised by that the whole pipeline is exposed to the same load over time.

Applied to pipelines, system effects are present for:

— pressure containment
— collapse, in as installed configuration
— installation.

The first two are handled by the use of thickness t_1. This is also why thickness t_2 and not t_1 is used for the burst capacity in the local buckling for pressurised pipes, since it is a local check.

Regarding installation, an extreme environmental load is not likely to occur when the weakest pipe section is at the most exposed location indicating that system effects not are present. However, combined with a more representative environmental load (in the extreme case, flat sea), the whole pipeline will undergo the same deformation over time, hence, having a system effect present.

In Table 4-4, load effect factor combination a has a load effect factor of 1.2 for the functional load to cover the system effect combined with a 0.7 load effect factor for the extreme environmental load giving a more representative environmental load, applicable for the above.

Another example of where system effects are present is for reeling where the whole pipe is exposed to the same deformation (neglecting the variation in drum diameter increase). For this application, a condition load factor of 0.82 applies, giving the total load effect factor of 1.2 × 0.82 close to unity.

Hence, load combination b shall always be checked while load combination a normally is checked for installation only.

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Table 4-4 Load effect factor combinations

Limit state/load combination	*Load effect combination*		*Functional loads* [1]	*Environmental load*	*Interference loads*	*Accidental loads*
			γ_F	γ_E	γ_F	γ_A
ULS	*a*	System check[2]	1.2	0.7		
	b	Local check	1.1	1.3	1.1	
FLS	*c*		1.0	1.0	1.0	
ALS	*d*		1.0	1.0	1.0	1.0

1) If the functional load effect reduces the combined load effects, γ_F shall be taken as 1/1.1.

2) This load effect factor combination shall only be checked when system effects are present, i.e. when the major part of the pipeline is exposed to the same functional load. This will typically only apply to pipeline installation.

4.7.3.4 The condition load effect factor applies to the conditions in Table 4-5. Condition load effect factors are in addition to the load effect factors and are referred to explicitly in Equation (4.5) - Equation (4.8).

Guidance note:

Uneven seabed refers to pipeline resting on the seabed and not to installation on un-even seabed. Several condition factors may be required simultaneously, e.g. for pressure testing of pipelines on seabed, the resulting condition factor will be 1.07 · 0.93 = 1.00.

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Table 4-5 Condition load effect factors, γ_C

Condition	γ_C
Pipeline resting on uneven seabed	1.07
J-tube pull-in [1]	0.82
System pressure test	0.93
S-lay installation; Local buckling load control check on stinger[2]	0.80
Reeling installation; Displacement controlled check, seamless pipes[2]	0.77
Reeling installation; Displacement controlled check, welded pipes[2,3]	0.82
Otherwise	1.00

1) Load combination a needs not to be analysed
2) For installation both load combination a and b shall always be analysed, see also [5.8.2]
3) This factor has not been re-assessed but reflects the less uniform material properties around the circumference

4.7.4 Load effect calculations

4.7.4.1 The load effect calculations shall be based on accepted principles of statics, dynamics, strength of materials and soil mechanics.

4.7.4.2 Industry recognised calculations tools, or tools documented to provide corresponding results, should be used for design and construction analyses of the submarine pipeline system.

4.7.4.3 Model tests may be used in combination with, or instead of, theoretical calculations. In cases where theoretical methods are inadequate, model or full-scale tests may be required.

4.7.4.4 The dynamic effect shall be taken into account when determining responses to dynamic loads.

4.7.4.5 Load effects shall be split into functional, environmental, interference and accidental load effects.

4.7.4.6 The effect of statistical uncertainty due to the amount and accuracy of data shall be assessed and, if significant, shall be included in the evaluation of the characteristic load effect.

4.7.4.7 Load effect calculation should be performed applying nominal (non-corroded) cross-section values unless otherwise required by the standard or recommended practice. For displacement controlled conditions this may be non-conservative and should be evaluated. For pipelines with internal clad or liner the bending stiffness contribution should be included in the load effect calculations.

4.7.4.8 Special attention shall be given to ensure that conservative load effect calculations are performed, implying that the applied cross-section values are conservative. In case larger positive wall thickness tolerances are agreed (see Table 7-20 and Table 7-21) it should be noted that larger steel cross-sectional area will generate larger expansion forces.

4.7.4.9 The effective axial force that determines the global response of a pipeline is denoted S. Counting tensile force as positive:

$$S(p_i) = N - p_i \cdot A_i + p_e \cdot A_e = N - \frac{\pi}{4} \cdot \left(p_i \cdot (D - 2 \cdot t_2)^2 - p_e \cdot D^2\right) \quad (4.9)$$

4.7.4.10 The effective axial force of a totally restrained pipe in the linear elastic stress range based on thick wall stress formulation is:

$$S = H - \Delta p_i \cdot A_i \cdot (1 - 2 \cdot \nu) - A_s \cdot E \cdot \alpha \cdot \Delta T \quad (4.10)$$

where:

H = effective (residual) lay tension. The effective axial force in the as-laid condition when the pipe temperature and pressure is equal to as during laying.

Δp_i = internal pressure difference relative to as laid

ΔT = temperature difference relative to as laid

4.7.4.11 When non-linear material is required in the analyses for load controlled limit states the stress-strain curve shall be based on specified minimum values accounting for temperature de-rating (f_y and f_u) considered being engineering stress values. For displacement controlled or partially displacement controlled limit states additional analyses based on mean or upper bound stress-strain curves may be required to ensure an acceptable safety level. Illustration of different stress-strain properties is given in Table 1-8.

Guidance note:

The strain at f_u is normally considerably less than the fracture strain and is normally in the order of 6 to 10%. This may be determined from tests of similar material.

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4.7.4.12 Stress concentration factors (SCF) and strain concentration factors (SNCF) may be applied to the calculated load effects to reflect different aspects (local geometries, coating, variations in properties) not captured directly in the load effect calculation.

4.7.4.13 SCF's are mainly used in the linear material range and SNCF's in the non-linear material range. These may reflect local or global effects.

4.7.4.14 SNCF shall be adjusted for the non-linear stress-strain relationship for the relevant load level. Plastic strain shall be calculated from the point where the material stress-strain curve deviates from a linear relationship, see Table 1-8

4.7.4.15 Local SCF's and SNCF's may be applied to reflect:

— variations in actual material yield stress and strain hardenability between pipeline joints and in the weld metal
— local discontinuities in the weld
— welded attachments

4.7.4.16 Global SCF's and SNCF's may be applied to reflect:

— stiffening effects of coating and variations in coating thickness
— variations in cross-sectional area between pipe joints not included in the load effect calculations.

Most of these effects should be captured by the load effect calculations (like nominal diameter or nominal wall thickness difference between pipe joints e.g. buckle arrestor or wall thickness change due to safety zone).

4.7.4.17 Application of SCF and SNCF depend on the limit state and shall be applied according to Table 4-6.

Table 4-6 Application of stress concentration factors and strain concentration factors

	Stress concentration factors (SCF)		*Strain concentration factors (SNCF)*	
Limit state	Local	Global	Local	Global
Load controlled local buckling	-	-	-	-
Displacement controlled local buckling	-	Yes	-	-
Fatigue	Yes[1]	Yes[1]	Yes[1]	Yes[1]
Fracture	Yes	Yes	Yes	Yes
1) The use of SCF/SNCF shall be consistent with the SN-curve used				

4.7.4.18 Recommended practice for calculation of the SNCF/SCF for fracture assessment is given in DNVGL-RP-F108.

SECTION 5 DESIGN – LIMIT STATE CRITERIA

5.1 General

5.1.1 Objective

5.1.1.1 This section provides limit state criteria and general requirements for the submarine pipeline systems.

5.1.2 Application

5.1.2.1 This standard includes no limitations on water depth. However, when this standard is applied in deep water where experience is limited, special consideration shall be given to:

— other failure mechanisms than those given in this section
— validity of parameter range (environmental/design/operational parameters)
— dynamic effects.

5.1.2.2 This standard does not specify any explicit limitations with respect to elastic displacements or vibrations, provided that the effects of large displacements and dynamic behaviour, including fatigue effect of vibrations, operational constraints and ratcheting, are taken into account in the strength analyses and found acceptable.

5.1.2.3 This standard does not specify any limitations on pipe geometries but some limit states were developed for a limited geometry and load range that is stated with the criterion. For geometries and loads outside these limits, criteria need to be developed in accordance with the safety philosophy in Sec.2.

5.1.2.4 The local buckling limit states, see [5.4.3] to [5.4.6], are only applicable to pipelines that are straight in stress-free condition and are not applicable to e.g. bends.

5.1.2.5 For parts of the submarine pipeline system which extend onshore complementary requirements are given in App.F.

5.1.2.6 For spiral welded pipes, the following additional limitations apply:

— when supplementary requirement F (fracture arrest properties) is specified, see Sec.7, the possibility for a running fracture to continue from a weld in one pipe joint to the weld of the next pipe joint shall be assessed
— external pressure resistance should be documented
— the design shall be based on the load controlled condition, see [5.4.6], unless the feasibility for use of displacement controlled condition can be documented.

Guidance note:

The limitations to fracture arrest and load controlled condition are due to limited experience with spiral welded pipes subjected to running fracture or large strains.

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5.1.3 Systematic review

5.1.3.1 The overall requirement to systematic review in Sec.2 implies for this section:

— A clear definition of code break between components and pipeline system.
— Clear definition of the codes' pressure definitions correspondence.

— A clear description of the overall system including interfaces and responsibilities, covering both temporary and permanent phases.
— An overall review of all potential failure modes shall be conducted.
— The structural integrity and functionality of pipeline components shall comply with the safety requirements for the connected pipeline system see Sec.2.
— Pre-commissioning activities.

Guidance note:

The above will include a HAZID of the installation activity to identify potential impact on design such as selection of safety class during installation (see [10.6.7]).

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5.2 System design requirements

5.2.1 Submarine pipeline system layout

5.2.1.1 Pipelines shall be protected against impact loads from mechanical interaction.

5.2.1.2 Crossing between pipelines and pipelines or cables should be kept separated by a minimum vertical distance of 0.3 m. Potential electrical interference and associated consequences between pipelines and cables shall be considered.

5.2.1.3 The submarine pipeline system shall be protected against unacceptable damage caused by e.g. dropped objects, fishing gear, ships, anchoring etc. Protection may be achieved by one or a combination of the following means:

— concrete coating
— burial
— cover (e.g. sand, gravel, mattress)
— other mechanical protection.

5.2.1.4 Relative settlement between the protective structure and the submarine pipeline system shall be properly assessed in the design of protective structures, and shall cover the full design life of the submarine pipeline system. Adequate clearance between the pipeline components and the members of the protective structure shall be provided to avoid fouling.

5.2.1.5 Attachment to pipeline and other pressure containing parts should be welded via doubler plate and not directly to the pipe/pressure containing parts. Doubler plate should be fully encircling sleeves, if not, it shall be circular. The objective of the doubler plate is to distribute stresses in order to reduce the risk of initiating cracks into the pipe.

5.2.1.6 For structural items welded directly to pressure containing parts and doubler plates the following apply:

— Design shall be performed for all relevant failure modes, e.g. yielding, fatigue and fracture.
— For duplex stainless steels and 13Cr martensitic stainless steels a stress analysis shall be performed in each case to determine that local stresses will not initiate HISC. Recommended practice for design of duplex stainless steels is given in DNVGL-RP-F112.
— Welding directly to the pressure containing parts shall be performed in accordance with qualified welding procedures according to App.C.
— NDT shall be performed to ensure structural integrity of the pressure containing parts.
— The toe-to-toe distance from other welds shall be minimum $2 \cdot t$ or 50 mm, whichever is larger.

5.2.1.7 For doubler plates the following apply:

- The longitudinal welds of fully encircling sleeves shall be made with backing strips avoiding penetration into the main pipe material unless pre-fabricated and slid onto the pipe.
- Welds between doubler plates and pressure containing parts shall be continuous, and made in a manner minimising the risk of root cracking and lamellar tearing.

5.2.1.8 Girth welds should not be covered under doubler plates, clamps, or other items.

The requirement to not cover the girth weld is to allow for required NDT, corrosion protection (coating, anodes or premises for other corrosion evaluations) and leakage detection during FAT testing. For FAT testing based on pressure drop, see [8.7.4], the encircling sleeve is not allowed to constitute a pressure barrier, i.e. pressure built up in the void shall be monitored or avoided.

5.2.1.9 The use of mitre welds to correct angular misalignment of more than 2 degrees between the axis of two adjoining pipes is not permitted and a series of purpose made misalignments are not allowed to constitute a bend. Moments caused by the axial misalignment and axial force shall be evaluated. For loads causing yielding, detailed calculations shall be made.

5.2.1.10 For requirements to transitions, see [5.6.1.13] through [5.6.1.16].

5.2.1.11 For piggable components the internal diameter of the component shall meet the requirements imposed by the pig-train.

Guidance note:

It is recommended that bends radius are designed with a radius not less than 5 × nominal internal pipe diameter (5D bend).

3D bends may be acceptable if PIG is designed for it, typically taking into account:

- length of the pig
- pig-body diameter
- position of the seal- and guide-discs
- material and size of the discs
- position of the gauge-plate.

In addition, a trial fit to be performed.

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5.2.2 Pressure test philosophy and criteria

5.2.2.1 The pressure containment structural integrity of the pipeline system is ensured by:

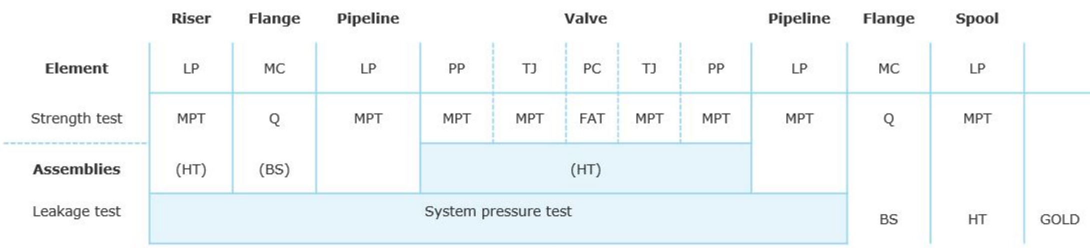
- design criteria and safety factors
- manufacturing requirements
- pressure testing all pressure containing parts by
  - strength test prior to being installed in the pipeline system; by strength pressure test (mill pressure test for pipe joints [7.5.1] and FAT/hydrostatic test for components [8.7]), or through qualification programs and
  - gross error leak test; system pressure test ([5.2.2.2] and [10.10.3]) and hydrostatic test for pipeline assemblies [7.5.1]. For single connections, making up parts of the pipelines after system pressure test, the following apply:
    - girth welds shall have additional NDT (Golden Weld), see [10.5.3]
    - mechanical components shall be back seal tested after installation.

  Unless waived by [5.2.2.3] or [7.5.1.6].

Guidance note:

The above requirements imply that each element of the pipeline system shall be both strength tested and gross error leak tested.

A typical pressure test regime may look like indicated in the following figure:



Q	Strength of item proven by qualification	MC	Mechanical connection
()	Recommended test, not mandatory	MPT	Mill pressure test
BS	Back seal test	PC	Pipeline components
FAT	Factory Acceptance Test	LP	Line pipe joint
GOLD	Golden Weld	PP	Pup-piece
HT	Hydrostatic test (of assembly)	TJ	Taper joint

The following comments apply:

— Tie-in flanges and couplings may be back-seal tested in order to reveal any leakage as early as possible. If these are not part of the system pressure test, back seal test shall be performed.

— Pipeline assemblies (risers, spools etc.) may be hydrostatically leak tested as a risk reducing measure in order to reveal any leakage as early as possible. If these pipeline assembles are not part of the system pressure test, hydrostatic leak test shall be performed.

The expressions related to the system pressure test have been altered over a few revisions but are now referred to as leakage test. The reason why it is now considered being a leakage test is that the girth weld, which is the only part not previously tested, has a very low utilisation during the system pressure test, less than 48% of SMYS and is therefore very unlikely to fail structurally.

The reason why this term has changed of the revisions is that ISO 13623 operates with two pressure levels for the system pressure test (pressure test). The strength test is 1.25 times the design pressure and shall be kept for a minimum of 1 hour. The leak test is 1.1 times the design pressure and shall be kept for a minimum of 8 hours.

DNVGL-ST-F101 only operates with one pressure level 1.05 times the incidental pressure (1.15 times the design pressure) which shall be kept for minimum 24 hours.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.2.2 The pipeline system shall be system pressure tested after installation in accordance with [10.10.3] unless this is waived by agreement in accordance with [5.2.2.3] below. The local test pressure (p_{lt}) during the system pressure test should fulfil the following requirement for the safety class during normal operation:

$$p_{lt} \geq \alpha_{spt} \, p_{li} \qquad (5.1)$$

α_{spt} see Table 5-8.

Note that a system test pressure less than the above may reduce the allowable incidental pressure as given by Equation (5.6) and Equation (5.7).

Guidance note:

With an incidental pressure of 10% above design pressure, the above gives a system test pressure of approximately 1.15 times the local design pressure (for safety class medium and high) at the highest point (given that the test medium density is higher than α_{spt} * density of the medium in operation of the pipeline system part tested), see Table 1-8.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

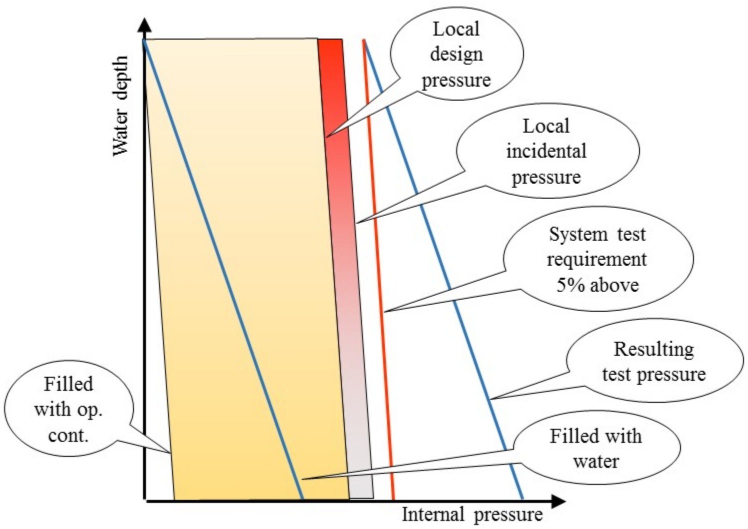


Figure 5-1 Illustration of local pressures and requirements to system pressure test

5.2.2.3 For pipelines where the disadvantages with the system pressure test are extraordinary, alternative means to ensure the same level of integrity as with the system pressure test are allowed by agreement.

Alternative means to the system pressure test may be considered when all the following criteria have been met:

— The pipeline section does not contain non-welded connections unless these have been separately tested after installation in the pipeline system.
— The mill pressure test requirement of [7.5.1] has been met and not waived in accordance with [7.5.1.6].
— Extensive experience with similar pipelines documenting a good track record with respect to defects and leakages during system pressure test. This implies that:
    — Only C-Mn steel pipelines with a steel grade less than - or equal to X70 may be considered.
    — Only pipelines consisting of seamless or SAW pipe joints may be considered.
    — Welding, including repair, by cellulosic electrodes is not allowed.
    — The pipeline shall not be exposed to nominal tensile longitudinal strains above 0.4% from mill testing to commissioning.

5.2.2.4 The alternative means shall be established by use of a systematic approach, e.g. FMECA. It shall be demonstrated that the identified failure modes, i.e. the gross errors and defects which may be revealed by the system pressure test, will be mitigated or revealed by the alternative means.

5.2.2.5 A risk assessment shall be carried out addressing not only the risk related to the elements of the above systematic approach, but also other aspects that are affected by replacing the system pressure test. Typical other aspects include consequences of accidental water ingress during construction, cleaning of pipe, interfaces and contractual issues. The systematic approach and the risk assessment shall lead to a technical assurance program that is implemented and followed up in all relevant phases.

5.2.2.6 During system pressure test, all limit states for safety class low shall be satisfied, see [5.4].

5.2.2.7 Recommended practice for system pressure test including all pre-commissioning activities is given in DNVGL-RP-F115.

5.2.3 Monitoring/inspection during operation

5.2.3.1 The parameter safety envelope established in the conceptual phase, see [3.3.1] and [5.4.2], shall be extended/modified in the design phase by the parameters which could violate limit states of a pipeline system. These shall be monitored, inspected and evaluated with a frequency which enables remedial actions to be carried out before the system is damaged, see Sec.11.

Guidance note:

As a minimum the monitoring/inspection frequency should be such that the pipeline system will not be endangered due to any realistic degradation/deterioration that may occur between two consecutive inspection intervals.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.3.2 Special focus shall be on monitoring and inspection strategies for live pipeline systems i.e. pipeline systems that are designed to change the configuration during its design life.

Guidance note:

Example of such systems may be pipelines that are designed to experience global buckling or possible free-span developments or potential pipeline walking.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.3.3 Instrumentation of the pipeline system may be required when visual inspection or simple measurements are not considered practical or reliable, and available design methods and previous experience are not sufficient for a reliable prediction of the performance of the system.

5.2.3.4 Operating requirements affecting safety and reliability of the pipeline system shall be identified during the design phase, and shall be documented in the DFI Resumé and reflected in the PIM system.

5.3 Design format

5.3.1 General

5.3.1.1 The design format in this standard is based on a load and resistance factor design (LRFD) format.

5.3.1.2 The fundamental principle of the LRFD format is to verify that design load effects, L_{Sd}, do not exceed design resistances, R_{Rd}, for any of the considered failure modes in any load scenario:

$$f\left(\left(\frac{L_{Sd}}{R_{Rd}}\right)_i\right) \leq 1 \qquad (5.2)$$

Where the fractions *i* denotes the different loading types that enters the limit state.

5.3.1.3 A design load effect is obtained by combining the characteristic load effects from the different load categories and certain load effect factors, see [4.7].

5.3.1.4 A design resistance is obtained by dividing the characteristic resistance by resistance factors that depends on the safety class, reflecting the consequences of failures, see [5.3.2].

5.3.1.5 Design criteria in this standard are based on pipe statistical properties resulting from construction based on this standard.

Guidance note:

Use of e.g. other line pipe specifications need therefor to be assessed

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.3.2 Design resistance

5.3.2.1 The design resistance, R_{Rd}, can generally be expressed in the following format:

$$R_{Rd} = \frac{R_c(t_c, f_c, O_o)}{\gamma_m \cdot \gamma_{SC,i}} \tag{5.3}$$

where:

R_c	=	the characteristic resistance
f_c	=	the characteristic material strength, see Equation (5.4) and Equation (5.5)
t_c	=	the characteristic thickness, see Table 5-5 and Table 5-6
O_0	=	the out of roundness of the pipe, prior to loading
γ_m	=	the material factor (not used for displacement controlled criteria), see Table 5-1
$\gamma_{SC,i}$	=	the partial resistance factor, see Table 5-2

5.3.2.2 Ovality of the pipeline is defined in Equation (5.14). This will affect the structural capacity of the pipeline and shall be taken as the maximum ovality prior to loading. Advantage of an ovality less than 0.5% is not allowed. Ovality in excess of 3% shall be assessed in line with [5.4.12].

5.3.2.3 The material resistance factor, γ_m, is dependent on the limit state category and is defined in Table 5-1.

Table 5-1 Material resistance factor, γ_m

Limit state category[1)]	*SLS/ULS/ALS*	*FLS*
γ_m	1.15	1.00
1) The limit states (SLS, ULS, ALS and FLS) are defined in [5.4].		

5.3.2.4 Based on potential failure consequences the pipeline shall be classified into a safety class see [2.3.4]. This will be reflected in the safety level by the safety class resistance factor $\gamma_{SC,i}$ given in Table 5-2.

Guidance note:

The safety class may vary for different phases and different locations.

The safety class resistance factors for pressure containment as listed in Table 5-2 are based on the corresponding hoop stress design factors for offshore pipelines as given in the referenced ISO 13623 standard for pipeline transport systems. As such the bursting utilisation using this document will be in line with what has been the industry practice for decades and represents a failure rate for such pipeline systems that has been perceived as acceptable for all stakeholders including the society at large. When it comes to other failure modes/limit states calibration of safety factors using structural reliability analyses has concluded with the same safety class resistance factors as for pressure containment for safety classes Low and Medium while a slightly different value for safety class High.

DNVGL-ST-F201 utilises the same safety class resistance factor for all failure modes/limit states within the same safety class, i.e. it does not make any difference between pressure containment and the other limit states. The main reason for this difference towards this standard is that DNVGL-ST-F201 refers to another ISO standard than this standard, namely the ISO 13628-7 for WO/C risers which has a somewhat different burst criterion than ISO 13623 and is allowing a somewhat higher utilisation with respect to bursting.

As such the different safety class resistance factors for pressure containment and safety class high in this standard and DNVGL-ST-F201 are explained by the different utilisation in the underlying ISO standards. Another more practical explanation is that it can be claimed that the system effect is more significant for a pipeline in location class 2 than for a riser. For a riser it is typically just a few joints in the splash zone that is most heavily utilised, while for a pipeline it is normally the whole length in the location class 2.

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Table 5-2 Safety class resistance factors, γ_{SC}

Limit state	*Safety class resistance factor*	*Safety class*		
		Low	*Medium*	*High*
Pressure containment 1)	$\gamma_{SC,PC}$	1.046 2),3)	1.138	1.308 4)
Local buckling, collapse and load controlled	$\gamma_{SC,LB}$	1.04	1.14	1.26
Local buckling, displacement controlled	$\gamma_{SC,DC}$	2.0	2.5	3.3

1) The number of significant digits is given in order to comply with the ISO usage factors.
2) Safety class low will be governed by the system pressure test which is required to be 3% above the incidental pressure. Hence, for operation in safety class low, the resistance factor will effectively be minimum 3% higher.
3) For system pressure test, α_U shall be equal to 1.00, which gives an allowable hoop stress of 96% of SMYS both for materials fulfilling supplementary requirement U and those not.
4) For parts of pipelines in location class 1, resistance safety class medium may be applied (1.138).

5.3.2.5 Possible beneficial strengthening effect of weight coating on a steel pipe shall not be taken into account in the characteristic resistance, unless the strengthening effect is documented. Coating which adds significant bending stiffness to the pipe may increase the stresses/strains in the pipe at any discontinuity in the coating (e.g. at field joints). When appropriate, this effect shall be taken into account.

5.3.2.6 Possible beneficial strengthening effect of cladding or liner on a steel pipe shall not be taken into account in the characteristic resistance, unless the strengthening effect is documented.

5.3.3 Characteristic material properties

5.3.3.1 Characteristic material properties shall be used in the resistance calculations. The yield stress and tensile strength in the limit state formulations shall be based on the engineering stress-strain curve.

5.3.3.2 The characteristic material strength f_y and f_u, values to be used in the limit state criteria are:

$$f_y = (SMYS - f_{y,temp}) \cdot \alpha_U \tag{5.4}$$

$$f_u = (SMTS - f_{u,temp}) \cdot \alpha_U \tag{5.5}$$

Where:

$f_{y,temp}$ and $f_{u,temp}$	=	the de-rating values due to the temperature of the yield stress and the tensile strength respectively, see [5.3.3.4].
α_U	=	the material strength factor, see Table 5-3.

5.3.3.3 The different mechanical properties refer to room temperature unless otherwise stated.

5.3.3.4 The material properties shall be selected with due regard to material type and potential temperature and/or ageing effects and shall include:

— yield stress
— tensile strength
— Young's modulus
— temperature expansion coefficient.

For C-Mn steel and 13Cr this shall be considered for temperatures above 50°C, and for 22Cr and 25Cr for temperatures above 20°C.

Guidance note:
Field joint coating application during installation may also impose temperatures in excess of the above.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:
If no other information of de-rating effects on the yield stress exist the recommendations for C-Mn steel, 22Cr and 25Cr Figure 5-2 may be used. For 13Cr testing is normally required.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:
If no other information on de-rating effect of the ultimate stress exists, the de-rating of the yield stress can be conservatively applied.

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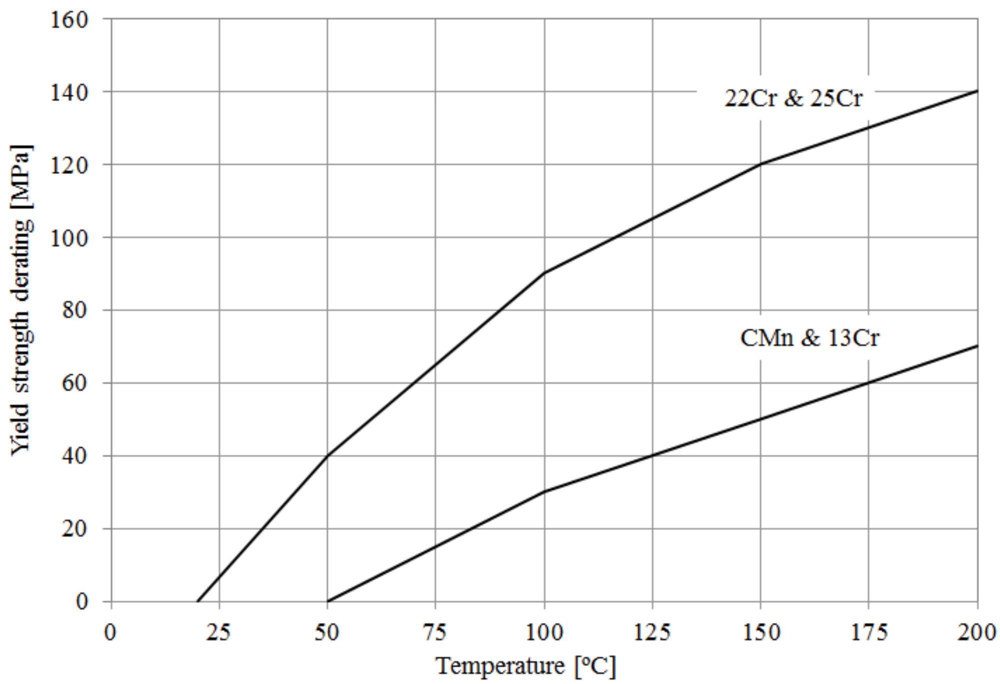

Figure 5-2 Proposed de-rating values for yield stress of C-Mn, 13Cr, 22Cr and 25Cr

5.3.3.5 Any difference in the de-rating effect of temperature for tension and compression shall be accounted for.

Guidance note:

Difference in de-rating effect for tension and compression has been experienced on 13Cr steel material.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.3.3.6 The material strength factor, α_U, depend on Supplementary requirement U as shown in Table 5-3. For upgrade of material, see [7.9.5]

Table 5-3 Material strength factor, α_U

Loading scenario	α_U	
	Normal	*Supplementary requirement P*
System pressure test	1.00	1.00
Other	0.96	1.00

5.3.3.7 For manufacturing processes which introduce cold deformations giving different strength in tension and compression, a fabrication factor, α_{fab}, shall be determined. If no other information exists, maximum fabrication factors for pipes manufactured by specific processes are given in Table 5-4.

The fabrication factor may be increased through heat treatment or external cold sizing (compression), if documented.

Table 5-4 Maximum fabrication factor, α_{fab}

Pipe	*Seamless*	*UO, TRB, ERW and HFW*	*UOE*
α_{fab}	1.00	0.93	0.85

5.3.4 Characteristic wall thickness

5.3.4.1 Two different characterisations of the wall thickness are used; t_1 and t_2 and are referred to explicitly in the design criteria. Thickness t_1 is used where failure is likely to occur in connection with a low capacity (i.e. system effects are present) while thickness t_2 is used where failure is likely to occur in connection with an extreme load effect at a location with average thickness. These are defined in Table 5-5.

Table 5-5 Characteristic wall thickness

Characteristic thickness	*Prior to operation*[1)]	*Operation*[2)]
t_1	$t-t_{fab}$	$t-t_{fab}-t_{corr}$
t_2	t	$t-t_{corr}$
1) Is intended when there is negligible corrosion (mill pressure test, construction (installation) and system pressure test condition). If corrosion exist, this shall be subtracted similar to as for operation. 2) Is intended when there is corrosion.		

5.3.4.2 If relevant, erosion allowance shall be compensated for in the similar way as the corrosion allowance.

5.3.4.3 Minimum wall thickness independent on limit state requirements are given in Table 5-6.
The minimum wall thickness requirement is based on failure statistics, which clearly indicate that impact loads and corrosion are the most likely causes of failure and have the decisive effect on thickness design (not D/t_2).

Table 5-6 Minimum wall thickness requirements

Safety class	*Location class*	*Nominal thickness*
High	2	Minimum 12 mm unless equivalent protection against accidental loads, other external loads and excessive corrosion is provided by other means. For diameters less than 219 mm (8”) minimum wall thickness can be less but shall be determined including the above considerations.

5.3.4.4 Wall thickness for on bottom stability calculations is given in [5.5.5.2].

5.3.4.5 The wall thickness should be sufficient to ensure no damage during handling.

Guidance note:

For pipelines with D/t<45 this is normally not a problem with exception for very small diameter pipelines.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4 Limit states

5.4.1 General

5.4.1.1 All relevant limit states (failure modes) shall be considered in design for all relevant phases and scenarios listed in Sec.4.

Guidance note:

Limit state design implies that the pipeline is checked for all relevant failure modes. The failure modes vary in criticality and are split into the following limit state categories:

- serviceability limit state category
- ultimate limit state category
  - fatigue limit states
  - accidental limit state.

Fatigue and accidental limit states are sub-categories of ultimate limit states accounting for accumulated cyclic load effects and accidental (in-frequent) loads respectively.

Pipeline limit state checks are typically split into different scenarios. A scenario is not identical with a limit state, and may include different limit states. A typical link between scenarios and limit states is given in Table 5-7.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 5-7 Typical link between scenarios and limit states

	Ultimate limit states							*Serviceability limit states*			
	Fracture			*Instability*							
				Local buckling							
Scenario	Pressure containment	Fatigue	Fracture	System collapse	Propagating buckling	Combined loading	Global buckling	Dent	Ovalisation	Accumulated deformation	Displacement
Wall thickness design	X			X	X						
Installation		X	X	X	X	X			X		X
Free-span	(X)	X	X			X					
Trawling/3rd party	(X)					X		X			
On bottom stability	(X)	(X)	(X)			(X)		(X)	(X)		X[1]
Pipeline Walking						X					
Global Buckling	(X)	X	X			X				X	
1) Typically applied as a simplified way to avoid checking each relevant limit state											

5.4.1.2 In case no specific design criterion is given for a specific limit state this shall be developed in compliance with the safety philosophy in Sec.2.

5.4.2 Pressure containment (bursting)

5.4.2.1 The pressure containment shall fulfil the following criteria:

$$p_{li} - p_e \leq Min\left(\frac{p_b(t_1)}{\gamma_m \cdot \gamma_{SC,PC}} ; \frac{p_{lt}}{\alpha_{spt}} - p_e ; \frac{p_{mpt} \cdot \alpha_U}{\alpha_{mpt}} \right) \tag{5.6}$$

$$p_{lt} - p_e \le Min\left(\frac{p_b(t_1)}{\gamma_m \cdot \gamma_{SC,PC}}; p_{mpt}\right) \tag{5.7}$$

unless:

— the mill test has been waived in accordance with [7.5.1.6],
— the mill test pressure has been reduced in accordance with [7.5.1.4], or
— the system pressure test has been replaced by alternative means in accordance with [5.2.2.3].

α_{mpt} and α_{spt} are given in Table 5-8.

Table 5-8 Pressure test factors

Safety class during operation	*Low*	*Medium*	*High*
α_{mpt} [1]	1.000	1.088	1.251
α_{spt}	1.03	1.05	1.05

1) This factor is given by:

$$\frac{\gamma_m \cdot \gamma_{SC,PC} \cdot 0.96}{2/\sqrt{3}}$$

5.4.2.2 The pressure containment resistance $p_b(t)$ is given by:

$$p_b(t) = \frac{2 \cdot t}{D - t} \cdot f_{cb} \cdot \frac{2}{\sqrt{3}} \tag{5.8}$$

where:

$$f_{cb} = Min\left[f_y; \frac{f_u}{1.15}\right] \tag{5.9}$$

Guidance note:

In the above formulae, t shall be replaced by t_1 when used in Equation (5.7) and t_2 when used in Equation (5.19).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.2.3 Reduction in pressure containment resistance due to true compressive forces (load controlled), N, shall be considered. Recommended practice for reduction in pressure containment capacity due to compressive axial stresses is given in DNVGL-RP-F101.

5.4.3 Local buckling - general

5.4.3.1 Local buckling (pipe wall buckling) implies gross deformation of the cross-section. The following criteria shall be fulfilled:

— system collapse (external over pressure only)
— propagation buckling (external over pressure only)
— combined loading criteria, i.e. interaction between external or internal pressure, axial force and bending moment.

These will be given in the following sub-sections.

5.4.3.2 Large accumulated plastic strain may aggravate local buckling and shall be considered.

5.4.4 Local buckling – system collapse (external over pressure only)

5.4.4.1 The external pressure at any point along the pipeline shall fulfil the following criterion (system collapse check):

$$p_e - p_{\min} \leq \frac{p_c(t_1)}{\gamma_m \cdot \gamma_{SC,LB}} \qquad (5.10)$$

where:

p_{min} = the minimum internal pressure that can be sustained. This is normally taken as zero for as-laid pipeline.

Guidance note:

The system collapse will occur at the weakest point in the pipeline. This will normally be represented by f_y and the minimum wall thickness, t_1.

A seamless produced line pipe's weakest section may not be well represented by the minimum wall thickness since it is not likely to be present around the whole circumference. A larger thickness, between t_1 and t_2, may be used for such pipes if this can be documented representing the lowest collapse capacity of the pipeline.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.4.2 The characteristic collapse pressure (p_c) (resistance for external over pressure) shall be calculated as:

$$\left[p_c(t) - p_{el}(t)\right]\left[p_c(t)^2 - p_p(t)^2\right] = p_c(t) \cdot p_{el}(t) \cdot p_p(t) \cdot O_0 \cdot \frac{D}{t} \qquad (5.11)$$

where:

$$p_{el}(t) = \frac{2 \cdot E \cdot \left(\frac{t}{D}\right)^3}{1-\nu^2} \quad (5.12)$$

$$p_p(t) = f_y \cdot \alpha_{fab} \cdot \frac{2 \cdot t}{D} \quad (5.13)$$

$$O_0 = \frac{D_{\max} - D_{\min}}{D} \quad (5.14)$$

not to be taken less than 0.5%.
Ovalisation caused during the construction phase shall be included in the total ovality to be used in design. Ovalisation due to external water pressure or bending moment shall not be included.

α_{fab} = the fabrication factor, see Table 5-4.

Guidance note:
In the above formulas, t shall be replaced by t_1 or t_2 as given in the design criteria.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.5 Local buckling - propagation buckling

5.4.5.1 Propagation buckling cannot be initiated unless local buckling has occurred. In case the external pressure exceeds the criterion given below, buckle arrestors should be installed and spacing determined based on cost and spare pipe philosophy. The propagating buckle criterion reads:

$$p_e - p_{\min} \leq \frac{p_{pr}(t_2)}{\gamma_m \cdot \gamma_{SC,LB}} \quad (5.15)$$

where:

p_{min} is the minimum internal pressure that can be sustained. This is normally taken as zero for as-laid pipeline.

$$p_{pr} = 35 \cdot f_y \cdot \alpha_{fab} \cdot \left(\frac{t_2}{D}\right)^{2.5} \quad (5.16)$$

Applies for
$15 < D/t_2 < 45$

α_{fab} is the fabrication factor, see Table 5-4.

Guidance note:

Collapse pressure, p_c, is the pressure required to buckle a pipeline.

Initiation pressure, p_{init}, is the pressure required to start a propagating buckle from a given buckle. This pressure will depend on the size of the initial buckle.

Propagating pressure, p_{pr}, is the pressure required to continue a propagating buckle. A propagating buckle will stop when the pressure is less than the propagating pressure.

The relationship between the different pressures are: $p_c > p_{init} > p_{pr}$

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.5.2 A buckle arrestor capacity depends on

— propagating buckle resistance of adjacent pipe
— propagating buckle resistance of an infinite buckle arrestor
— length of arrestor.

An integral buckle arrestor may be designed by:

$$p_e \leq \frac{p_x}{1.1 \cdot \gamma_m \cdot \gamma_{SC,LB}} \quad (5.17)$$

where the crossover pressure p_x is:

$$p_X = p_{pr} + \left(p_{pr,BA} - p_{pr}\right) \cdot \left[1 - EXP\left(-20 \frac{t_2 \cdot L_{BA}}{D^2}\right)\right] \quad (5.18)$$

where:

$p_{pr,BA}$ = the propagating buckle capacity of an infinite arrestor. This is calculated by Equation (5.16) with the buckle arrestor properties

L_{BA} = buckle arrestor length
(Other parameters refers to line pipe properties, see [13.4.8]).

Guidance note:

The propagating buckle criterion, Equation (5.15), corresponds to a nominal failure probability that is one order of magnitude higher than the target nominal failure probability. This is because it is dependent on an initiating even. However, for a buckle arrestor, it is recommended to have a larger confidence and a safety class higher than for the propagating pressure is recommended.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6 Local buckling - combined loading criteria

5.4.6.1 Differentiation is made between:

— load controlled condition (LC condition)
— displacement controlled condition (DC condition).

Different limit states apply to these two conditions.

Guidance note:

What is required to document the local buckling capacity for pipelines outside the D/t range of 15-45, is partly discussed in [13.4.9] but is further outlined below. The current formulation has been developed from experiments and a set of FE-analyses of straight pipes with 15<D/t<60. The main failure mode for this formulation is maximum moment capacity based on gross ovalisation of the pipe. In this range wrinkling, i.e. local wave-shaped deformation on the compressive side, may also be experienced but will normally occur beyond the point of maximum moment capacity and, hence, not affecting the above defined capacity. For higher D/t this wrinkling failure mode may be triggered earlier by imperfections like misalignment over the girth weld. This was not modelled in the FE analyses referred to above, and it is considered being likely to happen above D/t=45, hence the limitation. For D/t>45 it is therefore required to check the possibility that the established high-low criterion will not trigger this failure mode and give a lower capacity. Alternatively it is needed to determine the capacity accounting for this type of imperfection and failure mode. To do this, a FE-model capable of modelling this failure mode should be established and; • Reproducing the capacity for D/t=45 • Determine the capacity for the actual D/t • Apply this reduction (i.e. b/a) to the local buckling capacity for D/t=45 By applying the reduction, any offset in models is avoided. If the difference between this standard's capacity at D/t=45 deviates significantly from the FE results at this D/t value, this needs to be assessed and the difference identified. For D/t<15 a similar exercise is required, but it is not required to analyse any high-low trigger mechanism.

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5.4.6.2 A load-controlled condition is one in which the structural response is primarily governed by the imposed loads.

5.4.6.3 A displacement-controlled condition is one in which the structural response is primarily governed by imposed geometric displacements.

Guidance note:

A pipeline checked for displacement controlled criteria will typically have tensile strains in excess of 0.4% and fracture assessment is then required, see [5.4.8].

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6.4 A load controlled design criterion can always be applied in place of a displacement controlled design criterion.

Guidance note:

An example of a purely displacement-controlled condition is a pipeline bent into conformity with a continuous curved structure, such as a J-tube. In that case, the curvature of the pipe axis is imposed but the circumferential bending that leads to ovalisation is determined by the interaction between the curvature of the axis and the internal forces induced by the curvature.

A less clear-cut example is a pipeline in contact with the rollers of a lay barge stinger. On a large scale, the configuration of the pipeline has to conform to the rollers, and in that sense is displacement controlled. On a local scale however, bending of the pipe between the rollers is determined by the interaction between weight and tension and is load-controlled. Contact with the rollers will further reduce the capacity. The stinger tip will, however, always be load controlled.

Another intermediate case is an expansion spool in contact with the seabed. Pipeline expansion induced by temperature and pressure imposes a displacement at the end of the spool. The structural response of the spool itself has little effect on the imposed expansion displacement, and the response is primarily displacement-controlled. However, the lateral resistance to movement of the spool across the seabed also plays a significant part and induces a degree of load control.

System effect has also a slightly different effect in local buckling – combined loading than for bursting and collapse. A uniform moment/curvature cannot be applied to the whole pipeline at once but will typically occur as a peak moment moving along the pipeline. This applies to sag bend, stinger and reeling. Local buckling – combined loading will then be governed by the maximum moment capacity variation along the pipe. This will occur a small distance (typically in the order of a diameter) into the weak part, when the peak moment moves from strong to weak section. For such applications, more detailed assessment can be based on a weak link evaluation, where this weak link is the extreme variation from one joint to another.

The answer to the question on if a condition is load controlled or displacement controlled is impossible since the questions in wrong, the question should be; how can one take partial benefit of that a condition is partially displacement controlled element? On a general basis this needs sensitivity analyses. A load controlled criterion can, however, always be applied

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:

If the design is based on extreme variation from one joint to the other, benefit may be taken from selection of matching, as closely as possible, wall thickness/diameter of the pipes and the actual yield stress on both sides of the weld.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6.5 Pipe members subjected to bending moment, effective axial force and internal over pressure shall be designed to satisfy the following criterion at all cross-sections:

$$\left[\gamma_m \cdot \gamma_{SC,LB} \cdot \frac{|M_{Sd}|}{\alpha_c \cdot M_p(t_2)} + \left(\gamma_m \cdot \gamma_{SC,LB} \cdot \frac{S_{Sd}(p_i)}{\alpha_c \cdot S_p(t_2)}\right)^2\right]^2 + \left[\gamma_p \cdot \frac{p_i - p_e}{\alpha_c \cdot p_b(t_2)}\right]^2 \leq 1 \tag{5.19}$$

Applies for:

$15 \leq D/t_2 \leq 45$

$P_i > P_e$

$|S_{Sd}|/S_p < 0.4$

where:

M_{Sd}	=	the design moment load effect, see Equation (4.6)
S_{Sd}	=	the design effective axial force load effect, see Equation (4.8)
p_i	=	the internal pressure, see Table 4-3
p_e	=	the external pressure, see [4.2.2]
p_b	=	the burst pressure, Equation (5.8)
S_p and M_p	=	denote the plastic capacities for a pipe defined by:

$$S_p(t) = f_y \cdot \pi \cdot (D - t) \cdot t \tag{5.20}$$

$$M_p(t) = f_y \cdot (D - t)^2 \cdot t \tag{5.21}$$

$$\alpha_c = (1 - \beta) + \beta \cdot \frac{f_u}{f_y} \tag{5.22}$$

$$\gamma_p = \begin{cases} 1 - \beta & \frac{P_i - P_e}{P_b} \leq \frac{2}{3} \\ 1 - 3 \cdot \beta\left(1 - \frac{P_i - P_e}{P_b}\right) & \frac{P_i - P_e}{P_b} > \frac{2}{3} \end{cases} \tag{5.23}$$

$$\beta = \frac{60 - D/t_2}{90} \tag{5.24}$$

α_c is a flow stress parameter and γ_p account for effect of D/t_2 ratio.

Guidance note:

For applications outside the axial load limitations, see DNVGL-ST-F201.

The left hand side of the combined loading criterion is referred to as interaction ratio in order not to mix it with unity check. In a unity check, the loads are normally directly proportional to the utilisation while the axial load and internal pressure are squared in this criterion.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6.6 If the pipeline in addition to the axial load, pressure and moment also has a lateral point load, this should be included by a modification of the plastic moment capacity as follows:

$$M_{p,\text{pointload}} = M_p \cdot \alpha_{pm} \tag{5.25}$$

where:

α_{pm} = plastic moment reduction factor accounting for point load.

$$\alpha_{pm} = 1 - \frac{D/t_2}{130}\frac{R}{R_y} \tag{5.26}$$

R = reaction force from point load

$$R_y = 3.9 \cdot f_y \cdot t_2^{\,2} \tag{5.27}$$

Applies for $R/R_y<0.5$

5.4.6.7 Pipe members subjected to bending moment, effective axial force and external overpressure shall be designed to satisfy the following criterion at all cross-sections:

$$\left[\gamma_m \cdot \gamma_{SC,LB} \cdot \frac{|M_{Sd}|}{\alpha_c \cdot M_p(t_2)} + \left(\gamma_m \cdot \gamma_{SC,LB} \cdot \frac{S_{Sd}(p_i)}{\alpha_c \cdot S_p(t_2)}\right)^2\right]^2 + \left[\left(\gamma_m \cdot \gamma_{SC,LB} \cdot \frac{p_e - p_{\min}}{p_c(t_2)}\right)\right]^2 \leq 1 \tag{5.28}$$

Applies for
$15 \leq D/t_2 \leq 45$
$P_{min} < P_e$
$|S_{Sd}|/S_p < 0.4$

where:

p_{min} = the minimum internal pressure that can be sustained. This is normally taken as zero for installation except for cases where the pipeline is installed water filled

p_c = the characteristic collapse pressure, Equation (5.10). This shall be based on thickness t_2.

Guidance note:

For applications outside the axial load limitations, see DNVGL-ST-F201

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6.8 Pipe members subjected to longitudinal compressive strain due to applied displacements and internal over pressure shall be designed to satisfy the following criterion at all cross-sections:

$$\epsilon_{Sd} \leq \epsilon_{Rd} = \frac{\epsilon_c(t_2, p_{\min} - p_e)}{\gamma_{SC,DC}} \tag{5.29}$$

Applies for
$15 \leq D/t_2 \leq 45$
$p_{min} \leq p_e$

where:

ε_{Sd} = design compressive strain Equation (4.7)

$$\epsilon_c(t, p_{\min} - p_e) = \tilde{\epsilon} \cdot \alpha_p \cdot \alpha_{mat} \tag{5.30}$$

$$\tilde{\varepsilon} = \left(\frac{t}{D} - 0.01\right)\left(\frac{0.85}{\alpha_h}\right)^{1.5} \cdot \alpha_{gw} \tag{5.31}$$

$$\alpha_p = 1 + \frac{20}{3} \cdot \left(\frac{p_{\min} - p_e}{p_b(t)}\right)^2 \tag{5.32}$$

for material having a Lüder plateau:

$$\alpha_{mat} = \begin{cases} 1 & \tilde{\varepsilon} \cdot \alpha_p > 0.025 \\ 0.6 & \tilde{\varepsilon} \cdot \alpha_p < 0.015 \\ 0.6 + 40 \cdot \left(\tilde{\varepsilon} \cdot \alpha_p - 0.015\right) & else \end{cases} \tag{5.33}$$

For other materials:

$$\alpha_{mat} = 1.0$$

where:

p_{min} = minimum internal pressure that can be continuously sustained with the associated strain
$\gamma_{SC,DC}$ = strain resistance factor, Table 5-2
α_h =

$$\left(\frac{R_{t0,5}}{R_m}\right)_{max}$$

Table 7-5 and Table 7-11
α_{gw} = see Sec.13.

5.4.6.9 If the pipeline in addition to the axial load, pressure and curvature also has a lateral point load, this should be included by a modification of the curvature capacity as follows:

$$\epsilon_{c,\text{point}} = \epsilon_c\left(t, p_{\min} - p_e\right)\left(1 - \sqrt{\frac{\frac{D}{t_2}}{80} \cdot \frac{R}{R_y}}\right) \tag{5.34}$$

5.4.6.10 Pipe members subjected to longitudinal compressive strain (bending moment and axial force) and external over pressure shall be designed to satisfy the following criterion at all cross-sections:

$$\left[\frac{\epsilon_{Sd}}{\frac{\epsilon_c\left(t_2, 0\right)}{\gamma_{SC,\,DC}}}\right]^{0.8} + \frac{p_e - p_{\min}}{\frac{p_c\left(t_2\right)}{\gamma_m \cdot \gamma_{SC,\,LB}}} \leq 1 \tag{5.35}$$

Applies for:

$15 \leq D/t_2 < 45$
$p_{min} < p_e$

Guidance note:

For $D/t_2 < 23$, the utilisation may be increased provided that full scale testing, observation, or former experience indicate sufficient safety margin in compliance with this standard.

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Guidance note:

System effects are normally not present for local buckling considerations and, hence, t_2 should be used. However, for reeling, a large portion of the pipeline will be exposed to similar curvature and load combination "a" shall be used combined with the condition factor and the nominal thickness can be used also for this criteria. The thickness and yield stress variation along the pipe, in particular between two pipe joints should be evaluated in addition to this system effect.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.6.11 A higher probability of failure corresponding to a serviceability limit state may be allowed during the installation phase provided that:

— aids to detect buckle are provided
— repair of potential damage is feasible and may be performed during laying
— buckle arrestors are installed if the external pressure exceeds the initiation propagating pressure.

Relevant resistance factors may then be calibrated according to the SLS requirements in Sec.2.

5.4.7 Global buckling

5.4.7.1 Global buckling implies buckling of the pipe as a bar in compression.

5.4.7.2 The effect of internal and external pressures should be taken into account using the concept of an effective axial force, see [4.7.4]. The procedure is as for ordinary compression members in air.

5.4.7.3 Distinction shall be made between load-controlled and displacement-controlled global buckling.

Load controlled global buckling condition is characterised by that the applied load is independent on the deflection of the pipeline

Displacement controlled, or partially displacement controlled global buckling condition is characterised by that the major part of the applied load is dependent on the deflection of the pipeline. Expansion force due to pressure and temperature are examples of such.

5.4.7.4 Load-controlled global buckling may be designed in accordance with DNVGL-OS-C101.

5.4.7.5 For displacement controlled global buckling, see [5.5.3].

5.4.8 Fatigue and fracture limit state

5.4.8.1 The submarine pipeline system shall have adequate safety against fracture failures within the design life of the system. This is in general achieved by selecting materials with adequate fracture toughness properties, tensile properties and weld quality combined with sound design principles.

5.4.8.2 The fatigue and fracture limit state is in general applicable to all types of materials specified in Table 1-1 as long as the representative materials properties needed to perform the assessments are known or established. Welds are in general most critical considering the fatigue and fracture limit state because welds typically have higher stresses due to stress concentrations and weld residual stresses and may include flaws. This may result in shorter initiation time for fatigue crack growth, tearing or unstable fracture in case of high stresses/strains combined with low fracture toughness properties.

5.4.8.3 Special consideration shall be given to the fatigue assessment of construction details likely to cause stress concentrations, and to the possibility of having low-cycle high strain fatigue. The specific design criterion to be used depends upon the analysis method, which may be categorized into:

— methods based upon fatigue tests (typically dedicated S-N curves) (see [5.4.8.7]- [5.4.8.14])
— methods based upon fracture mechanics (see [5.4.8.5], [5.4.8.6] and [5.4.8.15]-[5.4.8.18]).

Guidance note:

S-N based and fracture mechanics based fatigue crack growth assessments are different approaches with somewhat different objectives. Fatigue analyses based on S-N curves are most applicable for evaluating fatigue initiation from weld toes or other geometrical stress concentrations that are included in the actual S-N curve. Fatigue assessments based on fracture mechanics is based on the assumption that there is a flaw in the material and that this flaw will grow as a fatigue crack until a defined length is reached, unstable fracture occurs or the crack is through the wall thickness. This means that these two approaches may predict different fatigue lives. Currently there are some inconsistencies in the industry when the two approaches are to be applied and it is recommended that expert advices are sought when in doubt. Recommended practice for how to conclude the fatigue and fracture limit state based on fracture mechanics are specified in DNVGL-RP-F108.

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Some guidance on low-cycle fatigue assessments may be found in DNVGL-RP-C203, DNVGL-RP-F108 and Norsok N-006.

5.4.8.4 The different failure modes considered in this limit state are:

— unacceptable fatigue damage according to S-N fatigue assessment approach
— unstable fracture based on fracture mechanics analyses (may be tearing instability or plastic collapse)
— fatigue crack growth until unstable fracture or a defined crack size.

5.4.8.5 Fracture assessment should be based on:

— recognized fracture assessment procedure and local longitudinal stress across the girth weld determined as follows;
    — $\varepsilon_{l,nom}$ from global FE analyses and relevant stress or strain concentration factors reflecting details not covered by the global FE analyses, or
    — local FE analyses were all relevant geometrical (thickness variation, misalignment, coating) and material variations are modelled explicitly
— detailed FE-based fracture assessment where the safety margin is ensured by recognised procedure.

Recommended practice on fracture assessment is given in DNVGL-RP-F108.

5.4.8.6 The fatigue and fracture limit state is considered satisfactory if the requirements in Table 5-9 are met.

Table 5-9 Requirements to fatigue and fracture limit state

Total nominal longitudinal strain 1),2)	*Requirements*
$\varepsilon_{l,nom} \leq 0.4\%$	The welds shall have acceptable fatigue damage (S-N approach). The linear damage hypothesis (Miner's sum) may be used, see [5.4.8.10] and [5.4.8.11].
	Weld flaw acceptance criteria differing from App.D and App.E may be determined based on fracture mechanics analyses. Recommended procedure is given in DNVGL-RP-F108.
$\varepsilon_{l,nom} > 0.4\%$	The welds shall have acceptable fatigue damage (S-N approach). The linear damage hypothesis (Miner's sum) may be used, see [5.4.8.10] and [5.4.8.11].

	The fatigue and fracture integrity shall also be proven by determining maximum allowable size of weld flaws based on fracture mechanics assessments. Recommended practice for pipeline girth welds is given in DNVGL-RP-F108 (procedure may also be applied to other types of welds).
1) The strain levels refer to strains aroused after pipe manufacturing process. 2) For pipelines subjected to longitudinal strain exceeding 1.0% or accumulated plastic strain exceeding 2.0% the supplementary requirement P applies to the line pipes (parent material) 3) The S-N curves and material properties used in analyses shall represent the actual environment and temperature conditions.	

5.4.8.7 All stress fluctuations imposed on the pipeline system during the entire design life, including the construction phase, which have magnitude and corresponding number of cycles large enough to cause fatigue effects shall be taken into account when determining the long-term distribution of stress ranges. The fatigue check shall include both low-cycle fatigue and high-cycle fatigue.

Guidance note:

Typical causes of stress fluctuations in a pipeline system are:

— direct wave action
— vibrations of the pipeline system, e.g. due to vortex shedding (current, waves, wind, towing) or fluid flow
— supporting structure movements, e.g. installation vessel
— fluctuations in operating pressure and temperature.

Locations to be checked are the girth welds, seam welds and construction details. Seam welds will be more vulnerable to fatigue for higher steel grades.

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5.4.8.8 As most of the loads which contribute to fatigue are of a random nature, statistical consideration is normally required in determining the long-term distribution of fatigue loading effects. Where appropriate, deterministic or spectral analysis may be used.

5.4.8.9 When using calculation methods based upon fatigue tests, the following shall be considered:

— determination of long-term distribution of stress range, see [5.4.8.7]
— selection of appropriate S-N curve (characteristic resistance) considering geometry and NDT requirements, see [5.4.8.10]
— determination of stress concentration factor (SCF) not included in the S-N curve
— the environmental condition
— determination of accumulated damage, see [5.4.8.11].

5.4.8.10 The characteristic resistance is normally given as S-N curves, i.e. stress ranges versus number of cycles to failure, N. The S-N curve shall be applicable for the material, construction detail, NDT acceptance criteria (weld quality) and stress component (longitudinal vs. hoop etc.), as well as to the surrounding environment. The S-N curve shall be based on the mean curve of log (N) with the subtraction of two standard deviations in log (N).

Quality requirements for welds not classified as fatigue sensitive are given in Table D-4, Table D-5 and Table D-6 for manual NDT and Table E-1 for AUT.

Welds classified as fatigue sensitive shall satisfy Table E-2.

It is acceptable to determine less strict AUT acceptance criteria based on maximum allowable flaw sizes assessed using fracture mechanics assessments. Recommended approaches for assessing maximum allowable flaw sizes are given in DNVGL-RP-F108. However, it is not recommended to use fracture mechanics assessments to allow for lower weld quality than specified in Table E-1. If AUT acceptance criteria are determined based on fracture mechanics analyses, it is not necessary to re-calculate the fatigue life and satisfy Miner's sum using S-N curves representing the lower weld quality.

5.4.8.11 In the general case where stress fluctuations occur with varying amplitude of random order, the linear damage hypothesis (Miner's rule) may be used. The application of Miner's rule implies that the long-term distribution of stress range is replaced by a stress histogram, consisting of a number of constant amplitude stress or strain range blocks, $(\sigma_r)_i$ or $(\varepsilon_r)_i$, and the corresponding number of repetitions, n_i. Thus, the fatigue criterion is given by:

$$D_{fat} \cdot DFF \leq 1.0 \tag{5.36}$$

$$D_{fat} = \sum_{i=1}^{k} \frac{n_i}{N_i} \tag{5.37}$$

Where:

D_{fat} = Miner's sum
k = number of stress blocks
n_i = number of stress cycles in stress block i
N_i = number of cycles to failure at constant stress range of magnitude $(\sigma_r)_i$ or strain range $(\varepsilon_r)_i$.
DFF = design fatigue factor, see Table 5-10.

5.4.8.12 Allowable design fatigue factors are given in Table 5-10.

Table 5-10 Allowable design fatigue factor

Safety class	*Low*	*Medium*	*High*
DFF	3	6	10

5.4.8.13 Recommend practice for S-N fatigue strength analysis is given in DNVGL-RP-C203 Sec.5.

5.4.8.14 The split between different phases of the design fatigue life shall be agreed in the initiation phase of the project and be based on the highest safety class during the lifetime.

Guidance note:

For a pipeline where e.g. 50% of the design lifetime can be utilized during the installation and which is classified as safety class medium (DFF_{S-N}=6) during the operational phase, this will correspond to a damage ratio of 50/6=8.3% of the operational lifetime. A common split between installation, as laid and operation is 10%, 10% and 80% but depend on the need for fatigue capacity in the different phases. Other split than the normal 10/10/80 may be defined in agreement with the pipeline operator.

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Guidance note:

DNVGL-RP-F105 Sec.5 has a partial safety factor format on allowable fatigue damage. Other standards will generally have other safety factor formats, or most often an allowable utilization without partial safety factors. If DNVGL-RP-F105 Sec.5 is applied to calculate partial damage contributions, and these are added to damage from other sources to adhere to a criterion in a different standard, the damage in DNVGL-RP-F105 shall be normalized in an appropriate manner.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.8.15 Recommended practice for combined fatigue and fracture assessments of pipelines with focus on girth welds is given in DNVGL-RP-F108 (the approach may also be applicable to other types of welds and pipeline details).

Guidance note:

Assessment of crack growth due to cyclic loading applying fracture mechanics does typically not included the initiation time of the fatigue crack. This may be accounted for in the total fatigue life estimate if properly documented by test data.

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5.4.8.16 If the required girth weld quality is determined based on fracture mechanics assessments, both maximum longitudinal stress/strain (static loads used to perform fracture check) and dynamic loads (used to perform fatigue crack growth assessments) shall be considered. Recommended procedures are given in DNVGL-RP-F108.

Guidance note:

The likelihood that the same girth weld will be subjected to fatigue and maximum longitudinal strain/stress during installation and later in the as-laid stage may be quite small and it may be acceptable not to combine all load cases in the fracture mechanics assessments, see DNVGL-RP-F108 for some guidance.

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5.4.8.17 The tensile stress-strain curves and fracture toughness/tearing resistance are important input to the fracture mechanics analyses. Hence, these parameters shall reflect the relevant material condition (as-welded, strained, strained and aged), temperature and environment representative for the loading assessed, see DNVGL-RP-F108 for further guidance. Supplementary requirements for line pipes (parent pipe requirements) in H_2S services are provided in [7.9.2].

5.4.8.18 If it is uncertain whether the environment may reduce the fracture toughness compared to in air environment or it is uncertain if the fatigue crack growth parameters specified in BS 7910 are representative the fatigue and fracture limit state is considered fulfilled if all the following requirements are satisfied:

— $\varepsilon_{l,nom} \leq 0.4\%$ and
— acceptable fatigue damage according to [5.4.8.10] and [5.4.8.11] using S-N curve applicable to the environment and
— single value fracture toughness testing as described in DNVGL-RP-F108 Sec.7 is performed in the representative environment with $CTOD_{mat} \geq 0.15mm$. If J_{mat} is tested the J_{mat} requirement may be derived from $CTOD_{mat} = 0.15mm$ in accordance with BS 7910, i.e.:

$$J_{mat} \geq 0.15 \cdot R_{p0.2} \cdot 1.517 \left(\frac{R_{p0.2}}{R_m}\right)^{-0.3188} \qquad (5.1) \qquad (5.38)$$

where $R_{p0.2}$ and R_m represents the actual material at the test temperature and relevant environment.

Or:

Maximum allowable flaw sizes are determined in accordance with DNVGL-RP-F108 where all required testing is performed in the actual environment.

5.4.8.19 For duplex stainless steels and 13Cr martensitic stainless steels or other materials susceptible to HISC local stresses shall be sufficient low to avoid initiation of HISC. Recommended practice for design of duplex stainless steels is given in DNVGL-RP-F112.

5.4.9 Running ductile failure (fracture arrest properties, supplementary requirement F)

5.4.9.1 Pipeline systems transporting gas or mixed gas and liquids under high pressure shall have adequate resistance to running ductile fractures. This may be achieved by using:

— material with low transition temperature and adequate Charpy V-notch toughness
— adequate DWTT shear fracture area
— lowering the stress level
— use of mechanical crack arrestors
— by a combination of these methods.

Design solutions shall be validated by calculations based upon relevant experience and/or suitable tests. Requirements to fracture arrest properties need not be applied when the pipeline design tensile hoop stress is below 40% of f_y.

Guidance note:

CO_2 is normally in the liquid dense phase during normal operation of a pipeline. When decompressed, CO_2 will change phase from liquid to gas, and this decompression behavior is significantly different compared to natural gas, and needs to be accounted for in running ductile fracture assessments for pipelines conveying CO_2.

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5.4.9.2 Material meeting the supplementary requirement for fracture arrest properties (F), [7.9.2] is considered to have adequate resistance to running ductile fracture for applications carrying essentially pure methane up to 80% usage factor, 15 MPa internal pressure and 30 mm wall thickness. For depths down to 10 meters and onshore, the required Charpy V-notch impact energy shall be specially considered.

5.4.10 Ultimate limit state – accidental loads

5.4.10.1 The design against accidental loads may be performed by direct calculation of the effects imposed by the loads on the structure, or indirectly, by design of the structure as tolerable to accidents.

5.4.10.2 The acceptance criterion for ALS relate to the overall allowable probability of severe consequences.

5.4.10.3 Design with respect to accidental load shall ensure that the overall nominal failure probability complies with the nominal failure probability target values in Sec.2. The overall nominal failure probability from accidental loads can be expressed as:

$$\sum_i P_{fi|Di} \cdot P_{Di} \leq P_{f,target} \tag{5.39}$$

where:

$P_{fi\|Di}$	=	the probability of failure for the damaging event i
P_{Di}	=	the probability of the damaging event i within a year
$P_{f,target}$	=	the relevant nominal target probability of failure within a year, see [2.3]. The number of discretisation levels shall be large enough to ensure that the resulting probability is evaluated with sufficient accuracy.

Guidance note:

The above criterion implies that analyses of a 1000 year event becomes similar to normal ULS design (analysing for a 100 year event) with one safety class lower, given that the uncertainties are similar

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.4.10.4 The inherent uncertainty of the frequency and magnitude of the accidental loads, as well as the approximate nature of the methods for determination of accidental load effects, shall be recognised. Sound engineering judgement and pragmatic evaluations are hence required.

5.4.10.5 If non-linear, dynamic finite element analysis is applied, it shall be ensured that system performance and local failure modes (e.g. strain rate, local buckling, joint overloading and joint fracture) are adequately accounted for by the models and procedures applied.

5.4.10.6 A simplified design check with respect to accidental load may be performed as shown in Table 5-11 using appropriate partial safety factors. The adequacy of simplified design check shall be assessed on the basis of the summation above in order to verify that the overall failure probability complies with the target values in Sec.2.

Table 5-11 Simplified design check versus accidental loads

Prob. of occurrence [1)]	*Safety class low*	*Safety class medium*	*Safety class high*
$\geq 10^{-2}$	Accidental loads may be regarded similar to environmental loads and may be evaluated similar to ULS design check		
$10^{-2} > P_F \geq 10^{-3}$	To be evaluated on a case by case basis		
$10^{-3} > P_F \geq 10^{-4}$	$\gamma_C = 1.0$	$\gamma_C = 1.0$	$\gamma_C = 1.0$
$10^{-4} > P_F \geq 10^{-5}$	Accidental loads or events may be disregarded	$\gamma_C = 0.9$	$\gamma_C = 0.9$
$10^{-5} > P_F \geq 10^{-6}$			$\gamma_C = 0.8$
$< 10^{-6}$			

1) When failure mode is bursting the probability of occurrence should be 1-2 order of magnitudes lower, see Table 2-5.

Note to table: Standard industry practice assumes safety factors equal to 1.0 for an accidental event with a probability of occurrence less than 10^{-2} within a year and survival of the pipeline is merely related to a conservative definition of characteristic resistance. In this standard, accidental loads and events are introduced in a more general context with a link between probability of occurrence and actual failure consequence. For combined loading the simplified design check proposes a total factor in the range 1.1-1.2, which is consistent with standard industry practice interpreted as corresponding to safety class medium for accidental loads with a probability of occurrence equal to 10^{-4}.

5.4.11 Dent

5.4.11.1 The acceptance criterion for impact refer to an acceptable dent size. The maximum accepted ratio of permanent dent depth to the pipe diameter is given in the following criterion:

$$\frac{H_P}{D} \leq 0.05\eta \tag{5.40}$$

where:

H_p = permanent plastic dent depth
η = usage factor given in Table 5-12. Load effect factors equal to unity.

Table 5-12 Usage factor (η) for impact

Impact frequency (per year per km)	*Usage factor* η
> 100	0
1-100	0.3
10^{-4}-1	0.7

5.4.11.2 When allowing for permanent dents, additional failure modes such as fatigue and collapse shall be taken into account. Any beneficial effect of internal over-pressure, i.e. pop-out should not be included. The beneficial effects of protective coating may be taken into account. The impact effectiveness of coating shall be documented.

5.4.12 Ovalisation

5.4.12.1 The submarine pipeline system shall not be subject to excessive ovalisation. The residual flattening due to bending and point loads, together with the out-of-roundness tolerance from fabrication of the pipe, is not to exceed 3%, defined as:

$$O_0 = \frac{D_{max} - D_{min}}{D} \leq 0.03 \qquad (5.41)$$

The requirement may be relaxed if:

— a corresponding reduction in moment resistance has been included
— geometrical restrictions are met, such as pigging requirements
— additional cyclic stresses caused by the ovalisation have been considered
— tolerances in the relevant repair system are met.

5.4.12.2 Ovalisation shall be checked for point loads at any point along the submarine pipeline system. Such point loads may arise at free-span shoulders, artificial supports and support settlements.

5.4.13 Accumulated deformation

5.4.13.1 Accumulated plastic deformation of pipe caused by cyclic loads leading to increased diameter or ovality (ratcheting) shall be considered. If the ratcheting causes increased ovality, special consideration shall also be made of the effect on buckling resistance.

5.4.14 Displacement

5.4.14.1 Accumulated longitudinal displacement of the pipeline (pipeline walking) shall be considered. This may occur during start-up/shut-down for:

— pipeline shorter than two anchor lengths, or

— pipeline parts with virtual anchor, and
— pipeline laying on seabed slope, or
— pipeline connected to pulling force (e.g. connected to SCR).

5.4.14.2 Design of pipeline shall ensure that the displacement is acceptable. This may be limited by:

— interference with other structures or (seabed) features
— exposures to other loads or threats
— change in configuration causing un-acceptable loading conditions, e.g. excessive free-spans.

5.5 Special considerations

5.5.1 General

5.5.1.1 This subsection gives guidance on scenarios that shall be evaluated separately. Both the load effects and acceptance criteria are affected.

5.5.2 Pipe soil interaction

5.5.2.1 For limit states influenced by the interaction between the pipeline and the soil, this interaction shall be determined taking due account for all relevant parameters and the uncertainties related to these.

In general pipeline soil interaction depends on the characteristics of the soil and the pipeline, on the entire interaction history since and including laying and on the failure mode in question, which shall all be properly accounted for in the simulation of the pipeline soil interaction.

5.5.2.2 The main soil characteristics governing the interaction are the shear strength and deformation properties.

5.5.2.3 Pipeline characteristics of importance are submerged weight in all phases, diameter, stiffness, roughness of the pipeline surface, and initial embedment from installation which shall all be accounted for as relevant for the limit state in question.

5.5.2.4 All relevant load effects shall be considered. This includes:

— load duration and history effects (e.g. varying vertical reactions from installation laying pressures in possible combination with horizontal motions)
— variations in the unit weight of the pipe (e.g. empty, water filled and operation conditions)
— cyclic loading effects (both directly from pipe as well as hydrodynamic loads).

5.5.2.5 Calculation of soil resistance for a design situation shall be based on the worst case of high and low estimates of shear strength affecting the end result for the design situation, as described in [3.3.7.5]. Where best estimate and upper and lower bounds of the soil resistance shall be defined these shall all relate to the worst case shear strength definition, but reflect for all other uncertainties, such as assumptions of laying effects and uncertainties related to selection of calculation method.

5.5.2.6 Some soils have different resistance values for long term loading and for short term loading, related to the difference in drained and undrained behaviour and to creep effects in drained and undrained condition. This shall be taken into account.

5.5.2.7 For limit states involving or allowing for large displacements (e.g. lateral pull-in, pipeline expansion of expansion loops, global buckling or when displacements are allowed for on-bottom condition) the soil will be loaded far beyond failure, involving large non-linearities, remoulding of soil, ploughing of soil etc. Such non-linear effects and the uncertainties related to these shall be considered.

5.5.2.8 For pipelines that are buried (trenched and/or covered by gravel) and susceptible to global buckling the uplift resistance and possible increased axial resistance shall be considered. The possible effect of backfill material from trenching shall be considered.

5.5.2.9 Due to the uncertainties in governing soil parameters, load effects, idealization of calculation models etc., it is difficult to define universally valid methods for simulation of pipe soil interaction effects. The limitations of the methods used, whether theoretically or empirically based, shall be thoroughly considered in relation to the problem at hand. Extrapolation beyond documented validity of a method shall be performed with care, as shall simplifications from the problem at hand to the calculation model used. When large uncertainties exist, the use of more than one calculation approach shall be considered.

5.5.2.10 Recommended practice on pipe-soil interaction and geotechnical surveys is given in DNVGL-RP-F114.

5.5.3 Global buckling

5.5.3.1 For load controlled global buckling, see [5.4.7].

5.5.3.2 Displacement or partially displacement controlled global buckling may be allowed. This implies that global buckling may be allowed provided that:

— pipeline integrity is maintained in post-buckling configurations (e.g. local buckling, fracture, fatigue etc.)
— displacement of the pipeline is acceptable.

Guidance note:

It is not sufficient to design HP/HT pipelines for global buckling based on worst case axial and lateral soil resistance combined with displacement controlled local buckling criteria only. These upper and lower bound soil resistance values will typically have a probability of exceedance in the order of a couple of per cent and will not alone prove a sufficient nominal failure probability. A more total evaluation of the failure probability is, hence, required.

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5.5.3.3 The pipeline may buckle globally, either downwards (in a free span), laterally (snaking on the seabed), or vertically (as upheaval buckling of a buried pipeline or on a free-span shoulder of an exposed pipeline).

5.5.3.4 The following global buckling initiators shall be considered:

— trawl board impact, pullover and hooking
— out of straightness.

5.5.3.5 Recommended practice for structural assessment of high pressure/high temperature pipelines is given in DNVGL-RP-F110.

5.5.4 Free spanning pipelines

5.5.4.1 Spanning pipelines shall have adequate safety against local buckling, fatigue, fracture and ovality and these shall be documented.

5.5.4.2 Recommended practice for free spanning pipelines is given in DNVGL-RP-F105.

5.5.5 On bottom stability

5.5.5.1 The pipeline shall not move from its as-installed position. This does not include permissible lateral or vertical movements, thermal expansion, and a limited amount of settlement after installation. This applies for the entire lifetime of the pipeline (including metal loss due to corrosion or erosion). The stability of the pipeline shall be documented.

Guidance note:

The acceptance criterion on permissible movements may vary along the pipeline route. Examples of possible limitations to pipeline movements include:

— local buckling, fatigue and fracture of pipe
— deterioration/wear of coating
— geometrical limitations of supports
— distance from other pipelines, structures or obstacles.

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5.5.5.2 For weight calculations of the pipe, the nominal wall thickness shall be reduced to compensate for the expected average weight reduction due to metal loss. For pipelines with minor corrosion allowance this reduction may be omitted and the nominal thickness used.

5.5.5.3 The submarine pipeline system shall have a specific gravity sufficient to avoid floatation. If a sufficient low probability of negative buoyancy is not documented, the following criterion applies:

$$\gamma_w \cdot \frac{b}{W_{sub} + b} \leq 1.00 \qquad (5.42)$$

Where:

γ_w = safety factor on weight, 1.1
b = buoyancy
W_{sub} = submerged weight.

5.5.5.4 Pipelines shall have adequate safety against sinking. Special considerations shall here be made to mechanical components such as valves and Tee's. If the soil is, or is likely to be, liquefied, it shall be documented that the depth of sinking will be satisfactorily limited (either by the depth of liquefaction or by the build-up of vertical resistance during sinking).

Guidance note:

If the specific submerged weight of the water-filled pipe is less than that of the soil, then no further analyses are required to document safety against sinking.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.5.5.5 Buried pipelines shall have adequate safety against floatation in soil.

5.5.5.6 When the pipeline is routed in areas that may be influenced by unstable slopes that could lead to slope failure and flow of soil that will impact the pipeline, the probability of such slope failures shall be evaluated. Any relevant slope failure triggering effect, such as wave loading, earthquake loading or man made activities (e.g. the pipe-laying itself), shall be considered. Possible flow rates and densities at the pipeline shall be evaluated for stability. If stability cannot be guaranteed by sufficient weight of the pipeline, by burial of the pipeline or by other means, re-routing of the pipeline shall be required.

5.5.5.7 The most unfavourable combination of simultaneously acting vertical and horizontal forces on the pipeline shall be considered. When determining this unfavourable combination, the variation in forces along the line, including directionality effects of waves and current, should be addressed.

5.5.5.8 Axial (longitudinal) stability shall be checked. The anode structural connection (when exposed to friction, e.g., pipelines without weight coating) shall be sufficient to sustain the anticipated friction force.

5.5.5.9 Pipeline movements due to thermal axial expansion, shall be allowed for near platforms/structures (e.g. at riser tie-in point) and where the pipeline changes direction (e.g. at offset spools). The expansion calculations shall be based upon conservative values for the axial frictional resistance.

5.5.5.10 In shallow water, the repeated loading effects due to wave action may lead to a reduction of the shear strength of the soil. This shall be considered in the analysis, particularly if the back fill consists of loose sand, and in general if the soil consists of silt or sand with high silt content. Both cases may be susceptible to liquefaction.

5.5.5.11 If the stability of the pipeline depends on the stability of the seabed, the latter should be checked.

5.5.5.12 Recommended practice for stability of pipelines exposed to wave and current loads is given in DNVGL-RP-F109.

5.5.6 Trawling interference

5.5.6.1 The submarine pipeline system shall be checked for all three loading phases due to trawl gear interaction, as outlined in [4.5].

5.5.6.2 The acceptance criteria are dependent on the trawling frequency (impact) and the safety class.

5.5.6.3 Trawl pullover loads shall be checked in combination with other relevant load effects. Trawl pullover shall be combined with global buckling. Accumulation of damage due to subsequent trawling is not normally allowed.

5.5.6.4 Hooking loads shall be checked in combination with other relevant load effects. All relevant failures modes shall be checked.

5.5.6.5 Recommended practice for trawl and pipeline interference is given in DNVGL-RP-F111.

5.5.7 Third party loads, dropped objects

5.5.7.1 The submarine pipeline system shall be designed for impact forces caused by, e.g. dropped objects, fishing gear or collisions. The design may be achieved either by design of pipe, protection or means to avoid impacts.

5.5.7.2 The design criteria shall be based upon the frequency/likelihood of the impact force and classified as accidental, environmental or functional correspondingly, see [5.4.10].

5.5.7.3 Recommended practice for risk assessment of pipeline protection is given in DNVGL-RP-F107 Sec.5.

5.5.8 Earthquakes

5.5.8.1 The submarine pipeline system shall have adequate resistance against earthquakes.

Guidance note:

The following scenarios will typically be considered:

- Local buckling, collapse etc. of the pipeline due to seabed motions and movements
- Indirect effects (e.g. caused by movements of secondary structures)
- Failure of gravel supports
- Potential damage from mud-slides.

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5.5.8.2 For design against earthquakes, see ISO 19901-2.

5.5.9 Thermal insulation

5.5.9.1 If the submarine pipeline system is thermally insulated,

- it shall be documented that the insulation is resistant to the combination of water, temperature and hydrostatic pressure.
- It should be documented that the insulation is resistant to oil and oil-based products, if relevant.
- It shall be documented that the required mechanical resistance to external loads is sufficient, as applicable.
- Degradation of the insulation during construction and operation shall be considered.

5.5.10 Settings from plugs

5.5.10.1 Recommended practice for loads from plugs is given in DNVGL-RP-F113 Sec.5.

5.5.11 Pipe-in-pipe and bundles

5.5.11.1 This standard is based on limit state design methodology and may therefore in general be applied to pipe-in-pipe and bundles if the load effect calculations are performed adequately.

5.5.11.2 Safety class shall be specified for each element in the pipe-in-pipe system and for each phase. The classification shall be based on the requirements in Sec.2.

5.5.11.3 No specific limit states are given for pipe-in-pipe and bundle configurations. Relevant failure modes shall be identified for each element in the pipe-in-pipe system and corresponding limit state as appropriate. In case the consequences are different for the different failure modes, different safety class may be selected correspondingly.

5.5.11.4 Progressive failure shall be considered when selecting the safety class, i.e. the impact from failure of one element on another element. This shall include both structural failures as well as functional failures.

5.5.11.5 In case the combined capacity is utilised, the potential for progressive failure should be considered in selection of the relevant safety class.

5.5.11.6 Inspection possibilities are more limited for pipe-in-pipe and bundles, and hence detection of corrosion in annulus and external corrosion is challenging. Further, detection of leaks into annulus (from internal or external fluids) may not be easily identified and the associated environment in the annulus cannot be fully controlled or reversed. Documentation of the integrity in the operation phase may be limited for a pipe-in-pipe compared to a single pipe. This will again affect the life-time extension and re-assessment of the pipeline.

5.6 Pipeline components

5.6.1 General

5.6.1.1 This subsection is applicable to pressure containing components (e.g. bends, flanges and connectors, tees, valves, pipe-in-pipe bulkheads) used in the submarine pipeline system. Supporting structure requirements are given in [5.7].

5.6.1.2 Design of pipeline components shall be according to a recognized standards or recommended practices combined with the additional requirements listed in Table 5-13.

5.6.1.3 Design of pipeline components shall also comply with the material, manufacturing and test requirements for components in Sec.8.

Table 5-13 Referenced standards for structural design of components

Component	*Example of design standards or recommended practices* 1)	*Additional design requirements*
All Components listed below 2)	ASME VIII Division 2/EN 13445/PD 5500	[5.6.1]
Induction Bends	ISO 15590-1	[5.6.2]
Fittings	Tees: ASME B31.4, B31.8	[5.6.3]
Flanges	ISO 15590-3/ISO 7005-1 or NORSOK L005/EN 1591-1/API 6A/ISO 13628-7	
Valves	ISO 14723	[5.6.4]
Mechanical connectors	ASME VIII Division 2/EN 13445/PD 5500/ISO 13628-7	
CP Insulating joints	ASME VIII Division 2/EN 13445/PD 5500	[5.6.5]
Anchor flanges	N.A. see note 2)	
Bolting	ASME VIII Division 2/EN 13445/PD 5500	
Pig traps	ASME VIII Division 2/EN 13445/PD 5500	[5.6.6]
Repair clamps, repair couplings and hot taps	DNVGL-RP-F113	Hot tap's: API RP 2201
Bulkheads	ASME VIII Division 2/EN 13445/PD 5500; see note 3)	See [13.6.5]

1) Other recognised equivalent standards or recommended practices may be used. The listed standards or recommended practices shall not be used outside its applicability

2) Required in case the standards or recommended practices used in the design of a component does not take into account forces other than the internal pressure, see [5.6.1.6].

3) Allowable stresses may be based on API 6A (see guidance note)

Guidance note:

An alternative method of calculating the limit stress for the elastic or elastic-perfectly plastic analysis methods of ASME VIII Division 2 is provided in section 5.2.3.5 of API 6A.

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5.6.1.4 All pressure containing components used in the submarine pipeline system should represent at least the same safety level as the connecting riser/pipeline section.

5.6.1.5 The design pressure for the pipeline component shall be harmonised with the design pressure of the submarine pipeline systems.

Guidance note:

This implies that the design pressure for the component shall be selected such that it is consistent with the design and incidental pressure in the submarine pipeline system. Different design standards or recommended practices have different definitions of design pressure, and a thorough evaluation is required to ensure the consistency in the approach to be taken.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.6.1.6 The component shall be designed to accommodate the loading from the connected pipeline section and vice versa with appropriate level of safety. If the standard or recommended practice used in the design of a component does not take into account forces other than the internal pressure, additional evaluations, e.g. FE analyses according to; ASME VIII Division 2/EN 13445/PD 5500 are required in order to address the maximum forces that can be transferred to the component from the connecting pipeline sections under installation and operation.

The strength shall, as a minimum be:

— equivalent to the connecting pipeline, or
— sufficient to accommodate the most probable maximum 100-year load effect that will be transferred to the component from the connecting pipeline under installation and operation, see Sec.4.

5.6.1.7 The use of other standards and recommended practices for structural design and construction will require code breaks. The code break shall be maintained for all phases (i.e. not changed from design to construction phase).

Guidance note:

The code break between line pipe and the relevant component standard may be located at the component weld neck, see Figure 5-3(a).

In practice, the component is likely to be thicker than the pipeline. This requires a transition length, see Figure 5-3(b). The code break may be located within the component provided the part of the component covered by the pipeline standard or recommended practice satisfies the material requirements of the pipeline code. Stress and strain concentrations at the girth weld may be avoided by including a constant wall thickness section. This pipe section (or nib) is recommended to be minimum 4 times the elastic length of the pipeline section at code break, see DNVGL-RP-C203 App.D. The length may be reduced provided detailed analyses show nominal pipe section stresses at shorter length.

The elastic length is defined as:

$$l_e = \frac{\sqrt{r\,t}}{\sqrt[4]{3(1-\nu^2)}} \qquad (5.43)$$

where:

r	=	radius to mid surface of the pipeline dimension
t	=	all thickness of the pipeline
ν	=	Poisson's ratio.

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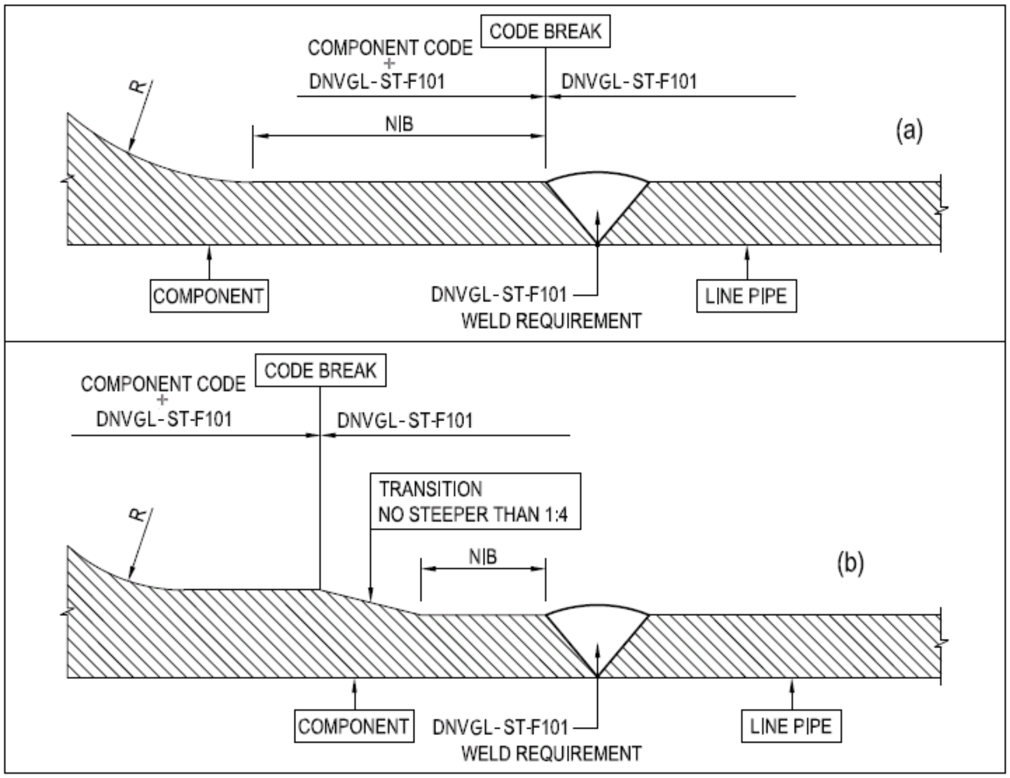

Figure 5-3 Code breaks between the line pipe and component connection; (a) material-based code break, and (b) geometry-based code break

5.6.1.8 The same design standard or recommended practice should be applied for all phases, i.e. design, fabrication, NDT, FAT, installation, commissioning, operation. E.g. if the weld at the code break is performed according to the component standard or recommended practice, it should also be factory acceptance tested according to the component standard or recommended practice.

5.6.1.9 The load scenarios as described in Sec.4 as well as particular loads associated with the component shall be analysed. This implies that also external hydrostatic pressure shall be considered in the design with respect to both strength and internal leakage when relevant.

5.6.1.10 For material susceptible to HISC, see [6.4.5].

5.6.1.11 Sealing systems should be designed to allow testing without pressurising the pipeline.

5.6.1.12 The pigging requirements in [E.8.4.3] and [3.4.1.2] shall be considered for the component.

5.6.1.13 Transitions in C-Mn and low alloy steels where the nominal material thickness or yield stress is unequal shall be in accordance with ASME B 31.8 Appendix I, Figure I-5 or equally recognised standard or recommended practice. Transition in C-Mn line pipe by means of an external or internal taper shall be no steeper than 1:4. If transitions to these requirements are not feasible, a transition piece shall be inserted.

5.6.1.14 Transitions in duplex stainless steels and 13Cr martensitic stainless steels shall be such that the local stresses will not initiate HISC. Recommended practice for design of duplex stainless steels is given in DNVGL-RP-F112.

5.6.1.15 Internal transitions between different wall thicknesses and internal diameters for girth welds in pipes of equal SMYS may be made in the base material provided radiographic examination only is specified.

5.6.1.16 For welds to be examined by ultrasonic testing, transition tapering in the base material should be avoided. If tapering is unavoidable the pipe ends shall be machined to provide parallel external and internal surfaces before the start of the taper. The length of the parallel surfaces shall at least be sufficient to allow scanning from the external surface and sufficient for the required reflection off the parallel internal surface.

5.6.1.17 Specifications for installation and make-up of the component shall be established.

5.6.1.18 For pressure testing requirements of components, see Sec.8.

5.6.2 Induction bends

5.6.2.1 This standard does not provide any limit state criteria for pipeline bends.

Guidance note:

Bends exposed to bending moments behave differently from straight pipes. Ovalisation becomes the first order of deformation and changes the stress pattern considerably compared to straight pipes.

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5.6.2.2 As an alternative to recognised standards or recommended practices the following simplified Allowable Stress Design (ASD) check may be used provided that:

— The pressure containment criterion in [5.4.2] based on the bend minimum thickness is fulfilled.
— The applied moment and axial load can be considered displacement controlled.
— The moment and axial loads are calculated based on pipe elements, not including the benefit of reduced stiffness in bends.
— The bend is exposed to internal over pressure or that the bend has no potential for collapse. This can be considered fulfilled if the system collapse design capacity is three times the external overpressure in question. The external pressure differential for the collapse limit state, p_e - p_{min}, shall hence be multiplied by a factor of 3 in Equation (5.10).

Guidance note:

Calculation of t_1 is shown in Table 5-5. The wall thickness tolerances should include the effect of thinning and thinning will therefore not affect the determination of t_1. If an excessive thinning is agreed the effect of this is considered minor.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

— That the imposed shape distortion (e.g. ovalisation) is acceptable.

The ASD criteria read:

$$\sigma_e \leq \eta \cdot f_y \tag{5.44}$$

$$|\sigma_l| \leq \eta \cdot f_y \tag{5.45}$$

where:

$$\sigma_e \leq \sqrt{\sigma_h^2 + \sigma_l^2 - \sigma_h \cdot \sigma_l + 3 \cdot \tau_{hl}^2} \tag{5.46}$$

$$\sigma_h = (p_i - p_e)\frac{D-t_2}{2\cdot t_2} \tag{5.47}$$

$$\sigma_l = \frac{N}{\pi\cdot(D-t_2)\cdot t_2} + \frac{M}{\frac{\pi\cdot(D^4-(D-2\cdot t_2)^4)}{32\cdot D}} \tag{5.48}$$

η = usage factor as given by Table 5-14

p_i = design pressure in line with ISO 13623

N = pipe wall force

M = bending moment, the most critical of tensile or compressive side shall be used.

Guidance note:

The ovalisation of the bend has typically to be determined by finite element calculation. The acceptable distortion will typically be governed by the bullet points in [5.4.12].

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Table 5-14 Usage factors for equivalent stress check

	Safety class		
	Low	*Medium*	*High*
η	1.00	0.90	0.80

5.6.3 Fittings

5.6.3.1 Tees shall be of the extruded outlet, integral reinforcement type when exceeding the maximum of 2 inches (2 3/8”) or an intersection angle of 72°. The design shall be according to ASME B31.4, B31.8 or equivalent.

5.6.3.2 Bars of barred tees should not be welded directly to the high stress areas around the extrusion neck. The bars transverse to the flow direction should be welded to a pup piece, and the bars parallel to the flow direction should be welded to the transverse bars only. If this is impracticable, alternative designs should be considered in order to avoid peak stresses at the ends.

5.6.3.3 Wyes- and tees where the axis of the outlet is not perpendicular to the axis of the run (lateral tees) shall not be designed to ASME B31.4 or B31.8, as these items require special consideration, i.e. design by finite element analysis.

5.6.3.4 Standard butt welding fittings complying with ANSI B16.9, MSS SP-75 or equivalent standards may be used provided that:

— the weld is qualified as full penetration weld in compliance with requirements given in App.C.
— the weld is examined by RT or UT meeting the requirements given in App.D.
— the sweepolet meets the fabrication requirements and mechanical properties outlined in Sec.8.
— the geometrical restraints shall be determined based on external nominal dimensions of the branch pipe (i.e. covering less than 20% of the primary pipe circumference

— the weld shall be considered equivalent to a girth weld w.r.t toe-to-toe distance etc.

5.6.4 Valves

5.6.4.1 The design shall ensure that internal gaskets are able to seal, and shall include a documented safety margin which is valid during all relevant pipeline operating conditions. Sealing will be sensitive to internal deflections, enlargement of gaps and changes in their support conditions. Valve operation will be sensitive to friction and clearances.

Guidance note:

Guidance on sealing pressure may be found in ISO 13628-7

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5.6.4.2 Consideration should be given to requirements for durability when exposed to abrasive material (e.g. weld scale, sand etc.) or to fire loads.

5.6.4.3 Valves with requirements for fire durability shall be qualified by applicable fire tests. Reference may be made to API 6FA and ISO 10497 for test procedures.

5.6.4.4 Valve control systems and actuators shall be designed and manufactured in accordance with recognised standards. The valve actuator specification should define torque requirements for valve operation, with a suitable safety margin to accommodate deterioration and friction increase during service.

5.6.4.5 If the standard or recommended practice used for design of a component does not take into account the possibility for internal leakage due to forces transferred to the component from the connecting pipeline sections, the additional calculations or qualification tests shall be performed.

5.6.5 Insulating joints

5.6.5.1 CP insulating joints shall be of the boltless, monolithic coupling type and shall be provided with a double seal system.

5.6.5.2 Insulating joints shall be fitted with pup pieces with mechanical properties and dimensions identical to that of the adjoining pipeline.

5.6.5.3 Insulating joints shall be capable of meeting the test requirements given in [8.2.9] and to withstand the effects of the environment without loss of performance.

5.6.5.4 To protect insulating joints and CP equipment from lightning effects, lightning protection shall be installed. Surge arrestors should be mounted across insulating joints and output terminals of D.C. voltage sources. Such measures should take into account the need for potential equalisation between the pipeline, anodes, power supplies, reference electrodes, etc. during lightning strikes. Alternative devices to the spark gap type can be used if documented to be reliable.

5.6.5.5 Bolting shall meet the requirements of [6.3.4].

5.6.5.6 All elastomeric materials used shall have a documented performance. The sealing materials shall have documented decompression, creep and temperature properties. O-ring seals shall be resistant to explosive decompression and AED certified. AED certification is not required for seals other than O-rings, provided they are enclosed in a completely confined space.

Sealing surfaces exposed to sea water shall be made of materials resistant to sea water at ambient temperature.

5.6.5.7 The insulating materials, including dielectric strength, compressive strength and suitability for use at the design temperatures shall be documented by testing in accordance with ASTM D 695.

5.6.6 Pig traps

5.6.6.1 The design of closures and items such as nozzle reinforcements, saddle supports, vent- kick and drain branches shall comply with the applied design standard.

5.6.6.2 Closures shall be designed such that the closure cannot be opened while the pig trap is pressurised. An interlock arrangement with the main pipeline valve should be provided.

5.7 Supporting structure

5.7.1 General

5.7.1.1 Structural items such as support and protective structures that are not welded onto pressurized parts are considered as structural elements.

5.7.1.2 Steel structural elements shall be designed according to DNVGL-OS-C101*Design of offshore steel structures, general (LRFD method)*.

5.7.2 Stability of gravel supports and gravel covers

5.7.2.1 This applies to all types of gravel supports and covers, such as free span supports for installation and operating phases (excessive bending and fatigue), separation and pipeline stabilisation at crossings, suppressing of upheaval buckling, axial restraints/locking, stabilisation of pipeline etc.

5.7.2.2 The design of the gravel supports and covers shall consider the consequence of failure.

5.7.2.3 The design of the gravel supports and covers shall consider:

— weight of gravel supports and/or covers and pipeline
— loads imposed by pipeline (e.g. due expansion)
— seabed slope, both longitudinal and horizontal
— uncertainty in soil characteristics
— resistance against hydrodynamic loads
— slope failure (e.g. due to earthquakes)
— uncertainty in survey data
— subsea gravel installation tolerances, both horizontal and vertical.

5.8 Installation and repair

5.8.1 General

5.8.1.1 The line pipe transportation should comply with the requirements of API RP 5L1 and API RP 5LW.

5.8.1.2 The pipeline strength and stability shall be documented according to the limit states in [5.4] and to the scenarios in [5.5] above.

Guidance note:

According to this standard, equivalent limit states are used for all phases. Hence the design criteria in this section also apply to the installation phase. Installation is usually classified as a lower safety class (safety class low) than operation, corresponding to lower partial safety factors (higher failure probability).

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5.8.2 Installation analyses

5.8.2.1 The design analysis for the submarine pipeline system shall include both installation and repair activities, in order to ensure that they can be installed and repaired without suffering damage or requiring hazardous installation or repair work.

5.8.2.2 The design shall verify adequate strength during all relevant installation phases and techniques to be used, including:

— initiation of pipe laying operation
— normal continuous pipe laying
— pipe lay abandonment and pipeline retrieval
— termination of laying operation
— tow out operations (bottom tow, off-bottom tow, controlled depth tow and surface tow)
— pipeline reeling and unreeling
— trenching and back filling
— spool installation
— tie-in operations
— landfalls.

5.8.2.3 The configuration of pipeline sections under installation shall be determined from the laying vessel to the final position on the seabed. The configuration shall be such that the load effect levels are acceptable when all relevant effects are taken into account. Discontinuities due to weight coating, buckle arrestors, in-line assemblies etc. shall be considered.

5.8.2.4 Critical sea states and directions versus laying parameter ranges shall be determined for the installation limit condition. The design load effect shall be determined from the characteristic load effects multiplied by load effect factors as given in [4.3.6] and [10.6.1].

The design load effects shall meet the criteria in Table 5-15.

Guidance note:

During installation, the whole pipeline will be exposed to the same deformation unless larger environmental loads are imposed. Without environmental loads, system effects are present as failure will occur at the weakest point. With environmental loads there are no system effects as the failure will occur for the highest load. These considerations are included by check of load combination a), when system effects are present and load combination b) when system effects are not present. The higher load effect factor in load combination a is therefor used with a nominal thickness, t_2, instead of a minimum wall thickness t_1.

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Table 5-15 Installation limit state criteria

Design condition	*Equation no.*	*Safety factors*
On-reeling	Equation (5.29)	Load combination a: γ_F = 1.2, γ_c = 0.77 (Seamless pipes) γ_F = 1.2, γ_c = 0.82 (Welded pipes)
Alternatively	Design by detailed analyses considering statistical strength mis-match between pipe joints	
Over bend[2] (S-lay)	Equation (5.28)	$\gamma_{SC,LB}$ = 1.0[1], γ_c = 0.80
Over bend[3](alternatively)	Equation (5.35)	- [4]
Stinger tip[2]	Equation (5.28)	-
Sag bend[2]	Equation (5.28)	Benefit of partial displacement controlled condition may be included if documented
1) When allowing a higher failure probability in compliance with [5.4.6.10] 2) Effect of point load in accordance with Equation (5.25) – Equation (5.27) applies in line with [5.8.2.5] below. 3) Effect of point load in accordance with Equation (5.34) applies in line with [5.8.2.5] below. 4) To be determined considering the effect of point load and varying stiffness, subject to agreement		

5.8.2.5 The moment and curvature capacities of the pipeline shall be reduced due to the effect of point load by Equation (5.25) – Equation (5.27) or Equation (5.34). This typically applies to the rollers of the stinger and at touch down point in case of a mechanical support or similar. For V-rollers where the contact force is equally balanced from the two rollers such reduction is not required and applies to the over bend with exception of the last V-rollers in contact with the pipe.

Guidance note:

The last v-roller in contact with the pipeline will take lateral reactions from vessel movements and will therefore not be equally balanced by the two rollers.

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5.8.2.6 The local buckling criteria referred to i Table 5-15 applies to line pipe only. For in-line components and line pipe welded to in-line components, criteria that provides sufficient integrity in the relevant sea-state shall be determined.

5.8.2.7 Influence from different applied design concepts from vessel to seabed shall be allowed for throughout the design life.

Guidance note:

Examples hereof may be;

— influence of increased ovalisation caused by large bending strains during reeling or on over bend on collapse capacity,
— influence of permanent curvature caused by plastic bending strains during reeling or on over bend on operational condition.

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5.8.2.8 The flattening due to a permanent bending curvature, together with the out-of-roundness tolerances from fabrication of the pipe shall meet the requirements defined in [5.4.12].

5.8.2.9

If the installation and repair analyses for the submarine pipeline system show that the required parameters cannot be obtained with the equipment to be used, the submarine pipeline system shall be modified accordingly.

5.8.3 Pipe straightness and rotation instability

5.8.3.1 The primary requirement regarding permanent deformation during construction, installation and repair is the resulting straightness of the pipeline. This shall be determined and evaluated with due considerations of effects on:

— instability
— positioning of pipeline components e.g. valves and Tee-joints
— operation.

5.8.3.2 The possibility of instability due to out of straightness during installation (twisting) and the corresponding consequence shall be determined.

5.8.3.3 If in-line assemblies are to be installed potential rotation of the pipe due to out of straightness shall be controlled such that the load effects are acceptable and no damage to the pipeline or the in-line assembly occurs, and positioned on the seabed within defined limits.

5.8.3.4 Other effects can also give rotation (curved lay route, eccentric weight, hydrodynamic loads, reduced rotational resistance during pulls due to lateral play/elasticity in tensioners/pads/tracks etc.) and need to be considered.

5.8.3.5 Instability during operation, due to out of straightness caused by the installation method and the corresponding consequences, shall be determined. Residual stresses affecting present and future operations and modifications shall also be considered.

5.8.3.6 The requirement for straightness applies to the assumed most unfavourable functional and environmental load conditions during installation and repair. This requirement also applies to sections of a pipeline where the strains are completely controlled by the curvature of a rigid ramp (e.g. stinger on installation vessel), whether or not environmental loads are acting on the pipe.

Guidance note:

Rotation of the pipe may take place within the tensioner clamps due to elasticity of the rubber.

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5.8.4 Weight coating

5.8.4.1 Concrete crushing due to excessive compressive forces for static conditions in the concrete during bending at the overbend is not acceptable. See [5.5.9] for thermal insulation.

SECTION 6 DESIGN - MATERIALS ENGINEERING

6.1 General

6.1.1 Objective

6.1.1.1 This section provides requirements and recommendations to the selection of materials for submarine pipeline systems and to the external and internal corrosion control of such systems. Also covered is the specification of line pipe, pipeline components, coatings and cathodic protection. Finally, general considerations for fabrication applicable to the design phase are addressed.

6.1.1.2 The purpose of performing materials selection is to assess the feasibility of different candidate materials (including CRA's) to meet functional requirements for line pipe and for other components of a pipeline system. It may also include a cost comparison between candidate materials, including the calculated costs for operation and any associated risk cost (see [6.4.6.1]). This activity is generally carried out during conceptual design of submarine pipeline systems.

6.1.2 Application

6.1.2.1 This section is applicable to the conceptual and design phases for submarine pipeline systems. It contains both normative requirements and information. (Subsections containing only informative text are indicated *Informative* in heading).

6.1.2.2 Functional requirements for materials and manufacturing procedures for line pipe and pipeline components are contained in Sec.7 and Sec.8, respectively. Manufacture and installation of systems for external corrosion control is addressed in Sec.9. Sec.9 also contains functional requirements to any concrete coating.

6.1.3 Systematic review

6.1.3.1 The overall requirement to systematic review in Sec.2 will for this section imply:

— Identification and evaluation of threats, the consequences of single failures and series of failures in the pipeline system applicable for the material selection and corrosion protection philosophy.
— Identification and evaluation of needs for supplementary requirements defined in this standard.
— Identification and evaluation of needs for supplementary requirements not accounted for in this standard. E.g. for CRA materials, and in particular for lined and clad pipes, it is possible that project specific requirements and design assumptions lead to requirements and technical solutions that are not fully accounted for in this standard.
— Review of potential contractors, evaluation of their capabilities and identification of special needs, e.g. manufacturing procedure qualification, technical audits, follow-up during manufacturing, etc.

6.2 Materials selection for line pipe and pipeline components

6.2.1 General

6.2.1.1 Materials for pipeline systems shall be selected with due consideration of the fluid to be transported, loads, temperature and possible failure modes during installation and operation. The selection of materials shall ensure compatibility of all components of the pipeline system. The following material characteristics shall be considered:

— mechanical properties
— hardness
— fracture toughness
— fatigue resistance
— weldability
— corrosion resistance.

6.2.1.2 Materials selection shall include identification of the following supplementary requirements for line pipe given in [7.9] as required:

— supplementary requirement S, H_2S service (see [6.2.2])
— supplementary requirement F, fracture arrest properties (see [7.5.1])
— supplementary requirement P, line pipe exposed to plastic deformation exceeding the thresholds specified in Table 5-10 (see Table 6-1 and) [E.8.8.10]
— supplementary requirement D, more stringent dimensional requirements (see [E.8.7.5])
— supplementary requirement U, increased utilisation (see [8.7.4.5]).

6.2.1.3 The mechanical properties, chemical composition, weldability and corrosion resistance of materials used in components shall be compatible with the part of the pipeline system where they are located. Low internal temperatures due to system depressurisation shall be considered during the material selection.

6.2.2 H_2S service

6.2.2.1 Pipelines to route fluids containing hydrogen sulphide (H_2S) shall be evaluated for H_2S service (also referred to as sour service) according to ISO 15156. For all pipeline components exposed to such internal fluids, materials shall be selected for compliance with this standard. For materials specified for H_2S service in ISO 15156, specific hardness requirements always apply. These are applicable both to manufactured materials as-delivered after manufacture and after fabrication (e.g. welding). For certain materials, restrictions for manufacture (e.g. heat treatment) and fabrication (e.g. cold forming) apply).

6.2.2.2 Any materials to be used that are not covered by ISO 15156 (e.g. C-Mn and low alloy steels with SMYS > 450 MPa, 13Cr martensitic stainless steels), shall be qualified according to the said standard. The same applies if a material specified for H_2S service is to be used beyond the conditions specified (e.g. max. hardness). In accordance with ISO 15156-2/3, the pipeline operator shall verify and retain the qualification records in case the testing was initiated by a contractor or supplier.

Guidance note:

Purchaser may consider to specify SSC testing of material grades meeting all requirements for H_2S service in ISO 15156 as a part of a program for pre-qualification of line pipe manufacturing or pipeline installation procedures. For such testing, the methods and acceptance criteria in ISO 15156-2/3 apply.

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6.2.2.3 ISO 15156, Sec.1, states that the standard is only applicable *to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria*. Any detrimental effects of induced loading will only apply if these are imposed during exposure to an H_2S-containing environment. ISO 15156 is thus not required to be fulfilled if H_2S is not present (e.g. for manufacture and installation of pipelines). Any restrictions for maximum allowable strain during operation are beyond the scope of this standard.

6.2.2.4 Supplementary requirements to H_2S service in this standard are given in [7.9.1] and [8.3.6].

6.2.3 Corrosion resistant alloys

6.2.3.1 Type 13Cr martensitic stainless steels (i.e. proprietary alloys developed for oil/gas pipelines) are generally considered fully resistant to CO_2-corrosion, provided welds have adequate PWHT. 22Cr and 25Cr duplex stainless steel and austenitic CRAs are also fully resistant and do not require PWHT. Duplex (ferritic-austenitic) and martensitic stainless steels may be less tolerant than C-Mn steel to well stimulation acids. Corrosion inhibitors for such acids developed for C-Mn steels may not be effective for CRAs.

6.2.3.2 Under conditions when water, oxygen and chloride can be present in the fluid, e.g. water injection, stainless steels can be susceptible to localised corrosion. Hence, the corrosion resistance shall be considered for each specific application. For special applications, corrosion testing should be considered to qualify the material for the intended use.

6.2.3.3 Alloy 625 (UNS N06625) is generally considered immune to ambient temperature seawater. Also type 25Cr duplex (e.g. UNS S32750/S32760) are generally resistant to ambient temperature seawater but require more stringent control of microstructure in base material and weld, consequently corrosion testing are often included for the qualification of manufacturing and fabrication procedures of these materials. Type 22Cr duplex, AISI 316 and Alloy 825 (UNS N08825) are not resistant to corrosion by raw seawater but are applicable for components exposed to treated seawater (deoxygenated to max. 10 ppb and max. 100 ppb as max monthly and daily residual concentrations of oxygen). For the latter materials, corrosion testing is not normally included in specifications for manufacture and fabrication.

6.2.3.4 Duplex and martensitic stainless steel line pipe and pipeline components require special considerations of the susceptibility of environmentally assisted cracking, primarily (HISC), see [6.4.5.2].

Guidance note:

In particular concerns of HISC apply to material subjected to plastic straining during installation, commissioning (in particular pressure testing) and operation with cathodic protection applied. PWHT is known to reduce the HISC susceptibility of welds for 13Cr martensitic stainless steel. Recommended practice for duplex stainless steel and HISC design is given in DNVGL-RP-F112.

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6.2.3.5 In addition to resistance to internal corrosion and environmentally assisted cracking, the following major parameters shall be considered:

— mechanical properties
— ease of fabrication, particularly weldability.

Guidance note:

Procurement conditions such as availability, lead times and costs should also be considered.

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6.2.4 Line pipe

6.2.4.1 Acceptance criteria and inspection requirements for line pipe, including pipe mill manufacturing welds, are given in Sec.7, with supplementary requirements specified in [7.9]. Additional information, relevant for the selection and specification of line pipe is provided in Table 6-1.

Table 6-1 Additional information for selection and specification of line pipe

Considered aspect	*Remark*
Uniform elongation	Uniform elongation will in many cases be more relevant than elongation-at-break. Uniform elongation is the plastic deformation that takes place before necking starts. With information of the uniform elongation for a material it will be possible to more accurately determine how much safety margin is in a structure. The uniform elongation can be determined by taking the total deformation at maximum load (i.e. the highest point of the stress-strain curve) and subtracting the elastic deformation (i.e. draw a line parallel to the initial loading curve down from the high point).
Dimensional tolerances	The most prominent benefit of specifying Supplementary requirement D is the eased fit-up prior to welding. Improved fit-up implies reduced stress concentrations and improved structural integrity. The tolerances specified in [7.9.4] are considered to be in the uppermost range of what may be achieved by reputable pipe mills. Stricter tolerances and additional requirements such as e.g. pipe eccentricity may be specified for further improvements, but may be costly as machining may be required. Supplementary requirement D is also beneficial when the pipe is exposed to high plastic straining due to reduced possibility for local buckling (reduced wall thickness difference between two adjoining pipes).
Corrosion testing of the CRA material of clad or lined line pipe	For Alloy 625 (UNS N06625) clad or lined pipe specified to be seawater resistant, testing according to ASTM G48, Method A, should be considered, with acceptance criteria as for 25Cr duplex, see [7.3.4.9].
Gripping force of lined line pipe	The gripping force (see [D.2.1.5]) should be determined with due consideration of the project requirements, especially the level of installation and operational bending stresses. If no particular requirements are identified, the requirement should be based on the gripping force obtained during MPQT.
Influence of coating application on mechanical properties	Pipe tensile properties may be affected by high temperature during coating application. During pipe coating, including field coating, the pipes might be exposed to temperatures up to approximately 250°C. For TMCP processed pipes and cold formed pipes not subjected to further heat treatment mechanical properties may change due to strain aging, causing e.g. increased yield stress. This may further affect the critical defect size considerably if the pipe is strained above the yield stress.

Considered aspect	*Remark*
Fracture arrest properties	Supplementary requirements to fracture arrest properties (F) are given in [7.9.2] and are valid for gas pipelines carrying essentially pure methane up to 80% usage factor, up to a pressure of 15 MPa, 30 mm wall thickness and 1120 mm diameter. For conditions outside the above limitations the required fracture arrest properties should be based on calculations which reflect the actual conditions or on full-scale tests. The fracture toughness required to arrest fracture propagation for rich gas, i.e. gas mixtures that enter the two-phase state during decompression can be much higher than for essentially pure methane. Calculations should be carried out by use of the Battelle Two Curve Method (TCM) and the appropriate correction factor for calculated required Charpy values ≥ 95 J. The Battelle TCM should be calibrated by use of data from full-scale test which are as close as possible to the actual pipeline conditions with regard to gas pressure, pipeline dimensions and gas composition. Although the Battelle TCM is based on physical models of the speed of crack propagation and the speed of decompression, it includes constants that are based on fitting data and calculations within a limited range of test conditions.
Reeling of longitudinally welded pipes and clad pipes	Due to the limited field experience, special considerations should be made for longitudinally welded pipes to ensure that both the longitudinal weld, heat affected zone and base material of such pipes are fit for intended use after significant straining. The weld metal strength of the pipe longitudinal weld should overmatch the strength of the base material. It is further recommended to have a limited cap reinforcement of the longitudinal weld in order to avoid strain concentrations.
Supplementary requirement U - qualification in retrospect	The purchaser may in retrospect upgrade a pipe delivery to be in accordance with supplementary requirement U. The requirements for such upgrade are stated in [7.9.5].

6.2.5 Pipeline components

6.2.5.1 Materials for components should be selected to comply with internationally recognised standards meeting the requirements given in Sec.7 and Sec.8. Modification of the chemical composition given in such standards may be necessary to obtain a sufficient combination of weldability, hardenability, strength, ductility, toughness and corrosion resistance.

6.2.5.2 A component should be forged rather than cast whenever a favourable grain flow pattern, a maximum degree of homogeneity, and the absence of internal flaws are of importance.

6.2.5.3 For component material delivered in the quenched and tempered condition, the tempering temperature should be sufficiently high to allow effective post weld heat treatment during later manufacture/installation. The minimum tempering temperature should, if lower than 610°C, be specified by the purchaser.

If welds between the component and other items such as line pipe are to be post weld heat treated at a later stage, or if any other heat treatment is intended, a simulated heat treatment of the test piece should, if required, be specified by the purchaser.

6.2.5.4 If the chemical composition and the delivery condition of components require qualification of a specific welding procedure for welding of the joint between the component and the connecting line pipe, then the component should be fitted with pup pieces of the line pipe material in order to avoid field welding of these components.

Alternatively, rings of the component material should be provided for welding procedure qualification of the field weld.

6.2.5.5 Particular consideration should be given to the suitability of elastomers and polymers for use in the specific application and service conditions. NORSOK M-710 and ISO 23936-2 give suitable description of methodology for establishing chemical compatibility and service life and may be used.

6.2.6 Bolts and nuts

6.2.6.1 For selection of bolting materials, see [8.3.5], plus [6.2.6.3] and [6.2.6.4] of this section.

6.2.6.2 When bolts and nuts shall be used at elevated temperature strength de-rating shall be applied, see [5.3.3]. See also guidance note in [8.3.5.2].

6.2.6.3 Stainless steel according to ASTM A193/ASTM A320 grade B8M (type AISI 316) is applicable but requires efficient cathodic protection for subsea use. UNS N06625 or other Ni-based solution hardening alloys with equivalent or higher PRE are applicable as subsea bolting material without cathodic protection. These bolts shall only be used in the solution annealed condition (ASTM B446) or cold-worked to SMYS 720 MPa maximum. Restrictions for H2S service according to ISO 15156 shall apply when applicable.

6.2.6.4 To restrict damage by HISC for low alloy and carbon steels, the hardness for any bolts and nuts to receive cathodic protection shall not exceed 35 HRC or 350 HV, as specified for the standard grades in Sec.8, Table 8-3. The same restriction shall apply for solution annealed or cold-worked type AISI 316 austenitic stainless steel and any other cold-worked austenitic alloys. Precipitation hardening Fe-or Ni-base alloys, duplex and martensitic stainless steels should not be specified as bolting material if subject to cathodic protection. For certification and traceability of bolts, see [6.3.4].

6.2.6.5 Any coating of bolts and nuts shall be selected with due considerations of how such coatings affect tensioning and as-installed properties.

Guidance note:

Zinc coating, phosphatising and epoxy based coatings are applicable; however, there have been concerns that hot-dip zinc coating may cause loss of bolt tensioning and that polymeric coatings may prevent efficient cathodic protection by electrically insulating the bolt from a cathodically protected surface. PTFE coatings have low friction coefficient and the torque has to be applied accordingly.

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6.2.7 Welding consumables

6.2.7.1 Requirements to welding are covered in App.C. Requirements that are specific for pipeline installation welding are given in Sec.10. Below is provided guidance regarding the influence of weld metal strength on allowable defect size as determined by ECA (if applicable).

6.2.7.2 The requirement for welds to have strength level equal to or higher than (overmatching properties) the base material is to minimise deformation in the area adjacent to any possible defects.

6.2.7.3 For pipes exposed to global yielding, i.e. when girth welds are exposed to strain $\varepsilon_{l,nom} \geq 0.4\%$, it is required to perform an ECA according to DNVGL-RP-F108. The ECA generally requires that the weld metal yield stress is matching or overmatching the longitudinal yield stress of the pipe. An ECA involving undermatching weld metal will require special considerations, see DNVGL-RP-F108.

6.2.7.4 It shall be noted that the reduction in yield stress at elevated temperature may be higher for the weld metal than the base material. Hence, undermatching may be experienced for high operation temperatures (e.g. snaking scenario). This is particularly relevant when welding clad or lined line pipe.

Whenever such situations occur, it will be required to perform transverse all weld tensile testing of the weld metal and fracture toughness testing at the relevant temperature.

6.3 Materials specification

6.3.1 General

6.3.1.1 Requirements to the manufacture of line pipe and pipeline components are covered in Sec.7 and Sec.8, respectively. This includes requirements to all relevant manufacturing steps from steel making to dispatch from the pipe mill or component manufacturing facility, but excluding any permanent external/ internal coating.

6.3.2 Line pipe specification

6.3.2.1 A specification reflecting the results of the materials selection according to this section and referring to Sec.7, shall be prepared by the purchaser. The specification shall state any options, additional requirements to and/or deviations from this standard pertaining to materials, manufacture, fabrication and testing of line pipe.

6.3.2.2 The material specification may be a Material Data Sheet referring to this standard.

6.3.2.3 The materials specification shall as a minimum include the following (as applicable):

— quantity (e.g., total mass or total length of pipe)
— manufacturing process (see [7.1.4])
— type of pipe (see [7.1.2.1])
— SMYS
— if the strain ageing effect achieved during external coating should be addressed (see Table 6-1)
— outside or inside diameter
— wall thickness
— wall thickness tolerances (see [4.7.4.6] and Table 7-20/Table 7-21)
— whether data of the wall thickness variation (t_{max} and t_{min}) or the standard deviation in wall thickness variation shall be supplied to facilitate girth welds AUT (see [E.2.1.7])
— length and type of length (random or approximate)
— application of supplementary requirements (S, F, P, D or U), see [6.2.1.2] and [6.2.1.3]
— delivery condition (see Sec.7, Table 7-1 and [7.8.2])
— minimum design temperature
— range of sizing ratio for cold-expanded pipe
— chemical composition for wall thickness > 25 mm (applicable to C-Mn steel pipe with delivery condition N or Q)
— chemical composition for wall thickness > 35 mm (applicable to C-Mn steel pipe with delivery condition M)
— if additional tensile testing in the longitudinal direction with stress strain curves shall be performed
— production tensile testing of base material at elevated temperatures is not required by this standard, however, if this is requested by purchaser, temperature (e.g. maximum design temperature), acceptance criteria and test frequency shall be defined
— CVN test temperature for wall thickness > 40 mm
— liner/cladding material (UNS number)
— mechanical and corrosion properties of liner/cladding material
— type of seal weld for lined line pipe
— thickness of carrier pipe and liner/cladding material
— any project specific requirements to gripping force of lined line pipe

— if the ultrasonically lamination checked zone at the pipe ends shall be wider than 50 mm
— if diameter at pipe ends shall be measured as ID or D
— if pipes shall be supplied with other than square cut ends (see [7.2.3.38])
— if criteria for reduced hydrostatic test pressure, as given in [7.5.1.4], is fulfilled, and if it may be applied
— if the outside weld bead shall be ground flush at least 250 mm from each pipe end to facilitate girth welds AUT (see Table 7-22)
— if inside machining of pipe ends is applicable, and the distance from pipe end to tapered portion (see [7.2.3.39], and [E.2.1.8])
— if pipes shall be supplied with bevel protectors, and in case of what type (see [7.8.3])
— if weldability testing is required
— if qualification testing shall be conducted after the pipe material has been heated to the expected coating temperature when fusion bonded epoxy is used (see Table 6-1 and [7.4.7.10])
— application of the alternative weld cap hardness of C-Mn steel pipe according to supplementary requirement S (see [7.9.1.7])
— if SSC testing shall be performed during MPQT for pipes conforming to supplementary requirement S
— if supplementary requirement P apply, the relevant straining for the installation process, possible corrective actions (e.g. reel on and reel off twice) and post installation conditions/operations introducing plastic deformation shall be specified.

6.3.3 Components specification

6.3.3.1 A specification reflecting the results of the materials selection according to this section and the pressure test philosophy in [5.2.2] and referring to Sec.8, shall be prepared by the purchaser. The specification shall state any options, additional requirements to and/or deviations from this standard pertaining to materials, manufacture, fabrication and testing of the components.

6.3.3.2 The materials specification shall as a minimum include the following (as applicable):

— quantity (i.e the total number of components of each type and size)
— design standard
— required design life
— material type, delivery condition, chemical composition and mechanical properties at design temperature
— nominal diameters, D or ID, out of roundness and wall thickness for adjoining pipes including required tolerances
— bend radius, see [8.2.3.15]
— type of component, piggable or not piggable
— gauging requirements, see [10.9.2.10]
— minimum design temperature (local)
— maximum design temperature (local)
— design pressure (local)
— water depth
— pipeline operating conditions including fluid characteristics
— details of field environmental conditions
— external loads and moments that will be transferred to the component from the connecting pipeline under installation and operation and any environmental loads
— functional requirements
— material specification including, material type, delivery condition, chemical composition and mechanical properties at design temperature
— required testing
— required weld overlay, corrosion resistant or hardfacing
— if pup pieces of the line pipe material shall be fitted

— coating/painting requirements.

6.3.4 Specification of bolts and nuts

6.3.4.1 .Bolts and nuts shall be supplied with certificates to EN 10204 Type 3.1 or ISO 10474 type 3.1.B. Bolts and nuts for pressure containing applications shall be marked for traceability to such certificates. Transfers of test results obtained by specific inspection on primary or incoming products shall not be acceptable for mechanical properties. Fasteners originating from different manufacturing lots shall not be commingled.

6.3.4.2 Bolts and nuts for pressure containing and main structural applications should be specified to have rolled threads.

6.3.4.3 Any coating of bolts shall be specified in the purchase document for bolting. Bolts to be installed continuously submerged in seawater shall be designed to receive cathodic protection and do not need any coating for corrosion control.

Guidance note:

See [6.2.6] for more information regarding use of bolts and nuts exposed to cathodic protection. For bolts to be exposed in splash zone or atmospheric zone corrosion protective coating may be considered.

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6.3.5 Coating specification

6.3.5.1 As a part of detailed design, project specific requirements to as-applied coating properties and to quality control of the manufacture of coating materials and of coating application shall be defined in a purchase specification.

6.3.5.2 The specification of line pipe coating, field joint coating and any weight coating shall include requirements to the qualification of coating materials, coating application and repair procedures, dimensions of the line pipe cut-back (including tolerances) and to documentation of inspection and testing. Cut-backs shall be defined to accommodate any AUT equipment.

6.3.5.3 For specific line pipe and field joint coating systems the minimum requirements in ISO 21809 (part 1-3) shall apply with some additional requirements given in [9.2] in this standard. For concrete coating the minimum requirements in ISO 21809-5 shall apply with additional requirements given in [9.3] in this standard.

6.3.5.4 Recommended practice for application of line pipe and field joint coating systems (some additional systems to those defined in ISO 21809) are given in DNVGL-RP-F106 and DNVGL-RP-F102.

Guidance note:

The above RPs complies with and refers to ISO 21809 and give some additional requirements and guidance to coating design and quality control of application.

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6.3.6 Galvanic anode specification

6.3.6.1 As a part of design, specifications for manufacture and installation of galvanic anodes shall be prepared. These documents shall define requirements to materials, properties of anodes and anode fastening (including any special provisions for electrical continuity), and associated quality control. Detailed requirements are given in Sec.9.

6.3.7 Concrete coating specification

6.3.7.1 If concrete coating is applicable, project specific requirements to concrete coating shall be defined in a purchaser specification as part of detail design. ISO 21809-5 gives requirements to information that shall be supplied by the purchaser and additional requirement given in [6.3.7.2] to [6.3.7.3] shall be included. Requirements to materials and concrete coating application are specified in Sec.9.

6.3.7.2 The amount of reinforcement shall be designed for the specific project; i.e. take into account the actual installation, laying and operation conditions for the pipeline. The percentage of reinforcement specified in [9.3] should be considered as absolute minimum amounts.

6.3.7.3 Minimum shear resistance capacity between concrete coating and corrosion coating shall be specified by the offshore laying contractor and included in the concrete coating specification.

For coal tar asphalt/coal tar enamel line pipe coating the effect of operating temperature (>40°C) on shear strength capacity should be considered to prevent axial sliding of pipeline inside concrete coating.

6.4 Corrosion control

6.4.1 General

6.4.1.1 All components of a pipeline system shall have adequate corrosion control both externally and internally to avoid failures caused or initiated by corrosion.

Guidance note:

Any corrosion damage may take the form of a more or less uniform reduction of pipe wall thickness, but scattered pitting and grooving corrosion oriented longitudinally or transversally to the pipe axis is more typical. Stress corrosion cracking is another form of damage. Uniform corrosion and corrosion grooving may interact with internal pressure or external operational loads, causing rupture by plastic collapse or brittle fracture. Discrete pitting attacks are more likely to cause a pinhole leakage once the full pipe wall has been penetrated.

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6.4.1.2 Pipeline systems may be exposed to a corrosive environment both internally and externally. Options for corrosion mitigation include use of corrosion protective coatings and linings, cathodic protection (externally only), and chemical treatment or fluid processing (internally only).

6.4.2 Corrosion allowance

6.4.2.1 For submarine pipeline systems a corrosion allowance may serve to compensate for internal and/or external corrosion and is mostly applied for control of internal or external pressure. For C-Mn steel components, a corrosion allowance may be applied either alone or in addition to some system for corrosion mitigation. However, for external corrosion protection of continuously submerged components, cathodic protection is mandatory and a corrosion allowance for external corrosion control is then superfluous.

Guidance note:

A requirement for wall thickness determined by installation forces and exceeding that needed for pressure containment at the initial design pressure, or wall thickness not needed for pressure containment due to a later down rating of operational pressure can be utilised for corrosion control but is not referred to in this document as a corrosion allowance.

A corrosion allowance is primarily used to compensate for forms of corrosion attack affecting the pipeline's pressure containment resistance, i.e. uniform attack and, to a lesser extent, corrosion damage as grooves or pits. Such damage is unlikely to affect the pipeline's pressure containment resistance but will cause a pinhole leak when the full wall thickness is penetrated. Any extra wall thickness will then only delay leakage in proportion to the increase in wall thickness.

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6.4.2.2 The needs for, and benefits of, corrosion allowance shall be evaluated, taking into account the following factors as a minimum:

- design life and potential corrosivity of fluid and/or external environment
- expected form of corrosion damage (see guidance note above)
- expected reliability of planned techniques and procedures for corrosion mitigation (e.g. chemical treatment of fluid, external coating, etc.)
- expected sensitivity and damage sizing capability of relevant tools for integrity monitoring, time to first inspection and planned frequency of inspection
- consequences of sudden leakage, requirements to safety and reliability
- any extra wall thickness applied during design for installation forces and not needed for control of internal and external pressure
- any potential for down-rating (or up-rating) of operating pressure.

6.4.2.3 An internal corrosion allowance of minimum 3 mm should be used for C-Mn steel pipelines of safety class medium and high carrying hydrocarbon fluids likely to contain liquid water during normal operation. For nominally dry gas and for other fluids considered as non-corrosive, no corrosion allowance is required.

6.4.3 Temporary corrosion protection

6.4.3.1 The need for temporary corrosion protection of external and internal surfaces during storage and transportation shall be considered during design/engineering for later inclusion in fabrication and installation specifications. Optional techniques include end caps or bevel protectors, temporary thin film coating and rust protective oil/wax.

Guidance note:

Outdoor storage of unprotected pipes for a period of up to about a year will not normally cause any significant loss of wall thickness. However, superficial rusting may cause increased surface roughness affecting pipeline coating operations. Conditions for storage should be such that water will not accumulate internally, or externally at any supports. End caps may retain water internally if damaged or lost at one end, allowing entry of rain water or condensation. Temporary coating applied at coating cut-backs may interfere with pipeline girth welding.

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6.4.3.2 The needs for corrosion protection during flooding shall be assessed for inclusion in installation specifications. Special precautions are required to avoid corrosion damage to CRA pipelines during system pressure testing using seawater. Type 13Cr line pipe may suffer superficial corrosion attack during outdoor storage.

Guidance note:

The use of a biocide for treatment of water for flooding is most essential (even with short duration) as incipient bacterial growth established during flooding may proceed during operation and cause corrosion damage (pipelines for dry gas are excluded). For uncoated C-Mn steel pipelines, an oxygen scavenger may be omitted since oxygen dissolved in sea-water will become rapidly consumed by uniform corrosion with-out causing significant loss of wall thickness. Film forming or passivating corrosion inhibitors are not actually required and may even be harmful. Type 13Cr steel is highly susceptible to damage by raw seawater or marginally treated seawater even at a short exposure period. Use of fresh water should be considered or seawater treated to a pH of 9 minimum.

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6.4.4 External pipeline coatings

6.4.4.1 Line pipe coating (also referred to as factory coating or parent coating) refers to factory applied external coating systems (mostly multiple-layer, with a total thickness of some millimetres) with a corrosion protection function, either alone or in combination with a thermal insulation function. Some coating systems may further include an outer layer for mechanical protection, primarily during laying and any rock dumping or trenching operations. Concrete coating for anti-buoyancy (weight coating, see [9.3]) is, however, not covered by the term line pipe coating.

6.4.4.2 Field joint coating (FJC) refers to single or multiple layers of coating applied to protect girth welds and the associated cut-back of the line pipe coating, irrespectively of whether such coating is actually applied in the field or in a factory (e.g. pipelines for reel laying). Coating field repairs refers to repairs of factory coating performed in the field (typically by the FJC contractor).

6.4.4.3 The line pipe (external) coating system should be selected based on consideration of the following major items:

— general corrosion-protective properties dictated by permeability for water, dissolved gases and salts, adhesion, freedom from pores, etc.
— resistance to physical, chemical and biological degradation leading to e.g. cracking or disbondment, primarily in service but also during storage prior to installation (temperature range and design life are decisive parameters)
— requirements for mechanical properties, primarily those related to adhesion and flexibility, during installation (min. temperature) and operation (max. temperature)
— coating system's compatibility with specific fabrication and installation procedures, including field joint coating and coating field repairs
— coating systems compatibility with concrete weight coating (see [9.3]), if applicable
— coating system's compatibility with CP, and capability of reducing current demand for CP, if applicable
— line pipe material's compatibility with CP considering susceptibility to HISC; see [6.2.3.4]
— line pipe material's susceptibility to corrosion in the actual environment, including stress corrosion cracking in the atmospheric zone and any onshore buried zone
— environmental compatibility and health hazards during coating application, fabrication/installation and operation.

6.4.4.4 For thermally insulating coatings, properties related to flow assurance also apply; e.g. specific heat capacity, thermal conductivity and the degradation of such properties by high operating external pressure and internal fluid temperature.

6.4.4.5 Pipeline components should have external coatings matching the corrosion protective properties of those to be used for line pipe. If this is not practical, CP design may compensate for inferior properties. However, risks associated with HISC by CP shall be duly considered (see [6.2.3.4] and [6.4.5.2] guidance note).

6.4.4.6 For the selection of FJC, the same considerations as for pipeline and riser coatings as in [6.4.4.3], [6.4.6.5] and [6.4.6.6] apply. In addition, sufficient time for application and cooling or curing is crucial during barge laying of pipelines.

6.4.4.7 For pipes with a weight coating or thermally insulated coating, the field joint coating (FJC) is typically made up of an inner corrosion protective coating and an in-fill. The objective of the in-fill is to provide a smooth transition to the pipeline coating and mechanical protection to the inner coating. For thermally insulated pipelines, requirements for adequate insulating properties may also apply. The requirements and guidelines to FJC are also applicable to any field repairs of factory coating

6.4.4.8 The design and quality control of field joint coatings is essential to the integrity of pipelines in HISC susceptible materials, including ferritic-austenitic (duplex) and martensitic stainless steel. Recommended practice for design and quality control of field joint coatings is given in DNVGL-RP-F102.

6.4.5 Cathodic protection

6.4.5.1 Pipelines in the submerged zone shall be furnished with a cathodic protection (CP) system to provide adequate corrosion protection for any defects occurring during coating application (including field joints), and also for any subsequent damage to the coating during installation and operation. The design of submarine pipeline CP systems shall meet the minimum requirements in ISO15589-2. See DNVGL-RP-F103 for some additional amendments and guidelines.

Guidance note:

CP may be achieved using either galvanic (sacrificial) anodes, or impressed current from a rectifier. Galvanic anodes are normally preferred.

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6.4.5.2 The CP systems shall be capable of suppressing the pipe-to-seawater (or pipe-to-sediment) electrochemical potential into the range -0.80 to -1.15 V rel. Ag/AgCl/ seawater. A less negative potential may be specified for pipelines in CRA materials.

Guidance note:

Potentials more negative than -1.15 V rel. Ag/AgCl/ seawater can be achieved using impressed current. Such potentials may cause detrimental secondary effects, including coating disbondment and HISC of line pipe materials and welds. Pipeline system components in high-strength steel, and particularly in martensitic or ferritic-austenitic (duplex) stainless steel, subject to high local stresses during subsea installation activities (e.g. pre-commissioning) or operation can suffer HISC by CP, also within the potential range given above. Such damage is primarily to be avoided by restricting straining subsea by design measures. In addition, special emphasis should be laid on ensuring adequate coating of components that may be subject to localised straining. It is essential that the coating systems to be applied (i.e. factory applied coating and field joint coating) for materials that are known to be susceptible to HISC have adequate resistance to disbonding by mechanical effects during installation as well as chemical/ physical effects during operation. Overlay welding of critical areas with austenitic CRA filler materials may be considered when organic coatings are not applicable. Thermally sprayed aluminium coating has also been applied for this purpose. Other measures to reduce or eliminate the risk of HISC include control of galvanic anodes by diodes and use of special anode alloys with less negative closed circuit potential. (These techniques require that the pipeline is electrically insulated from conventional CP systems on electrically connected structures). In case conventional bracelet anodes are still to be used, welding of anodes to any pressure containing components in these materials should be avoided.

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6.4.5.3 Galvanic anode CP systems should be designed to provide corrosion protection throughout the design life of the protected object.

Guidance note:

As retrofitting of galvanic anodes is generally costly (if practical at all), the likelihood of the initial pipeline design life being extended should be duly considered.

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6.4.5.4 Pipeline systems connected to other offshore installations shall have compatible CP systems unless an electrically isolating joint is to be installed. At any landfall of an offshore pipeline with galvanic anodes and with impressed current CP of the onshore section, the needs for an isolation joint shall be evaluated.

Guidance note:

Without isolating joints, some interaction with the CP system of electrically connected offshore structures cannot be avoided.
As the design parameters for subsea pipelines are typically more conservative than that of other structures, some current drain from riser and pipeline anodes to the CP system of the connecting system cannot be avoided, sometimes leading to premature consumption. When the structure has a correctly designed CP system such current drain is not critical as the net current drain will decrease with time and ultimately cease; i.e. unless the second structure has insufficient CP.

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6.4.5.5 Pipelines should be designed with a self-sustaining CP system based on bracelet anodes installed with a maximum distance of 300 m (in accordance with ISO 15589-2) and with electrical connections to the pipeline by pin brazing or aluminothermic welding of cable connections to the pipe wall. (See [C.5.5]).

For shorter pipelines (up to 30 km approximately), CP may be achieved by anodes installed on structures at the end of the pipeline (e.g. platform sub-structure, subsea template or riser base) electrically connected to the pipeline. This concept requires, however, that the design and quality control of factory applied coatings, field joint coatings and coating field repairs are closely defined (e.g. as in DNVGL-RP-F106 Sec.6 and DNVGL-RP-F102). A recommended procedure to calculate the protective length of anodes on an adjacent structure is given in DNVGL-RP-F103.

Guidance note:

ISO 15589-2 gives an alternative procedure but, contrary to DNVGL-RP-F103, does not define the primary parameters to be used for calculation of the protective length.

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Guidance note:

CP by anodes located on adjacent structures significantly reduces the cost of anode installation in case the pipeline installation concept would otherwise require anode installation offshore. Moreover, for buried pipelines in general and for hot buried lines in particular, the anode electrochemical efficiency and current output capacity increases since the anodes on such structures are freely exposed to seawater. The condition of such anodes can also be monitored. The concept of basing pipeline CP on anodes installed on adjacent structures further reduces the risk of HISC damage to pipelines in susceptible materials (e.g. martensitic and ferritic-austenitic stainless steels).

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6.4.5.6 Bracelet pipeline anodes are to be designed with due considerations of forces induced during pipeline installation. For anodes to be installed on top of the pipeline coating, this may require use of bolts for tensioning or welding of anode tabs with pressure applied on the bracelet assembly during the mounting. Connector cables shall be adequately protected; e.g. by locating the cables to the gap between the anode bracelets and filling with a moulding compound.

6.4.5.7 A calculation procedure for pipeline CP design using conventional bracelet anodes and a maximum anode spacing of 300 m is given in ISO 15589-2 and in DNVGL-RP-F103.

Guidance note:

The latter document generally refers to ISO 15589-2 for design parameters and design procedures to be used and recommends some default values which represent minimum requirements that do not need to be verified by special considerations and testing. DNVGL-RP-F103 emphasizes the importance of coating design and quality control of coating application when defining the CP current reducing effects of such coatings. It further contains additional guidance to the CP design. For alternative design procedures, see [6.4.5.5] and [6.4.5.6] above.

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6.4.5.8 The detailed engineering documentation of galvanic anode CP systems shall contain the following:

- design premises, including design life and reference to relevant project specifications, standards or recommended practices
- calculations of average and final current demands for individual sections of the pipeline
- calculations of total anode net mass for the individual sections, to meet the mean current demand
- calculation of final current anode output to verify that the final current demand can be met for the individual sections of the pipeline (applies to a conventional bracelet anode concept with max. 300 m anode spacing)
- number of bracelet anodes for the individual pipeline sections, and resulting net anode mass to be installed on each section
- outline drawing(s) of bracelet anodes with fastening devices and including tentative tolerances

— calculations of pipeline metallic resistance to verify the feasibility of CP by anodes on adjacent structure(s) or a bracelet anode concept exceeding a spacing of 300 m in case any of these options apply (see DNVGL-RP-F103)
— documentation of CP capacity on adjacent installation(s) to be utilized for CP of pipeline, if applicable.

Guidance note:

The above requirements for documentation of CP design is an amendment to ISO 15589-2.

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6.4.5.9 Recommended practice for CP design of pipeline system components with major surfaces in structural steel (e.g. riser bases) is given in DNVGL-RP-B401.

6.4.5.10 Design of any impressed current CP systems installed at land falls shall comply with ISO 15589-1. Requirements to electrically isolation joints are given in [8.2.8].

Guidance note:

Design of impressed current CP systems at landfalls is not covered by this standard. Some general guidance is given in ISO 15889.

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6.4.6 Internal corrosion control

6.4.6.1 Options for internal corrosion control should be evaluated aiming for the most cost-effective solution meeting the overall requirements of safety and environmental regulations. The selection of the most cost-effective strategy for corrosion control requires that all major costs associated with operation of the pipeline system, as well as investment costs for corrosion control, are evaluated (life cycle cost analysis). When fluid corrosivity and efficiency of corrosion mitigation cannot be assessed with any high degree of accuracy, a risk cost may be added for a specific option being evaluated. The risk cost is the product of estimated probability and consequences (expressed in monetary units) of a particular failure mode (e.g. rupture or pinhole leakage) due to malfunction of the corrosion control system being considered (e.g. inhibitor addition to a potentially corrosive fluid). The probability of such failures should reflect the designer's confidence in estimating the fluid corrosivity and the efficiency of options for corrosion control being evaluated. Depending on the failure mode, consequences of failure may include costs associated with increased maintenance, repairs, lost capacity and secondary damage to life, environment and other investments.

6.4.6.2 The selection of a system for internal corrosion protection of pipelines has a major effect on detailed design and shall therefore be evaluated during conceptual design. The following options for corrosion control may be considered:

— processing of fluid for removal of liquid water and/or corrosive agents
— use of line pip or internal (metallic) lining/cladding with intrinsic corrosion resistance (see [6.2.3])
— use of organic corrosion protective coatings or linings (normally in combination with a) or d))
— chemical treatment, i.e. addition of chemicals with corrosion mitigating function.

In addition, the benefits of a corrosion allowance (see [6.4.2]) should be duly considered for the above points.

6.4.6.3 Corrosion control by fluid processing may involve removal of water from gas/oil (dehydration), or of oxygen from seawater for injection (deoxygenation), for example. Consequences of operational upsets on material degradation should be taken into account. The necessity for corrosion allowance and redundant systems for fluid processing should be considered. On-line monitoring of fluid corrosion properties downstream of processing unit is normally required. For oil export pipelines carrying residual amounts of water, a biocide treatment should be considered as a back up for prevention of bacterial corrosion. Periodic pigging for removal of water and deposits counteracts internal corrosion in general and bacterial corrosion in particular.

6.4.6.4 If internal coatings or linings are to be evaluated as an option for corrosion control, the following main parameters shall be considered:

- chemical compatibility with all fluids to be conveyed or contacted during installation, commissioning and operation, including the effects of any additives for control of flow or internal corrosion (see [6.4.6.6])
- resistance to erosion by fluid and mechanical damage by pigging operations
- resistance to rapid decompression
- reliability of quality control during coating application
- reliability of (internal) field joint coating systems, if applicable
- consequences of failure and redundant techniques for corrosion mitigation.

6.4.6.5 Internal coating of pipelines (e.g. by thin film of epoxy) has primarily been applied for the purpose of friction reduction in dry gas pipelines (flow coatings or anti-friction coatings). Any such coatings should have a minimum specified thickness of 40 μm and should comply with the minimum requirements in API RP 5L2 or ISO 15741. Although such coatings can not be expected to be efficient in preventing corrosion attack if corrosive fluids are conveyed, any coating with adequate properties may still be beneficial in reducing forms of attack affecting membrane stresses and hence, the pressure retaining capacity of the pipeline.

6.4.6.6 Chemical treatment of fluids for corrosion control may include:

- corrosion inhibitors (e.g. film forming)
- pH-buffering chemicals
- biocides (for mitigation of bacterial corrosion)
- glycol or methanol (added at high concentrations for hydrate inhibition, diluting the water phase)
- dispersants (for emulsification of water in oil)
- scavengers (for removal of corrosive constituents at low concentrations).

6.4.6.7 The reliability of chemical treatment should be evaluated in detail during the conceptual design. Important parameters to be considered are:

- anticipated corrosion mitigating efficiency for the actual fluid to be treated, including possible effects of scales, deposits, etc. associated with this fluid
- capability of the conveyed fluid to distribute inhibitor in the pipeline system along its full length and circumference
- compatibility with all pipeline system and downstream materials, particularly elastomers and organic coatings
- compatibility with any other additives to be injected,
- health hazards and environmental compatibility
- provisions for injection and techniques/procedures for monitoring of inhibitor efficiency
- consequences of failure to achieve adequate protection, and redundant techniques.

For pipelines carrying untreated well fluid or other fluids with high corrosivity and with high requirements to safety and reliability, there is a need to verify the efficiency of chemical treatment by integrity monitoring using a tool allowing wall thickness measurements along the full length of the pipeline (see Sec.12). Corrosion probes and monitored spools are primarily for detection of changes in fluid corrosivity and are not applicable for verification of the integrity of the pipeline.

6.4.6.8 The design of corrosion control based on fluid processing and/or chemical treatments should be reviewed by operator’s operational organisation.

SECTION 7 CONSTRUCTION – LINEPIPE

7.1 General

7.1.1 Objective

7.1.1.1 This section specifies the requirements for manufacture, testing and documentation of linepipe. All mechanical properties and dimensional tolerances shall be met after heat treatment, expansion or impansion, and final shaping.

Guidance note:

Coating application of fusion bonded epoxy involves heating the material to 200-250 °C, but this is not considered a heat treatment by this standard. It is a low temperature for steel materials, still it may have a minor effect on the material properties. Test results prior to coating application can be considered representative of the final condition. During qualification it may be considered to perform some additional testing after coating application and compare with results obtained before coating. In case the difference is non-negligible, it indicates that the material is too sensitive to temperature increase and the chemical composition and manufacturing process should be reviewed. Typically the YS/TS ratio will have most noticeable variation, if any.

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7.1.1.2 Materials selection shall be performed in accordance with Sec.6.

7.1.1.3 This section does not cover any activities taking part after the pipes have been dispatched from the pipe mill, e.g. coating and girth welding.

7.1.1.4 The requirements stated herein for Carbon-Manganese (C-Mn) steel linepipe conform in general to ISO 3183 Annex J: *PSL 2 pipe ordered for offshore service*, with some additional and modified requirements.

7.1.1.5 Manufacturers shall have an implemented quality assurance system. For linepipe manufacturers a quality assurance system according to ISO 9001 is considered to meet requirements in Table D-4.

7.1.2 Application

7.1.2.1 The requirements are applicable for linepipe made of:

— C-Mn steel
— clad or lined steel
— corrosion resistant alloys (CRA) including ferritic - austenitic (duplex) stainless steels, austenitic stainless steels, martensitic stainless steels (13Cr), other stainless steels and nickel based alloys.

The principles from this standard may be applied for other materials, e.g. 9Ni steel. In such cases, specific material requirements shall be defined in the project specification.

7.1.2.2 Materials, manufacturing methods and procedures that comply with recognised practices or proprietary specifications will normally be acceptable provided they comply with the requirements of this section.

7.1.3 Systematic review

7.1.3.1 The overall requirements to systematic review in Sec.2 will apply for the linepipe manufacturers to review this section and evaluate if the requirements in the purchase order and this standard can be met.

7.1.4 Process of manufacture

7.1.4.1 C-Mn linepipe shall be manufactured according to one of the following processes:

Seamless (SMLS)

Pipe manufactured by a hot forming process without welding. In order to obtain the required dimensions, the hot forming may be followed by sizing or cold finishing.

High frequency welded (HFW)

Pipe formed from strip and welded with one longitudinal seam formed by electric-resistance welding applied by induction or conduction with a welding current frequency ≥ 70 kHz, without the use of filler metal. The forming may be followed by cold expansion or reduction.

Submerged arc-welded (SAW)

Pipe manufactured by forming from strip or plate and with one longitudinal (SAWL) or helical (SAWH) seam formed by the submerged arc process, with at least one pass made on the inside and one pass from the outside of the pipe. The forming may be followed by cold expansion or reduction.

7.1.4.2 CRA linepipe may, in addition to SMLS and SAWL, be manufactured according to one of the following processes:

Electron beam welded (EBW) and laser beam welded (LBW)

Pipe formed from strip and welded with one longitudinal seam, with or without the use of filler metal. The forming may be followed by cold expansion or reduction to obtain the required dimensional tolerances. These welding processes shall be subject to pre-qualification testing according to App.C.

Multiple welding processes (MWP)

Pipe formed from strip or plate and longitudinally welded using a combination of two or more welding processes. If the combination of welding processes has not been used previously, pre-qualification testing should be conducted according to App.C.

7.1.4.3 The backing steel of lined linepipe shall comply with [7.4].

7.1.4.4 The liner pipe of lined linepipe shall be manufactured in accordance with API 5LC.

7.1.4.5 Clad linepipe shall be manufactured from CRA clad C-Mn steel plate by application of a single longitudinal weld. With respect to the backing steel, the pipe manufacturing shall be in general compliance with one of the manufacturing routes for SAW pipe as given in Table 7-1. The longitudinal weld shall be MWP (see [7.1.4.2]).

7.1.5 Supplementary requirements

7.1.5.1 When requested by the purchaser and stated in the materials specification (as required in [7.1.6]), linepipe to this standard shall meet supplementary requirements given in subsection [7.9], for:

— H_2S service (also referred to as sour service), suffix S (see [7.9.1])
— fracture arrest properties, suffix F (see [7.9.2])
— linepipe for plastic deformation, suffix P (see [7.9.3])
— enhanced dimensional requirements for linepipe, suffix D (see [7.9.4])
— high utilisation, suffix U (see [7.9.5]).

7.1.6 Linepipe specification

7.1.6.1 A linepipe specification reflecting the results of the materials selection (see [6.3.2]), referring to this section of the offshore standard, shall be prepared by the purchaser. The specification shall state any additional requirements to and/or deviations from this standard related to materials, manufacture, fabrication and testing of linepipe.

7.1.7 Manufacturing procedure specification

7.1.7.1 Prior to start of production, the manufacturer shall prepare a manufacturing procedure specification (MPS). The MPS shall demonstrate how the specified properties may be achieved and verified throughout the proposed manufacturing route.

The MPS shall address all factors that influence the quality and consistency of the product. All main manufacturing steps from control of received raw material to shipment of finished pipe, including all examination and check points, shall be outlined in detail.

References to the procedures established for the execution of all the individual production steps shall be included.

7.1.7.2 The MPS shall as a minimum contain the following information (as applicable):

— steel producer
— plan(s) and process flow description/diagram
— project specific quality control plan
— manufacturing process
— target chemical composition
— steel making and casting techniques
— ladle treatments (secondary refining), degassing, details of inclusion shape control, super heat
— method used to ensure that sufficient amount of intermixed zones between different orders are removed
— details and follow-up of limiting macro, as well as micro segregation, e.g. soft reduction and electro magnetic stirring (EMS) used during continuous casting
— manufacturer and manufacturing location of raw material and/or plate for welded pipes
— billets reheating temperature for seamless
— allowable variation in slab reheating temperature, and start and stop temperatures for finishing mill and accelerated cooling
— methods for controlling the hydrogen level (e.g. stacking of slabs and/or plates)
— pipe-forming procedure, including preparation of edges and control of alignment and shape (including width of strip for HFW)
— procedure for handling of welding consumable and flux, including frequency of flux moisture testing
— all activities related to production and repair welding, including welding procedures and qualification
— heat treatment procedures (including in-line heat treatment of the weld seam) including allowable variation in process parameters
— method for cold expansion/reduction/sizing/finishing, target and maximum sizing ratio
— hydrostatic test procedures
— NDT procedures (also for strip/plate as applicable)
— list of specified mechanical and corrosion testing
— dimensional control procedures
— pipe number allocation
— pipe tracking procedure (traceability procedure)
— marking, coating and protection procedures
— handling, loading and shipping procedures
— for coiled line pipe; strip end and circumferential welds (if applicable) welding and NDT procedures.

7.1.8 Manufacturing procedure qualification test

7.1.8.1 The MPS shall be qualified for each nominal pipe diameter; either as part of first-day production or as a separate MPQT prior to full-scale production. For C-Mn steels with SMYS < 485 MPa that are not intended for H_2S service, relevant documentation may be agreed in lieu of qualification testing providing all essential variables in [7.1.8.7] are adhered to.

Guidance note:

Depending on the criticality of the project, it is recommended for all projects to carefully evaluate if the MPQT should be conducted prior to start of production.

It is not necessary to perform repeated qualification testing during one and the same project, even if the fabrication is interrupted by some weeks. This is provided that all procedures and equipment remain unchanged, and that all essential variables are adhered to.

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7.1.8.2 For C-Mn steels with SMYS > 450 MPa, the qualification of the MPS should be completed prior to start of production.

7.1.8.3 Each MPQT shall include full qualification of one pipe from two different test units of different heats (a total of two pipes). If the entire production is limited to one heat, the MPQT may be performed on a single pipe from that heat. The minimum type and extent of chemical, mechanical, and non-destructive testing are given in this section. This includes all production tests plus additional tests given in Table 7-8. Table 7-13 and Table 7-15.

7.1.8.4 For pipes delivered as coiled line pipe, qualification of strip end welds shall also be included as part of the MPQT.

7.1.8.5 If the cold forming of C-Mn steel exceeds 5% strain after heat treatment, ageing tests shall be performed as part of the qualification testing. The cold forming shall take into account all operations on the steel, including but not limited to levelling of plate, pipe forming and expansion. The tests shall be performed on the actual pipe without any straightening or additional deformation, see [B.2.11.1]. The absorbed Charpy V-notch impact energy in the aged condition shall meet the requirements in Table 7-5.

7.1.8.6 Additional MPS qualification testing may be required by purchaser (e.g. weldability testing, analysis for trace elements for steel made from scrap), as part of the qualification of the MPS (see [7.1.8.1]). Weldability tests should be performed using the same welding equipment as used during installation or on the lay barge.

7.1.8.7 The validity of the MPQT shall be limited to the steelmaking, rolling, and manufacturing/fabrication facilities used during the qualification.

7.1.8.8 In addition to the requirements stated above, the following changes (as applicable) to the manufacturing processes will require re-qualification of the MPS (essential variables):

- any change in steelmaking practice
- for C-Mn steel, change in the superheat exceeding ±20°C, change in the slab thickness exceeding ±20%, change in the casting speed exceeding ±30%, any change in the use of soft reduction and electromagnetic stirring.
- changes beyond the allowable variation for rolling practice, accelerated cooling and/or QT process
- for C-Mn steel plate, changes exceeding for slab reheating ±60°C, final rolling temperature ±30°C, accelerated cooling start temperature ±40°C, accelerated cooling stop temperature ±60°C
- change in nominal wall thickness exceeding + 5% to -10%
- change in ladle analysis for C-Mn steels outside ± 0.02% C, ± 0.03 CE and/or ± 0.02 in Pcm
- any change in pipe forming process, between UOE, JCOE, three-roll bend or other forming method,

— any change in s_r > ±0.0025 (see [7.2.3.34] and [7.2.3.35])
— any change in alignment and joint design for welding
— change in welding heat input ± 15%
— any change in welding wire type, thickness and configuration (including number of wires)
— any change in welding flux
— any change in shielding gas
— any change in make, type and model of welding equipment.

The following additional essential variable applies to HFW, EBW and LBW pipe:

— any change in nominal thickness
— change in welding heat coefficient Q = (amps × volts)/(travel speed × thickness) ± 5%
— addition or deletion of an impeder
— change in rollers position and strip width outside agreed tolerances.

In case issues only related to the welding process have been changed, the re-qualification of the MPS may be limited to the weld and HAZ only (e.g. not base material testing).

7.1.8.9 If one or more tests in the MPQT fail, the MPS shall be reviewed and modified accordingly, and a complete re-qualification performed. Re-testing may be allowed subject to agreement. In the specific case of failed fusion line CVN tests (with reference to local brittle zones), retesting of further 2 sets removed from the failed MPQ pipe (at the same position relative to the wall thickness) is permitted prior to declaring the MPQT as having failed (see [7.2.5.10]).

Guidance note:

For toughness in fusion line there is general industry understanding that the results can have very large variation – and this does not necessarily mean that the general material properties are unacceptable. Local brittle zones (LZB) are known to be present in the heat affected zone (HAZ) of welds with high heat input. Such LBZs are inevitable, and their extent should be kept as low as possible. Even a very low amount of LBZs can lead to some unacceptable toughness results.

The standard allows retesting of the same pipe if there is a low toughness result in the fusion line (FL), and it can be attributed to LBZs. Retesting gives a larger set of results, and will clearly show whether the quantity of LBZs is low (i.e. few low toughness results) or high (i.e. many low toughness results). Since LBZs are most likely present in all pipes, rejecting pipes with few low toughness results does not improve the quality of the products. The neighbouring pipes will most likely have similar properties.

The intention of allowing retesting the same pipe in case of low toughness in FL is to have a realistic approach to quality assurance and integrity control – while not rejecting pipes that are in principle acceptable.

Local brittle zones may influence all types of toughness tests, not only Charpy impact toughness testing.

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7.2 Carbon Manganese (C-Mn) steel linepipe

7.2.1 General

7.2.1.1 C-Mn steel linepipe fabricated according to this standard generally conform to the requirements in ISO 3183 Annex J: *PSL 2 pipe ordered for offshore service*. Any additional or modified requirements to ISO 3183 Annex J are highlighted in this subsection ([7.2]) as described in [7.2.1.2] and [7.2.1.3].

7.2.1.2 Paragraphs with additional requirements to ISO 3183 are marked at the end of the relevant paragraph with AR.

Paragraphs with modified requirements compared to ISO 3183 are marked at the end of the relevant paragraph with MR.

7.2.1.3 Additional or modified requirements when given in tables are marked in accordance with [7.2.1.2] with AR and MR in the relevant table cells.

7.2.2 Pipe designation

7.2.2.1 C-Mn steel linepipe shall be designated with:

— DNV GL
— process of manufacture
— SMYS
— supplementary requirement suffix (see [7.9]), as applicable. MR

Guidance note:

E.g. "DNVGL SMLS 450 SP" designates a seamless pipe with SMYS 450 MPa, meeting the supplementary requirements for H_2S service and plastic deformation (e.g. reeling installation) properties.

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7.2.3 Manufacturing

7.2.3.1 C-Mn steel linepipe shall be manufactured in accordance with the processes given in [7.1.4] using the starting materials and corresponding forming methods and final heat treatment as given in Table 7-1.

7.2.3.2 All manufacturing including steel making and the raw materials used shall be in accordance with the qualified MPS, follow the same activity sequence, and stay within the agreed allowable variations.

7.2.3.3 All steels shall be made by an electric or one of the basic oxygen processes. C-Mn steel shall be fully killed and made to a fine grain practice. The final product should have a maximum hydrogen content of 2 ppm. The hydrogen content in the ladle shall be determined by direct measurements or by a relevant model. If a model is used, the input parameters shall be stated. The maximum allowable hydrogen content in the ladle shall be determined by the manufacturer, and justified by relevant data.

7.2.3.4 SMLS pipe shall be manufactured from continuously (strand) cast or ingot steel.

7.2.3.5 If the process of cold finishing is used, this shall be stated in the inspection document.

7.2.3.6 Pipe ends shall be cut back sufficiently after rolling to ensure freedom from defects. AR

7.2.3.7 Strip and plate used for the manufacture of welded pipe should be rolled from continuously (strand) cast or pressure cast slabs. Strip or plate shall not contain any repair welds.

7.2.3.8 The strip width for spiral welded pipes should not be less than 0.8 and not more than 3.0 times the pipe diameter. Strip and plate shall be inspected visually after rolling, either of the plate, of the uncoiled strip or of the coil edges.

7.2.3.9 If agreed, strip and plate shall be inspected ultrasonically for laminar imperfections or mechanical damage, either before or after cutting the strip or plate, or the completed pipe shall be subjected to full-body inspection, including ultrasonic inspection, see Table 7-16.

7.2.3.10 Plate or strip shall be cut to the required width and the weld bevel prepared by milling or other agreed methods before forming. AR

7.2.3.11 Cold forming (i.e. below 250°C) of C-Mn steel shall not introduce a plastic deformation exceeding 5%, unless heat treatment is performed or ageing tests show acceptable results (see [7.1.8.5]). AR

7.2.3.12 Normalising forming of materials and weldments shall be performed as recommended by the manufacturers of the plate/strip and welding consumables. AR

7.2.3.13 Welding personnel for execution of all welding operations shall be qualified by in-house training. The in-house training program shall be available for review on request by purchaser. AR

7.2.3.14 Welding and repair welding procedures for the seam weld shall be qualified as part of MPQT. AR

7.2.3.15 The following types of repair welding procedure shall, as a minimum, be qualified:

— Arc stop/restart
— Shallow repair (single pass is not allowed, a minimum of 2 passes)
— Deep repair (minimum 10% of WT, but not covering through thickness repair). The depth of the groove should be set by the manufacturer.

Other repair procedures may be qualified, if agreed. Repair welding shall be qualified in a manner realistically simulating the repair situation to be qualified. AR

7.2.3.16 Welds containing defects may be locally repaired by welding, after complete removal of all defects. AR

7.2.3.17 The manufacturer shall ensure stable temperature conditions during welding. A minimum pre-welding temperature shall be established. If SAW seam welding is done in more than one pass per side, then a maximum interpass temperature shall be qualified. AR

7.2.3.18 Low hydrogen welding consumables shall be used and shall give a diffusible hydrogen content of maximum 5 ml/100 g weld metal. Unless comparative tests result of diffusible hydrogen versus flux moisture content are provided to meet this requirement for SAW, the maximum residual moisture content of agglomerated flux shall be 0.03%. AR

7.2.3.19 Welding consumables shall be individually marked and supplied with an inspection certificate according to EN 10204 or an equivalent material certification scheme. Welding wire shall be supplied with certificate type 3.1, while certificate type 2.2 is sufficient for SAW Flux. AR

7.2.3.20 Handling of welding consumables and the execution and quality assurance of welding shall meet the requirements of in-house quality procedures. AR

7.2.3.21 Any lubricant and contamination on the weld bevel or the surrounding areas shall be removed before making the seam welds of SAWL pipes or SAWH pipes.

7.2.3.22 Tack welds shall be made by: manual or semi-automatic submerged-arc welding, electric welding, gas metal-arc welding, gas tungsten-arc welding, flux-cored arc welding; or shielded metal-arc welding using a low hydrogen electrode. Tack welds shall be melted and coalesced into the final weld seam or removed by machining.

7.2.3.23 Intermittent tack welding of the SAWL groove shall not be used unless purchaser has approved data furnished by manufacturer to demonstrate that all mechanical properties specified for the pipe are obtainable at both the tack weld and intermediate positions.

7.2.3.24 For linepipe welding, the flux moisture needs to be controlled. Flux sampling should be from the weld head, rotating between welding machines on a regular basis. Test frequency should take into account risk of moisture fluctuation due to environmental conditions, storage conditions and handling practice. The acceptance criteria for flux moisture shall be determined by the manufacturer, based on correlation with diffusable hydrogen content in final product, see [7.2.3.18]. For agglomerated flux, a maximum residual moisture content of 0.03% can be used, unless comparative test results justify a higher limit. For fused flux, no suggested limit has been established.

7.2.3.25 General requirements to repair welding:

— Any repair welding shall be carried out prior to cold expansion and final heat treatment.

— Repeated repairs shall be subject to agreement.
— Repair welding of cracks is not permitted.
— A local weld repair shall be at least 50 mm long or 4 times the repair depth, whichever is longer.
— The excavated portion of the weld shall be large enough to ensure complete removal of the defect, and the ends and sides of the excavation shall have a gradual taper from the bottom of the excavation to the surface. If air-arc gouging is used, the last 3 mm shall be removed by mechanical means to remove any carbon enriched zones. Removal of less than 3 mm may be accepted if it can be documented that the carbon enriched zones has been satisfactorily removed.
— Weld repairs shall be ground to merge smoothly into the original weld contour.

7.2.3.26 Qualification testing of repair welds shall be described in the MPS. It shall be documented that the repair weld metal, including all transition zones (e.g. interface between new and old weld metal) meets the same requirements as the original weld metal and HAZ. AR

Guidance note:

It is recommended to review the test and qualification regime described in Table C-4.

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7.2.3.27 The abutting edges of the strip or plate should be milled or machined immediately before welding of HFW pipes. The weld flash shall be removed on both external and internal surface as required in Table D-4.

7.2.3.28 The width of the strip or plate should be continuously monitored during production of HFW pipes. AR

7.2.3.29 The weld seam and the HAZ shall be fully normalized subsequent to welding of HFW pipes. MR

7.2.3.30 For pipes to be supplied as coiled line pipe, strip/plate end welds are permitted and shall be at an acute angle to the edges of the strip. Strip/plate end welds shall comply with all applicable requirements in this section given to helical welded pipes and NDT requirements given in [7.6].

7.2.3.31 If used, circumferential welds between coiled pipes shall be qualified according to requirements for pipeline girth welds given in App.C. See also DNVGL-RP-F108 for considerations when fracture mechanics testing is not possible due to size limitations for such circumferential welds.

7.2.3.32 Heat treatments of SMLS and welded pipe shall be performed according to documented procedures used during MPQT.

7.2.3.33 The documented procedures shall be in accordance with any recommendations from the material manufacturer with regard to heating and cooling rates, soaking time, and soaking temperature. AR

7.2.3.34 The extent of cold sizing and cold forming expressed as the sizing ratio s_r, shall be calculated according to the following formula:

$$s_r = |D_a - D_b| / D_b \tag{7.1}$$

where:

D_a = the actual outside diameter after sizing
D_b = the actual outside diameter before sizing.

The actual outside diameter should be measured with a tape measure (i.e. perimeter as an average of all possible diameters). The sizing ratio should be checked every shift, preferably at both ends of the pipe. MR

7.2.3.35 The sizing ratio of cold expanded pipe should be within the range $0.003 < s_r \leq 0.015$. Expansion shall not introduce high local deformations.

7.2.3.36 Pipes may be cold sized to their final dimensions by expansion or reduction. This shall not produce excessive permanent strain. The sizing ratio, s_r , shall not exceed 0.015 if no subsequent heat treatment or only heat treatment of the weld area is performed.

7.2.3.37 The sizing ratio, s_r , for cold sizing of pipe ends shall not exceed 0.015 unless the entire pipe ends are subsequently stress relieved.

7.2.3.38 Pipe ends should be cut square and be free from burrs. MR

Table 7-1 C-Mn steels, acceptable manufacturing routes

Type of pipe	*Starting material*	*Pipe forming*	*Final heat treatment*	*Delivery condition* 1)
SMLS	Ingot, bloom or billet	Normalising forming	None	N
		Hot forming	Normalising or QT 2)	N or Q
		Hot forming and cold finishing		N or Q
HFW	Normalising rolled strip	Cold forming	Normalising of weld area	N
	Thermo-mechanical rolled strip		Heat treating of weld area	M
			Heat treating of weld area and stress relieving of entire pipe	M
	Hot rolled or normalising rolled strip	Cold forming	Normalising of entire pipe	N
			QT 2) of entire pipe	Q
		Cold forming and hot reduction under controlled temperature, resulting in a normalised condition	None	N
		Cold forming followed by thermomechanical forming of pipe		M
SAW	Normalised or normalising rolled plate or strip	Cold forming	None, unless required due to degree of cold forming	N
	Thermo-mechanical rolled plate or strip			M
	QT 2) plate or strip			Q
	As-rolled, QT 2), normalised or normalising rolled plate or strip	Normalising forming	None	N
		Cold forming	Normalising	N
			QT 2)	Q

Notes

1) The delivery conditions are:
   - N - normalised
   - Q - quenched and tempered
   - M - thermo-mechanical rolled or formed.
2) Quenched and tempered.

7.2.3.39 If agreed, internal machining or grinding may be carried out. In case of machining, the following requirements shall be adhered to:

- if required in the purchase order the internal taper shall be located at a defined minimum distance from future bevel to facilitate UT or AUT
- the angle of the internal taper, measured from the longitudinal axis shall not exceed 7.0° for welded pipe. For SMLS pipe the maximum angle of the internal taper shall be as given in Table 7-2. MR

Table 7-2 Maximum angle of internal taper for SMLS pipe

Wall thickness t [mm]	*Max. angle of taper [°]*
< 10.5	7.0
10.5 ≤ t < 14.0	9.5
14.0 ≤ t < 17.0	11.0
≥ 17.0	14.0

7.2.3.40 Jointers should not be used.

7.2.3.41 If used, the jointer circumferential weld shall be qualified according to the requirements for pipeline girth welds given in App.C. Production testing requirements for jointers shall be in accordance with ISO 3183. Other manufacturing requirements shall comply with Annex A of ISO 3183.

7.2.3.42 Apart from linepipe supplied as coiled tubing, strip/plate end welds should not be permitted. see [7.2.3.30]. MR

7.2.3.43 In case any mechanical tests fail during production of pipe from delivery condition N or Q, it is acceptable to conduct one re-heat treatment cycle of the entire test unit. All mechanical testing shall be repeated after re-heat treatment. No re-processing is allowed of delivery condition M material unless otherwise agreed. AR

7.2.3.44 A system for traceability of the heat number, heat treatment batch and test unit number and the records from all required tests to each individual pipe shall be established and described in the MPS (see [7.1.7.2]). Required repairs and records of dimensional testing and all other required inspections shall be included. Care shall be exercised during storage and handling to preserve the identification of materials. MR

7.2.4 Acceptance criteria

7.2.4.1 The chemical compositions given in Table 7-3 are applicable to pipes with delivery condition N or Q (normalised or quenched and tempered according to Table 7-1), with nominal wall thickness t ≤ 25 mm.

7.2.4.2 The chemical compositions given in Table 7-4 are applicable to pipes with delivery condition M (thermomechanical formed or rolled according to Table 7-1), with nominal thickness t ≤ 35 mm. MR

7.2.4.3 For pipes with nominal wall thickness larger than the limits indicated in [7.2.4.1] and [7.2.4.2], the chemical composition shall be subject to agreement.

7.2.4.4 For pipe with a carbon content ≤ 0.12% (product analysis), carbon equivalents shall be determined using the P_{cm} formula as given in Table 7-3 and Table 7-4. If the heat analysis for boron is less than 0.0005%, then it is not necessary for the product analysis to include boron, and the boron content may be considered to be zero for the P_{cm} calculation.

7.2.4.5 For pipe with a carbon content > 0.12% (product analysis) carbon equivalents shall be determined using the CE formula as given in Table 7-3.

7.2.4.6 The tensile properties shall be as given in Table 7-5.

Guidance note:

The elongation requirements in Table 7-5 are based on a formula identical in API 5L and ISO 3183. The formula is calibrated for use with tensile test specimens prepared according to ASTM A370 (i.e. API test specimens). It should be noted that the same material tested with specimens based on ASTM A370 and ISO 6892 can give different elongation results due to the different specimen geometries.

In general it should be considered to use ASTM A370 specimens for normal tensile testing, since this would give the best correspondence with the requirements in Table 7-5.

Tensile specimens based on ISO 6892 can be used, but then the acceptance criteria should be reviewed. Some options are; (i) use the values from Table 7-5, (ii) during qualification perform a number of tests on both types of specimens to establish an empirical correspondence for the specific material or (iii) define elongation criteria based on relevant testing experience and existing documentation.

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Guidance note:

There is increasing interest among operators and installation contractors for digital/electronic version of the stress-strain curves. The advantage of digitally stored tensile test data is the ease of further analysis and use in calculations – both statistical for a production run and also in load/strain simulations.

Manufacturers should make preparations in case a project-specific requirement is included in a contract or specification. As a minimum all tensile tests during qualification should be stored and transmitted electronically.

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7.2.4.7 For transverse weld tensile testing, the ultimate tensile strength shall be at least equal to the SMTS.

7.2.4.8 The hardness in the base material (BM), weld metal (WM) and the heat affected zone (HAZ) shall comply with Table 7-5. AR

7.2.4.9 Requirements for Charpy V-notch impact properties for linepipe BM, WM and HAZ are given in Table 7-5. These values shall be met when tested at the temperatures given in Table 7-6. MR

7.2.4.10 Testing of Charpy V-notch impact properties shall, in general, be performed on test specimens 10 × 10 mm. Where test pieces of width < 10 mm are used, the measured average impact energy (KV_m) and the test piece cross-section measured under the notch (A) (mm^2) shall be reported. For comparison with the values in Table 7-5, the measured energy shall be converted to the impact energy (KV) in Joules using the formula:

$$KV = \frac{8 \times 10 \times KV_{\mathrm{m}}}{A} \tag{7.2}$$

AR

7.2.4.11 From the set of three Charpy V-notch impact specimens, only one is allowed to be below the specified average value and shall meet the minimum single value requirement. AR

7.2.4.12 For flattening test of HFW pipe with SMYS ≥ 415 MPa and wall thickness ≥ 12.7 mm, there shall be no opening of the weld before the distance between the plates is less than 66% of the original outside diameter. For flattening test of all other combinations of pipe grade and specified wall thickness, there shall be no opening of the weld before the distance between the plates is less than 50% of the original outside diameter.

7.2.4.13 For flattening test of HFW pipe with a $D/t_2 > 10$, there shall be no cracks or breaks other than in the weld before the distance between the plates is less than 33% of the original outside diameter.

Guidance note:

The weld extends to a distance, on each side of the weld line, of 6.4 mm for $D < 60.3$ mm, and 13 mm for $D \geq 60.3$ mm.

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7.2.4.14 The guided-bend test pieces shall not:

— fracture completely
— reveal any cracks or ruptures in the weld metal longer than 3.2 mm, regardless of depth, or
— reveal any cracks or ruptures in the parent metal, HAZ, or fusion line longer than 3.2 mm or deeper than 12.5% of the specified wall thickness.

However, cracks that occur at the edges of the test piece during testing shall not be cause for rejection, provided that they are not longer than 6.4 mm.

Table 7-3 Chemical composition for C-Mn steel pipe with delivery condition N or Q, applicable for seamless and welded pipe

SMYS	*Product analysis, maximum. wt.%*									*Carbon equivalents*	
	C [1)]	*Si*	*Mn* [1)]	*P*	*S*	*V*	*Nb*	*Ti*	*Other* [2)]	*CE* [3)]	P_{cm} [4)]
Pipe with delivery condition N (normalised according to Table 7-1)											
245	0.14	0.40	1.35	0.020	0.010	Note [5)]	Note [5)]	0.04	Notes [6,7)]	0.36	0.19 [8)]
290	0.14	0.40	1.35	0.020	0.010	0.05	0.05	0.04	Note [7)]	0.36	0.19 [8)]
320	0.14	0.40	1.40	0.020	0.010	0.07	0.05	0.04	Notes [6,7)]	0.38	0.20 [8)]
360	0.16	0.45	1.65	0.020	0.010	0.10	0.05	0.04	Note [6)]	0.43	0.22 [8)]
Pipe with delivery condition Q (quenched and tempered according to Table 7-1)											
245	0.14	0.40	1.35	0.020	0.010	0.04	0.04	0.04	Note [7)]	0.34	0.19 [8)]
290	0.14	0.40	1.35	0.020	0.010	0.04	0.04	0.04	Note [7)]	0.34	0.19 [8)]
320	0.15	0.45	1.40	0.020	0.010	0.05	0.05	0.04	Note [7)]	0.36	0.20 [8)]
360	0.16	0.45	1.65	0.020	0.010	0.07	0.05	0.04	Notes [6,9)]	0.39	0.20 [8)]
390	0.16	0.45	1.65	0.020	0.010	0.07	0.05	0.04	Notes [6,9)]	0.40	0.21 [8)]
415	0.16	0.45	1.65	0.020	0.010	0.08	0.05	0.04	Notes [6,9)]	0.41	0.22 [8)]
450	0.16	0.45	1.65	0.020	0.010	0.09	0.05	0.06	Notes [6,9)]	0.42	0.22 [8)]
485	0.17	0.45	1.75	0.020	0.010	0.10	0.05	0.06	Notes [6,9)]	0.42	0.23 [8)]
555	0.17	0.45	1.85	0.020	0.010	0.10	0.06	0.06	Notes [6,9)]	As agreed	

Notes

1) For each reduction of 0.01% below the specified maximum for carbon, an increase of 0.05% above the specified maximum for manganese is permissible, up to a maximum increase of 0.20%.
2) Al total ≤ 0.060%; N ≤ 0.012%; Al/N ≥ 2:1 (not applicable to titanium-killed steel or titanium-treated steel).
3)

$$CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

4)

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

5) The sum of the niobium and vanadium contents should be ≤ 0.06%.
6) The sum of the niobium, vanadium, and titanium contents shall be ≤ 0.15%.
7) Cu ≤ 0.35%; Ni ≤ 0.30%; Cr ≤ 0.30%; Mo ≤ 0.10%; B ≤ 0.0005%.
8) For SMLS pipe, the listed value is increased by 0.03, up to a maximum of 0.25.
9) Cu ≤ 0.50%; Ni ≤ 0.50%; Cr ≤ 0.50%; Mo ≤ 0.50%; B ≤ 0.0005%.

Table 7-4 Chemical composition for C-Mn steel pipe with delivery condition M (thermo-mechanical formed or rolled according to Table 7-1)

SMYS	*Product analysis, maximum. wt.%*									*Carbon equivalent*
	C [1)]	*Si*	*Mn* [1)]	*P*	*S*	*V*	*Nb*	*Ti*	*Other* [2)]	*P_{cm}* [3)]
245	0.12	0.40	1.25	0.020	0.010	0.04	0.04	0.04	Note [4)]	0.19
290	0.12	0.40	1.35	0.020	0.010	0.04	0.04	0.04	Note [4)]	0.19
320	0.12	0.45	1.35	0.020	0.010	0.05	0.05	0.04	Note [4)]	0.20
360	0.12	0.45	1.65	0.020	0.010	0.05	0.05	0.04	Notes [5,6)]	0.20
390	0.12	0.45	1.65	0.020	0.010	0.06	0.08	0.04	Notes [5,6)]	0.21
415	0.12	0.45	1.65	0.020	0.010	0.08	0.08	0.06	Notes [5,6)]	0.21
450	0.12	0.45	1.65	0.020	0.010	0.10	0.08	0.06	Notes [5,6)]	0.22
485	0.12	0.45	1.75	0.020	0.010	0.10	0.08	0.06	Notes [5,6)]	0.22 [7)]
555	0.12	0.45	1.85	0.020	0.010	0.10	0.08	0.06	Notes [5,6)]	0.24 [7)]

Notes

1) For each reduction of 0.01% below the specified maximum for carbon, an increase of 0.05% above the specified maximum for manganese is permissible, up to a maximum increase of 0.20%.
2) Al total ≤ 0.060%; N ≤ 0.012%; Al/N ≥ 2:1 (not applicable to titanium-killed steel or titanium-treated steel).
3)

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

4) Cu ≤ 0.35%; Ni ≤ 0.30%; Cr ≤ 0.30%; Mo ≤ 0.10%; B ≤ 0.0005%.
5) The sum of the niobium, vanadium, and titanium contents shall be ≤ 0.15%.
6) Cu ≤ 0.50%; Ni ≤ 0.50%; Cr ≤ 0.50%; Mo ≤ 0.50%; B ≤ 0.0005%.
7) For nominal wall thickness t > 25 mm the carbon equivalent may be increased with 0.01.

Table 7-5 C-Mn steel pipe, mechanical properties

	Yield strength $R_{t0,5}$ [MPa]		*Tensile strength* *Rm* [MPa]		*Ratio* $R_{t0,5}/R_m$	*Elongation in 50.8 mm* A_f [%]	*Hardness* [HV10]		*Charpy V-notch energy (KVT) for BM, WM and HAZ* [1)] [J]	
							BM, WM	*HAZ*		
SMYS	*min.*	*max.*	*min.* [2)]	*max.*	*max.*	*min.*	*max.*		*average*	*Min.*
245	245	450 [3)]	415	760	0.93	Note 4)	270	300	27	22
290	290	495	415	760			270		30	24
320	320	520	435	760			270		32	27
360	360	525	460	760			270		36	30
390	390	540	490	760			270		39	33
415	415	565	520	760			270		42	35
450	450	570	535	760			270		45	38
485	485	605	570	760			300		50	40
555	555	675	625	825			300		56	45

Notes

1) The required KVL (longitudinal direction specimens) values shall be 50% higher than the required KVT values.
2) If tested in the longitudinal direction, a minimum tensile strength 5% less than the required value is acceptable (does not apply to all weld tensile tests).
3) For pipe with specified outside diameter < 219.1 mm, the yield strength shall be ≤ 495 MPa.
4) The specified minimum elongation in 50.8 mm, A_f, expressed in percent, rounded to the nearest percent shall be as determined using the following equation:

$$A_f = C \frac{A_{XC}^{0,2}}{U^{0,9}}$$

where:

C = 1940 for calculations using SI units;

A_{XC} = the applicable tensile test piece cross-sectional area, as follows:

— for circular cross-section test pieces, 130 mm^2 for 12.7 mm and 8.9 mm diameter test pieces; and 65 mm^2 for 6.4 mm test pieces
— for full-section test pieces, the lesser of a) 485 mm^2 and b) the cross-sectional area of the test piece, calculated using the specified outside diameter and the specified wall thickness of the pipe, rounded to the nearest 10 mm^2
— for strip test pieces, the lesser of a) 485 mm^2 and b) the cross-sectional area of the test piece, calculated using the specified width of the test piece and the specified wall thickness of the pipe, rounded to the nearest 10 mm^2

U is the specified minimum tensile strength, in MPa.

Table 7-6 C-Mn steel linepipe, Charpy V-notch impact testing temperatures T_0 (°C) as a function of T_{min} (°C) (minimum design temperature)

Nominal wall thickness (mm)	*Pipelines and risers*
$t \leq 20$	$T_0 = T_{min}$
$20 < t \leq 40$	$T_0 = T_{min} - 10$
$t > 40$	T_0 = to be agreed in each case

7.2.4.15 The measured fracture toughness shall as a minimum have a CTOD value of 0.15 mm, when tested at the minimum design temperature. AR

7.2.4.16 The macro section shall show a sound weld merging smoothly into the base material without weld defects according to Table D-4. Complete re-melting of tack welds shall be demonstrated for double sided SAW pipes. MPQT welds shall meet the requirements of ISO 5817 quality level C. AR

7.2.4.17 The misalignment of the axes of internal and external weld seams and the weld interpenetration of double sided SAW pipes shall be verified on the macro section and meet the requirements given in Table 7-22.

7.2.4.18 The metallographic examination shall be documented by micrographs at sufficient magnification and resolution to demonstrate that no detrimental oxides from the welding process are present along the weld line. AR

7.2.4.19 It shall be verified that the entire HAZ has been appropriately heat treated over the full wall thickness and that no untempered martensite remains.

7.2.4.20 The pipe shall withstand the hydrostatic test without leakage through the weld seam or the pipe body.

7.2.4.21 Linepipe joints that fails the hydrostatic test shall be rejected. AR For pipes delivered as coiled line pipe, the failed section may be removed, butt welded, and retested subject to agreement. Prior to any retesting a root cause analysis shall be submitted for approval.

7.2.4.22 Requirements to visual examination performed at the plate mill are given in [D.7]. Requirements for visual inspection of welds and pipe surfaces are given in [D.8.5]. MR and AR

7.2.4.23 Requirements to dimensions, mass and tolerances shall be as given in [7.7].

7.2.4.24 If agreed, the manufacturer shall supply weldability data or perform weldability tests. The details for carrying out the tests and the acceptance criteria shall be as specified in the purchase order.

7.2.4.25 If requested, the linepipe supplier shall provide information regarding the maximum post weld heat treatment (PWHT) temperature for the respective materials. AR

7.2.5 Inspection

7.2.5.1 Compliance with the requirements of the purchase order shall be checked by specific inspection in accordance with EN 10204. Records from the qualification of the MPS and other documentation shall be in accordance with the requirements in Sec.12.

The inspection frequency during production shall be as given in Table 7-7 and the frequency of testing for MPQT as given in Table 7-8. Reference to the relevant acceptance criteria is given in these tables. Pipes for testing should be evenly distributed, both throughout the production period and between welding stations. MR

Pipes for production testing shall be representative of all pipes produced. This means that sample pipes should be taken from as many work shifts as possible (distributing the sampling throughout the production period), and sampling should be rotated between the different welding stations.

It is not acceptable practice to select one plate from a number of heats in order to concentrate the production of pipes for sampling.

7.2.5.2 A test unit is a prescribed quantity of pipe that is made to the same specified outside diameter and specified wall thickness, by the same pipe-manufacturing process, from the same heat, and under the same pipe-manufacturing conditions.

7.2.5.3 For coiled line pipe, all required mechanical testing in Table 7-7 shall be performed at each pipe end or for each heat, whichever gives the highest number of tests. Strip end welds for coiled tubing shall be tested according to tests specified for strip end welds for SAWH in ISO 3183 Annex J. AR

7.2.5.4 Sampling for mechanical and any corrosion testing shall be performed after heat treatment, expansion and final shaping, but may be carried out before pipe end sizing process for pipes subjected to heat treatment and when the associated sizing ratio is below 0.015 [7.2.3.36]. The number and orientation of the samples for mechanical testing are given in Table 7-9. The samples shall not be prepared in a manner that may influence their mechanical properties.

7.2.5.5 In case of large quantities of longitudinally welded large diameter and heavy wall thickness pipe, where the test unit is governed by the heat size, it may be agreed that pipes from several heats represents one test unit. The first 30 000 tons shall be tested with a frequency according to normal practice of this standard. After exceeding 30 000 tons, the below testing philosophy may be applied:

— each test unit may consist of pipes from maximum 3 heats
— in case of test failure, the test frequency shall revert to the normal rate of testing until again 30 000 tons with satisfactory results are documented.

7.2.5.6 In order to accept or reject a test unit as a result of a test unit release failure, re-testing shall be conducted in accordance with [7.2.5.7] through [7.2.5.11].

7.2.5.7 If a test fails to meet the requirements, two re-tests shall be performed (for the failed test only) on samples taken from two different pipes within the same test unit. Both re-tests shall meet the specified requirements. The test unit shall be rejected if one or both of the re-tests do not meet the specified requirements.

7.2.5.8 The reason for the failure of any test shall be established and the appropriate corrective action to prevent re-occurrence of the test failures shall be taken accordingly.

7.2.5.9 If a test unit has been rejected, the manufacturer may conduct individual testing of all the remaining pipes in the test unit. If the total rejection of all the pipes within one test unit exceeds 25%, the test unit shall be rejected. In this situation the manufacturer shall investigate and report the reason for failure and shall change the manufacturing process if required. Re-qualification of the MPS is required if the agreed allowable variation of any parameter is exceeded (see [7.1.8.8] and [7.1.8.9]).

7.2.5.10 Re-testing of failed pipes shall not be permitted. If a pipe fails due to low CVN values in the fusion line (HAZ) or weld line in HFW pipe, testing of samples from the same pipe may be performed subject to agreement (see 7.1.8.9 for guidance on local brittle zones (LBZ)). Refer to [7.2.3.43] for re-processing of pipe.

7.2.5.11 For any of the mechanical tests, any test piece that shows material imperfections unrelated to the intent of the particular mechanical test, whether observed before or after testing, may be discarded and replaced by another test piece from the same pipe. If the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample shall be replaced by a correctly prepared sample from the same pipe and a new test performed.

7.2.5.12 Heat and product analysis shall be performed in accordance with App.B. MR

7.2.5.13 If the value of any elements, or combination of elements, fails to meet the requirements, two re-tests shall be performed on samples taken from two different pipes from the same heat. If one or both re-tests fail to meet the requirements, the heat shall be rejected. MR

7.2.5.14 All mechanical testing shall be performed according to App.B. MR

7.2.5.15 Macro examination and metallographic examination shall be performed in accordance with App.B.

7.2.5.16 Hydrostatic testing shall be performed in accordance with [7.5]. MR

7.2.5.17 NDT, including visual inspection, shall be carried out in accordance with [7.6]. AR and MR

7.2.5.18 Dimensional testing shall be performed according to [7.7]. MR

7.2.5.19 Surface imperfections and defects shall be treated according to [D.8.3]. MR

Table 7-7 Inspection frequency for C-Mn steel linepipe during production 1, 2)

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	Heat analysis	One analysis per heat	Table 7-3 or Table 7-4
	Product analysis	Two analyses per heat (taken from separate product items)	
	Tensile testing of the pipe body	Once per test unit of not more than 50/100 3) pipes with the same cold-expansion ratio	Table 7-5
	CVN impact testing of the pipe body 7)	Once per test unit of not more than 50/100 4) pipes with the same cold-expansion ratio	Table 7-5 and Table 7-6
	Hardness testing	Once per test unit of not more than 50/100 3) pipes with the same cold-expansion ratio(AR)	Table 7-5
	Hydrostatic testing	Each pipe	[7.2.4.20] to [7.2.4.21]
	Pipe dimensional testing	See [7.7]	See [7.7]
	NDT including visual inspection	See [7.6] (MR and AR)	See [7.6] (MR and AR)
SAWL, SAWH, HFW	Tensile testing of the seam weld (cross weld test)	Once per test unit of not more than 50/100 5) pipes with the same cold-expansion ratio (MR)	[7.2.4.6] and [7.2.4.7]

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
	CVN impact testing of the seam weld of pipe with specified wall thickness as given in Table 22 of ISO 3183	Once per test unit of not more than 50/100 4) pipes with the same cold-expansion ratio (MR)	Table 7-5 and Table 7-6
	Hardness testing of hard spots	Any hard spot exceeding 50 mm in any direction	[D.8.5]
	Macrographic testing of seam weld	At least once per operating shift 6)	[7.2.4.16]
SAWL, SAWH	Guided-bend testing of the seam weld of welded pipe	Once per test unit of not more than 50/100 3) pipes with the same cold-expansion ratio (MR)	[7.2.4.14]
HFW	Flattening test	As shown in Figure 6 of ISO3183	[7.2.4.12] and [7.2.4.13]
	Metallographic examination	At least once per operating shift 6)	[7.2.4.18] and [7.2.4.19] (MR)
Pipes supplied as coiled line pipe	CVN impact testing of the coil/plate end weld 7)	At least once per 50 coil/ plate end welds from pipe with the same cold-expansion ratio 8)	Table 7-5 and Table 7-6

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B. For tensile, CVN, hardness, guided-bend and flattening testing App.B refers to ISO 3183 without additional requirements.
2) The number orientation and location of test pieces per sample for mechanical tests shall be in accordance with Table 7-9.
3) Not more than 100 pipes with $D \leq 508$ mm and not more than 50 pipes for $D > 508$ mm.
4) Not more than 100 pipes with 114.3 mm $\leq D \leq$ 508 mm and not more than 50 pipes for $D > 508$ mm.
5) Not more than 100 pipes with 219.1 mm $\leq D \leq$ 508 mm and not more than 50 pipes for $D > 508$ mm.
6) At least once per operating shift plus whenever any change of pipe size occurs during the operating shift.
7) Applicable to pipes with wall thickness > 6 mm.
8) Testing shall be performed on finished pipe.

where

D = Specified outside diameter

Table 7-8 Additional testing for manufacturing procedure qualification test for C-Mn steel pipe 1)

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	All production tests as stated in Table 7-7	One test for each pipe provided for manufacturing procedure qualification [5)]	See Table 7-7
	Base metal longitudinal tensile test [2)], AR		
SMLS pipe [3, 4)] with t > 25 mm	CVN testing at ID of quenched and tempered seamless pipe with t > 25 mm AR		Table 7-5 and Table 7-6
SAWL, SAWH pipe [4)] with t > 25 mm	CVN testing at ID of the seam weld		
Welded pipe (all types)	All-weld tensile test AR		Table 7-5 [9)]
	Fracture toughness (CTOD) test of weld metal [6, 7)] AR		[7.2.4.15]
	Ageing test [8)], see [7.1.8.5] AR		Table 7-5

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B.
2) Additional longitudinal test specimen is not necessary if already required by Table 7-7 and Table 7-9 for production testing.
3) Only applicable to pipe delivered in the quenched and tempered condition.
4) Sampling shall be 2 mm from the internal surface, see [B.2.4].
5) One pipe from two different test units of different heats shall be selected for the MPQT, see [7.1.8] (a total of 2 pipes).
6) CTOD testing is not required for pipes with t < 13 mm. CTOD testing is not required of HAZ, only the centre of the weld.
7) For HFW pipe the testing applies to the fusion line (weld centre line).
8) Only when cold forming during pipe manufacture exceeds 5% strain.
9) Only SMYS, SMTS and elongation applies.

where

t = specified nominal wall thickness

Table 7-9 Number, orientation, and location of test specimens per tested pipe [1, 2)]

Applicable to	Sample location	Type of test	Wall thickness			
			≤ 25 mm		> 25 mm	
			Specified outside diameter		Specified outside diameter	
			< 219.1 mm	≥ 219.1 mm	< 219.1 mm	≥ 219.1 mm
SMLS, not cold expanded pipe	Pipe body	Tensile	1L [3)]	1L	1L [3)]	1L
		CVN	3T	3T	3T	3T
		Hardness	1T	1T	1T	1T
SMLS, cold expanded pipe	Pipe body	Tensile	1L [3)]	1T [4)]	1L [3)]	1T [4)]
		CVN	3T	3T	3T	3T
		Hardness	1T	1T	1T	1T
HFW pipe	Pipe body	Tensile	1L90 [3)]	1T180 [4)]	1L90 [3)]	1T180 [4)]
		CVN	3T90	3T90	3T90	3T90
	Seam weld	Tensile	—	1W	—	1W
		CVN	3W and 3HAZ [5)] MR		6W and 6HAZ [5)] MR	
		Hardness	1W	1W	1W	1W
	Pipe body and weld	Flattening	As shown in Figure 6 of ISO 3183			
SAWL pipe	Pipe body	Tensile	1L90 [3)]	1T180 [4)]	1L90 [3)]	1T180 [4)]
		CVN	3T90	3T90	3T90	3T90
	Seam weld	Tensile	—	1W	—	1W
		CVN	3W and 6HAZ [6)] MR		6W and 12HAZ [6)] MR	
		Guided-bend	2W	2W	2W	2W
		Hardness	1W	1W	1W	1W
SAWH pipe	Pipe body	Tensile	1L [3)]	1T [4)]	1L [3)]	1T [4)]
		CVN	3T	3T	3T	3T
	Seam weld	Tensile	—	1W	—	1W
		CVN	3W and 6HAZ [6)] MR		6W and 12HAZ [6)] MR	
		Guided-bend	2W	2W	2W	2W
		Hardness	1W	1W	1W	1W

Applicable to	Sample location	Type of test	Wall thickness			
			≤ 25 mm		> 25 mm	
			Specified outside diameter		Specified outside diameter	
			< 219.1 mm	≥ 219.1 mm	< 219.1 mm	≥ 219.1 mm

Notes

1) See Figure 5 of ISO 3183 for explanation of symbols used to designate orientation and location.
2) All destructive tests may be sampled from pipe ends.
3) Full-section longitudinal test pieces may be used at the option of the manufacturer, see App.B.
4) If agreed, annular test pieces may be used for the determination of transverse yield strength by the hydraulic ring expansion test in accordance with ASTM A370.
5) For the HF weld seam, W means that the notch shall be located in the FL, while HAZ means that the notch shall be located in FL +2 (see Figure B-6).
6) HAZ means that the notch shall be located in FL and FL +2 (see Figure B-5).

7.3 Corrosion resistant alloy linepipe

7.3.1 General

7.3.1.1 All requirements of this subsection are applicable to welded and seamless linepipe in duplex stainless steel and seamless martensitic 13Cr stainless steel.

7.3.1.2 Austenitic stainless steel and nickel based corrosion resistant alloy (CRA) linepipe shall be supplied in accordance with a recognised standard that defines the chemical composition, mechanical properties, delivery condition and all the details listed in Sec.6 and as specified in the following. If a recognised standard is not available, a specification shall be prepared that defines these requirements.

7.3.2 Pipe designation

7.3.2.1 CRA linepipe to be used to this standard shall be designated with:

— DNVGL
— process of manufacture (see [7.1.4])
— grade (see Table 7-11 or [7.3.1.2], as applicable)
— supplementary requirement suffix (see [7.1.5]).

Guidance note:

e.g. "DNVGL SMLS 22Cr D" designates a seamless 22Cr duplex steel linepipe meeting the supplementary requirements for enhanced dimensional requirements.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.3.3 Manufacturing

7.3.3.1 CRA linepipe shall be manufactured in accordance with the processes given in [7.1.4.2] using the raw materials stated in the qualified MPS, follow the same activity sequence, and stay within the agreed allowable variations. The manufacturing practice and instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be described in the MPS.

7.3.3.2 All steels shall be made by an electric or one of the basic oxygen processes.

7.3.3.3 In addition to the requirements in [7.3.3.4] and [7.3.3.5] below, the following requirements given for C-Mn steel pipe are also applicable for CRA pipes:

— [7.2.3.4]- [7.2.3.6]for seamless pipe
— [7.2.3.7]-[7.2.3.10]and [7.2.3.13]-[7.2.3.20]for all welded pipes
— [7.2.3.21]-[7.2.3.26]for SAW and MWP pipe
— [7.2.3.32]-[7.2.3.44]for all pipe.

7.3.3.4 Before further processing, the slabs/ingots shall be inspected and fulfil the surface finish requirements specified in the MPS.

7.3.3.5 Duplex and austenitic stainless steel pipe shall be delivered in solution-annealed and water-quenched condition.

7.3.4 Acceptance criteria

7.3.4.1 The chemical composition of duplex stainless steel and martensitic 13Cr stainless steel parent materials shall be according to Table 7-10. Modifications are subject to agreement. The limits and tolerances for trace elements for martensitic 13Cr stainless steels, i.e. elements not listed in Table 7-10, shall be subject to agreement.

7.3.4.2 Requirements for tensile, hardness and Charpy V-notch properties are given in Table 7-11. Weldment shall meet the requirement for KVT impact properties. The Charpy V-notch specimens shall be tested at the temperatures given in Table 7-6.

7.3.4.3 In addition to the requirements in [7.3.4.4] and [7.3.4.5] below, the following acceptance criteria given for C-Mn steel pipe are also applicable to CRA pipe (as applicable):

— [7.2.4.7] for transverse weld tensile testing
— [7.2.4.10] and [7.2.4.11] for Charpy V-notch impact testing
— [7.2.4.14] for guided-bend testing
— [7.2.4.15] for fracture toughness testing of the seam weld.

7.3.4.4 For the flattening test of pipe with wall thickness ≥ 12.7 mm, there shall be no opening of the weld, including the HAZ, until the distance between the plates is less than 66% of the original outside diameter. For pipe with wall thickness < 12.7 mm there shall be no opening of the weld, including the HAZ, until the distance between the plates is less than 50% of the original outside diameter.

7.3.4.5 For pipe with a $D/t_2 > 10$, there shall be no cracks or breaks other than in the weld, including the HAZ, until the distance between the plates is less than 33% of the original outside diameter.

7.3.4.6 The macro examination of weld seam shall meet the requirements in [7.2.4.16] and [7.2.4.17].

7.3.4.7 The microstructure of duplex stainless steel shall be essentially free from grain boundary carbides, nitrides and intermetallic phases after solution heat treatment. Essentially free implies that occasional strings of detrimental phases along the centreline of the base material is acceptable given that the phase content within one field of vision (at 400X magnification) is < 1.0% (max. 0.5% intermetallic phases).

7.3.4.8 The base material ferrite content of duplex stainless steel shall be within the range 35-55%. For weld metal the ferrite content shall be within the range 30-65%.

7.3.4.9 Pitting corrosion test according to ASTM G48 is only required for 25Cr duplex stainless steel. The maximum allowable weight loss for is 4.0 g/m^2 tested for 24 hours at 50°C and there shall be no pitting at 20 X magnification.

Table 7-10 Duplex[1)] - and martensitic stainless steel linepipe, chemical composition

Element [2)]	*Product analysis, wt.%*			
	Grade 22Cr duplex	*Grade 25Cr duplex*	*Grade 13Cr - 2 Mo*	*Grade 13Cr - 2.5 Mo*
C	0.030 max	0.030 max	0.015 max	0.015 max
Mn	2.00 max	1.20 max	-	-
Si	1.00 max	1.00 max	-	-
P	0.030 max	0.035 max	0.025 max	0.025 max
S	0.020 max	0.020 max	0.003 max	0.003 max
Ni	4.50 - 6.50	6.00 – 8.00	4.50 min	6.00 min
Cr	21.0 - 23.0	24.0 – 26.0	12.0 min	12.0 min
Mo	2.50 – 3.50	3.00 – 4.00	2.00 min	2.50 min
N	0.14 – 0.20	0.20 – 0.34	-	-
PRE	-	min. 40 [3)]	-	-

Notes

1) It is acknowledged that there are other duplex stainless steels commercially available, e.g. UNS S82551, which may be considered subject to agreement provided all mechanical and corrosion properties, as relevant.
2) If other alloying elements than specified in this table are being used, the elements and the maximum content shall be agreed in each case.
3) PRE = %Cr+3.3%(Mo+0.5W)+16%N.

Table 7-11 Duplex and martensitic 13Cr stainless steel linepipe, mechanical properties

Grade	*SMYS* *MPa*	*SMTS* *MPa*	*Ratio* $R_{t0.5} / R_m$	*Maximum hardness (HV10)*		*Elongation in 50.8 mm* A_f *[%]*	*Charpy V-notch energy (KVT) for BM, WM and HAZ* [1)] *[J]*	
				BM	*WM HAZ*		*Mean*	*Single*
22Cr	450	620	0.92	290	350	Note [2)]	45	35
25Cr	550	750	0.92	330	350		55	45
13Cr-2 Mo and 13Cr-2.5 Mo	550	700	0.92	300	na		55	45

Notes

1) The required KVL (longitudinal direction specimens) values shall be 50% higher than the required KVT values.
2) See note 4) in Table 7-5

7.3.5 Inspection

7.3.5.1 Compliance with the requirements of the purchase order shall be checked by specific inspection in accordance with EN 10204, or an equivalent material inspection scheme. Records from the qualification of the MPS and other documentation shall be in accordance with the requirements in Sec.12.

7.3.5.2 The inspection frequency during production and MPQT shall be as given in Table 7-12 and Table 7-13, respectively. Reference to the relevant acceptance criteria is given in the tables.

7.3.5.3 A test unit is a prescribed quantity of pipe that is made to the same specified outside diameter and specified wall thickness, by the same pipe-manufacturing process, from the same heat, and under the same pipe-manufacturing conditions.

7.3.5.4 Sampling for mechanical and corrosion testing shall be performed after heat treatment, expansion and final shaping. The samples shall not be prepared in a manner that may influence their mechanical properties. See [7.2.5.5] for reduced frequency of testing in case of large quantities of pipe.

7.3.5.5 The number and orientation of the samples for SMLS and SAWL/SAWH pipe shall be according to Table 7-9.

7.3.5.6 For EBW and LBW pipe, the number and orientation of the samples shall be as for HFW in Table 7-9.

7.3.5.7 For MWP pipe, the number and orientation of the samples shall be as for SAWL pipe in Table 7-9.

7.3.5.8 Requirements for retesting shall be according to [7.2.5.7] to [7.2.5.11].

7.3.5.9 Heat and product analysis shall be performed in accordance with App.B.

7.3.5.10 All elements listed in the relevant requirement/standard shall be determined and reported. Other elements added for controlling the material properties may be added, subject to agreement.

7.3.5.11 If the value of any elements, or combination of elements, fails to meet the requirements, two re-tests shall be performed on samples taken from two different pipes from the same heat. If one or both re-tests fail to meet the requirements, the heat shall be rejected.

7.3.5.12 All mechanical testing shall be performed according to App.B.

7.3.5.13 Metallographic examination shall be performed in accordance with App.B.

7.3.5.14 Corrosion testing of 25Cr duplex stainless steels according to ASTM G48 shall be performed in accordance with [B.3.2]. ASTM G48 testing is not applicable for 22Cr duplex or other CRAs with PRE lower than 40.

7.3.5.15 Hydrostatic testing shall be performed in accordance with [7.5].

7.3.5.16 NDT, including visual inspection, shall be in accordance with [7.6].

7.3.5.17 Dimensional testing shall be performed according to [7.7].

7.3.5.18 Surface imperfections and defects shall be treated according to [D.8.3].

Table 7-12 Inspection frequency for CRA linepipe [1)]

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	All tests in Table 7-7 applicable to all pipe	As given in Table 7-7	Table 7-10 and Table 7-11
SAWL and MWP pipe	All tests in Table 7-7 applicable to SAWL		
EBW and LBW pipe [2)]	Flattening test	As shown in Figure 6 of ISO3183	[7.3.4.4] and [7.3.4.5]
Duplex stainless steel pipe	Metallographic examination	Once per test unit of not more than 50/100 [3)]	[7.3.4.7] and [7.3.4.8]
25Cr duplex stainless steel pipe	Pitting corrosion test (ASTM G48 Method A)	Once per test unit of not more than 50/100 [3)]	[7.3.4.9]

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B. The number orientation and location of test pieces per sample for mechanical tests shall be according to [7.3.5.5] to [7.3.5.7].

2) For EBW and LBW pipes the testing applies to the fusion line.

3) Not more than 100 pipes with 114.3 mm ≤ D ≤ 508 mm and not more than 50 pipes for D > 508 mm.

1) where :

D = specified outside diameter.

Table 7-13 Additional testing for manufacturing procedure qualification test of CRA linepipe [1)]

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	All production tests as stated in Table 7-12	One test for each pipe provided for manufacturing procedure qualification [3)]	[7.3.4]
Welded pipe (all types)	All-weld tensile test		Table 7-11
	Fracture toughness (CTOD) test of weld metal [2)]		[7.2.4.15]

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B. The number, orientation and location of test pieces per sample for mechanical tests shall be according to [7.3.5.5] to [7.3.5.7].

2) CTOD testing is not required for pipes with t < 13 mm.

3) Two pipes shall be provided for MPQT. The two pipes provided shall be from two different test units of different heats.

7.4 Clad or lined steel linepipe

7.4.1 General

7.4.1.1 The requirements below are applicable to linepipe consisting of a C-Mn steel backing material with a thinner internal CRA layer.

7.4.1.2 The backing steel of lined pipe shall fulfil the requirements in [7.2].

7.4.1.3 The manufacturing process for clad or lined linepipe shall be according to [7.1.4.3] to [7.1.4.5].

7.4.1.4 Cladding and liner materials shall be specified according to recognised standards. If a recognised standard is not available, a specification shall be prepared that defines chemical composition. If agreed corrosion testing and acceptance criteria shall be specified.

7.4.1.5 The cladding/liner material thickness should not be less than 2.5 mm.

7.4.2 Pipe designation

7.4.2.1 In addition to the designation of the backing material (see [7.1.4]) clad/lined pipes shall be designated with:

— C, for clad pipe, or
— L, for lined pipe
— UNS number for the cladding material or liner pipe (B) and end weld (E), when applicable.

Guidance note:

e.g. "DNVGL MWPL 415 D L - UNS S31600 (B) UNS N06625 (E)" designates a longitudinal welded pipe using multiple welding processes with SMYS 415 MPa, meeting the supplementary requirements for dimensions, lined with a UNS designated material for pipe body of stainless steel 316 and pipe ends of nickel alloy 625.

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7.4.3 Manufacturing procedure specification

7.4.3.1 In addition to the applicable information given in [7.1.7] and [7.1.8], the MPS for clad linepipe shall as a minimum contain the following information (as applicable):

For roll bonded clad plates:

— slab reheating temperature and initial rolling practice of cladding alloy and backing material prior to sandwich assembly
— method used to assemble the sandwich or one-sided-open package, as applicable, prior to reheating and rolling
— package (sandwich or one-side-open) reheating temperature, start and stop rolling temperatures, means of temperature and thickness control, start and stop temperatures for accelerated cooling (if applicable) and inspection
— final plate heat treatment, e.g. quench and tempering (if applicable)
— method used to cut and separate the metallurgically roll bonded plates after rolling (separation of the sandwich between the CRA layers
— details regarding any CRA clad welding to pipe ends.

For explosion welded clad plates:

— details for fabrication of backing and CRA layer (separate MPS can be submitted by the rolling mills)
— quality control checks for the pre-bond, explosion weld and post-bond process
— details of data to be recorded (e.g. CRA layer seam welding, surface preparation, plate assembly, stand-off, surface finish)
— final plate heat treatment, e.g. quench and tempering (if applicable)
— cutting of side and end scrap.

7.4.3.2 In addition to the applicable information given in [7.1.7] and [7.1.8], the MPS for lined linepipe shall as a minimum contain the following information (as applicable):

— details for fabrication of backing pipe and liner
— quality control checks for the lining process

— details of data to be recorded (e.g. expansion pressure/force, strain, deformation)
— procedure for cut back prior to seal welding or cladding to attach liner to carrier pipe
— seal welding procedures
— details regarding any CRA clad welding to pipe ends.

7.4.3.3 The following additional essential variables apply to the qualification of the MPS for clad linepipe (see [7.1.8.8]]):

For roll bonded clad plates:

— sequence of welding.

For explosion welded clad plates:

— stand-off distance between backing plate and CRA layer
— type of explosive powder
— explosive load
— location for ignition point on plate.

7.4.4 Manufacturing

7.4.4.1 During all stages of manufacturing, contamination of CRA with carbon steel shall be avoided. Direct contact of the CRA layer with carbon steel handling equipment (e.g. hooks, belts, rolls, etc.) is prohibited. Direct contact may be allowed providing subsequent pickling is performed.

7.4.4.2 All work shall be undertaken in clean areas and controlled environment to avoid contamination and condensation.

7.4.4.3 In addition to the requirements stated in [7.2.3] and [7.3.3] (as applicable), the following shall apply:

7.4.4.4 The welding consumables for seam welds and liner seal welds shall be selected taking into consideration the reduction of alloying elements by dilution of iron from the base material. The corrosion properties of the weld consumable shall be equal or superior to the clad or liner material.

7.4.5 General requirements to manufacture of clad pipelines

7.4.5.1 The cladding alloy shall be produced from plate, and shall be supplied in a solution or soft annealed condition, as applicable.

7.4.5.2 The steel backing material and the cladding alloy shall be cleaned, dried and inspected to ensure that the level of humidity and particles between the respective plates are equal to or less than for the MPQT plates.

7.4.5.3 The mating plate surfaces should as a minimum be blast cleaned to a surface cleanliness of ISO 8501 Sa2.

7.4.5.4 The metallurgical bonding of base and CRA layer shall be ensured by hot rolling of the sandwich (or one-side-open packages, as applicable) or by explosion welding of the backer steel plate and the CRA layer. If a seam weld (pre-weld) of the CRA layer is applied (prior to explosion bonding), the WPS shall be qualified prior to start of any production welding. Qualification and production welding shall follow the principles in App.C and testing in accordance with Table C-3, except all-weld testing is not required.

7.4.5.5 The package assembly for roll bonding consisting of sandwich or one-side-open, shall be manufactured through a TMCP route, or receive a final heat treatment (e.g. QT). For explosion welded clad material the backing steel plate shall be manufactured through a TMCP route, or receive a final heat treatment (e.g. QT).

7.4.5.6 In addition to the applicable requirements given in [7.2.3.7] to [7.2.3.33], the following requirements shall apply for welding of clad linepipe:

— the corrosion properties of the CRA weld consumable (e.g. root and hot pass) shall be equal or superior to the clad material
— except for single pass per side welds, the longitudinal weld shall be back purged with welding grade inert gas and be free from high temperature oxides
— tack welds shall be made using GTAW, GMAW, G-FCAW or SMAW using low hydrogen electrodes
— weld seam tracking of continuous welding shall be automatically controlled.

7.4.6 General requirements to manufacture of lined pipeline

7.4.6.1 The liner for lined pipe shall be manufactured according to API 5LC.

7.4.6.2 The internal surface of the C-Mn steel backing pipe shall be blast cleaned to a surface cleanliness of ISO 8501 Sa2 along the complete length of the pipe prior to fabrication of lined pipe. The external surface of the liner pipe shall be blast cleaned as specified above or pickled.

7.4.6.3 The liner pipe shall be inserted into the backing C-Mn steel pipe after both pipes have been carefully cleaned, dried and inspected to ensure that the level of humidity and particles in the annular space between these two pipes are equal to or less than for the MPQT pipes.

7.4.6.4 The humidity during assembly shall be less than 80%, and the carbon steel and CRA surfaces shall be maintained at least 5°C above the dew point temperature. Temperature and humidity shall continuously be measured and recorded.

7.4.6.5 After having lined up the two pipes, the liner shall be expanded by a suitable method to ensure adequate gripping. The carbon steel pipe shall not receive a sizing ratio, s_r , exceeding 0.015 during the expansion process (see [7.2.3.34]).

7.4.6.6 The liner for lined pipe shall be welded according to API 5LC.

7.4.6.7 Seal welds, i.e. pipe end clad welds or fillet welds, shall be qualified according to [C.5.4], [C.5.6.5] and [C.5.6.6], respectively. Production welding shall follow the principles in App.C.

7.4.6.8 Subsequent to expansion, the liner or backing pipe shall be machined at each end and further fixed to the backing pipe by a seal weld (clad or fillet weld) to ensure that no humidity can enter the annulus during storage, transportation and preparation for installation.

7.4.6.9 In addition to the applicable requirements given in [7.2.3.7] to [7.2.3.33], the following requirements shall apply for welding of lined linepipe:

— the corrosion properties of the CRA weld consumable (e.g. fillet or clad weld) shall be equal or superior to the liner material
— the weld shall be purged with welding grade inert gas and be free from high temperature oxides.

7.4.7 Acceptance criteria

7.4.7.1 The backing material of the manufactured clad or lined linepipe shall comply with the requirements for C-Mn steel given in [7.2]. H_2S service requirements according to [7.9.1] shall not apply to the backing material unless required according to [7.9.1.15].

7.4.7.2 The cladding/liner material shall be removed from the test pieces prior to mechanical testing of the backing material.

7.4.7.3 The hardness of the base material, cladding material, HAZ, weld metal and the metallurgical bonded area shall meet the relevant requirements of this standard.

7.4.7.4 After bend testing in accordance with [B.2.5.9] (see Table 7-14), there shall be no sign of cracking or separation on the edges of the specimens.

7.4.7.5 After longitudinal weld root bend testing in accordance with [B.2.5.7] (see Table 7-16), the bend test specimen shall not show any open defects in any direction exceeding 3 mm. Minor ductile tears less than 6 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

7.4.7.6 The minimum shear strength shall be 140 MPa.

7.4.7.7 The CRA material shall meet the requirements of the relevant reference standard, e.g. API 5LD.

7.4.7.8 The chemical composition of the longitudinal seam weld (or overlay weld if applicable) of clad pipes, pipe end clad welds, and the liner seal welds (if exposed to the pipe fluid), shall be analysed during MPQT. The composition of the deposited weld metal as analysed on the exposed surface should meet the requirements of the base material specification.

The calculated PRE (see Table 7-10, note 2) for alloy 625 weld metal should not be less than for the clad pipe base material or liner material.

7.4.7.9 The weld metal and the HAZ in the root area of the clad pipe seam welds, any pipe end clad welds and the seal welds of lined pipe shall be essentially free from grain boundary carbides, nitrides and intermetallic phases.

7.4.7.10 Acceptance criteria for gripping force production testing of lined linepipe shall be agreed based on project specific requirements (see [6.2.4]) and/or test results obtained during MPQT.

7.4.7.11 After the test for presence of moisture in the annulus between the liner and the backing material, the pipe shall be inspected and no ripples or buckles in the liner or carbon steel pipe shall be in evidence when viewed with the naked eye.

7.4.8 Inspection

7.4.8.1 Compliance with the requirements of the purchase order shall be checked by specific inspection in accordance with EN 10204. Records from the qualification of the MPS and other documentation shall be in accordance with the requirements in Sec.12.

7.4.8.2 The inspection frequency during production and MPQT shall be as given in Table 7-14 and Table 7-15, respectively.

7.4.8.3 For clad pipe, the number and orientation of the samples shall be as for SAWL pipe in Table 7-9

7.4.8.4 For lined pipe, the number and orientation of the samples for the backing steel shall be according to Table 7-9. Testing of the liner for lined pipe shall be according to API 5LC.

7.4.8.5 Requirements for retesting shall be according to [7.2.5.7] to [7.2.5.11].

7.4.8.6 Heat and product analysis shall be performed in accordance with [7.2.5] and [7.3.5] for the backing steel and the CRA liner or cladding, respectively.

7.4.8.7 All mechanical testing of clad pipe and the backing steel of lined pipe shall be performed according to App.B. Mechanical testing of the liner for lined pipe shall be according to API 5LC.

7.4.8.8 Hardness testing of welded linepipe shall be performed on a test piece comprising the full cross-section of the weld. Indentations shall be made in the base material, cladding material and the metallurgical bonded area as detailed in App.B.

7.4.8.9 Unless specified by purchaser, corrosion testing of roll bonded clad pipes or any longitudinal weld seams is not required.

Guidance note:

ASTM G48 Method A testing is relevant in case flooding with raw sea water of material clad/lined with Alloy 625 is a design requirement/assumption. Such testing is not relevant if the CRA material is UNS S31600, UNS S31603 or UNS N08825.

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7.4.8.10 Metallographic examination shall be performed in accordance with App.B.

7.4.8.11 Moisture between liner and backing steel may evaporate during coating and cause external pressure to the liner and thereby implosion of the liner. To check for the presence of moisture in the annulus, one finished pipe or a section thereof (minimum length of 6 m) shall be heated to 200°C for 15 minutes and air cooled. This pipe shall be within the first 10 pipes produced.

7.4.8.12 Gripping force of lined pipe shall be measured in accordance with API 5LD. Equivalent tests may be applied subject to agreement. Inspection frequency for production testing shall be agreed based on test results obtained during the MPQT (see [7.4.3]).

7.4.8.13 Hydrostatic testing shall be performed in accordance with [7.5].

7.4.8.14 NDT, including visual inspection, shall be in accordance with [7.6].

7.4.8.15 Dimensional testing shall be performed according to [7.7].

7.4.8.16 Surface imperfections and defects shall be treated according to [D.8.3].

Table 7-14 Inspection frequency for clad or lined steel linepipe

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	All tests in Table 7-7 applicable to all pipe	See Table 7-7 and [7.4.6]	[7.4.7.1]
Clad pipe	All tests in Table 7-7 applicable to SAWL		
	Bend tests (2 specimens)	Once per test unit of not more than 50 pipes	[7.4.7.5]
	Shear strength		[7.4.7.6]
CRA material of clad pipe	According to reference standard (see [7.4.7.7])		
Liner pipe	According to API 5LC (see [7.4.7.7])		
Lined pipe	Macrographic examination of seal weld	Once per test unit of not more than 50 pipes	[C.6.4.5]
	Gripping force test	To be agreed, see [7.4.8.12]	[7.4.7.10]

Table 7-15 Additional testing for manufacturing procedure qualification test of clad or lined steel linepipe 1)

Applicable to	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	All production tests in Table 7-14	One test for each pipe provided for manufacturing procedure qualification	See Table 7-14
	Relevant qualification tests in Table 7-8		See Table 7-8
	Corrosion testing of welds, if agreed, see [7.4.8.9]		To be agreed
Clad pipe	Chemical composition of seam weld and clad weld 2)		[7.4.7.8]
	Metallographic examination of the seam weld and clad weld 2)		[7.4.7.9]
	Longitudinal weld root bend test		[7.4.7.5]
Lined pipe	Chemical composition of seal or clad welds 2)		[7.4.7.8]
	Metallographic examination of seal welds		[7.4.7.9]
	Liner collapse test		[7.4.7.11]

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B. The number, orientation and location of test pieces per sample for mechanical tests shall be according to [7.4.8.3] and [7.4.8.4].

2) As applicable, according to [7.4.7.8] and [7.4.7.9].

7.5 Hydrostatic testing

7.5.1 Mill pressure test

7.5.1.1 Each length of linepipe shall be hydrostatically tested, unless the alternative approach described in [7.5.1.6] is used. The water for testing should be clean and free from any suspended or dissolved substance that can be harmful to the linepipe material.

7.5.1.2 The mill test pressure, p_{mpt}, should be:

$$p_{mpt} = k \cdot \frac{2 \cdot t_{min}}{D - t_{min}} \cdot Min\left[SMYS \cdot 0.96; SMTS \cdot 0.84\right] \qquad (7.3)$$

where:

$$k = \frac{1}{\sqrt{1 - \alpha + \alpha^2}} \qquad (7.4)$$

$$\alpha = \frac{\sigma_l}{\sigma_k} \qquad (7.5)$$

The following values are relevant for k for a mill pressure test:

— 1.00 for pipelines without end-cap (set up not introducing axial stresses)

— 1.15 for a mill pressure test with end cap effect transferred to the pipe.

7.5.1.3 In case a lower mill test pressure than specified in [7.5.1.2] is applied, a reduction in system test pressure and incidental pressure in line with [5.4.2.1] shall be applied with the exception of the corrosion allowance as discussed in [7.5.1.4] and waiving of mill pressure test in [7.5.1.6].

Guidance note:

A reduction in mill test pressure in line with this paragraph may be applicable for ultra deep water pipelines or where the wall thickness is governed by other limit states, e.g. for reeling installation.

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7.5.1.4 In case significant corrosion allowance has been specified (as stated by the purchaser in the material specification) or significant temperature de-rating of the mechanical properties take place, the mill test pressure may be significantly higher than the incidental pressure. For such conditions and where the mill pressure test capacity is limited, the mill test pressure may be limited to $p_h = 1.4 \cdot p_{li}$, (where p_{li} is the local incidental pressure).

7.5.1.5 The test configuration shall permit bleeding of trapped air prior to pressurisation of the pipe. The pressure test equipment shall be equipped with a calibrated recording gauge. The applied pressure and the duration of each hydrostatic test shall be recorded together with the identification of the pipe tested. The equipment shall be capable of registering a pressure drop of minimum 2% of the applied pressure. The holding time at test pressure shall be minimum 10 seconds. Calibration records for the equipment shall be available.

7.5.1.6 Subject to agreement, the hydrostatic testing may be omitted for expanded pipes manufactured by the UOE process. It shall in such situations be documented that the expansion process and subsequent pipe inspection will:

— ensure that the pipe material stress-strain curve is linear up to a stress corresponding to [7.5.1.2]
— identify defects with the potential for through-thickness propagation under pressure loading
— identify pipes subject to excessive permanent deformation under pressure loading to a degree equivalent to that provided by hydrostatic testing.

Workmanship and inspection shall be at the same level as for hydrostatically tested pipe.

The expansion process parameters and inspection results shall be recorded for each pipe.

7.5.1.7 For pipe classified as coiled line pipe, the mill pressure test of the finished coiled line pipe shall be performed at a pressure corresponding to [7.5.1.2] using tmin. Pressure shall be held for not less than two hours.

7.6 Non-destructive testing

7.6.1 Visual inspection

7.6.1.1 Visual inspection shall be in accordance with [D.8.5].

7.6.1.2 If visual inspection for detection of surface imperfections is substituted with alternative inspection methods then the substitution shall conform to the requirements in [D.8.5.5].

7.6.2 Non-destructive testing

7.6.2.1 Requirements for non-destructive testing (NDT) of linepipe are given in [D.8].

7.6.2.2 Requirements for NDT (laminar imperfections) and visual examination of plate, coil and strip performed at plate mill are given in [D.7].

7.6.2.3 Table 7-16 lists the required NDT of linepipe including lamination check for welded linepipe. For welded pipe, lamination checks may be performed on linepipe or plate/strip at the discretion of the manufacturer.

7.6.2.4 Alternative test methods may be accepted subject to agreement according to [D.8.4.1] and [D.8.4.2].

Table 7-16 Type and extent of non-destructive testing 1)

Applicable to	*Scope of testing*	*Type of test* 2)	*Frequency of testing*	Reference
All	Visual inspection	-	100%	[D.8.5]
	Residual magnetism	-	5% 3)	[D.8.5]
	Imperfections in un-tested ends	UT+ST	100% or cut off	[D.8.6]
Pipe ends of all pipe	Laminar imperfections pipe ends 4)	UT	100%	[D.8.7]
	Laminar imperfections pipe end face/bevel	ST	100%	
SMLS	Laminar imperfections in pipe body	UT	100%	[D.8.8]
	Longitudinal imperfections in pipe body	UT	100%	
	Transverse imperfections in pipe body	UT	100/10% 6)	
	Wall thickness testing	UT	100% 7)	
	Longitudinal surface imperfections in pipe body 5)	ST	100/10% 6)	
HFW, EBW and LBW	Laminar imperfections in pipe body	UT	100%	[D.8.9]
	Laminar imperfections in area adjacent to weld	UT	100%	
	Longitudinal imperfections in weld	UT	100%	
Coiled line pipe	Laminar imperfections in pipe body	UT or EC 8)	100%	[D.8.9]
	Laminar imperfections in area adjacent to weld	UT or EC	100%	
	Longitudinal imperfections in weld	UT	100%	
	Skelp end weld – imperfections in weld	UT or RT	100%	
	Skelp end weld – surface imperfections	ST	100%/R 9)	

SAWL, SAWH and MWP	Laminar imperfections in pipe body	UT	100%	[D.8.13]
	Laminar imperfections in area adjacent to weld	UT	100%	
	Imperfections in weld	UT	100%	
	Surface imperfections in weld area 5)	ST	100%/R 10)	
	Imperfections at weld ends	RT+UT	100%	
Clad pipe	Lack of bonding in pipe body and pipe ends 11)	UT	100%	[D.8.12]
	Laminar imperfections in pipe body	UT	100%	
	Longitudinal and transverse imperfections in weld	UT	100%	
	Laminar imperfections in area adjacent to weld	UT	100%	
	Surface imperfections in weld area	ST	100%/R 12)	
	Imperfections in welds	RT	100%	
CRA liner pipe	Longitudinal and transverse imperfections in weld	EC or RT	100%	[D.8.10]
Lined pipe	As required for the type of backing material used, see above	-	100%	-
	Seal and clad welds	ST	100%	[D.8.11]
	Clad welds (bonding imperfections)	UT	100%	

Notes

1) The indicated test methods are considered to be industry standard. Alternative methods may be used as required in [D.8.4].
2) Nomenclature: UT = ultrasonic testing, ST = surface testing, e.g. magnetic particle testing or EMI (flux leakage) for magnetic materials and liquid penetrant testing for non-magnetic materials, RT = radiographic testing and EC = eddy current testing, see App.D.
3) 5% = testing of 5% of the pipes produced but at least once per 4 hour per operating shift.
4) Laminar inspection is not applicable to pipe with $t \leq 5$ mm. Standard width of band to be tested is 50 mm, but a wider band may be tested if specified by the purchaser.
5) Applicable to external surface only.
6) 100/10% = 100% testing of the first 20 pipes manufactured and if all pipes are within specification, thereafter random testing (minimum five pipes per 8-hour shift) during the production of 10% of the remaining pipes.
7) The wall thickness shall be controlled by continuously operating measuring devices.
8) EC for lamination inspection is acceptable for WT < 10 mm.
9) 100%/R = 100% testing of the first 20 strip end welds. If all welds are within specification, thereafter random testing of a minimum of one weld per 8-hour shift.
10) 100%/R = 100% testing of the first 20 pipes manufactured. If all pipes are within specification, thereafter random testing of a minimum of one pipe per 8-hour shift.
11) Applies to pipe ends irrespective if clad welds are applied to pipe ends or not.
12) For external weld note 10) shall apply. For internal weld the frequency shall be 100%.

7.7 Dimensions, mass and tolerances

7.7.1 General

7.7.1.1 Linepipe shall be delivered to the dimensions specified in the linepipe specification, subject to the tolerances in this standard or client specification (whichever are more stringent). Dimensions shall be checked in final delivery condition and one dimensional feature shall be considered at a time.

Guidance note:

In practice dimensional control can be done at different stages in the pipe production. The key consideration is that the dimension to be checked is in its final delivery condition at the time of measurement. For instance the weld reinforcement geometry of welded pipe will not be influenced by pipe end bevelling – consequently it can be measured at an intermediary stage of production. Consequently each dimension can be checked upon completion of all operations that can influence on the measured parameter.

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Guidance note:

When measuring the linepipe dimensions and geometrical features it is reasonable to consider that each parameter (e.g. wall thickness, diameter, out-of-roundness etc) is fully independent of the others. This means that the linepipe should be considered to have nominal values for all parameters, except the one parameter being measured.

This might not fully reflect the reality; the pipe out-of-roundness may very well influence the diameter, and the wall thickness variations can influence offset measurements and diameter measurements. Still, in order to have a common approach to linepipe dimensions and geometry inspection it is important to consider one feature at a time.

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7.7.1.2 Suitable methods shall be used for the verification of conformance with the dimensional and geometrical tolerances. Unless particular methods are specified in this standard or in the client specification, the methods to be used shall be at the discretion of the manufacturer.

The manufacturer shall ensure sufficient training and instruction of the personnel, in order to provide a stable and repeatable inspection practice.

7.7.1.3 All test equipment shall be calibrated, and the measurement resolution shall be sufficient to properly evaluate the tolerances. Dimensional testing by automatic measuring devices is acceptable, and may replace manual methods specified in this standard, provided the accuracy and precision of the measuring devices is documented and found to be at least equal to relevant manual measurements.

Guidance note:

There are no explicit requirements to the measurement resolution and accuracy of equipment and methods for geometry control. It is recommended that the manufacturer should be able to demonstrate a resolution of 10% of the allowed tolerance/variation (i.e. if the allowed tolerance/variation is 1 mm, then the measurements should distinguish between features that differ by 0.1 mm).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:

The accuracy and error of a measurement practice depends on equipment, method and personnel. There is no requirement to determine the overall accuracy/error of a measurement practice over time.

For manual practices this may be impossible, because the human factor plays a dominating role. Probably the best that can be achieved is to approximate the measurement error to the calibration tolerance of the equipment, and rather in design calculations keep in mind that there are limits to the practice accuracy that can be achieved (e.g. out-of-roundness can be difficult to measure manually, and it would not be reasonable to require a maximum OoR on the order of 2-3 millimeters).

For automated practices it is quite feasible to establish an overall accuracy of the equipment and document the stability of measurements over time. This can be achieved by using a reference object that is characterised at the start of a production run, and later regularly measured during the production. Some statistical analysis of these data will give a good indication of the global accuracy and error for the given measurement practice.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.7.2 Tolerances

7.7.2.1 The diameter and out-of-roundness shall be within the tolerances given in Table 7-17 to Table 7-19.

7.7.2.2 The wall thickness shall be within the tolerances given in Table 7-20 and Table 7-21. This also applies for grinded areas, see [D.8.3.8] and [D.8.3.9]. For welded pipes, the plus tolerances do not apply for the weld.

7.7.2.3 Pipe length, including tolerances and statistical distribution (if relevant), shall be specified by the purchaser. The application and/or installation approach should be considered.

Guidance note:

Typically an average length of 12.1 m may be the optimum length for handling on several S-lay barges in operation, but this could change in the course of time. An average length of 12.1 m is not necessarily optimum for deepwater J-lay practice and can vary according to the J-lay system used. It is the responsibility of the purchaser to agree with both the linepipe manufacturer and the pipe-lay contractor the length range to be supplied. Pipe used for other applications, such as mother pipe for bends, may have different length requirements.

The following should be considered:

- Will the installation method benefit from another standard linepipe length?

- Should a significant quantity of the delivered linepipes (subject to agreement) be within ±0.2m or ±0.1m of the required standard linepipe length?

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.7.2.4 Other parameters shall be within the tolerances given in Table 7-22.

7.7.2.5 Tolerances for the weld seam of welded pipe, i.e.:

— root penetration MR*
— weld interpenetration (for double-sided SAW only) MR*
— cap and root concavity
— misalignment of weld beads for double sided welds
— undercut
— arc burns
— start/stop craters/poor restart
— surface porosity
— cracks
— lack of penetration/lack of fusion
— systematic imperfections
— burn through

shall be within the tolerances given in Table D-4.

*) MR indicates that the requirement is modified compared to ISO 3183.

7.7.2.6 Requirements for dents are given in [D.8.5].

7.7.3 Inspection

7.7.3.1 The frequency of dimensional testing shall be according to Table 7-23.

7.7.3.2 All specified tests shall be recorded as acceptable or non-acceptable. Recording frequency of actual measured value shall be according to Table 7-23. During MPQT the actual value of all parameters for all inspected pipes shall be recorded.

7.7.3.3 Diameter measurements shall be based on measurements using circumferential tape, if done by manually. MR

7.7.3.4 Diameter values at pipe ends shall be determined based on inside (i.e. pipe internal surface) measurements. For linepipe with internal diameter less than 150 mm outside measurements are allowed. Pipe body diameter shall be measured towards the middle of the pipe and the choice between inside or outside measurements is at the manufacturer's discretion. When measurements are done on inside, the tolerances applied shall be calculated based on nominal outside diameter (same as for outside diameter measurements).MR

7.7.3.5 The out-of-roundness is the difference between the largest and smallest diameter in a given cross-sectional plane (i.e. plane perpendicular to the pipe longitudinal axis). The out-of roundness should be measured using a rod gauge or similar equipment and rotate this around the circumference in a given cross-section in order to search for the largest and smallest diameter. The measurements shall evaluate the full circumference of the pipe. For welded pipes the measurements shall exclude only the weld itself. MR

7.7.3.6 Out-of-roundness values at pipe ends shall be determined from inside (i.e. pipe internal surface) measurements. For linepipe with internal diameter less than 150 mm outside measurements are allowed. Pipe body out-of-roundness shall be measured towards the middle of the pipe and the choice between inside or outside measurements is at the manufacturer's discretion. MR

7.7.3.7 For welded pipes where wall thickness measurements have been done on the plate or strip, the final pipe shall be measured as follows;

— One measurement on each pipe end for every pipe
— One measurement on the pipe body for minimum three pipes per eight hours of production

For seamless pipes, wall thickness measurements shall be done on each pipe with a suitable method and with measurement locations sufficient to properly document that the pipe wall thickness is within acceptable limits.

For pipe with clad or lined CRA material, the WT shall be measured and reported for each material layer.

7.7.3.8 Wall thickness measurements shall be made with an automatic or manual non-destructive device, or mechanical calliper. In case of dispute, the measurement determined by use of the mechanical calliper shall govern. The mechanical calliper shall be fitted with contact pins having circular cross-sections of 6.35 mm in diameter. The end of the pin contacting the inside surface of the pipe shall be rounded to a maximum radius of 38.1 mm for pipe of size 168.3 mm or larger, and up to a radius of d/4 for pipe smaller than size 168.3 mm with a minimum radius of 3.2 mm. The end of the pin contacting the outside surface of the pipe shall be either flat or rounded to a radius of not less than 38.1 mm.

7.7.3.9 Geometric deviations from the nominal cylindrical contour of the pipe (e.g. flat spots and peaks) resulting from the pipe forming or manufacturing operations (i.e. not including dents) shall not exceed the criteria in Table 7-22. Geometric deviations shall be measured as the gap between the extreme point (i.e. deepest or highest) of the deviation and the prolongation of the contour of the pipe. A template with a curvature equal to the nominal ID or OD of the pipe to be inspected shall be used. The length of the gauges shall be 200 mm or 0.25 D, whichever is less. The gauges shall be made with a notch so that it can fit over the weld cap.

At pipe ends the full internal circumference shall be inspected, over a length of minimum 100 mm from the pipe end bevel.

Inspection of the external surface shall be performed along the weld and around the circumference whenever indicated by visual inspection. MR

7.7.3.10 Straightness shall be measured according to Figure 1 and Figure 2 in ISO 3183. Measuring full length straightness should be done at the concave orientation of the pipe, with a straight reference line (e.g. a string) lifted equally above the surface at both ends (e.g. 10-15 mm).

7.7.3.11 Out-of squareness at pipe ends shall be measured according to Figure 3 in ISO 3183.

7.7.3.12 The pipe length shall be measured individually.

7.7.3.13

The weight of each pipe with D ≥ 141.3 mm shall be measured individually. For pipe with D < 141.3 mm, the linepipes shall be weighed either individually or in convenient lots selected by the manufacturer.

7.7.3.14 The mass per unit length, rl, shall be used for the determination of pipe nominal weight and shall be calculated using the following equation:

$$r_l = t(D-t) \cdot C \tag{7.6}$$

where:

r_l is the mass per unit length, in kg/m

D is the nominal outer diameter, expressed in mm

t is the nominal wall thickness, in mm

C is 0.02466.

7.7.3.15 The cap reinforcement height shall be measured relative to the base metal immediately next to the weld toe.

7.7.3.16 At the pipe ends the weld cap shall be removed (e.g. by machining or grinding), in order to allow for AUT of the girth weld during installation. The height of the remaining weld metal shall be measured relative to the base metal at the weld toe. The transition between areas with and without weld cap shall be rounded (i.e. not a sharp feature). For external surface, the transition to the base material/pipe body shall be smooth.

Guidance note:

The purpose of removing weld cap at the ends is to allow UT probes to pass without snagging (external surface).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.7.3.17 The radial offset shall be measured as the difference in height (i.e. radial difference) of the base metal within 100 mm of the weld toes. This can be measured either at external or internal surface, at the manufacturer's discretion.

7.7.3.18 A straight line shall be oriented parallel to the longitudinal axis of the weld (e.g. the longitudinal axis of the pipe). The distance from this line to the weld toe shall be determined, and the difference between the point closest and farthest from the line shall not exceed the acceptance criteria.

Guidance note:

The intention is to determine the presence of both waving bead/dogleg and widening/narrowing of the weld cap - both of which indicates unstable welding process. This should not be a reason to reject the pipe, since the cap can be ground. Pipe purchaser can require to be informed before any grinding, and require implementation of measures to improve the welding practice.

This control can be performed with a straight ruler of length 300 mm.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.7.3.19 The weld flash on HFW pipes shall be removed on both external and internal surfaces as required in Table 7-22.

Table 7-17 Diameter tolerances, SMLS pipe

Diameter [mm]	*Pipe body* [1)]	*Pipe ends* [2), 3)]
D < 66.7	±0.5 mm	±0.5 mm
66.7 ≤ D < 100	±0.0075*D	
100 ≤ D < 320		±0.005*D
320 ≤ D ≤ 610		±1.6 mm
610 < D < 1422	±0.01*D	±2.0 mm
D = Nominal outside diameter 1) Dimensions of pipe body shall be measured approximately in the middle of the pipe length. 2) The pipe end includes a length of 100 mm at each of the pipe extremities. 3) The tolerances apply for t ≤ 25.0 mm. For heavier wall thickness the tolerances shall be agreed between purchaser and supplier, but in any case not larger than ±2.0 mm .		

Table 7-18 Diameter tolerances, welded pipe

<table>
<tr><td rowspan="2">Diameter [mm]</td><td>Pipe body 1)</td><td>Pipe end 2)</td><td>Pipe end lined/clad 2)</td></tr>
<tr><td>-</td><td>-</td><td>Suppl. req. D</td></tr>
<tr><td>D < 66.7</td><td>±0.5 mm</td><td rowspan="2">±0.5 mm</td><td rowspan="3">±0.5 mm</td></tr>
<tr><td>66.7 ≤ D < 100</td><td rowspan="4">±0.0075*D</td></tr>
<tr><td>100 ≤ D < 200</td><td rowspan="2">±0.005*D</td></tr>
<tr><td>200 ≤ D < 320</td><td rowspan="5">±1.0 mm</td></tr>
<tr><td>320 ≤ D < 426.7</td><td rowspan="4">±1.6 mm</td></tr>
<tr><td>426.7 ≤ D ≤ 610</td><td>±3.2 mm</td></tr>
<tr><td>610 < D < 800</td><td>±0.005*D</td></tr>
<tr><td>800 ≤ D ≤ 1422</td><td>±4.0 mm</td></tr>
<tr><td>1422 < D</td><td colspan="3">As agreed</td></tr>
<tr><td colspan="4">D = Nominal outside diameter
1) Dimensions of pipe body shall be measured approximately in the middle of the pipe length.
2) The pipe end includes a length of 100 mm at each of the pipe extremities.</td></tr>
</table>

Table 7-19 Out-of-roundness tolerances, all pipes 1)

<table>
<tr><td>Diameter [mm]</td><td>Pipe end 2)</td><td>Pipe body 3)</td><td>Pipe end all pipe, except lined/clad</td><td>Pipe end lined/clad</td></tr>
<tr><td></td><td>-</td><td>-</td><td>Suppl. req. D</td><td>Suppl. req. D</td></tr>
<tr><td>D < 60.3</td><td colspan="3">Included in the diameter tolerance</td><td rowspan="2">0.0075*D</td></tr>
<tr><td>60.3 ≤ D < 400</td><td rowspan="3">0.01*D</td><td rowspan="3">0.015*D</td><td rowspan="2">0.01*D</td></tr>
<tr><td>400 ≤ D < 450</td><td rowspan="7">3.0 mm</td></tr>
<tr><td>450 ≤ D ≤ 610</td><td rowspan="2">4.5 mm</td></tr>
<tr><td>610 < D < 666.7</td><td rowspan="3">0.0075*D</td><td rowspan="2">0.01*D</td></tr>
<tr><td>666.7 ≤ D < 1000</td><td rowspan="3">5.0 mm</td></tr>
<tr><td>1000 ≤ D < 1066.7</td><td rowspan="2">10 mm</td></tr>
<tr><td>1066.7 ≤ D < 1422</td><td>8 mm</td></tr>
<tr><td>1422 ≤ D</td><td colspan="3">As agreed</td></tr>
<tr><td colspan="5">D = Nominal outside diameter
1) For pipes with both D > 610 mm and D/t > 75, the tolerances shall be agreed between purchaser and supplier.
2) The pipe end includes a length of 100 mm at each of the pipe extremities.
3) For SMLS pipe body, the tolerances apply for t ≤ 25.0 mm, and the tolerances for heavier wall pipe shall be agreed between purchaser and supplier.</td></tr>
</table>

Table 7-20 Wall thickness tolerances, seamless pipes

Wall thickness [mm]	*Normal tolerances* [1, 2)]	*Suppl. req. D*
t < 4.0	+0.6 mm ; -0.5 mm	
4.0 ≤ t < 10.0	+0.15*t ; -0.125*t	
10.0 ≤ t < 25.0	±0.125*t	+0.125*t ; -0.10*t
25.0 ≤ t < 30.0	+3.7 mm ; -3.0 mm	± 3.0 mm
30.0 ≤ t < 37.0	+3.7 mm ; -0.10*t	
t ≥ 37.0	±0.10*t	

t = specified nominal wall thickness

1) If the purchase order specifies a minus tolerance for wall thickness smaller than the applicable value given in this table, the plus tolerance for wall thickness shall be increased by an amount sufficient to maintain the applicable tolerance range.

2) For pipe with D ≥ 355.6 mm and t ≥ 25.0 mm, the tolerance is ±0.125*t.

Table 7-21 Wall thickness tolerances, welded pipes [1, 2, 3)]

Wall thickness [mm]	*Normal tolerances*	*Suppl. req. D*
t ≤ 6.0	± 0.5 mm	± 0.4 mm
6 < t ≤ 10	± 0.7 mm	± 0.6 mm
10 < t ≤ 20	± 1.0 mm	± 0.8 mm
t > 20.0	+1.5, -1.0	± 1.0 mm

t = specified nominal wall thickness

1) If the purchase order specifies a minus tolerance for wall thickness smaller than the applicable value given in this table, the plus tolerance for wall thickness shall be increased by an amount sufficient to maintain the applicable tolerance range.

2) Subject to agreement a larger plus tolerance for metallurgically clad pipes may be applied.

3) The plus tolerance for wall thickness does not apply to the weld area.

Table 7-22 Tolerances for pipe geometric properties not covered in Tables 7-18 to Table 7-21

Characteristic to be tested	*Tolerances*
Geometric deviations (peaking and flats). Only applicable to welded pipes.	0.005 D or 2.5 mm, whichever is less
	Suppl. req. D: 0.005 D or 1.5 mm, whichever is less
Straightness, max. for full length of pipe	≤ 0.0015 L
Straightness, max. deviation for pipe end region. End region is 1.0 m at each of the pipe extremities.	3 mm
Out-of squareness at pipe ends	≤ 1.6 mm from true 90°
Length	See [7.7.2.3]
Weight of each single pipe/pipe bundle	-3.5% / +10% of nominal weight
Cap reinforcement height (longitudinal weld)	External weld: For t < 13 mm: max 3.0 mm. For t ≥ 13 mm: max 4.0 mm
	Internal weld: Max 3.5 mm
Cap reinforcement height (longitudinal weld) – pipe ends both external and internal. Not applicable to HFW linepipes. After grinding, the specified minimum WT shall be met.	Maximum height 0.5 mm Minimum height 0.0 mm Length of cap to be removed, measured from pipe end bevel; External weld: minimum 250 mm Internal weld: minimum 100 mm
Radial offset of strip/plate edges (longitudinal weld)	For t ≤ 15 mm: max 1.3 mm For 15 mm < t ≤ 25 mm: max 0.1 t For t > 25 mm: max 2.0 mm
	The radial offset of HFW linepipe shall not reduce the thickness of the weld to less than t_{min}.
	For welds in clad/lined material, the radial offset shall not reduce the effective thickness of the cladding/liner in the root area.
Deviation of weld toe from a straight line (double-sided SAW in pipe mills)	The weld toe shall run parallel to the weld longitudinal axis. The maximum deviation within any section of 300 mm length is 0.20 t, but not more than 4.0 mm.

Weld flash (HFW longitudinal welds only)	The flash trimming shall not reduce the wall thickness to below t_{min}. External surface : Removed to be essentially flush with the pipe surface, without any noticeable radial step. Internal surface : Removed to be maximum 0.3 mm + 0.05t above the contour of the pipe. The resulting internal groove shall have a smooth transition to the base metal without notches. The groove depth shall be maximum 0.05t (see also ISO 3183 Table 15).

Table 7-23 Inspection and recording frequency, all pipes

Characteristic to be tested	*Inspection frequency*		*Record test values, as frequency of inspected pipes*
	Normal	*Suppl. req. D*	
Diameter, pipe end	5 %, but minimum 3 pipes per 8-hour shift For D ≤ 168.3 mm; once per test unit of not more than 100 lengths of pipe, but minimum one (1) and maximum 6 pipes per 8-hour shift.	Each pipe end	10 %
Out-of-roundness, pipe end			10 %
Diameter and out-of-roundness, pipe body		5 %, but minimum 3 pipes per 8-hour shift	10 %
Wall thickness	Each pipe	Each pipe	10 %
Geometric deviations (only welded pipes)	10 %	10 %	-
Straightness, full length and pipe end region	5 %, but minimum 3 pipes per 8-hour shift For D ≤ 168.3 mm; maximum 6 pipes per 8-hour shift.	5 %, but minimum 3 pipes per 8-hour shift	-
Out-of-squareness			
Length	100 %	100 %	100 %
Weight			
Cap reinforcement height (longitudinal weld)	5 %, but minimum 3 pipes per 8-hour shift	5 %, but minimum 3 pipes per 8-hour shift	100 %
Cap reinforcement height (longitudinal weld) – pipe ends	100 %	100 %	-
Radial offset of strip/plate edges (longitudinal weld)	5 %, but minimum 3 pipes per 8-hour shift	5 %, but minimum 3 pipes per 8-hour shift	100%
Deviation of weld toe from a straight line (double-sided SAW in pipe mills)			
Weld flash (HFW longitudinal welds only)			

7.8 Marking, delivery condition and documentation

7.8.1 Marking

7.8.1.1 All marking shall be easily identifiable and durable in order to withstand pipe loading, shipping, and normal installation activities.

7.8.1.2 Marking shall include DNV GL linepipe designation (see [7.2.2], [7.3.2] and [7.4.2]). Other type of marking shall be subject to agreement.

7.8.1.3 Each linepipe shall be marked with a unique number. The marking shall reflect the correlation between the product and the respective inspection document.

7.8.2 Delivery condition

7.8.2.1 The delivery condition of C-Mn steel pipe shall be according to Table 7-1.

7.8.2.2 The internal surface of CRA pipes shall be pickled in accordance with the purchase order. If agreed the external surface of CRA pipes shall be cleaned.

7.8.3 Handling and storage

7.8.3.1 On customer's request, each linepipe shall be protected until taken into use.

7.8.3.2 For temporary storage see [6.4.3].

7.8.4 Documentation, records and certification

7.8.4.1 Linepipe shall be delivered with inspection certificate 3.1 according to European Standard EN 10204 (*Metallic Products - Types of Inspection Documents*) or an accepted equivalent.

7.8.4.2 Inspection documents shall be in printed form or in electronic form as an EDI transmission that conforms to any EDI agreement between the purchaser and the manufacturer.

7.8.4.3 The inspection certificate shall identify the products represented by the certificate, with reference to product number, heat number and heat treatment batch. The specified outside diameter, specified wall thickness, pipe designation, type of pipe, and the delivery condition shall be stated.

7.8.4.4 The certificate shall include or refer to the results of all specified inspection, testing and measurements including any supplementary testing specified in the purchase order. For HFW pipe, the minimum temperature for heat treatment of the weld seam shall be stated.

7.8.4.5 Records from the qualification of the MPS and other documentation shall be in accordance with the requirements in [12.3.1].

7.9 Supplementary requirements

7.9.1 Supplementary requirement, H_2S service (S)

7.9.1.1 Linepipe for H_2S service (also referred to as sour service) shall conform to the requirements below. [6.2.2] provides guidance for material selection.

7.9.1.2 All mandatory requirements in ISO 15156-2/3 shall apply, in combination with the additional requirements of this standard.

Guidance note:

ISO 15156-1/2/3, Sec.1, states that the standard is only applicable *to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria*. Any detrimental effects of induced strain will only apply if these are imposed during exposure to an H_2S-containing environment; hence, for manufacture and installation of pipelines the restrictions imposed in the ISO standard are applicable also to strain based design. Any restrictions for maximum allowable strain during operation are beyond the scope of this standard.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.9.1.3 C-Mn steel linepipe for H_2S service shall conform to [7.2], and to the modified and additional requirements below, which conform to the requirements in ISO 3183 Annex H.

7.9.1.4 The chemical compositions given in Table 7-3 and Table 7-4 shall be modified according to Table 7-24 and Table 7-25, respectively.

Table 7-24 Chemical composition for SMLS and welded C-Mn steel pipe with delivery condition N or Q for Supplementary requirement, H_2S service

SMYS	*Product analysis, maximum. weight %*			
	C [1)]	*Mn* [1)]	*S* [2)]	*Other* [3)]
Pipe with delivery condition N - according to Table 7-1				
245	-	-	0.003	-
290	-	-	0.003	-
320	-	-	0.003	-
360	-	-	0.003	-
Pipe with delivery condition Q - according to Table 7-1				
245	-	-	0.003	-
290	-	-	0.003	-
320	-	-	0.003	-
360	-	-	0.003	-
390	-	-	0.003	-
415	-	-	0.003	Note [4)]
450	-	-	0.003	Note [4)]
485	0.16	1.65	0.003	Notes [4, 5)]

Notes

1) For each reduction of 0.01% below the specified maximum for carbon, an increase of 0.05% above the specified maximum for manganese is permissible, up to a maximum increase of 0.20%.
2) If agreed the sulphur content may be increased to ≤ 0.008% for SMLS and ≤ 0.006% for welded pipe, and in such cases lower Ca/S may be agreed.
3) Unless otherwise agreed, for welded pipe where calcium is intentionally added, Ca/S ≥ 1.5 if S > 0.0015%. For SMLS and welded pipe Ca ≤ 0.006%.
4) If agreed Mo ≤ 0.35%.
5) The maximum allowable P_{cm} value shall be 0.22 for welded pipe and 0.25 for SMLS pipe.

Table 7-25 Chemical composition for welded C-Mn steel pipe with delivery condition M for supplementary requirement, H_2S service

SMYS	*Product analysis, maximum. weight %*			
	C 1)	*Mn* 1)	*S* 2)	*Other* 3)
245	0.10	-	0.002	-
290	0.10	-	0.002	-
320	0.10	-	0.002	-
360	0.10	1.45	0.002	-
390	0.10	1.45	0.002	-
415	0.10	1.45	0.002	Note 4)
450	0.10	1.60	0.002	Notes 4)
485	0.10	1.60	0.002	Notes 4)
Notes 1 to 4) See Table 7-24.				

7.9.1.5 Vacuum degassing or alternative processes to reduce the gas content of the steel should be applied.

7.9.1.6 The molten steel shall be treated for inclusion shape control.

7.9.1.7 The requirements for mechanical properties in [7.2.4] shall apply, except for the hardness.

7.9.1.8 During MPQT and production, the hardness in the pipe body, weld and HAZ shall not exceed 250 HV10. If agreed, (see ISO 15156-2) and provided the parent pipe wall thickness is greater than 9 mm and the weld cap is not exposed directly to the H_2S environment, 275 HV10 is acceptable for the weld cap area.

Guidance note:

It is recommended to specify a maximum hardness of 235 HV10 for the base material in order to allow for hardness increase during installation girth welding. If 275 HV10 is allowed in the cap area, the hardness in the corresponding base metal should be limited to 250 HV10.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.9.1.9 Any hard spot larger than 50 mm in any direction, see Table 7-7, shall be classified as a defect if its hardness, based upon individual indentations, exceeds:

— 250 HV10 on the internal surface of the pipe, or
— 275 HV10 on the external surface of the pipe.

Pipes that contain such defects shall be treated in accordance with [D.8.3].

7.9.1.10 The acceptance criteria for the HIC test shall be the following, with each ratio being the maximum permissible average for three sections per test specimen when tested in solution (Environment) A (see Table B.3 of ISO 15156-2):

— crack sensitivity ratio (CSR) ≤ 2%
— crack length ratio (CLR) ≤ 15%, and
— crack thickness ratio (CTR) ≤ 5%.

If HIC tests are conducted in alternative media (see [B.3.3.2]) to simulate specific service conditions, alternative acceptance criteria may be agreed.

7.9.1.11 By examination of the tension surface of the SSC specimen under a low power microscope at X10 magnification there shall be no surface breaking fissures or cracks, unless it can be demonstrated that these are not the result of sulphide stress cracking.

7.9.1.12 CRA linepipe for H_2S service shall conform to [7.3], and the recommendations given in [6.2.2].

7.9.1.13 Linepipe grades, associated hardness criteria, and requirements to manufacturing/fabrication shall comply with ISO 15156-3.

7.9.1.14 Clad or lined steel or linepipe for H_2S service shall conform to [7.4], and to the modified and additional requirements below.

7.9.1.15 Materials selection for cladding/liner, the associated hardness criteria, and requirements to manufacturing and fabrication shall comply with ISO 15156-3. The same applies to welding consumables for weldments exposed to the internal fluid. For selection of the C-Mn steel base material the considerations in A13.1 of ISO 15156-3 shall apply.

7.9.1.16 During qualification of welding procedures and production, hardness measurements shall be performed as outlined in App.B. The hardness in the internal heat-affected zone and in the fused zone of the cladding/lining shall comply with relevant requirements of ISO 15156-3.

7.9.1.17 The frequency of inspection shall be as given in Table 7-7, Table 7-8, Table 7-12, Table 7-13, Table 7-14 and Table 7-15 as relevant, and with additional testing given in Table 7-26.

7.9.1.18 HIC testing during production shall be performed on one randomly selected pipe from each of the three (3) first heats, or until three consecutive heats have shown acceptable test results. After three consecutive heats have shown acceptable test results, the testing frequency for the subsequent production may be reduced to one test per casting sequence of not more than ten (10) heats.

7.9.1.19 If any of the tests during the subsequent testing fail, three pipes from three different heats of the last ten heats, selecting the heats with the lowest Ca/S ratio (based on heat analysis), shall be tested, unless the S level is below 0.0015. For heat with S level greater than 0.0015 heats shall be selected with the lowest Ca/S ratio. Providing these three tests show acceptable results, the ten heats are acceptable. However, if any of these three tests fail, then all the ten heats shall be tested. Further, one pipe from every consecutive heat shall be tested until the test results from three consecutive heats have been found acceptable. After three consecutive heats have shown acceptable test results, the testing frequency may again be reduced to one test per ten heats.

7.9.1.20 SSC testing is required unless the pipe material is pre-qualified in ISO 15156, see [6.2.2.2]. If the material is pre-qualified, the purchaser may specify SSC testing. SSC testing shall be performed in accordance with ISO 15156 2/3 as applicable. (see [6.2.2.2]).

Table 7-26 Applicable testing for supplementary requirement S 1)

Type of pipe	*Type of test*	*Frequency of testing*	*Acceptance criteria*
Production tests			
Welded C-Mn steel pipe	HIC test	In accordance with [7.9.1.18] and [7.9.1.18]	[7.9.1.10]
Tests for manufacturing procedure qualification test 2			
Type of pipe	Type of test	Frequency of testing	Acceptance criteria
Welded C-Mn steel pipe	HIC test	One test (3 test pieces) for each pipe provided for manufacturing procedure qualification	[7.9.1.10]
All pipe 3)	SSC test		[7.9.1.11]

Notes

1) Sampling of specimens and test execution shall be performed in accordance with App.B.
2) To be performed on strain and aged material if Supplementary requirement P (see [7.9.3.7]) has been specified
3) SSC testing is required for C-Mn and low alloy steels with SMYS > 450 MPa, 13Cr martensitic stainless steels and other materials not listed for H_2S service in ISO 15156. (See [6.2.2.2].

7.9.2 Supplementary requirement, fracture arrest properties (F)

7.9.2.1 The requirements to fracture arrest properties are valid for gas pipelines carrying essentially pure methane up to 80% usage factor (see Table 13-1), up to a pressure of 15 MPa, 30 mm wall thickness and 1120 mm diameter

Testing shall be according to Table 7-28.

7.9.2.2 A Charpy V-notch transition curve shall be established for the linepipe base material. The Charpy V-notch energy value in the transverse direction at T_{min} shall, as a minimum, meet the values given in Table 7-27. Five sets of specimens shall be tested at different temperatures, including $T_{min,}$ and the results documented in the qualification report.

7.9.2.3 This paragraph does not apply to C-Mn linepipes delivered with a final heat treatment (e.g. normalising or quench and tempering), or 22Cr and 25Cr linepipes. A Charpy V-notch transition curve shall be established for the linepipe base material in the aged condition. The plastic deformation shall be equal to the actual deformation introduced during manufacturing (no additional straining is required). The samples shall be aged for 1 hour at 250°C. Five sets of specimens shall be tested at different temperatures, including T_{min}. The Charpy V-notch energy value in the transverse direction, at T_{min}, shall as a minimum meet the values given in Table 7-27 in the aged condition. Values obtained at other test temperatures are for information.

7.9.2.4 Drop Weight Tear Testing (DWTT) shall only be performed on all linepipes with outer diameter > 400 mm, wall thickness > 8 mm and SMYS > 360 MPa. A DWTT transition curve shall be established for the linepipe base material. Minimum five sets of specimens shall be tested at different temperatures, including T_{min}. Each set shall consist of two specimens taken from the same test coupon. The test shall be performed in accordance with App.B. The specimens tested at the minimum design temperature and all temperatures above, shall as a minimum, meet an average of 85% shear area with one minimum value of 75%.

Guidance note:

It is globally recognised that inversed fracture appearance may occur in high toughness pipeline materials which could negatively affect the test results. DNV GL supports the statement given in API RP 5L3, section 4.2.

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7.9.2.5 If supplementary requirements for H_2S service as in [7.9.1] are specified for linepipe material with SMYS ≥ 450 MPa the acceptance criteria stated in [7.9.2.4] (average and minimum shear area) may be subject to agreement.

Table 7-27 Charpy V-notch impact test requirements for fracture arrest properties tested at T min (joules; transverse values; average value of three full size base material specimens) 1, 2)

Wall thickness	*≤30 mm* 3)		
	D (mm)		
SMYS	*≤610*	*≤820*	*≤1120*
245	40	40	40
290	40	43	52
360	50	61	75
415	64	77	95
450	73	89	109
485	82	100	124
555 4)	103	126	155

Notes

1) Minimum individual results to exceed 75% of these values, (max 1 specimen per set)
2) The values obtained in the longitudinal direction, when tested, shall be at least 50% higher than the values required in the transverse direction.
3) Fracture arrest properties for larger wall thicknesses and diameters shall be subject to agreement (see [5.4.9])
4) SMYS 550 for 22Cr, 25Cr and 13Cr

Table 7-28 Applicable testing for supplementary requirement F

Production tests			
Type of pipe	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	DWT testing (with limitations give to dimensions in [7.9.2.4])	Once per test unit of not more than 50/100 1) pipes	[7.9.2.4] (see also Table 7-28)
Tests for manufacturing procedure qualification test 2			
All pipe	CVN impact testing of the pipe body for establishment of transition curve	One test for each pipe provided for manufacturing procedure qualification	Table 7-27 3)
Welded pipe except CRA pipe	CVN impact testing of the pipe body for establishment of transition curve, aged condition 3)		Table 7-27 3)
All pipe	DWT testing of the pipe body for establishment of transition curve (with limitations give to dimensions in [7.9.2.4])		[7.9.2.4] (see also [7.9.2.5])

Notes

1) Not more than 100 pipes with D ≤ 508 mm and not more than 50 pipes for D > 508 mm.
2) To be performed on strain and aged material if Supplementary requirement P (see [7.9.3.7]) has been specified
3) The values obtained in the longitudinal direction, when tested, shall at least be 50% higher than the values required in the transverse direction.

7.9.3 Supplementary requirement, linepipe for plastic deformation (P)

7.9.3.1 The objectives of supplementary requirement P are to:

— mitigate the effect of variations in mechanical and geometrical properties along the pipe, in particular across the girth welds (between two adjacent line pipes), through
— reduced variation in mechanical properties
— reduced variation in geometrical tolerances at the pipe ends
— increased strain hardening
— ensure that the level of straining not cause sub-standard specific material properties.

7.9.3.2 Supplementary requirement (P) is applicable to line pipe (including C-Mn backing steel for lined/ clad pipes) when the total nominal strain in longitudinal direction from a single event exceeds 1.0% or the accumulated nominal plastic strain in longitudinal direction exceeds 2.0%, see Table 5-10. The requirements are only applicable to single event strains below 5%.

7.9.3.3 Supplementary requirement (D) should be specified.

Table 7-29 Additional testing for supplementary requirement P 1)

As manufactured condition			
Type of pipe	*Type of test*	*Frequency of testing*	*Acceptance criteria*
All pipe	Tensile testing of the pipe body, longitudinal specimen of proportional type 2)	Production testing: Once per test unit of not more than 50/100 3) pipes	Max(YS) - Min(YS)≤100 MPa 5) YS/TS≤0.90 6)
		Manufacturing procedure qualification: One test for one of the pipes	UEL > 5% 9)
Strained and aged condition 7			
Type of pipe	Type of test	Frequency of testing	Acceptance criteria
All pipe	Tensile testing of the pipe body, longitudinal specimen 2)	Manufacturing procedure qualification: One test for one of the pipes	UTS (R_m)> YS ($R_{t0.5}$) 8) UEL > 5% 9)
	CVN impact testing of the pipe body		Table 7-5 or Table 7-11, as relevant
	Hardness testing		
Welded pipe	Tensile testing of weld filler metal (all weld test) 10)		UTS (R_m)> YS ($R_{t0.5}$) 8) UEL > 5% 9)
	CVN impact testing of the seam weld 4)		Table 7-5 or Table 7-11, as relevant
	Hardness testing of the seam weld		

Notes

1) Mechanical and corrosion testing shall be performed in accordance with App.B.
2) Proportional type specimens according to ISO 6892 should be tested, see [B.2.3.8]. For smaller diameter pipes tensile testing may be performed using full sized specimens (full pipe if it is impossible to prepare proportional type specimen due to size constraints.
3) Not more than 100 pipes with D < 508 mm and not more than 50 pipes for D ≥ 508 mm.
4) CVN testing performed unless excepted, see [B.2.4.2].
5) Applicable for C-Mn steel with SMYS up to and including 450 MPa, otherwise subject to agreement.
6) See [7.9.3.5].
7) See [7.9.3.6].
8) For material with last cycle in tension.
9) See [6.2.4.1]. Subject to agreement, lower UEL for strained and aged condition can be applied. A lower UEL should conservatively reflect the strain level in the pipeline in operation, and should not be lower than 2.5%.
10) This applies to pipes with weld filler material

7.9.3.4 Mechanical testing shall be performed both in the as-manufactured (prior to any reeling) and in the strained and aged condition in accordance with Table 7-29.

7.9.3.5 As an alternative to the requirements in Table 7-29, all relevant failure modes in [5.4] shall be evaluated for the relevant maximum YS/TS ratio and variations in YS, TS and wall thickness, but the YS/TS ratio shall not exceed 0.98.

7.9.3.6 As part of qualification of the pipe material, the line pipe material shall be strained and aged to simulate the representative plastic deformation during installation. The plastic deformation shall either be simulated by full scale testing of a pipe or strip specimens extracted from pipes (see [B.2.11.2] to [B.2.11.10]). Mechanical testing shall be performed on material which has been subjected to last strain increment in tension. Recommended practice for straining of strips is given in DNVGL-RP-F108. The samples shall be artificially aged at 250°C for one hour before testing.

7.9.3.7 If the supplementary requirement for H_2S service (S) and/or fracture arrest properties (F) is required, the testing for these supplementary requirements shall be performed on samples that are removed, strained and artificially aged in accordance with [7.9.3.6]. Testing shall be performed on material which has been subjected to last strain increment in tension. The relevant acceptance criteria shall be met.

7.9.3.8 Qualification for supplementary requirement P may be based on historical data to be documented by the manufacturer, subject to agreement. This may be applied if all relevant parameters are identical (WT, ID, chemical composition, deformation scenario (e.g. same or less onerous deformation scenario), steelmaking/rolling practice, heat treatments).

7.9.4 Supplementary requirement, dimensions (D)

7.9.4.1 Supplementary requirements for enhanced dimensional requirements for linepipe (D) are given in Table 7-18 to Table 7-23. Implementing supplementary requirement D should be done by the purchaser considering the influence of dimensions and tolerances on the subsequent fabrication/installation activities and the welding facilities to be used.

Guidance note:

Supplementary requirement D is beneficial for local buckling during reel-lay installation. The requirements of D are applicable to as milled pipe prior to reeling.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.9.5 Supplementary requirement, high utilisation (U)

7.9.5.1 Supplementary requirement U is required in order to apply a material strength factor α_U of 1.00. The purpose of supplementary requirement U is to have sufficient confidence that there are no pipes with yield strength below the minimum required value (i.e. insignificant tail below the requirement).

This supplementary requirement is only valid for:

— material yield strength
— both tensile and compressive testing
— both transverse and longitudinal direction.

The supplementary requirement can be applied to one or several of the properties mentioned above. In this sub-section requirements are related to SMYS. If supplementary requirement is applied to compressive strength, the agreed minimum requirement value shall be used, as relevant. Compressive testing is not required by this standard, but may be relevant for some projects.

Guidance note:

When applied, supplementary requirement U is typically relevant for transverse tensile yield strength in cases where pressure containment is a governing limit state. When installation loads are a concern, supplementary requirement U can be applied to longitudinal tensile yield strength.

Supplementary requirement U may be relevant for transverse compressive yield strength in case of large water depth.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.9.5.2 There are two separate approaches to achieve supplementary requirement U, and it is sufficient to use only one of them:

— modified testing regime during production, as described in this subsection
— retrospective documentation.

Review and analysis of records from fabrication and testing may justify an increase of the SMYS. This shall be done only by agreement, and based on an evaluation of the fabrication process and documentation. It may be allowed to increase the SMYS up to but not including the next material grade.

Guidance note:

The purpose of both approaches is the same. However, it is not guaranteed that the modified testing regime will give an average yield strength value that is two standard deviations above the minimum required value.

The modified testing regime has been designed so that the confidence in the desired outcome is high. It is an approach based on probability functions and expected distribution –there will always be some uncertainty.

Consequently supplementary requirement U should be considered fulfilled if the modified testing regime has been followed – even if a retrospective analysis of the pipes may show that the actual average value is somewhat less than 2.0 standard deviations from the minimum required value.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.9.5.3 The modified testing regime has a set of re-testing steps, based on the results.

Re-testing of failed pipes is not permitted. However, if the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample shall be replaced by a correctly prepared sample from the same pipe, and a new test performed.

7.9.5.4 The production test of the modified testing regime shall have:

— testing frequency as stated in Table 7-7 or Table 7-12.
— result equal to or larger than SMYS x 1.03 times.

If the result meets the requirement, the test unit is accepted. If the result does not meet the requirement, then retesting shall be carried out – or the test unit shall be rejected.

7.9.5.5 If the production test result is below SMYS, the tested pipe shall be rejected. Four additional pipes within the same test unit shall be sampled, for a total of four new tests. If all four re-tests meet SMYS, the test unit is acceptable. If at least one of the re-tests is below SMYS, the test unit shall be rejected.

7.9.5.6 If the production test result is between 1.03 x SMYS and SMYS, the tested pipe is acceptable. In addition, two pipes within the same test unit shall be sampled, for a total of two confirmatory tests. If both confirmatory tests meet SMYS, the test unit is acceptable. If at least one of the confirmatory tests is below SMYS, further re-testing is allowed.

If one or both of the confirmatory tests fall below SMYS, the re-test program given in [7.9.5.8] shall apply.

7.9.5.7 If one or both of the confirmatory tests fail to meet SMYS, two re-tests taken from two additional pipes within the same test unit shall be tested (a total of four tests). If all re-tests meet SMYS, the test unit is acceptable. If any of the re-tests fall below SMYS, the test unit shall be rejected.

7.9.5.8 If a test unit has been rejected after re-testing, the manufacturer may conduct individual testing of all the remaining pipes in the test unit. If the total rejection of all the pipes within one test unit exceeds 15%, including the pipes failing the production and/or confirmatory tests, the test unit shall be rejected.

7.9.5.9 Retrospective documentation, see [7.9.5.2], shall meet the following requirements;

— More than 50 test units: The average yield strength shall be at least 2.0 standard deviations above SMYS.
— From 21 to 50 test units: The average yield strength shall be at least 2.1 standard deviations above SMYS.
— From 10 to 20 test units: The average yield strength shall be at least 2.3 standard deviations above SMYS.
— Less than 10 test units: supplementary requirement U is not applicable.

The statistical analysis shall be based on a group of test units that are all within the same MPQT essential variables (e.g. different supply routes shall be analysed separately).

The statistical analysis shall take into account all test results from the test units proposed for supplementary requirement U. This includes test results for pipes rejected from the test units. All test results shall be considered as an individual data point (e.g. the results from a double re-test shall be considered as two separate values).

SECTION 8 CONSTRUCTION - COMPONENTS AND PIPELINE ASSEMBLIES

8.1 General

8.1.1 Objective

8.1.1.1 This section specifies requirements to the construction of the components as defined in Table 8-1 and pipeline assemblies, see Table 6-1.

8.1.2 Application

8.1.2.1 This section is applicable to pressure containing components listed in Table 8-1 used in the submarine pipeline system. Design of components shall be in accordance with [5.6].

Table 8-1 Manufacture and testing of pipeline components and pipeline assemblies

Components	*Requirements for manufacture and testing given in this section*	*Reference standards or recommended practices and applicable class or designation* 1)	Pressure strength test in accordance with [8.7]
Bends 2)	[8.2.3]	ISO 15590-1, PSL 2 for non-H_2S and PSL 2S for H_2S service	Mill pressure test of mother pipe 6).Hydrostatic test of bend may be specified
Fittings 2), 3), 4)	[8.2.4]	ISO 15590-2, class C for non-sour and class CS for sour service	FAT 7)/ Qualification 8)/Mill pressure test 10)
Flanges 2), 4)	[8.2.5]	ISO 15590-3, designation (L) for non-sour and designation (LS) for sour service, Norsok L-005	Qualification 8)
Valves 2), 4)	[8.2.6]	ISO 14723	FAT 7) in accordance with ISO 14723 Clause 11
Mechanical connectors 2), 4)	[8.2.7]	ASME VIII Div.2/EN 13445/PD5500 5)	Qualification 8)
CP Isolation joints 2), 4)	[8.2.8]	ASME VIII Div.2/EN 13445/PD5500 5)	FAT 7)
Anchor flanges 2), 4)	[8.2.9]	See Table 5-13	Qualification 8)
Buckle and fracture arrestors 4)	[8.2.10]		Mill pressure test 6)
Pig traps 2), 4)	[8.2.11]	ASME VIII Div.2/EN 13445/PD5500 5)	FAT 7)
Repair clamps and repair couplings 2), 4)	[8.2.12]	DNVGL-RP-F113 Sec.8 5)	Qualification 8)
Pipeline assemblies	[8.6]		9)

Notes

1) The listed reference standards or recommended practices only cover C-Mn steels, for other materials reference is given to this section. The listed standards or recommended practices shall be used within the applicability of the standards or recommended practices.
2) Supplementary requirements F, P, D or U are not applicable.
3) Fittings include: Elbows, caps, tees, wyes, single or multiple extruded headers, reducers and transition sections.
4) Where components are constructed from C-Mn or low alloy steel forgings, forgings complying with the requirements in DNVGL-RP-0034 for steel forging class SFC 2 or SFC 3 may be considered as equivalent and therefore an acceptable alternative to the corresponding requirements in this standard.
5) Not covered by specific reference standards or recommended practices, however, these codes are listed as relevant standards or recommended practices.
6) See [7.5.1]
7) Shall be pressure tested in accordance with applied design standard. This is often higher than the pressure test requirement of this standard which is typically 15% above the design pressure. This implies that the pressure testing has to be performed within the code breaks, i.e. typically before the transition piece and pup-pieces are added.
8) Shall be qualified or type approved. Recommended practice on qualification is given in DNVGL-RP-A203
9) The benefit of detection leakage early is beneficial and the current industry practice of hydrostatic testing of pipeline assemblies are reflected in Table 8-5.
10) Mill test may be performed of mother pipe to original size, prior to machining

8.1.2.2 Materials selection for components shall be in accordance with Sec.6.

8.1.3 Systematic review

8.1.3.1 The overall requirements to systematic review in Sec.2 will for this section apply for the component manufacturers and imply:

— Review of this section and evaluate if the requirements in the purchase order and of this standard can be met.
— Identify any possible threats, evaluate the possible consequences and define necessary remedial measures.

8.2 Component requirements

8.2.1 General

8.2.1.1 References to requirements are listed in Table 8-1.

8.2.1.2 In paragraphs of subsection [8.2.2] to [8.2.6], ISO references are given between slashes, e.g.: /Annex A/. The paragraph text shall be read as either additional or modified requirement to ISO 15590/ISO 14723.

8.2.2 Component specification

8.2.2.1 A component specification reflecting the results of the materials selection (see [6.2]), and referring to this section of the offshore standard, shall be prepared by the purchaser. The specification shall state any additional requirements to and/or deviations from this standard pertaining to materials, manufacture, fabrication and testing of linepipe. For components covered by ISO 15590, see Table 8-1, the component specification should preferably refer to the applicable ISO standard with necessary modifications in line with this section.

8.2.3 Induction bends – additional and modified requirements to ISO 15590-1:2009

8.2.3.1 /Annex A/ The following additional requirements shall be stated in the MPS:

- the number and location of the pyrometers used (minimum two, located 120 to 180° apart) and the allowable temperature difference between them
- the centring tolerances for the coil
- the number of water nozzles and flow rate.

8.2.3.2 /9.1/ The chemical composition of C-Mn steel mother pipe, including the backing steel of clad mother pipe, shall be in agreement with the composition for the linepipe grades listed in Table 7-3, Table 7-4, Table 7-24 or Table 7-25. The maximum carbon equivalent (CE) of quenched and tempered or normalised C-Mn steel mother pipe (delivery condition N or Q, respectively) shall be according to Table 8-2. The carbon equivalent (P_{cm}) of thermo-mechanical formed or rolled C-Mn steel mother pipe (delivery condition M) shall be maximum 0.02 higher than as required in Table 7-4.

Guidance note:

Hot expanded mother pipe may experience dimensional instability after post bending heat treatment.

Bends may be made from spare sections of normal linepipe. It should be noted that linepipe, particularly pipe manufactured from TMCP plate, may not have adequate hardenability to achieve the required mechanical properties after induction bending and subsequent post bending heat treatment.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 8-2 Carbon equivalent values for mother pipe

SMYS	*CE* [1]*, max.*
245	0.36
290	0.38
320	0.40
360	0.43
390	0.43
415	0.44
450	0.45
485	0.46
555	0.47

Note

1)

$$CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

8.2.3.3 /9.1/ The chemical composition of mother pipe for CRA materials shall meet the applicable requirements for the relevant material type and grade given in Sec.7.

8.2.3.4 /9.1/ Mother pipe shall be subjected to NDT as required for linepipe in Sec.7, except NDT of mother pipe ends if the ends will be cut off during bend fabrication.

8.2.3.5 /9.1/ Induction bends shall not be produced from CRA lined steel pipe.

8.2.3.6 /9.1/ All mother pipes shall be mill pressure tested in accordance with [7.5], where [7.5.1.6] does not apply.

8.2.3.7 (/9.2/ and /Table 1/) The following parameters shall be additional to or modification of the essential variables given in /Table 1/:

— Heat of steel: This essential variable shall be replaced by: Change in ladle analysis for C-Mn steels outside ± 0.02% C, ± 0.03 CE and/or ± 0.02 in Pcm, or any change in nominal chemical composition for CRA's.
— Bending radius: Qualified MPS qualifies all larger radii, but not smaller.
— Any change in number and position of pyrometers used and in the allowable temperature difference between the pyrometers.
— Any change in the stated tolerances for coil centring.
— Any change in the number and size of cooling nozzles and flow rate or water pressure.

8.2.3.8 /9.4/ Heat treatment equipment and procedures shall be in accordance with [8.4.5].

8.2.3.9 /10.4.4.2/ Hardness shall be measured in Hardness Vickers.

8.2.3.10 /Table 2/ and /10.4.3/ For bends from mother pipe with nominal wall thickness greater than 25 mm, additional CVN testing shall during MPQT be performed at mid thickness for CRA and 2 mm below inner surface for C-Mn in the following locations:

— transition zones base metal extrados start and stop
— bend extrados base metal
— bend intrados base metal
— bend weld metal.

Acceptance criteria for mechanical testing shall meet the requirements given in applicable mother pipe material specification.

8.2.3.11 /10.4.5/ Surface hardness testing using portable equipment shall be performed in accordance with App.B.

8.2.3.12 /10.4.6/ For metallographic evaluation of CRA or clad induction bends, the acceptance criteria shall be in accordance with in [7.3.4] and [7.3.5].

8.2.3.13 /10.5/ Additional NDT shall be performed in accordance with [D.8] as applicable.

Acceptance criteria for the additional testing shall be according to [D.8].

8.2.3.14 /10.6/ Ovality of cross-sections shall be kept within the specified tolerances. The bend radius shall be as specified by the purchaser, and large enough (e.g. 5× outer diameter) to allow passage of inspection vehicles when relevant.

Dimensional control shall include the following additional or modified tests and acceptance criteria:

— ID at bend ends (always measure ID) shall be as specified for mother pipe body
— out-of-roundness of bend ends shall be maximum 1.5% and maximum 3% for the body
— the bend angle shall be within ±0.75°
— weld seam location ± 15° from the neutral axis
— end squareness shall be as specified for mother pipe end (only applicable for final dimension).

8.2.3.15 /10.7/ Gauging shall be performed as specified in the Component specification, see [6.3.3].

8.2.3.16 /12.0/ Marking requirements shall be specified to distinguish between bends manufactured and tested to the requirements above and unmodified ISO 15590-1 bends.

8.2.4 Fittings - additional and modified requirements to ISO 15590-2

8.2.4.1 /1/ The following components shall be defined as fittings: Elbows, caps, tees, wyes, single or multiple extruded headers, reducers and transition sections.

8.2.4.2 /6.2/ Tees and headers shall be of the integral (non-welded) reinforcement type. Outlets should be extruded. Bars of barred tees and wyes shall not be welded directly to the high stress areas around the extrusion neck. The bars transverse to the flow direction should be welded to a pup piece, and the bars parallel to the flow direction should be welded to the transverse bars only. If this is impractical, alternative designs shall be considered in order to avoid peak stresses at the bar ends.

8.2.4.3 /7/ The information required in [6.3.3.2] shall be provided.

8.2.4.4 /8/ The following additional information shall be provided:

The MPS should specify the following items, as applicable:

— For the starting material
    — delivery condition
    — chemical composition, and
    — NDT procedures for examination of starting materials.
— For fitting manufacture
    — NDT procedures
    — hydrostatic test procedures
    — dimensional control procedures
    — coating and protection procedures
    — handling, loading and shipping procedures, and
    — at-site installation recommendations.

For one-off fittings designed and manufactured for a specific purpose, the following additional information shall be provided:

— plan and process flow description/diagram
— order specific quality plan including supply of material and subcontracts, and
— manufacturing processes including process- and process control procedures.

8.2.4.5 /8.2/ Starting material shall be subject to 100% NDT at an appropriate stage of manufacture according to:

— C-Mn steel and duplex stainless steel pipe shall be tested as required in Sec.7 or [D.3.2].
— [D.2.2], for RT of welds in starting materials other than pipe
— [D.2.3] or [D.2.4] as applicable, for UT of welds in starting materials other than pipe
— [D.4.2], for C-Mn steel forgings
— [D.4.3], for duplex stainless steel forgings
— [D.3.2], for UT of plate material

with acceptance criteria according to the corresponding requirements of App.D.

Subject to agreement, equivalent NDT standards with regard to method and acceptance criteria may be applied.

8.2.4.6 /8.3.2/ Welding and repair welding shall be performed in accordance with qualified procedures meeting the requirements in App.C.

8.2.4.7 /8.3.3/ Heat treatment equipment and procedures shall be in accordance with [8.4.5].

8.2.4.8 /9.2/ Testing requirements shall be in accordance with [8.5.1].

8.2.4.9 /Table 2/ Inspection, testing and acceptance criteria shall be in accordance with class C with the following additional and modified requirements:

— the level of hardeneability elements, e.g Ni, Cr, Mo, Cu, may be adjusted based on a hardeneability assessment, providing requirements in [8.3.2.5] to carbon equivalent is maintained
— the chemical composition of duplex stainless steel materials shall be according to [8.3.3]
— mechanical and hardness testing of weld seams shall be performed in accordance with App.B and acceptance criteria shall be in accordance with [8.5.2] and [8.5.3] as applicable
— surface hardness testing of fittings of class CS shall be performed with acceptance criteria according to Table 6-1
— metallographic examination for welds and body of duplex stainless steel fittings shall be performed in accordance with App.B and with acceptance criteria according to [8.5.3]
— HIC testing shall be performed on fittings in class CS manufactured from rolled material as required in Table 8-4
— 25Cr duplex stainless steel fittings shall be corrosion tested as required in Table 8-4, and
— NDT of fitting bodies shall be performed according to [8.2.5.12].

8.2.4.10 /Table 3/ The extent of testing and examination shall comprise the following additional requirements:

— the test unit definition shall be amended to: Fitting or test piece of the same designation, starting material wall thickness, heat, manufacturing procedure specification and heat treatment batch
— surface hardness tests shall be performed on two fittings per test unit
— metallography of duplex stainless steel fittings with the largest thickness exceeding 25 mm shall be performed as one per test unit
— HIC testing shall be performed for qualification of the MPS for fittings in class CS manufactured from rolled material, and
— 25Cr duplex stainless steel fittings shall be corrosion tested for qualification of the MPS, in accordance with Table 8-4.

8.2.4.11 /Table 2/ and /9.5/ NDT of each completed fitting shall be performed in accordance with the /Table 2/, class C with the following additional requirements:

— the body of fittings manufactured from plates and pipes shall be subject to 100% magnetic particle testing for C-Mn steels and 100% dye penetrant/eddy current testing for duplex stainless steel
— the extrusion area for tees and headers with adjoining pipe wall thickness ≥ 12 mm shall be subject to 100% volumetric ultrasonic and 100% magnetic particle testing for C-Mn steels and 100% volumetric ultrasonic and 100% dye penetrant/eddy current testing for duplex stainless steel
— the extrusion area for tees and headers with adjoining pipe wall thickness < 12 mm shall be subject to 100% magnetic particle testing for C-Mn steels and 100% dye penetrant/eddy current testing for duplex stainless steel
— overlay welds shall be tested 100%.

8.2.4.12 NDT shall be performed in accordance with App.D (as applicable):

— [D.3.4], for visual inspection
— [D.4.2], for UT and MT of C-Mn/low alloy steel forgings
— [D.4.3], for UT and PT of duplex stainless steel forgings
— [D.3.2.6] through [D.3.2.13], for UT of a 50 mm wide band inside ends/bevels
— [D.3.2.21], for MT of ends/bevels
— [D.3.2.22], for PT of ends/bevels

— [D.2.2], for RT of welds
— [D.2.3], for UT of welds in C-Mn/low alloy steel
— [D.2.4], for UT of welds in duplex stainless steel
— [D.2.5], for MT of welds in C-Mn/low alloy steel
— [D.2.6], for DP of welds in duplex stainless steel
— [D.3.3], for NDT of overlay welds
— [D.4.4], for visual inspection of forgings
— [D.2.8], for visual inspection of welds, and
— [D.3.5], for residual magnetism.

Acceptance criteria shall be according to the corresponding requirements of App.D.

8.2.4.13 /11/ Marking requirements shall be specified to distinguish between fittings manufactured and tested to the requirements above and unmodified ISO 15590-2 fittings.

8.2.5 Flanges and flanged connections - additional requirements to ISO 15590-3

8.2.5.1 /7/ The following additional information shall be provided:

— required design life
— nominal diameters, D or ID, out of roundness and wall thickness for adjoining pipes including required tolerances
— dimensional requirements and tolerance if different from ISO 7005-1
— minimum design temperature (local)
— maximum design temperature (local)
— external loads and moments that will be transferred to the component from the connecting pipeline under installation and operation and any environmental loads (e.g. nominal longitudinal strain)
— material type and grade, delivery condition, chemical composition and mechanical properties at design temperature
— required testing
— corrosion resistant weld overlay.

8.2.5.2 /8/ Overlay welding shall be performed according to qualified welding procedures meeting the requirements of App.C.

8.2.5.3 /8.1/ The MPS shall be in accordance with [8.4.1].

8.2.5.4 /8.2/ and /Table 4/

— the level of hardeneability elements, e.g Ni, Cr, Mo, Cu, may be adjusted based on a hardeneability assessment, providing requirements in [8.3.2.5] to Carbon Equivalent is maintained
— The chemical composition of duplex stainless steel materials shall be according to [8.3.3].

8.2.5.5 /8.4/ Heat treatment equipment and procedures shall be in accordance with [8.4.5].

8.2.5.6 /Table 3/ Mechanical testing shall be performed with the following additional requirements:

— Tensile, impact and through thickness hardness shall be performed once per test unit with the test unit defined as; Flanges of the same size, heat, manufacturing procedure specification and heat treatment batch.
— Surface hardness testing shall be performed once per test unit for flanges in class LS.
— Mechanical, hardness and corrosion testing of flanges shall be performed as required by [8.5.1], acceptance criteria to [8.5.2] or [8.5.3] as applicable.

— Metallographic examination for duplex stainless steel flanges shall be performed according to [8.5.1], with acceptance criteria according to [8.5.3].

8.2.5.7 /Table 5/ The impact test temperature for C-Mn steel and low alloy flanges shall be 10°C below the minimum design temperature for all thicknesses and categories.

8.2.5.8 /9.4.4/ Hardness indentation locations shall be according to Table 8-4.

8.2.5.9 /9.4.5/ Metallographic examination of duplex stainless steel shall be performed in accordance with App.B, with acceptance criteria according to [7.3.4].

8.2.5.10 /9.4.6/ and /9.4.7/ Corrosion testing of duplex stainless steel shall be according to Table 8-4.

8.2.5.11 /9.5.4/ The extent of NDT shall be 100% magnetic particle testing of ferromagnetic materials and 100% liquid penetrant testing of non magnetic materials. A percentage test is not permitted.

8.2.5.12 /9.5.5/ 100% ultrasonic testing of the final 50 mm of each end of the flange shall be performed. 100% ultrasonic testing of the first 10 flanges of each type and size ordered. If no defects are found during the testing of the first 10 flanges of each type and size ordered the extent of testing may be reduced to 10% of each size and type. If defects are found in any tested flange, all flanges of the same size, heat, manufacturing procedure specification and heat treatment batch shall be 100% tested.

All flanges shall be subject to 100% visual inspection.

8.2.5.13 NDT shall be performed in accordance with App.D or ISO (as applicable):

— Magnetic particle testing shall be performed in accordance with [D.4.2] or ISO 13664
— Liquid penetrant testing shall be performed in accordance with [D.4.3] or ISO 12095
— Ultrasonic testing of C-Mn/low alloy steel forgings shall be performed in accordance with [D.4.2]
— Ultrasonic testing of duplex stainless steel forgings shall be performed in accordance with [D.4.3]
— Testing of overlay welds shall be performed in accordance with [D.3.3]
— Visual examination shall be in accordance with [D.4.4]

Acceptance criteria for forgings shall be in accordance with the corresponding requirements of [D.4.5] and for overlay welds only, in accordance with [D.3.6].

Subject to agreement, equivalent NDT standards with regard to method and acceptance criteria may be applied.

8.2.5.14 /9.6/ For flanges with specified dimensions and tolerances different from ISO 7005-1, these specified requirements shall be met.

8.2.5.15 /9.9/ Repair welding of flange bodies is not permitted.

8.2.5.16 /11/ Marking requirements shall be specified to distinguish between flanges manufactured and tested to the requirements above and unmodified ISO 15590-3 flanges.

8.2.5.17 Sealing rings shall be compatible with the finish and surface roughness of the flange contact faces.

8.2.5.18 Sealing rings shall be capable of withstanding the maximum pressure to which they could be subjected, as well as installation forces if flanges are laid in-line with the pipeline. Sealing rings for flanges shall be made from metallic materials that are resistant to the fluid to be transported in the pipeline system. Mechanical properties shall be maintained at the anticipated in service pressures and temperatures.

8.2.5.19 Bolts shall meet the requirements given in [8.3.5].

8.2.5.20 For the use of ANSI, RTJ and orifice flanges it shall be ensured that the flanges are suitable for subsea use, e.g. by means of materials compatibility and use of vent holes to avoid water trapping and pressure build up in the groove area for gaskets.

8.2.6 Valves – additional requirements to ISO 14723

8.2.6.1 /Annex B/ The following additional information shall be provided:

— design standard
— required design life
— minimum design temperature (local)
— maximum design temperature (local)
— design pressure (local)
— water depth, and
— weld overlay, corrosion resistant and/or wear resistant.

8.2.6.2 /8.1/ A manufacturing procedure specification in accordance with [8.4.1] shall be documented.

8.2.6.3 /8.1/, /8.4/ and /8.7/ Materials shall be specified to meet the requirements given in [8.3].

8.2.6.4 /8.5/ The impact test temperature shall be 10°C below the minimum design temperature

8.2.6.5 /8.6/ Bolting shall meet the requirements of [8.3.5].

8.2.6.6 /8/ Welding shall be performed according to qualified welding procedures meeting the requirements of App.C.

8.2.6.7 /9.4/ The extent, method and type of NDT of C-Mn/low alloy steels shall be in accordance with ISO 14723, Annex A, QL 2 requirements.

The extent and type of NDT of duplex stainless steels shall be in accordance with ISO 14723, Annex A, QL 2 requirements. Methods shall be according to App.D of this standard.

The extent and type of NDT of weld overlay shall be in accordance with ISO 14723, Annex A, QL 2 requirements. the method shall be according to App.D.

Acceptance criteria for NDT shall be in accordance with ISO 14723, Annex A with the following amendments:

For UT 2, VT 2 and VT 3 the acceptance criteria shall be in accordance with App.D of this standard.

8.2.6.8 /9.5/ Repair welding of forgings is not permitted.

8.2.6.9 /10.2/ Hydrostatic shell tests shall be performed in accordance with ISO 14723, Clause 11, or according to specified requirements in compliance with [5.2.2.1] as outlined in [8.7].

8.2.6.10 /11/ Marking requirements shall be specified to distinguish between valves manufactured and tested to the requirements above and unmodified ISO 14723 valves.

8.2.6.11 Valves with requirements for fire durability shall be qualified by applicable fire tests. Refer to API 6FA and BS 6755 Part 2 for test procedures.

8.2.7 Mechanical connectors

8.2.7.1 This section applies to end connections, such as hub and clamp connections connecting a pipeline to other installations.

Requirements to material, manufacture and mechanical testing of pressure containing parts shall be in accordance with [8.3], [8.4] and [8.5].

8.2.7.2 Bolting shall meet the requirements of [8.3.5].

8.2.7.3 End connections shall be forged.

8.2.7.4 The extent of NDT shall be:

— 100% magnetic particle testing of ferromagnetic materials and 100% liquid penetrant testing of non magnetic materials
— 100% ultrasonic testing of forgings and castings
— 100% RT of critical areas of castings
— 100% ultrasonic or radiographic testing of welds
— 100% magnetic particle testing/liquid penetrant testing of welds
— 100% visual inspection.

NDT shall be performed in accordance with App.D (as applicable):

— [D.3.4], for visual inspection
— [D.4.2], for UT and MT of C-Mn/low alloy steel forgings
— [D.4.3], for UT and PT of duplex stainless steel forgings
— [D.5.2], for UT and MT of C-Mn/low alloy steel castings
— [D.5.3], for UT and PT of duplex stainless steel castings
— [D.5.4], for RT of castings
— [D.3.2.21], for MT of ends/bevels
— [D.3.2.22], for DP of ends/bevels
— [D.2.2], for RT of welds
— [D.2.3], for UT of welds in C-Mn/low alloy steel
— [D.2.4], for UT of welds in duplex stainless steel
— [D.2.5], for MT of welds in C-Mn/low alloy steel
— [D.2.6], for DP of welds in duplex stainless steel
— [D.3.3], for overlay welds
— [D.4.4], for visual inspection of forgings
— [D.5.5], for visual examination of castings
— [D.2.8], for visual inspection of welds
— [D.3.5], for residual magnetism.

Acceptance criteria shall be according to the corresponding requirements of App.D.

8.2.8 CP Isolation joints

8.2.8.1 These requirements apply to manufacture and testing of boltless, monolithic coupling type of isolation joints for onshore applications.

8.2.8.2 CP isolation joints shall be manufactured from forgings. Requirements to material, manufacture and mechanical testing shall be in accordance with [8.3], [8.4] and [8.5].

8.2.8.3 Isolation joints shall be protected from electrical high current high voltage from welding and lightening etc. in the construction period. If high voltage surge protection is not provided in the construction period isolation joints shall be fitted with a temporary short-circuit cable clearly tagged with the instruction *not to be removed until installation of permanent high voltage surge protection*.

8.2.8.4 For manufacturers without previous experience in the design, manufacture and testing of isolation joints, one joint should be manufactured and destructively tested for the purpose of qualifying the design and materials of the joint.

The qualification programme should as a minimum contain the following elements:

— bending to maximum design bending moment
— tension to maximum design tension
— pressure testing to 1.5 times the design pressure
— pressure cycling from minimum to maximum design pressure 10 times at both minimum and maximum design temperature.

Before and after testing the resistance and electrical leakage tests should show the same and stable values.

In addition, after full tests the joint should be cut longitudinally into sections to confirm the integrity of the insulation and fill materials and the condition of the O-ring seals.

8.2.8.5 Isolation joint shall be forged close to the final shape (if applicable). Machining of up to 10% of the local wall thickness at the outside of the component is allowed.

8.2.8.6 The extent of NDT shall be:

— 100% magnetic particle testing of ferromagnetic materials and 100% liquid penetrant testing of non magnetic materials
— 100% ultrasonic testing of forgings
— 100% ultrasonic or radiographic testing of welds
— 100% magnetic particle testing/liquid penetrant testing of welds
— 100% visual inspection.

NDT shall be performed in accordance with App.D (as applicable):

— [D.3.4], for visual inspection
— [D.4.2], for C-Mn/low alloy steel forgings
— [D.4.3], for duplex stainless steel forgings
— [D.3.2.21], for MT of ends/bevels
— [D.3.2.22], for DP of ends/bevels
— [D.2.2], for RT of welds
— [D.2.3], for UT of welds in C-Mn/low alloy steel
— [D.2.4], for UT of welds in duplex stainless steel
— [D.2.5], for MT of welds in C-Mn/low alloy steel
— [D.2.6], for DP of welds in duplex stainless steel
— [D.3.3], for overlay welds
— [D.4.4], for visual inspection of forgings
— [D.2.8], for visual inspection of welds, and
— [D.3.5], for residual magnetism.

Acceptance criteria shall be according to the corresponding requirements of App.D.

8.2.8.7 Prior to hydrostatic testing, hydraulic fatigue test and the combined pressure-bending test/electrical leakage tests shall be performed and the results recorded.

8.2.8.8 Hydraulic fatigue testing of each isolation joint shall be performed. The test shall consist of 40 consecutive cycles with the pressure changed from 10 barg to 85 percent of the hydrostatic test pressure. At the completion of the test cycles the pressure shall be increased to the hydrostatic test pressure and maintained for 30 minutes. For acceptance criterion, see [E.4.5.6].

8.2.8.9 One isolation joint per size/design pressure shall also be tested to meet the specified bending moment requirements. The joint shall be pressurised to the specified hydrostatic test pressure and simultaneously be subjected to an external 4 point bending load sufficient to induce a total (bending plus axial pressure effect) longitudinal stress of 90% of SMYS in the adjoining pup pieces. The test duration shall be 2 hours. The acceptance criteria are no water leakage or permanent distortion.

8.2.8.10 After hydrostatic testing, all isolation joints shall be leak tested with air or nitrogen. The joints shall be leak tested at 10 barg for 10 minutes. The tightness shall be checked by immersion or with a frothing agent. The acceptance criterion is: no leakage.

8.2.8.11 The FAT shall be performed according to the accepted FAT programme. The FAT shall consist of:

— dielectric testing
— electrical resistance testing
— electrical leakage tests.

8.2.8.12 Prior to FAT isolation joints shall be stored for 48 hours at an ambient temperature between 20 and 25°C and a relative humidity of max. 93%.

8.2.8.13 Dielectric testing shall be performed by applying an AC sinusoidal current with a frequency of 50 - 60 Hz to the joint. The current shall be applied gradually, starting from an initial value not exceeding 1.2kV increasing to 5.0kV in a time not longer than 10 seconds and shall be maintained at peak value for 60 seconds. The test is acceptable if no breakdown of the isolation or surface arcing occurs during the test.

8.2.8.14 Electrical resistance testing shall be carried out at 1000 V DC. The test is acceptable if the electrical resistance is minimum 25 MOhm.

8.2.8.15 Electrical leakage tests shall be performed to assess any changes which may take place within a joint after hydrostatic testing, hydraulic fatigue test and the combined pressure-bending test. No significant changes in electrical leakage shall be accepted.

8.2.9 Anchor flanges

8.2.9.1 Anchor flanges shall be forged. Requirements to material, manufacture and mechanical testing shall be in accordance with [8.3], [8.4] and [8.5].

8.2.9.2 The extent of NDT shall be:

— 100% magnetic particle testing of ferromagnetic materials and 100% liquid penetrant testing of non magnetic materials
— 100% ultrasonic testing of forgings
— 100% ultrasonic or radiographic testing of welds
— 100% magnetic particle testing/liquid penetrant testing of welds
— 100% visual inspection.

NDT shall be performed in accordance with App.D (as applicable):

— [D.3.4], for visual inspection
— [D.2.2], for C-Mn/low alloy steel forgings
— [D.2.3], for duplex stainless steel forgings
— [D.3.2.21], for MT of ends/bevels
— [D.3.2.22], for DP of ends/bevels
— [D.2.2], for RT of welds
— [D.2.3], for UT of welds in C-Mn/low alloy steel
— [D.2.4], for UT of welds in duplex stainless steel
— [D.2.5], for MT of welds in C-Mn/low alloy steel
— [D.2.6], for DP of welds in duplex stainless steel

— [D.4.4], for visual inspection of forgings
— [D.2.8], for visual inspection of welds, and
— [D.3.5], for residual magnetism.

Acceptance criteria shall be according to the corresponding requirements of App.D.

8.2.10 Buckle- and fracture arrestors

8.2.10.1 The material for buckle and fracture arrestors and manufacture, inspection and testing shall be in accordance with [8.3], [8.4] and [8.5] (if forged/cast), or Sec.7 (if linepipe).

8.2.11 Pig traps

8.2.11.1 Materials shall comply with the requirements of the design standard or recommended practice or with the requirements of this section, including [8.3], [8.4] and [8.5], if more stringent.

8.2.11.2 Testing and acceptance criteria for qualification of welding procedures shall comply with the requirements of the design standard or recommended practice or with the requirements of App.C, if more stringent.

Essential variables for welding procedures and production welding shall comply with the requirements of App.C.

8.2.11.3 The extent, methods and acceptance criteria for NDT shall comply with the requirements of the design standard or recommended practice. In addition the requirements of [D.1] and [D.2.1] shall apply.

8.2.12 Repair clamps and repair couplings

8.2.12.1 Repair clamps and repair couplings to be installed according to DNVGL-RP-F113 shall be manufactured and tested in accordance with this section, including [8.3], [8.4] and [8.5].

8.3 Materials

8.3.1 General

8.3.1.1 The materials used shall comply with internationally recognised standards, provided that such standards have acceptable equivalence to the requirements given in Sec.7 and this section. Modification of the chemical composition given in such standards may be necessary to obtain a sufficient combination of weldability, hardenability, strength, ductility, toughness, and corrosion resistance.

8.3.1.2 Sampling for mechanical and corrosion testing shall be performed after final heat treatment, i.e. in the final condition. The testing shall be performed in accordance with App.B and [8.5.1].

8.3.2 C-Mn and low alloy steel forgings and castings

8.3.2.1 These requirements are applicable to C-Mn and low alloy steel forgings and castings with SMYS ≤ 555 MPa. Use of higher strength materials shall be subject to agreement.

8.3.2.2 All steels shall be made by an electric or one of the basic oxygen processes. C-Mn steel shall be fully killed and made to a fine grain practice.

8.3.2.3 The chemical composition for hot-formed, cast and forged components shall be in accordance with recognised international standards. The chemical composition shall be selected to ensure an acceptable balance between sufficient hardenability and weldability.

8.3.2.4 For materials to be quenched and tempered, a hardenability assessment shall be performed to ensure that the required mechanical properties can be met.

8.3.2.5 For C-Mn steels the maximum carbon equivalent (CE) shall not exceed 0.50, when calculated in accordance with:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15} \tag{8.1}$$

8.3.2.6 Acceptance criteria for tensile, hardness and Charpy V-notch impact properties are given in [8.5.2].

8.3.2.7 Forgings shall be delivered in normalised or quenched and tempered condition.

8.3.2.8 Castings shall be delivered in homogenised, normalised and stress relieved or homogenised, quenched and tempered condition.

8.3.2.9 For C-Mn and low alloy materials delivered in the quenched and tempered condition, the minimum tempering temperature shall be 610°C when PWHT will be applied, unless otherwise specified.

8.3.3 Duplex stainless steel, forgings and castings

8.3.3.1 All requirements with regard to chemical composition for 22Cr and 25Cr duplex stainless steel shall be in accordance with [7.3.4].

8.3.3.2 Acceptance criteria for tensile, hardness, Charpy V-notch impact properties and corrosion tests are given in [8.5.3].

8.3.3.3 Duplex stainless steel castings and forgings shall be delivered in the solution annealed and water quenched condition.

8.3.4 Pipe and plate material

8.3.4.1 Pipe and plate material shall meet the requirements in Sec.7.

8.3.4.2 For welded pipe it shall be assured that the mechanical properties of the material and longitudinal welds will not be affected by any heat treatment performed during manufacture of components.

8.3.4.3 In case PWHT is required, the mechanical testing should be conducted after simulated heat treatment.

8.3.5 Bolting materials

8.3.5.1 In general, bolting material selection shall be in line with the applicable design standards or recommended practices supplemented with [6.2.6] and [6.3.4], with limitations and additional requirements as given in [8.3.5.2] to [8.3.5.10].

8.3.5.2 For components based on ASME design codes, carbon and low alloy steel bolts and nuts for pressure containing and main structural applications shall be selected in accordance with Table 8-3.

For components based on other design standards or recommended practices, equivalent carbon and low alloy steel bolts in line with the design standards or recommended practices shall be selected.

The bolting materials listed in Table 8-3 may be used in combination with other design standards or recommended practices than ASME if properly considered by the designer. This shall include assessment of allowable utilisation and derating for elevated temperature applications, if relevant. Applicable ASME design codes list pre-defined allowable stresses, which are not necessarily based on SMYS and SMTS, while other design standards or recommended practices define utilisation based on safety factors on SMYS and SMTS. This shall be considered when mixing ASTM bolting materials with other standards or recommended practices than ASTM.

Table 8-3 Carbon and low alloy steel bolts and nuts for ASME design code applications

Temperature range (^{o} C)	*Bolt*	*Nut*	*Size range*
-100 to + 400	ASTM A320, Grade L7	ASTM A194, Grade 4/S3/S4/S5 or Grade 7/S3/S4/S5	< 65 mm
-100 to + 400	ASTM A320, Grade L7M	ASTM A194, Grade 7M/S3/S4/S5	< 65 mm
-100 to + 400	ASTM A320, Grade L43	ASTM A194, Grade 7/S3/S4/S5	< 100 mm

8.3.5.3 Carbon and low alloy steel bolting materials shall be Charpy-V impact tested. The bolting materials shall meet the requirements for the bolted connection, i.e. the materials to be bolted. See [8.5.1.5] and [8.5.2.1] for test temperature and acceptance criteria.

8.3.5.4 Stainless steel bolts according to ASTM A193/A320 grade B8M (type AISI 316) are applicable but require efficient cathodic protection for subsea use.

8.3.5.5 Ni-based bolts according to ASTM B446 type UNS N06625 or other Ni-based solution hardening alloys with equivalent or higher PRE are acceptable. However, these bolting materials shall only be used in the solution annealed condition, or cold worked to SMYS 720 MPa maximum.

8.3.5.6 Maximum hardness shall not exceed 35 HRC for carbon and low alloy steels, in addition to solution annealed or cold-worked type AISI 316 or any other cold-worked austenitic stainless steel (only applicable if the bolts will be exposed to cathodic protection).

8.3.5.7 Restrictions for H_2S service (also referred to as sour service) according to ISO 15156 shall apply when applicable.

8.3.5.8 The hardness of bolts and nuts shall be verified for each lot (i.e. bolts of the same size and material, from each heat of steel and heat treatment batch) and be traceable back to heat number.

Guidance note:

In order to ensure acceptable traceability, several Companies require higher frequency for hardness testing than one per lot for verification of subsea fasteners. The party installing the bolts should also consider to perform random testing of bolt properties.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

8.3.5.9 For acid cleaned and/or electrolytically plated bolts and nuts, baking at 200°C for a minimum of 2 hours is required in order to prevent hydrogen embrittlement.

8.3.5.10 Only unused bolting materials shall be applied.

8.3.6 H_2S service

8.3.6.1 For components in pipeline systems to be used for fluids containing hydrogen sulphide and defined as H_2S service according to ISO 15156, all requirements to chemical composition, maximum hardness, and manufacturing and fabrication procedures given in the above standard shall apply.

8.3.6.2 The sulphur content of C-Mn and low alloy steel forgings and castings shall not exceed 0.010%.

8.3.6.3 Pipe and plate material used for fabrication of components shall meet the requirements given in [7.9.1].

8.4 Manufacture

8.4.1 Manufacturing procedure specification

8.4.1.1 The requirements of this subsection are not applicable to induction bends and fittings that shall be manufactured in accordance with [8.2.3] and [8.2.4]

8.4.1.2 Components shall be manufactured in accordance with a documented and approved manufacturing procedure specification (MPS).

8.4.1.3 The manufacturing procedure specification (MPS) shall demonstrate how the fabrication will be performed and verified through the proposed fabrication steps. The MPS shall address all factors which influence the quality and reliability of production. All main fabrication steps from control of received material to shipment of the finished product(s), including all examination and check points, shall be covered in detail. References to the procedures and acceptance criteria established for the execution of all steps shall be included.

8.4.1.4 The MPS should be project specific and specify the following items as applicable:

- Starting materials
  - manufacturer
  - steel making process
  - steel grade
  - product form, delivery condition
  - chemical composition
  - welding procedure specification (WPS)
  - NDT procedures.
- Manufacturing
  - supply of material and subcontracts
  - manufacturing processes including process- and process control procedures

  — welding procedures
  — heat treatment procedures
  — NDT procedures
  — list of specified mechanical and corrosion testing
  — hydrostatic test procedures
  — functional test procedures
  — dimensional control procedures
  — FAT procedures
  — marking, coating and protection procedures
  — handling, loading and shipping procedures
  — at-site installation recommendations.

For one-off components and other components designed and manufactured for a specific purpose, the following additional information shall be provided:

— plan and process flow description/diagram
— order specific quality plan including supply of material and subcontracts
— manufacturing processes including process- and process control procedures.

8.4.2 Forging

8.4.2.1 Forging shall be performed in compliance with the accepted MPS. Each forged product shall be hot worked as far as practicable, to the final size with a minimum reduction ratio of 4:1.

8.4.2.2 The work piece shall be heated in a furnace to the required working temperature.

8.4.2.3 The working temperature shall be monitored during the forging process.

8.4.2.4 If the temperature falls below the working temperature the work piece shall be returned to the furnace and re-heated before resuming forging.

8.4.2.5 The identity and traceability of each work piece shall be maintained during the forging process.

8.4.2.6 Weld repair of forgings is not permitted.

8.4.3 Casting

8.4.3.1 Casting shall be performed in general compliance with ASTM A352.

8.4.3.2 A casting shall be made from a single heat and as a single unit.

8.4.3.3 Castings may be repaired by grinding to a depth of maximum 10% of the actual wall thickness, provided that the wall thickness in no place is below the minimum designed wall thickness. The ground areas shall merge smoothly with the surrounding material.

8.4.3.4 Defects deeper than those allowed by [8.4.3.3] may be repaired by welding. The maximum extent of repair welding should not exceed 20% of the total surface area. Excavations for welding shall be ground smooth and uniform and shall be suitably shaped to allow good access for welding.

8.4.3.5 All repair welding shall be performed by qualified welders and according to qualified welding procedures.

8.4.4 Hot forming

8.4.4.1 Hot forming shall be performed according to an agreed procedure containing:

— sequence of operations
— heating equipment
— material designation
— pipe diameter, wall thickness and bend radius
— heating/cooling rates
— maximum and minimum temperature during forming operation
— temperature maintenance/control
— recording equipment
— position of the longitudinal seam
— methods for avoiding local thinning
— post bending heat treatment (duplex stainless steel: full solution annealing and water quenching)
— hydrostatic testing procedure
— NDT procedures
— dimensional control procedures.

8.4.4.2 Hot forming of C-Mn and low alloy steel, including extrusion of branches, shall be performed below 1100°C. If microalloying elements have been added to prevent grain growth (e.g. Ti), the hot forming temperature may be increased to 1150°C. The temperature shall be monitored. The component shall be allowed to cool in still air.

8.4.4.3 For duplex stainless steel material, the hot forming shall be conducted between 1000 and 1150°C.

8.4.5 Heat treatment

8.4.5.1 Heat treatment procedures for furnace heat treatment shall as a minimum contain the following information:

— heating facilities
— furnace
— insulation (if applicable)
— measuring and recording equipment, both for furnace control and recording of component temperature
— calibration intervals for furnace temperature stability and uniformity and all thermocouples
— fixtures and loading conditions
— heating and cooling rates
— temperature gradients
— soaking temperature range and time
— maximum time required for moving the component from the furnace to the quench tank (if applicable)
— cooling rates (conditions)
— type of quenchant (if applicable)
— start and end maximum temperature of the quenchant (if applicable).

8.4.5.2 If PWHT in an enclosed furnace is not practical, local PWHT shall be performed according to [C.7.4].

8.4.5.3 The heat treatment equipment shall be calibrated at least once a year in order to ensure acceptable temperature stability and uniformity. The uniformity test shall be conducted in accordance with a recognised standard (e.g. ASTM A991). The temperature stability and uniformity throughout the furnace volume shall be within ± 10°C.

8.4.5.4 Whenever practical, thermocouple(s) should be attached to one of the components during the heat treatment cycle.

8.4.5.5 Components should be rough machined to near final dimensions prior to heat treatment. This is particularly important for large thickness components.

Guidance note:

The extent and amount of machining of forgings and castings prior to heat treatment should take into account the requirements for machining to flat or cylindrical shapes for ultrasonic examination. See also App.D.

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8.4.5.6 For components that shall be water quenched, the time from the components leave the furnace until being immersed in the quenchant shall not exceed 90 seconds for low alloy steel, and 60 seconds for duplex stainless steels.

8.4.5.7 The volume of quenchant shall be sufficient and shall be heavily agitated, preferably by cross flow to ensure adequate cooling rate. The maximum temperature of the quenchant shall never exceed 40°C. Temperature measurements of the quenchant shall be performed.

8.4.5.8 The hardness of the accessible surfaces of the component shall be tested. The hardness for C-Mn or low alloy steels and duplex stainless steels shall be in accordance with [8.5.2] and [8.5.3], respectively.

8.4.6 Welding

8.4.6.1 Welding and repair welding shall be performed in accordance with qualified procedures meeting the requirements of App.C.

8.4.7 NDT

8.4.7.1 NDT shall be performed in accordance with App.D.

8.5 Mechanical and corrosion testing

8.5.1 General testing requirements

8.5.1.1 Mechanical testing after hot forming, casting or forging shall be performed on material taken from a prolongation or sacrificial component from each test unit, i.e. components of the same size and material, from each heat and heat treatment batch. Number, orientation and location of test specimens shall be as given in Table 8-4, as far as geometry permits.

8.5.1.2 Sampling for mechanical and corrosion testing shall be conducted after final heat treatment. Testing shall be performed in accordance with App.B.

8.5.1.3 If agreed, separate test coupons may be allowed providing they are heat treated together with the material they represent, and the material thickness, forging reduction, and mass are representative of the actual component.

8.5.1.4 A simulated heat treatment of the test piece shall be performed if welds between the component and other items such as linepipe are to be PWHT at a later stage or if any other heat treatment is intended.

8.5.1.5 The CVN test temperature shall be 10°C below the minimum design temperature.

8.5.1.6 A sketch indicating the final shape of the component and the orientation and location of all specimens for mechanical testing shall be issued for review and acceptance prior to start of production.

8.5.1.7 For 25Cr duplex stainless steels corrosion testing according to ASTM G48 shall be performed in order to confirm that the applied manufacturing procedure ensures acceptable microstructure. Testing shall be performed in accordance with App.B at 50°C. The test period shall be 24 hours.

8.5.2 Acceptance criteria for C-Mn and low alloy steels

8.5.2.1 Tensile, hardness and Charpy V-notch impact properties shall meet the requirements for linepipe with equal SMYS as given in [7.2.4].

8.5.2.2 The hardness for components intended for non- H_2S service shall not exceed 300 HV10. For components intended for H_2S service the hardness shall be according to [7.9.1].

Table 8-4 Number, orientation, and location of test specimens per tested component

Type of test	*No. of tests*	*Test location, e.g. as shown in Figure 8-1* [1, 2)]
Tensile test for components having maximum section thickness T ≤ 50 mm	3	One specimen in tangential direction from the thickest section 1/2T below the internal surface. One specimen in both tangential and axial direction from the area with highest utilisation at 1/2T (after final machining), e.g. the weld neck area. [3)] Test specimens shall have the mid-length at least T or 100 mm, whichever is less from any second surface.
Tensile test for components having maximum section thickness T > 50 mm	3	One specimen in tangential direction from the thickest section 1/4T below the internal surface. One specimen in both tangential and axial direction from the area with highest utilisation at 1/2T (after final machining), e.g. the weld neck area. [3] Test specimens shall have the mid-length at least T or 100 mm, whichever is less from any second surface.
CVN impact testing for components having maximum section thickness T ≤ 50 mm[4, 5)]	3 sets	One set in tangential direction from the thickest section at 1/2T. One specimen in both tangential and axial direction from the area with highest utilisation at 1/2T (after final machining), e.g. the weld neck area.[3] Test specimens shall have the mid-length at least 50 mm from any second surface.
CVN impact testing for components having maximum section thickness T > 50 mm[4, 5)]	3 sets	One specimen in tangential direction from the thickest section 1/4T below the internal surface. One specimen in both tangential and axial direction from the area with highest utilisation at 1/2T (after final machining), e.g. the weld neck area. [3] Test specimens shall have the mid-length at least T or 100 mm, whichever is less from any second surface.

Type of test	*No. of tests*	*Test location, e.g. as shown in Figure 8-1* [1, 2)]
CVN impact testing for components having maximum section thickness [3] 30 mm 4, 5, ,6) [4, 5, 6)]	1 set	One set in the tangential direction 2 mm below the internal surface at the thickest section for hollow forgings. For solid forgings, one set in the tangential direction 2 mm below the surface at the thickest section.
Metallographic sample [7)]	2 or 3	As for the CVN impact testing sets
Hardness testing [8)]	3	As for the CVN impact testing sets
HIC and SSC test [9)]	1	In accordance with ISO 15156
ASTM G48 [10)]	1	See [8.5.1.7]

Notes

1) For welded components, the testing shall also include testing of the welds in accordance with App.C.
2) Internal and external surface refers to the surfaces of the finished component.
3) For Tees and Wyes both main run and branch weld necks shall be tested.
4) For CVN impact testing one set consists of three specimens.
5) The base of the notch shall be perpendicular to the component's surface.
6) Only applicable to C-Mn and low alloy steel. The section thickness is in the radial direction in the as-heat treated condition.
7) 2 samples for section thickness < 30 mm (only one sample from mid thickness location) and 3 samples for section thickness ≥ 30 mm.
8) A minimum of 3 hardness measurements shall be taken on each sample.
9) Only applicable for rolled C-Mn steels not meeting the requirements in [8.3.6].
10) Only applicable for 25Cr duplex steels.

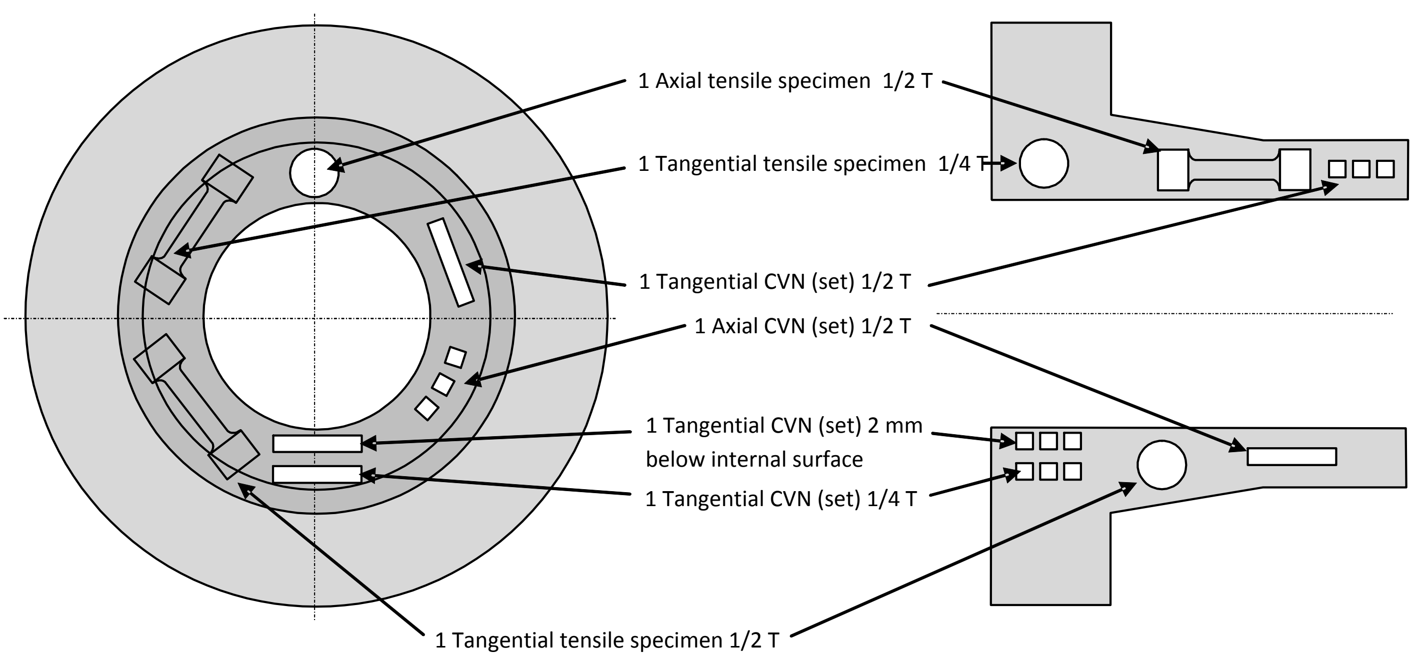

Figure 8-1 Location of tensile and CVN specimens, exemplified on a flange with maximum section thickness ≥ 50 mm

8.5.2.3 Specimens for hardness testing shall be examined, prior to testing, at a magnification of not less than X100. Grain-size measurement shall be performed in accordance with ASTM E112. The type of microstructure and actual grain size shall be recorded on the materials testing report.

8.5.3 Acceptance criteria for duplex stainless steels

8.5.3.1 Tensile, hardness and Charpy V-notch impact properties shall meet the requirements for linepipe as given in [7.3.4].

8.5.3.2 The metallographic samples shall comply with the requirements of [7.3.4].

8.5.3.3 For ASTM G48 testing the acceptance criteria is: maximum allowable weight loss 4.0 g/m^2.

8.6 Pipeline assemblies

8.6.1 General

8.6.1.1 This subsection is applicable for the fabrication of pipe strings (stalks) for reeling and towing, rigid risers, spools and expansion loops.

8.6.1.2 The fabrication shall be performed according to a specification giving the requirements for fabrication methods, procedures, extent of testing, acceptance criteria and required documentation. The specification shall be subject to agreement prior to start of production.

8.6.2 Materials

8.6.2.1 Linepipe shall comply with the requirements, including supplementary requirements (as applicable) given in Sec.7.

8.6.2.2 Induction bends shall comply with the requirements in this section, see [8.2.3].

8.6.2.3 Forged and cast material shall as a minimum meet the requirements given in this section.

8.6.3 Fabrication procedures, planning and mobilisation

8.6.3.1 The construction site shall establish the following:

— organisation and communication
— health, safety and environment manual
— emergency preparedness
— security plan including ISPS.

8.6.3.2 The construction site shall establish the following:

— material handling and storage (see [8.6.4])
— material receipt, identification and tracking (see [8.6.5])
— maintenance system.

8.6.3.3 All personnel shall be familiarized with the operation to be performed at the fabrication site. More detailed familiarization shall be performed for personnel specific work tasks.

8.6.3.4 Personnel involved in critical operations shall participate in a risk assessment for the specific operation.

8.6.3.5 Equipment needed for the operations at the fabrication site shall be defined and mobilised.

8.6.3.6 Before production commences, the fabricator shall prepare a manufacture procedure specification (MPS). The MPS shall be issued for review and acceptance prior to start of fabrication.

8.6.3.7 The MPS shall demonstrate how the fabrication will be performed and verified through the proposed fabrication steps. The MPS shall address all factors which influence the quality and reliability of production. All main fabrication steps from control of received material to shipment of the finished product(s), including all examination and check points, shall be covered in detail. References to the procedures and acceptance criteria established for the execution of all steps shall be included.

Guidance note:

The MPS will as a minimum typically contain the following information:

— fabrication plan(s) and process flow description/diagram
— supply of material, i.e. manufacturer and manufacturing location of material
— fabrication process procedures
— dimensional and weight control procedures
— welding procedures including repair
— heat treatment procedures
— NDT procedures
— coating procedures including repair and field joint coating
— marking and protection procedures and
— reeling procedures
— stalk drawings
— handling, lifting, loading and shipping procedures
— cleaning and gauging of pipes
— pressure test procedures, if applicable.

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8.6.3.8 Due consideration shall be given to the access and time required for adequate inspection and testing as fabrication proceeds.

8.6.3.9 Due consideration during fabrication shall be given to the control of weight and buoyancy distribution of pipe strings for towing.

8.6.4 Linepipe temporary storage and transportation

8.6.4.1 Temporary storage of pipes, both single joints or several joints, shall consider potential corrosion damage. Corrosion damage may affect quality of NDT and pipeline integrity.

8.6.4.2 It shall be documented that storage facilities have the sufficient foundation for the weight of the pipes. Each pipe joint and pipe stack shall withstand relevant weight and environmental loading (e.g. wind, waves, earth quakes). Drainage of water shall be ensured. Potential icing shall be considered and appropriate counter-active measures taken where found necessary.

8.6.4.3 Transportation and lifting of pipe joints shall be conducted safely to avoid damage to personnel, equipment and pipe joints. The equipment used for transportation and lifting shall not impose damage to the pipe joints.

8.6.4.4 Acceptable stacking heights shall be established and documented for temporary storage and transportation.

8.6.5 Material receipt, identification and tracking

8.6.5.1 All material shall be inspected for damage upon arrival. Quantities and identification of the material shall be verified. Damaged items shall be clearly marked, segregated and disposed of properly.

8.6.5.2 A system for ensuring correct traceability to the material shall be established. The identification of material shall be preserved during handling, storage and for all fabrication activities.

8.6.5.3 A pipe tracking system shall be used to maintain records of weld numbers, NDT records, pipe numbers, pipe lengths, bends, cumulative length, weight, anode installation, in-line assemblies and repair numbers. The system shall be capable of detecting duplicate records.

8.6.5.4 Pipes shall be inspected for loose material, debris, and other contamination, and shall be cleaned both internally and at the pipe ends before being added to the assembly. The cleaning method shall not cause damage to any internal coating.

8.6.5.5 The pipeline ends shall be protected against ingress of dust, water or any other material after cleaning and prior to being added to the assembly.

8.6.5.6 All debris caused by the welding shall be removed from the inside of the pipeline.

8.6.5.7 The individual pipes of pipe strings shall be marked in accordance with the established pipe tracking system using a suitable marine paint. The location, size and colour of the marking shall be suitable for reading by ROV during installation. In case installation of in-line assemblies or piggy back cables, it may be required to mark a band on top of the pipe string to verify if any rotation has occurred.

8.6.6 Hydrostatic testing

8.6.6.1 Detecting leakage early is beneficial and the current industry practice of hydrostatic testing of pipeline assemblies prior to installation in Table 8-5 may be applied. If the pipeline assembly not is part of the system pressure test, hydrostatic test shall be performed.

Table 8-5 Hydrostatic pressure test of pipeline assemblies[1)]

Pipeline assemblies	*Pressure[2]*	*Holding time*
Risers	$\sigma_{e=0.96\ SMYS}$	See Table 8-6
Spools		
Stalks		
PLEM/PLET's and other end terminations		

1) These hydrostatic tests may be performed prior to installation as a risk reduction measure, to reduce the probability of installing assemblies with leaks, which are discovered during the system test. The tests shall be performed if an assembly is not part of the system pressure test.
2) The differential pressure shall be minimum equal to the system test pressure. The stated pressure will always be higher than this and may be applied for simplicity.

8.6.7 Welding and non-destructive testing

8.6.7.1 Requirements for welding processes, welding procedure qualification, execution of welding and welding personnel are given in App.C.

8.6.7.2 Requirements for mechanical and corrosion testing for qualification of welding procedures are given in App.B.

8.6.7.3 Requirements for methods, equipment, procedures, acceptance criteria and the qualification and certification of personnel for visual examination and non-destructive testing (NDT) are given in App.D. Selection of non-destructive methods shall consider the requirements in [D.1.4].

8.6.7.4 Requirements to automated ultrasonic testing (AUT) are given in App.E.

8.6.7.5 Members to be welded shall be brought into correct alignment and held in position by clamps, other suitable devices, or tack welds, until welding has progressed to a stage where the holding devices or tack welds can be removed without danger of distortion, shrinkage or cracking. Suitable allowances shall be made for distortion and shrinkage where appropriate.

8.6.7.6 The fabrication and welding sequence shall be such that the amount of shrinkage, distortion and residual stress is minimised.

8.6.7.7 For production testing, see [C.7.5.25] to [C.7.5.31].

8.6.7.8 The extent of NDT for installation girth welds shall be 100% ultrasonic or radiographic testing. Radiographic testing should be supplemented with ultrasonic testing in order to enhance the probability of detection and/or characterisation/sizing of defects.

8.6.7.9 All welds shall be subject to 100% visual inspection.

8.6.7.10 For wall thickness > 25 mm, automated ultrasonic testing should be used.

8.6.7.11 Ultrasonic testing (UT) or automated ultrasonic testing (AUT) shall be used in the following cases:

— whenever sizing of flaw height and/or determination of the flaw depth is required (see Table 5-10).
— 100% lamination checks of a 50 mm wide band at ends of cut pipe.

Exception to this requirement may be given for wall thickness < 8 mm provided that it can be technically justified that alternative NDT processes provide sufficient inspection performance for the expected imperfections for the applied welding procedure, see [D.2.10.11].

8.6.7.12 When radiographic testing is the primary NDT method UT or AUT shall be used in the following cases:

— For the first 10 welds for welding processes with high potential for non-fusion type defects, when starting installation or when resuming production after suspension of welding
— to supplement radiographic testing for unfavourable groove configurations
— for wall thickness above 25 mm:
    — to provide additional random local spot checks during installation
    — to supplement radiographic testing to aid in characterising and sizing of ambiguous indications.

8.6.7.13 If UT reveals defects not discovered by radiography, the extent of UT shall be 100% for the next 10 welds. If the results of this extended testing are unsatisfactory, the welding shall be suspended until the causes of the defects have been established and rectified.

8.6.7.14 For welds where allowable defect sizes are based on an ECA, UT shall supplement radiographic testing, unless AUT is performed.

8.6.7.15 All NDT shall be performed after completion of all cold forming and heat treatment.

8.6.8 Cutting, forming and heat treatment

8.6.8.1 Attention shall be paid to local effects on material properties and any activities causing carbon contamination where this is relevant. Preheating of the area to be cut may be required. Carbon contamination shall be removed by grinding off the affected material.

Forming of material shall be according to agreed procedures.

8.6.9 Verification of dimensions and weight

8.6.9.1 Verification of dimensions should be performed in order to establish conformance with the required dimensions and tolerances.

8.6.9.2 Verification of dimensions verification of pipe strings for towing and spools shall include weight, and the distribution of weight and buoyancy.

8.6.10 Corrosion protection and thermal insulation

8.6.10.1 Application of coatings and installation of anodes shall meet the requirements of Sec.9.

8.6.10.2 Acceptable temperature ranges for spooling operations shall be defined.

Guidance note:

Undesired events such as cracking of field joints may occur for low temperatures.

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8.7 Hydrostatic testing

8.7.1 Preparations

8.7.1.1 Prior to performing hydrostatic testing the test object shall be cleaned and gauged.

8.7.1.2 The extent of the section to be tested shall be shown on drawings or sketches. The limits of the test, temporary blind flanges, end closures and the location and elevation of test instruments and equipment shall be shown. The elevation of the test instruments shall serve as a reference for the test pressure.

8.7.1.3 End closures and other temporary testing equipment shall be designed, fabricated, and tested to withstand the maximum test pressure, and in accordance with a recognised standards or recommended practices.

8.7.1.4 Testing should not be performed against in-line valves, unless possible leakage and damage to the valve is considered, and the valve is designed and tested for the pressure test condition. Blocking off or removal of small-bore branches and instrument tappings should be considered in order to avoid possible contamination.

Considerations shall be given to pre-filling valve body cavities with an inert liquid unless the valves have provisions for pressure equalisation across the valve seats.

8.7.1.5 Welds shall not be coated, painted or covered, if the purpose of the test is 100% visual inspection. However, thin primer coatings may be used where agreed.

8.7.1.6 Welds may be coated or painted if the acceptance criterion is based on pressure observations.

8.7.2 Instrumentation

8.7.2.1 Instruments and test equipment used for measurement of pressure, volume, and temperature shall be calibrated for accuracy, repeatability, and sensitivity. All instruments and test equipment shall possess valid calibration certificates with traceability to reference standards within the 6 months preceding the test. If the instruments and test equipment have been in frequent use, they should be calibrated specifically for the test.

8.7.2.2 Gauges and recorders shall be checked for correct function immediately before each test. All test equipment shall be located in a safe position outside the test boundary area.

8.7.2.3 The following requirements apply for instruments and test equipment:

- testers shall have a range of minimum 1.25 times the specified test pressure, with an accuracy better than ± 0.1 bar and a sensitivity better than 0.05 bar.
- temperature-measuring instruments and recorders shall have an accuracy better than ± 1.0°C
- pressure and temperature recorders shall be used to provide a graphical record of the pressure test for the total duration of the test.

8.7.3 Test medium and filling

8.7.3.1 The test medium should be fresh water or adequately treated sea water, as applicable.

Filling procedure shall ensure minimum air pockets.

8.7.4 Testing

8.7.4.1 Pressurisation shall be performed as a controlled operation with consideration for maximum allowable velocities in the inlet piping up to 95% of the test pressure. The final 5% up to the test pressure shall be raised at a reduced rate to ensure that the test pressure is not exceeded. Time shall be allowed for confirmation of temperature and pressure stabilisation before the test hold period begins.

8.7.4.2 The test pressure shall be according to the applied standards or recommended practices.

8.7.4.3 Leakage may be detected by visual observations or by pressure variations. When the test acceptance is based on observation of pressure variations, calculations showing the effect of temperature changes on the test pressure shall be developed prior to starting the test. Temperature measuring devices, if used, shall be positioned close to the test object and the distance between the devices shall be based on temperature gradients along the test object.

8.7.4.4 Hydrostatic pressure test hold times is given in Table 8-6

Table 8-6 Hydrostatic pressure test holding times (from DNVGL-RP-F113)

Item	*Volume*	*Hold time*[1)]	
		Visual detection[2)]	*Pressure monitoring*
Pipelines	>1000 m^3	NA	≥24 hrs
Short pipelines	100-1000 m^3	NA	8 hrs
Local repair sec.	10-100 m^3	2 hrs	8 hrs
Pipeline Assemblies	1-10 m^3	15 min	8 hrs
Pipeline Components	0.1-1 m^3	15 min	8 hrs
Back-seal tests	0.01-0.1 m^3	15 min	15 min

1) For unsupported seals supported by friction towards pipe wall and fitting surface (e.g. inflated- and tongue seal, without any grove or equivalent) additional holding time to document acceptable resistance against slippage needs to be assessed.
2) The holding time at test pressure shall be until 100% visual inspection is complete or the specified hold time, whichever is longer.

8.7.4.5 The pressure test is acceptable for:

— 100% visual inspection when there are no observed leaks (e.g. at welds, flanges, mechanical connectors) and the pressure has at no time during the hold period fallen below 99% of the test pressure. 100% visual inspection shall only be acceptable where there is no risk that a leak may go undetected due to prevailing environmental conditions
— 100% pressure observation when the pressure profile over the test hold period shows a clear convergence to a fixed value above 99% of the specified test pressure. This may required an extension of the holding time.

8.7.5 Alternative test pressures

8.7.5.1 For components fitted with pup pieces of material identical to the adjoining pipeline, the test pressure can be reduced to a pressure that produce an equivalent stress of 96% of SMYS in the pup piece.

8.7.5.2 If the alternative test pressure in [8.7.5.1] cannot be used and the strength of the pup piece is not sufficient:

— Testing shall be performed prior to welding of pup pieces. The weld between component and pup piece is regarded a pipeline weld and will be tested during pipeline system testing.

8.8 Documentation, records, certification and marking

8.8.1 General

8.8.1.1 All base material, fittings and, flanges, etc. shall be delivered with inspection certificate 3.1 according to European Standard EN 10204 or accepted equivalent.

The inspection certificate shall include:

- identification the products covered by the certificate with reference to heat number, heat treatment batch etc.
- dimensions and weights of products
- the results (or reference to the results) of all specified inspections and tests
- the supply condition and the temperature of the final heat treatment.

8.8.1.2 Records from the qualification of the MPS and other documentation shall be in accordance with Sec.12.

8.8.1.3 Each equipment or component item shall be adequately and uniquely marked for identification. The marking shall, as a minimum, provide correlation of the product with the related inspection documentation.

8.8.1.4 The marking shall be such that it easily will be identified, and retained during the subsequent activities.

8.8.1.5 Other markings required for identification may be required.

8.8.1.6 Equipment and components shall be adequately protected from harmful deterioration from the time of manufacture until taken into use.

SECTION 9 CONSTRUCTION - CORROSION PROTECTION AND WEIGHT COATING

9.1 General

9.1.1 Objective

9.1.1.1 This section gives requirements and recommendations on:

— application (manufacture) of external pipeline coatings including field joint coatings and infill
— application (manufacture) of concrete weight coatings
— manufacture of galvanic anodes
— installation of galvanic anodes.

9.1.1.2 The objectives are to ensure that the external corrosion control system and any weight coating are designed and fabricated to ensure proper function for the design life of the systems. As to the last item above, it is a further objective to ensure that the fastening does not impose any damage or hazards affecting the integrity of the pipeline system.

9.1.2 Application

9.1.2.1 This section is applicable to the preparation of specifications for manufacture/installation of external corrosion control systems and for the manufacture of concrete weight coating during the construction phase. Such specifications shall define the requirements to properties of the coatings and anodes, and to the associated quality control.

9.1.2.2 Manufacture/installation of any impressed current CP systems for landfalls is not covered by this standard. The requirements in ISO 15589-1 shall then apply.

9.1.3 Systematic review

9.1.3.1 An overall requirement to systematic review in Sec.2 shall for this section imply:

— The selection of coating system and its detailed design shall take into considerations e.g. the pipe laying method, pipe loading conditions and pipeline operating conditions in service.
— The selection of coating system and its detailed design shall take into consideration compatibility between linepipe coating system, field joint coating system, infill and concrete coating (when applicable).
— In the coating purchase specification, as-applied coating properties shall be defined and requirements to methods, frequency and acceptance criteria for their verification shall be specified.
— Prior to start of coating application, essential application process parameters shall be defined by the coating applicator. The essential process parameters shall be project specific and should be verified in a procedure qualification trial (PQT, see [9.2.2.2] and [9.3.4.2] below) to ensure that specified coating properties can be fulfilled. Quality control during production shall verify that the essential process parameters are maintained during production.

Guidance note:

Examples of how inadequate coating properties may result in failures are:

- Poor adhesion between steel surface and corrosion protective coating may result in partly or completely detachment of coating during storage or operation.
- Insufficient bonding to steel substrate/between coating layers, in combination with low ductility of as-applied coating may cause cracking of linepipe and/or field joints/infill during reeling of pipelines.
- Insufficient shear resistance capacity between corrosion coating and concrete coating may result in a safety risk during installation due to sudden sliding of the concrete coating relative to steel pipe, and/or damage to field joints and anodes during operation due to thermal axial expansion of the steel pipe relative to the concrete coating.

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9.2 External corrosion protective coatings

9.2.1 General

9.2.1.1 Properties of the coating (as-applied) and requirements to quality control during application shall be defined in a purchase specification (see [6.3.5]).

9.2.1.2 For application of 3-layer polyolefin coatings (3-layer polyethylene/polypropylene), single layer fusion-bonded epoxy coatings and field joint coatings, requirements in ISO 21809 (part 1-3) shall apply with the additional requirements as specified below.

9.2.1.3 Recommended practice for application of line pipe coatings and field joint coating are given in DNVGL-RP-F106 Sec.9 and DNVGL-RP-F102, respectively.

Guidance note:

DNVGL-RP-F106 Sec.9 and DNVGL-RP-F102 have emphasis on quality control procedures and documentation. They comply with and refer to ISO 21809 with some additional requirements for relevant coating systems (including some additional systems to those defined in ISO 21809). DNVGL-RP-F102 also covers field repairs of line pipe coating and infill, see [6.4.4]. These documents are applicable to the preparation of coating specifications and can also be used as a purchase document if amended to include project and any operator specific requirements.

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9.2.1.4 The design and quality control during application of field joint coatings is essential to the integrity of pipelines in HISC susceptible materials, including ferritic-austenitic (duplex) and martensitic stainless steel. Recommended practice for design and quality control during application of field joint coatings is given in DNVGL-RP-F102.

9.2.2 Coating materials, surface preparation, coating application and inspection/testing of coating

9.2.2.1 All coating work shall be carried out according to a project specific application procedure specification (APS, also referred to as manufacturing procedure specification, MPS). The following items shall be described in the procedure specification:

- receipt, handling and storage of coating materials
- surface preparation and inspection
- coating application and monitoring of essential process parameters
- inspection and testing of coating
- coating repairs and stripping of defect coating
- preparation of cut-backs (for linepipe coating)
- marking, traceability and handling of non-conformities

— handling and storage of coated pipes (for linepipe coating)
— documentation.

Material data sheets for coating, blasting and any other surface preparation materials may either be included in the APS or in a separate document. The purchaser may specify that the above documentation shall be submitted for approval prior to the start of production and any PQT (see [9.2.2.2]).

9.2.2.2 A coating procedure qualification trial (PQT; also referred to as an application procedure qualification test or pre-production qualification test) should be executed and accepted by purchaser before starting the coating work, especially for coating systems which rely on a curing process to achieve the specified properties. For field joint coating (FJC) and infill, a pre-production trial (PPT) should also be performed. The purpose of the qualification is to confirm, prior to the start of regular production, that the coating application procedure specification (APS), coating materials, tools/equipment and personnel to be used for production are adequate to achieve the specified properties of the coating.

9.2.2.3 An inspection and testing plan (ITP; sometimes referred to as an inspection plan or quality plan) shall be prepared and submitted to purchaser for acceptance. The ITP shall refer to the individual application and inspection/testing activities in consecutive order, define methods/standards, frequency of inspection/testing, checking/calibrations, and acceptance criteria. Reference shall further be made to applicable reporting documents and procedures for inspection, testing and calibrations.

9.2.2.4 Inspection and testing data, essential process parameters, repairs and checking/calibrations of equipment for quality control shall be recorded in a daily log that shall be updated on a daily basis and be available to purchaser on request at any time during coating production.

9.2.2.5 The daily log format and final documentation index should be prepared for acceptance by purchaser prior to start of production.

9.3 Concrete weight coating

9.3.1 General

9.3.1.1 The objectives of a concrete weight coating are to provide negative buoyancy to the pipeline, and to provide mechanical protection of the corrosion coating and linepipe during installation and throughout the pipeline's operational life.

9.3.1.2 The concrete weight coating (thickness, strength, density, amount of reinforcement) shall be designed for the specific project; i.e. the actual installation, laying and operation conditions for the pipeline shall then be taken into consideration.

9.3.1.3 For materials and application of concrete weight coating requirements in ISO 21809-5 shall apply with the additional requirements (AR) or modified requirements (MR) as specified below.

9.3.2 Materials

9.3.2.1 Cement shall be moderate sulphate resistant Portland cement equivalent to type II according to ASTM C150. MR

9.3.2.2 The tricalcium aluminate (C3A) content of the cement shall not exceed 8%. MR

9.3.2.3 The percentage of the recycled concrete used as aggregate shall not exceed 7% by weight. MR

9.3.2.4 The reclaimed concrete content in the concrete mix should not exceed 10% by weight. Use of higher amounts shall be verified by testing confirming that the required concrete coating properties can be achieved. AR

9.3.3 Concrete mix

9.3.3.1 The content of chloride in the concrete mix, calculated as free $CaCl_2$ shall not exceed 0.4% of the weight of the cement. AR

9.3.4 Coating application

9.3.4.1 All coating work shall be carried out according to an application procedure specification (APS), AR. The following items shall be described in the APS:

— raw materials, including receipt, handling and storage
— concrete mix design
— reinforcement percentage and placement
— coating application and curing
— inspection and testing, including calibrations of equipment
— coating repairs
— pipe tracking, marking and coating documentation
— handling and storage of coated pipes.

Purchaser may specify that the APS shall be subject to approval prior to start of production and any PQT. AR

9.3.4.2 A coating procedure qualification trial (PQT; in ISO 21809-5 referred to as qualification test) shall be executed and accepted by purchaser before starting the coating work.

9.3.4.3 Changes in type of linepipe coating and/or applicator and/or changes in concrete constituent materials and/or concrete mix shall require a new PQT. AR

9.3.4.4 Repair methods shall be included in the PQT. AR

9.3.4.5 The following inspections and tests shall also be carried out during PQT. AR:

— Testing aggregates according to ASTM C33 or equivalent
— Determining water content in the concrete mix
— Determining cement content in the concrete mix and water/cement ratio
— Inspection of linepipe coating (holiday detection)
— Calibration/verification of all measuring and weighting equipment

Guidance note:
Purchaser may consider performing a full scale water absorption test, shear resistance test and/or impact resistance test as an integral part of PQT. Also, purchaser may consider a requirement on production of several pipes to demonstrate the applicator capability of continuous production of conforming pipes.

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9.3.4.6 The following modification of acceptance criteria for inspections and tests during PQT shall apply. MR:

— The thickness of the concrete coating shall not be less than 40 mm.
— The minimum in-situ compressive strength of the concrete coating shall not be less than 40 MPa. The mean strength shall be calculated from compressive test results of three drilled cores obtained from one pipe, with no single test results less than 34 MPa.

9.3.4.7 The concrete coating shall be reinforced by steel bars welded to cages or by wire mesh steel. The minimum percentage of the steel reinforcement shall be 0.5% circumferentially and 0.08% longitudinally of the cross-sectional area of the concrete coating. MR

9.3.4.8 The minimum diameter of circumferential cage reinforcement shall be 5 mm. MR

9.3.4.9 The maximum spacing between circumferential and longitudinal cage reinforcement shall be 125 mm and 250 mm, respectively. AR

9.3.4.10 The minimum diameter of wire mesh reinforcement shall be 2 mm. MR

9.3.4.11 The minimum overlap of wire mesh reinforcement shall be 1.5 x distance between the wires or 25 mm (whichever is greater). AR

9.3.4.12 Minimum concrete cover to the reinforcement shall be 15 mm for concrete thickness less or equal to 50 mm and minimum 20 mm for concrete thickness greater than 50 mm. MR

9.3.4.13 The thickness of the concrete coating shall not be less than 40 mm. MR

9.3.5 Inspection and testing

9.3.5.1 An inspection and testing plan (ITP) shall be prepared and submitted to purchaser for acceptance in due time prior to start of production. The ITP shall define the methods and frequency of inspection, testing and calibrations, acceptance criteria and requirements to documentation. Reference shall further be made to applicable reporting documents and procedures for inspection, testing and calibration. AR

9.3.5.2 Other standards for testing than those specified in this standard may be used, provided that it is documented during PQT that the quality of materials and applied concrete weight coating will not be lower than when testing according to the standards specified in this rule. AR

9.3.5.3 The dimensions of cube and cylinder specimens (cast from fresh concrete) for testing the concrete compressive strength shall be 100 mm × 100 mm × 100 mm cubes or 100 mm × 100 mm cylinders. AR

9.3.5.4 For hardened concrete drill cores specimens, the diameter of the cylinder shall not be less than 38 mm and the preparation shall be according to ASTM C31 or EN 12390-2. AR

9.3.5.5 The following inspections and tests shall also be carried out during production. AR:

— inspection of linepipe coating (holiday detection) before concrete coating application
— calibration of all measuring and weighing equipment
— content of recycled and reclaimed materials in the concrete mix
— sounding test.

Guidance note:
Purchaser may consider performing a full scale water absorption test as part of production testing.

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9.3.5.6 The following modification of acceptance criteria for inspections/tests during production shall apply. MR:

— Concrete coating thickness: minimum 6 measurements on each pipe.

9.3.5.7 Inspection and testing data, repairs, essential process parameters and calibrations of equipment for quality control shall be recorded in a daily log that shall be updated on a daily basis and be available to the purchaser on request at any time during coating production. AR

9.3.5.8 The daily log format and final documentation index should be prepared for acceptance by purchaser prior to start of production.

9.4 Manufacture of galvanic anodes

9.4.1 Anode manufacture

9.4.1.1 Requirements to anode manufacture shall be detailed in a purchase specification (anode manufacturing specification). A manufacturing specification for pipeline bracelet anodes shall cover all requirements in ISO 15589-2.

Recommended practice for anode manufacture with some additional requirements and guidance to ISO, primarily for quality control, is given in DNVGL-RP-F103.

9.4.1.2 The manufacturer of bracelet anodes shall prepare a manufacturing procedure specification (MPS) describing anode alloy (e.g. limits for alloying and impurity elements) and anode core materials, anode core preparations, anode casting, inspection and testing, coating of bracelet anode surfaces facing the pipe surface, marking and handling of anodes, and documentation.

9.4.1.3 An inspection and testing plan (ITP) for manufacture of bracelet anodes, shall be prepared and submitted to the purchaser for acceptance. It is further recommended that the inspection and testing results are compiled in a daily log

See DNVGL-RP-F103 for requirements and guidance for preparation of these documents and to a procedure qualification trial (PQT). For manufacture of other types of anodes than pipeline bracelet anodes, see DNVGL-RP-B401.

Guidance note:

The requirement for an ITP is an amendment to ISO 15589-2.

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9.4.1.4 For each anode type/size, the manufacturer shall prepare a detailed drawing showing location and dimensions of anode inserts, anode gross weight and other details as specified in a purchase document

9.4.1.5 The anode manufacturer shall prepare a detailed procedure for electrochemical testing in compliance with the agreed standard. An outline procedure for electrochemical testing of anode material performance during anode manufacture is given in DNVGL-RP-B401 App.B and in Annex D of ISO 15589-2.

9.4.1.6 Marking of anodes shall ensure traceability to heat number. Anodes should be delivered according to ISO 10474, inspection certificate 3.1.B or EN 10204, inspection certificate 3.1.

9.5 Installation of galvanic anodes

9.5.1 Anode installation

9.5.1.1 Installation of anodes shall meet the requirements in ISO 15589-2. Recommended practise for installation of anodes with some additional requirements and guidelines, primarily for quality control, are given in DNVGL-RP-F103.

9.5.1.2 For martensitic and ferritic-austenitic (duplex) stainless steels and for other steels with SMYS > 450 MPa, no welding for anode fastening (including installation of doubling plates) should be carried out on linepipe or other pressure containing components.

Guidance note:

The requirement above is an amendment to ISO 15589-2. Most CP related HISC damage to pipeline components in CRA's have occurred at welded connections of galvanic anodes to the pipe walls. To secure adequate fastening of pipeline bracelet anodes for compatibility with the applicable installation techniques, forced clamping of anodes is applicable in combination with electrical cables attached to anodes and pipeline by brazing. However, for many applications, CP can be provided by anodes attached to other structures electrically connected to the pipeline (see [6.4.5]). For installation of anodes on such structures, see DNVGL-RP-B401.

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9.5.1.3 All welding or brazing of anode fastening devices and connector cables shall be carried out according to a qualified procedure (see App.C of this standard) to demonstrate that the requirements in ISO 13847 to maximum hardness (welding/brazing) and copper penetration (brazing including aluminothermic welding) are met.

9.5.1.4 For linepipe to be concrete weight coated, electrical contact between concrete reinforcement and the anodes shall be prevented. The gaps between the anode half shells may be filled with asphalt mastic, polyurethane or similar. Any spillage of filling compound on the external anode surfaces shall be removed.

SECTION 10 CONSTRUCTION – OFFSHORE

10.1 General

10.1.1 Objective

10.1.1.1 This section provides requirements as to studies, analyses and documentation shall be prepared and agreed for the offshore construction, and further to provide requirements for the installation and testing of the complete submarine pipeline system. For associated marine operations reference is also made to DNVGL-ST-N001.

10.1.2 Application

10.1.2.1 This section is applicable to offshore construction of submarine pipeline systems designed and constructed according to this standard.

10.1.3 Systematic review

10.1.3.1 The overall requirement to systematic review in Sec.2 shall be reflected in the offshore construction of the pipeline.

10.1.3.2 Systematic analyses of equipment and offshore construction shall be performed in order to identify possible critical items or activities which could cause or aggravate a hazardous condition, and to ensure that effective remedial measures are taken.

10.1.3.3 The extent of systematic review shall depend on criticality of operations and experience from previous similar operations.

10.1.3.4 The systematic analyses should be carried out as a failure mode effect analysis (FMEA) for equipment and hazard and operability studies (HAZOP) for critical operations. Recommended practice for FMEA and HAZOP is given in DNVGL-RP-N101. For HAZOP, see also API RP 17N.

Guidance note:

Typical items to be covered for HAZOP include:

— simultaneous operations
— lifting operations including pipe joints transportation and storage
— dry and wet buckles including flooding of pipe
— initiation and lay down including shore pull
— operations inside safety zones
— critical operations (laying in short radii curves, areas with steep slopes etc.)
— failure of equipment and measuring and monitoring devices
— tie-in operation
— pre-commissioning activities
— environmental conditions and weather criteria
— emergency abandonment
— loss of station keeping capabilities
— survey.

It is desired to mitigate potential hazards by engineering measures.

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10.1.3.5 The results of the FMEA analysis or HAZOP studies shall also be used in determining the extent and depth of verification of equipment and procedures.

10.1.4 Installation manual

10.1.4.1 An installation manual shall be prepared by the contractor, see [10.12].

10.1.5 Quality assurance

10.1.5.1

The contractor shall as a minimum have an implemented quality assurance system as outlined in [2.2.5].For installation contractors a quality assurance system according to ISO 9001 is considered to meet requirements in [2.2.5].

10.1.5.2

The installation contractor shall demonstrate compliance with QA/QC system.

10.1.5.3

The Contractor shall use competent personnel at all stages of the project. Permanent technical, managerial and planning personnel shall have adequate education, training and experience commensurate with their duties and level of supervision under which the work is performed. These requirements shall be part of the contractor's quality management system.

10.1.5.4

All engineering analysis and calculations required to support installation procedures shall be performed by technical staff with the appropriate educational qualifications and experience. Such work shall be discipline checked and approved by responsible engineers in the contractor's organization or external consultants.

10.1.5.5

For offshore personnel, contractor shall have a competence assurance program similar to the IMCA Competence Assurance and Assessment framework or equivalent, for all personnel involved in marine, diving, offshore survey, remote operations and ROV work.

10.1.5.6

A master language for communications shall be defined. Platforms for where master language shall be used shall be defined.

Guidance note:

The purpose of defining a master language is to avoid miscommunications and to ensure that all parties may receive and understand communications. The master language is normally defined by the operator. For platforms where master language is not required, other languages may be used as appropriate.

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10.1.5.7

Key personnel shall have sufficient verbal communication skills in the common language used during operations.

10.2 Pipe assemblies onshore

10.2.1 Pipe assemblies onshore

10.2.1.1 For pipe assemblies onshore, see [8.6].

10.2.1.2 For linepipe temporary storage and transportation, see [8.6.4].

10.3 Pipeline route, pre-installation survey and preparation

10.3.1 Pre-installation route survey

10.3.1.1 A pre-installation survey of the pipeline route should be performed in addition to the route survey required for design purposes covered by [3.3.6] if:

— the time elapsed since the previous survey is significant
— a change in seabed conditions is likely to have occurred
— the route is in areas with heavy marine activity
— new installations or facilities are present in the area
— seabed preparation work is performed within the route corridor after previous survey.

10.3.1.2 The pre-installation survey should determine:

— potential new/previously not identified hazards to the pipeline and the installation operations
— location of wrecks, submarine installations and other obstructions such as mines, debris, rocks and boulders that might interfere with, or impose restrictions on, the installation operations
— that the present seabed conditions confirm those of the survey required in Sec.3
— any other potential hazards due to the nature of the succeeding operations.

10.3.1.3 The extent of, and the requirements for, the pre-installation route survey shall be specified.

10.3.2 Seabed preparation including shore approaches

10.3.2.1 Seabed preparation may be required to:

— remove obstacles and potential hazards interfering with the installation operations
— prevent loads or load effects that occur as a result of seabed conditions or shore area such as unstable slopes, sand waves, deep valleys and possible erosion and scour from exceeding the design criteria
— prepare for pipeline and cable crossings
— infill depressions and remove high-spots to prevent unacceptable free spans
— carry out any other preparation due to the nature of the succeeding operations
— avoid damage to coating and anodes and other attachments to the pipeline.

10.3.2.2 The extent of, and the requirements for, seabed preparation shall be specified. The laying tolerances shall be considered when the extent of seabed preparation is determined.

10.3.2.3 Where trench excavation is required before pipelaying, trench shall be excavated to a sufficiently smooth profile.

10.3.3 Existing pipelines and cables including crossings

10.3.3.1 The location of any other pipelines, cables or other infrastructure shall be identified.

10.3.3.2 Preparations for crossing of pipelines and cables shall be carried out according to a specification detailing the measures adopted to avoid damage to both installations. The operations should be monitored to confirm proper placement and configuration of the supports. Support and profile over the existing installation shall be in accordance with the accepted design.

10.3.3.3 The specification shall state requirements concerning:

- minimum separation between existing installation and the pipeline
- co-ordinates of crossing
- marking of existing installation
- confirmation of position and orientation of existing installations on both sides of the crossing
- lay-out and profile of crossing
- depth of cover
- vessel anchoring
- installation of supporting structures or gravel beds
- methods to prevent scour and erosion around supports
- monitoring and inspection methods
- tolerance requirements
- condition of landfall
- any other requirements.

10.4 Installation spread

10.4.1 General

10.4.1.1 These requirements are applicable for vessels performing pipeline and riser installation and supporting operations. Specific requirements for installation equipment onboard vessels performing installation operations are given in the relevant subsections.

10.4.1.2 The organisation of key personnel with defined responsibilities and lines of communication shall be established prior to start of the operations. Interfaces with other parties shall be defined.

10.4.1.3 All personnel shall be qualified for their assigned work. Key personnel shall have sufficient verbal communication skills in the common language used during operations.

10.4.1.4 Manning level should comply with IMO Res. A.1047 (27) - *Principles of minimum safe manning*. Non-self propelled vessels shall have similar manning and organisation as required for self propelled units of same type and size.

10.4.1.5 Vessels and equipment shall have a documented maintenance programme covering all systems vital for the safety and operational performance of the vessel, related to the operation to be performed. The maintenance programme shall be presented in a maintenance manual or similar document.

10.4.2 Vessels

10.4.2.1 All vessels shall have valid class with a recognised classification society. The valid class shall cover all systems of importance for the safety of the operation. Further requirements to vessels shall be given in a specification stating requirements for:

- anchors, anchor lines and anchor winches
- anchoring systems
- thrusters in case of thruster assisted mooring
- positioning and survey equipment
- dynamic positioning equipment and reference system
- alarm systems, including remote alarms when required
- general seaworthiness of the vessel for the region
- cranes and lifting appliances

— pipeline installation equipment
— any other requirement due to the nature of the operations.

10.4.2.2 Status reports for any recommendations or requirements given by national authorities and/or classification societies, and status of all maintenance completed in relation to the maintenance planned for a relevant period, shall be available for review.

10.4.2.3 An inspection or survey shall subject to agreement be performed prior to mobilisation of the vessels to confirm that the vessels and their principal equipment meet the specified requirements and are suitable for the intended work.

10.4.2.4 The scale of fire fighting and lifesaving appliances on board shall, as a minimum, be in accordance with the scales prescribed in SOLAS corresponding to the number of personnel on board the vessel.

10.4.3 Positioning systems

10.4.3.1 The installation barge/vessel shall have a position/heading keeping system able to maintain a desired position/heading within the accuracy and reliability required for the planned operation and the environmental conditions. See [10.4.4] and [10.4.5] for more details.

10.4.3.2 The operation/installation shall be planned and executed with use of position/heading reference system(s) of suitable type, accuracy and reliability required for the operation(s) and type of vessel(s) involved.

10.4.3.3 The positioning/heading reference systems shall be calibrated and capable of operating within the specified limits of accuracy prior to start of the installation operations.

10.4.3.4 Installation in congested areas and work requiring precise relative location may require local systems of greater accuracy, such as acoustic transponder array systems. Use of ROV's to monitor and assist the operations is recommended and should be considered.

10.4.3.5 The positioning/heading reference system shall as a minimum provide information relating to:

— position relative to the grid reference system used
— geographical position
— heading
— offsets from given positions
— vertical reference datum(s).

10.4.4 Anchoring systems, anchor patterns and anchor handling

10.4.4.1 Anchoring systems for vessels kept in position/heading by anchors (with or without thruster assistance) while performing marine operations shall meet the following requirements:

— Instruments for reading anchor line tension and length of anchor lines shall be fitted in the operations control room or on the bridge, and also at the winch station.
— Remotely operated winches shall be monitored from the control room or bridge, by means of cameras or equivalent.
— Instrumentation for reading thruster output and available electrical power for thrusters shall be available at bridge and/or in the operation control room.

10.4.4.2 Anchor handling vessels shall be equipped with:

— a surface positioning reference system of sufficient accuracy. High accuracy is required for anchor drops in areas with strict requirements to control of anchor position, typical within safety zone of existing installations, proximity of pipelines or areas of archeological or environmental importance
— computing and interfacing facilities for interfacing with lay vessel, trenching vessel or other anchored vessels
— latest revision of charts for the whole area of operation.

10.4.4.3 Procedures for the anchor handling shall be established, ensuring that:

— anchor locations are in compliance with the anchor pattern for the location
— requirements of operators of other installations and pipelines for anchor handling in the vicinity of the installation are known, and communication lines established
— position prior to anchor drop is confirmed
— anchor positions are monitored at all times, particularly in the vicinity of other installations and pipelines
— any other requirement due to the nature of the operations is fulfilled.

Guidance note:

In order to ensure correct positioning of anchors, the line length measurements should be reset at the point of the anchor shackle being at the stern roller and accurate information of line tension should be ensured.

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10.4.4.4 All mooring equipment shall hold a valid certificate. There shall be procedures in place for handling and regular inspection of all mooring equipment.

10.4.4.5 For mooring systems using synthetic fibre lines, instructions for handling, use and storage as provided by manufacturer and/or stated on certificate shall be followed. Contact with the seabed shall be avoided at any time unless the fibre ropes have been certified for such contact.

10.4.4.6 Anchor patterns shall be predetermined for each vessel using anchors to maintain position. Different configurations for anchor patterns may be required for various sections of the pipeline, especially in the vicinity of fixed installations and other subsea installations or other pipelines or cables.

10.4.4.7 The minimum allowable number of anchors to be used during pipeline installation shall be established.

10.4.4.8 Anchor patterns shall be according to the results of mooring analyses and shall be verified to have the required capacity for the proposed location, time of year and duration of operation. Safe distance to other installation and non-anchoring zones shall be established, and the possibility to leave the site in an emergency situation shall be considered.

Guidance note:

For weather restricted operations and mooring, see DNVGL-ST-N001. For non-weather restricted operations and mooring, see DNVGL-OS-E301.

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10.4.4.9 The mooring system shall as a minimum be analysed for:

— an ultimate limit state (ULS) to ensure that the individual lines and anchors have adequate strength to withstand the load effects imposed by extreme environmental actions
— an ultimate limit state (ULS) to ensure that the individual lines have the adequate strength and the vessel/barge is kept within acceptable positions for the environmental limiting conditions for the operation
— an accidental limit state (ALS) to ensure that the mooring system has the adequate capacity to withstand the failure of one mooring line, or in case of thruster assisted mooring, failure of one truster or failure in trusters' control or power systems.

10.4.4.10 Holding capacity of anchor shall be documented, and potential dragging of anchors shall be assessed. The anchor holding capacity shall be based on actual soil condition and type of anchors to be used. Various anchors may have various performance in different soils, and evaluation of the appropriate anchor type shall be performed. Special caution should be paid to holding capacity on sand.

10.4.4.11 Each anchor pattern shall be clearly shown on a chart of adequate scale. The pattern should include allowable tolerances. All subsea installations, infrastructure and other anchor restricted zones shall be shown in the chart.

10.4.4.12 If using anchor handling tug as live anchor, the tug should as a minimum hold a DP class according to DP equipment class 2. The winch and DP system should be linked ensuring winch tension to be considered in the system. Live anchor should not be used in critical operations and inside the safety zone.

10.4.4.13 Station-keeping systems based on anchoring shall have adequate redundancy or back-up systems in order to ensure the pipeline integrity and that other vessels and installations are not endangered by partial failure.

Guidance note:

The pipeline integrity check should, as a minimum, include the following cases:

- Worst case for mooring failure
- Mooring failure for the most loaded case for pipeline as identified in dynamic analysis.

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10.4.4.14 Safe distances are to be specified between an anchor, its cable and any existing fixed or subsea installations and infrastructure, both for normal operations and emergency conditions.

Guidance note:

Minimum clearances may vary depending on requirements of operators of other installation/pipeline and national requirements. Additional guidance can be found in DNVGL-ST-N001.

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10.4.4.15 The anchor position, drop zone and wire catenary should be established taking into account the water depth, wire tension and wire length. Confirmation of anchor positioning after installation shall be confirmed at regular intervals depending on required accuracy and criticality, and counteractive measures taken when found required. Monitoring systems shall be considered.

10.4.4.16 During anchor running, attention shall be paid to the anchor cable and the catenary of the cable, to maintain minimum clearance between the anchor cable and any subsea installations and infrastructure or obstacles.

10.4.4.17 All anchors transported over subsea installations and infrastructure shall be secured on deck of the anchor handling vessel.

10.4.5 Dynamic positioning

10.4.5.1 Vessels performing pipelaying activities using dynamic positioning systems for station keeping and location purposes shall be designed, equipped and operated in accordance with IMO MSC/Circ.645 *Guidelines for Vessels with Dynamic Positioning Systems* or MSC 1./Circ.1580 *Guideline for Vessels and Units with Dynamic Positioning (DP) Systems* and the corresponding class notations from a recognised classification society.

10.4.5.2 Selection of required DP equipment class for the operation shall comply with national requirements and in addition be based upon a risk assessment of the actual installation and location.

Guidance note:

The following DP equipment class should apply:

— Minimum equipment class 2 for operations outside the safety zone for live installation (surface or subsea)
— Equipment class 3 for operations inside the safety zone for live installations
— Equipment class 3 for manned subsea operations or other operations where a sudden horizontal displacement of the vessel may have severe consequences for personnel.

For operations inside the safety zone, vessels with lower equipment classes may be accepted subject to agreement on a case by case basis. Elements to evaluate with regard to acceptance of lower equipment class are:

— the vessel does not exceed the vessel size of which the facility is designed for with regard to withstanding collision.
— the consequences of single failures, including fire and flooding, will not increase significantly
— availability of reliable positioning reference systems
— possibility of operating with open waters on leeward side
— risk reducing measures as extra DP manning, engine room manning and fire watch.

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10.4.5.3 Sufficient DP capacity shall be documented by capability plots. The plots shall be relevant for the planned project based on correct vessel lay-out, including project specific modifications, and relevant pipeline and tension. The plots shall cover normal operation as well as worst case single failure from FMEA.

Guidance note:

The capacity plots should be provided for two scenarios for the same weather conditions:

— all system fully functional
— worst case failure mode, or an amalgamation of the worst cases

For capacity plots, see IMCA M140. See also DNVGL-ST-O111.

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Guidance note:

For worst single failure concept, see DNVGL-RU-SHIP Pt.6 Ch.3*Navigation, manoeuvring and position keeping*, and in IMO MSC/circ. 645 or MSC 1./Circ.1580 *Guideline for Vessels and Units with Dynamic Positioning (DP)*.

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10.4.5.4 For critical operations monitoring/displaying of actual DP capacity for actual weather conditions at site are recommended.

Guidance note:

Equipment classes 2 and 3 has a software function, normally known as consequence analysis, which continuously verifies that the vessel will remain in position even if the worst case failure occurs. This analysis should verify that the thrusters remaining in operation after the worst case failure can generate the same resultant thruster force and moment as required before the failure.

The consequence analysis should provide an alarm if the occurrence of a worst case failure would lead to a loss of position due to insufficient thrust for the prevailing environmental conditions. For operations which will take a long time to safely terminate, the consequence analysis should include a function which simulates the thrust and power remaining after the worse case failure, based on manual input of weather trend.

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10.4.5.5 Due consideration should be given to the reference systems limitations regards reliability, accessibility and quality.

10.4.5.6 The DP operators shall be familiar with the vessel specific FMEA as well as the contingency plans for the operation in question.

10.4.5.7 Key elements of the contingency planning measures should be located in the vicinity of the DP operator station, so that situation specific required actions are immediately available to the DP operator.

10.4.5.8 DP operation station and tensioner system operation station should be located in the vicinity of each other ensuring close communication between the operators and availability/monitoring of vital information.

10.4.6 Cranes and lifting equipment

10.4.6.1 Cranes and lifting equipment shall meet applicable statutory requirements. Certificates for the equipment, valid for the operations and conditions under which they will be used, shall be available on board for review.

10.4.7 Layvessel arrangement, laying equipment and instrumentation

10.4.7.1 The tensioning system shall operate in a fail-safe mode and shall have adequate pulling force, holding force, braking capacity and squeeze pressure to maintain the pipe under controlled tension. The forces applied shall be controlled such that no detrimental damage to the pipeline or coating will occur.

10.4.7.2 The installation vessel tensioning system arrangement shall therefore be such that:

— the tensioning system capacity shall have sufficient redundancy to allow failure of individual components
— in case of failure in the tensioning system, the pipeline installation shall not re-start before the system has been repaired or have enough redundancy to allow for additional failures.

10.4.7.3 The pipe joints, stalks and pipeline shall be sufficiently supported by rollers, tracks or guides that allow the pipe to move axially. Supports shall prevent damage to coating, field joint coatings, anodes and in-line assemblies, and rollers shall move freely. The vertical and horizontal adjustment of the supports shall ensure a smooth transition from the vessel onto the stinger, ramp or lay tower, to maintain the loading on the pipeline within the specified limits. The support configuration shall be related to a clear and easily identifiable datum.

10.4.7.4 The abandonment and recovery system (A&R) should be able to abandon the pipeline safely if waterfilled. In case the recovery system is incapable of recovering the pipeline, alternative methods should be available.

10.4.7.5 A sufficient amount of instrumentation and measuring devices shall be installed to ensure that monitoring of essential equipment and continuous digital storage of all relevant parameters required for configuration control and control of the operating limit conditions can be performed.

The following minimum instrumentation and monitoring is required:

Tensioning system:

— actual tension, tension settings and variance to set point
— squeeze pressure.

Stinger, ramp:

— pipeline and A&R wire position with respect to the last roller or guide
— roller reaction loads on the roller introducing the stinger curvature
— roller reaction loads (vertical and horizontal), as a minimum for stinger tip
— stinger and ramp configuration.

Guidance note:

Pipeline and wire position with respect to the last roller or guide may be monitored using underwater camera(s), sonar, ROV or diver.

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Lay configuration:

— lay parameter monitoring and recording as applicable to the installation method (see [10.6.1.11]).

Touch down monitoring:

— appropriate systems for touch down monitoring capable of operating under the expected weather conditions.

Buckle detection:

— appropriate instrumentation and monitoring system for the applied buckle detection method
— pulling wire tension and length recorder in case buckle detector is chosen as buckle detection method.

Winches:

— abandonment and recovery system shall be equipped with wire tension and length recorder
— anchor winches shall meet the requirements given in [10.4.4].

Vessel:

— vessel position
— vessel movements such as roll, pitch, sway, heave
— water depth
— vessel draft and trim
— wind strength and direction
— direct or indirect indication of sagbend curvature and strain.

Vessels used for installation by towing:

— measuring equipment that continuously displays and records the towing speed and tensions
— measuring equipment that continuously displays and monitors the depth of the pipestring and its distance from the seabed
— measuring equipment that continuously display the position of any ballast valves. The flow rates during any ballasting and de-ballasting shall be displayed
— atrain gauges to monitor the stresses in the pipestring during tow and installation shall be considered.

10.4.7.6 All measuring equipment shall be calibrated and adequate documentation of calibration shall be available onboard the vessel prior to start of work and during the whole operation. All measuring equipment used shall be provided with an adequate amount of spares to ensure uninterrupted operation.

10.4.7.7 Direct reading and processing of stored records from all required essential instrumentation and measuring devices, shall be possible at the vessels bridge.

10.4.7.8 Correlation of recorded data and pipe identifications numbers shall be possible.

10.4.7.9 The function of essential measuring devices shall be verified at regular intervals.

10.4.7.10 Other measuring and recording systems or equipment shall be required if they are essential for the installation operation.

10.4.8 Mobilization

10.4.8.1 All personnel shall be familiarized with the operation to be performed. More detailed familiarization shall be performed for personnel specific work tasks.

10.4.8.2 Personnel involved in critical operations should participate in a risk assessment for the specific operation. Personnel involved in critical operations shall participate in a safe job analysis or toolbox talk ensuring that an understanding of the involved risk related to the operation is understood.

10.4.8.3 Equipment needed for the operation shall be defined in and mobilised according to the mobilisation manual.

10.4.8.4 Stinger, ramp or lay tower shall be adjusted to the correct configuration to ensure a smooth transition from the vessel to the outboard stinger, ramp or lay tower end, and to maintain the loading on the pipeline within the specified limits. The pipeline support geometry shall be verified prior to laying, and the accepted height and spacing of supports shall be permanently marked or otherwise indicated. If the stinger, ramp or lay tower can be adjusted during laying operations, it shall be possible to determine the position and configuration by reference to position markings or indicators.

10.4.8.5 Trim, tilt and ballasting shall also be verified to be according to procedures prior to laying.

10.4.8.6 Procedures for safe lifting operations shall be in place.

10.4.8.7 All pipes, anodes, consumables, equipment etc. shall be seafastened within the environmental limits expected for the area of the operation.

10.4.9 Qualification of vessel and equipment

10.4.9.1 Vessel and equipment shall be qualified to do installation work within the specified operating limits. Re-qualification is required if significant modification or alternation to the vessel, equipment or software has been made.

10.4.9.2 Qualification shall be done according to a qualification plan based on a systematic review of the specified operating limits for the vessel and all equipment.

10.4.9.3 Qualification shall be done based on a combination of desktop review, analyses, HAZID/HAZOP, FMECA, simulation tests and test laying.

10.4.9.4 Combined positioning system/tensioning system tests shall be done by simulating pipeline pull, tensioning system failures and redundancy tests during pull.

10.4.10 General calibration and testing

10.4.10.1 Essential equipment shall be calibrated against a certified load cell. If essential components for the equipment such as load cells, amplifiers or software are replaced or modified the equipment shall be tested and re-calibrated. Indications of equipment out of calibration should trigger a re-calibration.

Guidance note:

Typical essential equipment can be, but are not limited to, tensioners, clamps, reel, winches, cranes, lifting equipment, conveyor system, bevelling machines, internal line-up clamp, field joint coating system, positioning systems.

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10.4.10.2 The certified load cell used for calibration shall have a certificate from a recognised certification body. The certificate for the load cell used for calibration should not be older than 6 months.

Guidance note:

A recognised certification body will have a competent laboratory that can ensure traceability and adequate procedures. See ISO/IEC 17025.

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10.4.10.3 Testing and calibration shall be done according to the test procedures. Test procedures shall be subject to agreement.

10.4.10.4 The test procedures shall provide documented acceptance criteria for the testing and calibration.

10.4.10.5 The acceptance criteria shall be evaluated and set according to the pipeline integrity. Any deviation from the correct value shall be accounted for.

10.4.10.6 Calibration and testing should be performed and planned such that it can be witnessed in agreement with operator.

10.4.10.7 Equipment should be tested and calibrated to the maximum equipment capacity or alternatively up to maximum expected dynamic or accidental loads + 50%, whichever is less.

10.4.10.8 During testing and calibration the complete load range should be covered. For linear trends at least five load steps should be applied up to maximum expected dynamic loads, more steps are required when testing to maximum capacity. Non-linear trends require higher numbers of load steps. Cyclic loading should be considered.

Guidance note:

Loss of main power and loss of signal should be tested by removing fuses or cables.

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10.4.11 Calibration and testing frequency

10.4.11.1 The calibration and testing of essential equipment should as a minimum be performed for each project minimum once per year. the testing shall include:.

— Calibration checks.
— Tensioner system Review test. This includes test combinations of tensioners, clamps and reel, and testing of single tensioner failure when running two or more tensioners, test redundancy of single tensioners, fail safe actions, loss of main power and loss of signal.
— Pull test of the tensioning and pipe holding system to verify sufficient squeeze pressure and friction.
— Abandonment and recovery system test (fail safe actions, loss of main power and loss of signal).
— In-field dynamic positioning system test.
— Fail safe testing to max expected level of tension for the project.
— Buckle detection system, stinger control and monitoring devices including roller load cells.

10.4.11.2 For each specific project, the following shall be documented :

— Test results for the above testing.
— Calibration records of critical/essential equipment, including welding machines and automated NDT equipment.
— Maintenance records for critical/essential equipment, including welding machines and automated NDT equipment.
— Maintenance/calibration records of critical/essential equipment on support vessels.
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10.4.11.3 Subject to agreement,testing and calibration for one project may be sufficient for similar project. If testing is performed with a different set up (e.g. different clamps or pads or pipe diameter) re-testing should be performed.

10.4.11.4 Re-testing should be performed in case equipment is maintained. In case re-testing is not performed this shall be based upon an evaluation which shall be documented.

10.4.11.5 Re-testing shall be performed in case equipment is changed or modified.

10.5 Welding and non-destructive testing

10.5.1 General

10.5.1.1 Requirements for welding processes, welding procedure qualification, execution of welding and welding personnel are given in App.C.

10.5.1.2 Requirements for mechanical and corrosion testing for qualification of welding procedures are given in App.B.

10.5.1.3 Requirements for methods, equipment, procedures, acceptance criteria and the qualification and certification of personnel for visual examination and non-destructive testing (NDT) are given in App.D. Selection of non-destructive methods shall consider the requirements in [D.1.4].

10.5.1.4 Requirements to automated ultrasonic testing (AUT) are given in App.E.

10.5.2 Welding

10.5.2.1 Pipes shall be bevelled to the correct configuration, checked to be within tolerance, and inspected for damage. Internal line-up clamps should be used. Acceptable alignment, root gap and staggering of longitudinal welds shall be confirmed prior to welding.

10.5.2.2 A weld repair analysis should be performed. Bending and tensile stresses shall be considered. The analysis shall determine the maximum excavation length and depth combinations that may be performed, taking into account all stresses acting at the area of the repair. The analysis shall be performed in accordance with [5.4.8]. The analysis shall consider the reduction of yield and tensile strength in the material due to the heat input from defect excavation, preheating, and welding and also dynamic amplification due to weather conditions and reduced stiffness effect at field joints. Elevated temperature tensile testing should be performed.

10.5.2.3 In case multiple welding stations on the installation vessel, the root and the first filler pass shall, as a minimum, be completed at the first welding station before moving the pipe. Moving the pipe at an earlier stage may be permitted if an analysis is performed showing that this can be performed without any risk of introducing defects in the deposited weld material. This analysis shall consider the maximum misalignment allowed, the height of the deposited weld metal, the possible presence of flaws, support conditions for the pipe and any dynamic effects.

10.5.2.4 For production testing, see [C.7.5.25] to [C.7.5.31].

10.5.3 Non-destructive testing

10.5.3.1 The extent of NDT for installation girth welds shall be 100% ultrasonic or radiographic testing. Radiographic testing shall be supplemented with ultrasonic testing in order to enhance the probability of detection and/or characterisation/sizing of defects.

10.5.3.2 For wall thickness > 25 mm and for mechanized welds with weld bevel angles >6°, automated ultrasonic testing shall be used.

10.5.3.3 Automated ultrasonic testing (AUT) shall be used in the following cases:

— whenever sizing of flaw height and/or determination of the flaw depth is required (see [5.4.8]).
— 100% lamination checks of a 50 mm wide band at ends of cut pipe.

Exception to this requirement may be given for wall thickness < 8 mm provided that it can be technically justified that alternative NDT processes provide sufficient inspection performance for the expected imperfections for the applied welding procedure, see [D.2.10.11].

10.5.3.4 When radiographic testing is the primary NDT method UT or AUT shall be used in the following cases:

— For the first 10 welds for welding processes with high potential for non-fusion type defects, when starting installation or when resuming production after suspension of welding
— to supplement radiographic testing for unfavourable groove configurations
— for wall thickness above 25 mm:
    — to provide additional random local spot checks during installation
    — to supplement radiographic testing to aid in characterising and sizing of ambiguous indications.

10.5.3.5 If ultrasonic testing reveals defects not discovered by radiography, the extent of ultrasonic testing shall be 100% for the next 10 welds. If the results of this extended testing are unsatisfactory, the welding shall be suspended until the causes of the defects have been established and rectified.

10.5.3.6 For Golden Welds (critical welds e.g. tie-in welds that will not be subject to pressure testing, etc.) 100% ultrasonic testing, 100% radiographic testing, and 100% magnetic particle testing or 100% liquid penetrant testing of non- ferromagnetic materials shall be performed. If the ultrasonic testing is performed as automated ultrasonic testing, see App.E, the radiographic testing may be omitted subject to agreement.

10.5.3.7 Magnetic particle testing or liquid penetrant testing of non-ferromagnetic materials shall be performed to verify complete removal of defects before commencing weld repairs, and for 100% lamination checks at re-bevelled ends of cut pipe.

10.5.3.8 Visual Examination shall include:

— 100% examination of completed welds for surface flaws, shape and dimensions
— 100% examination of the visible pipe surface, prior to field joint coating.

10.6 Pipeline installation

10.6.1 General

10.6.1.1 The requirements of this subsection are generally applicable to pipeline installation, regardless of installation method. Additional requirements pertaining to specific installation methods are given in the following subsections.

10.6.1.2 This section addresses the main installation methods. Other installation methods may be suitable in special cases. A thorough study shall be performed to establish the feasibility of the installation method and the loads imposed during installation. Such methods are subject to agreement in each case.

10.6.1.3 Interfaces shall be established with other parties that may be affected by the operations or may affect the operation. The responsibilities of all parties and lines of communication shall be established.

10.6.1.4 Handling and storage of pipes and materials on supply and laying vessels shall ensure that damage to personnel, pipe, coatings, assemblies and accessories are avoided. Slings and other equipment used shall be designed to prevent damage of product. Storage of pipes, in-line assemblies and other accessories shall be seafastended to withstand design loads. All material shipped for installation shall be recorded.

10.6.1.5 All material shall be inspected for damage, quantity and identification upon arrival. Damaged items shall be quarantined, repaired or clearly marked and returned onshore.

10.6.1.6 Pipes and in-line assemblies shall be inspected for loose material, debris and other contamination and cleaned internally before being added to the line. The cleaning method shall not cause damage to any internal coating.

10.6.1.7 A pipe tracking system shall be used to maintain records of weld numbers, pipe numbers, NDT, pipe lengths, cumulative length, anode installation, field joints, in-line assemblies and repair numbers. The system shall be capable of detecting duplicate records.

10.6.1.8 The individual pipes of the pipeline shall be permanent marked in accordance with the established pipe tracking system. The marking shall be suitable for reading by ROV. Means of monitoring possible pipeline rotation may be applied. If damaged pipes are replaced, any sequential marking shall be maintained.

10.6.1.9 In-line assemblies shall be handled and stored to avoid damage prior to joining to the line, and shall further be handled such that damage is avoided through tensioning system, pipe supports/rollers or ramp, whichever is relevant. Any pipeline rotation shall be controlled.

10.6.1.10 Any applied field joint coating shall meet the requirements in Sec.9.

10.6.1.11 The lay configuration and loads shall be controlled in order to ensure that these are within established design parameters during installation. The configuration and loads may be controlled by various means, and these shall be clearly described including allowable ranges for the specific installation. Redundancy is required.

Guidance note:

The lay configuration may typically be controlled by tension, stinger tip clearance and lay back distance/touch down monitoring. Depending on the installation vessel and pipeline, the preferred methods may alter.

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10.6.1.12 Pipelay touch down monitoring shall be performed for critical operations and critical sections representing a risk for the pipeline or for existing infrastructure. Critical operations and critical sections are project specific, but will typically be initiation, laying of curves, narrow lay corridor, crossings, laying towards counteracts, boulder areas and lay down.

10.6.1.13 Pipelay in congested areas, in the vicinity of existing installations and at pipeline and cable crossings, shall be carried out using positioning systems with required accuracy. Measures shall be taken to avoid damage to existing infrastructure. ROV should be used to continuously monitor such operations. ROVs shall be capable of operating under the seastates expected for the operation in question.

10.6.1.14 The pipeline shall be installed within the lay corridor. Deviations to the lay corridor shall be checked and verified or corrected before pipelaying continues.

10.6.1.15 Where a buckle detector is used, the buckle detector load chart shall be monitored. The buckle detector shall be retrieved and inspected if there is reason to believe that buckling can have occurred. If the inspection shows indications of buckling or water ingress, the situation shall be investigated and remedial action performed.

10.6.1.16 The position of pipeline including start up and lay-down shall be verified as within their respective target areas prior to departure of the lay vessel from site.

10.6.1.17 Prior to abandonment of the pipeline, all internal equipment except the buckle detector should be removed. All welds, including the abandonment and recovery head welds, shall be filled to a level that the pipe can be safely abandoned on and retrieved from the seabed, and shall be clearly defined in advance.

10.6.1.18 During abandonment, winch tension and cable lengths shall be monitored and the values shall be within the specified range during the operation. The connection at the end of the wire shall be easily recoverable independently of waves and current conditions.

10.6.1.19 After abandonment and prior to recovery the pipeline shall be surveyed over a length away from the abandonment and recovery head, sufficient to ensure that no damage has occurred.

10.6.1.20 Diving and underwater operations shall be performed in accordance with agreed procedures covering applicable requirements.

10.6.1.21 In the event of buckling a survey of the pipeline shall be performed before repair to establish the extent of damage and feasibility of the repair procedure. After completion of the repair, a survey shall be performed of the pipeline over a length sufficient to ensure that no further damage has occurred.

10.6.1.22 If loss or major damage to weight and corrosion coating or anodes and their cables/connectors are observed, repair shall be performed and inspected according to established procedures.

10.6.1.23 For temporary storage and transportation of linepipe, see [8.6.4].

10.6.1.24 Initiation of pipeline installation shall be performed using adequate start-up piles or anchors to ensure safe operations.

10.6.1.25 Lay down of the pipeline should be performed such that the pipeline is inside the lay corridor and with the desired approach angle.

10.6.2 Additional requirements for installation method S-lay

10.6.2.1 The stinger and rollers shall be positioned to avoid exceeding any limit state for the pipeline, and to avoid damage to anodes or other attachments.

10.6.3 Additional requirements for installation method J-lay

10.6.3.1 The consequences in case losing internal welding clamp inside pipeline shall be established and agreed.

10.6.4 Additional requirements for installation methods introducing significant plastic strains

10.6.4.1 Additional requirements of this subsection are applicable to pipeline installation by methods which give total single event nominal strain > 1.0% or accumulated nominal plastic strain > 2.0%.

10.6.4.2 Pipelines used for such installation methods shall meet the supplementary requirement, pipe for plastic deformation (P), see [7.9.3].

10.6.4.3 Adequate support of the pipestring shall be provided when loading the reel. Sufficient tension shall be applied during reeling in order to ensure that the successive layers on the reel are sufficiently tightly packed to prevent slippage between the layers, and to control the curvature. Tension shall be monitored. Adequate measures shall be taken to protect the coating during reeling. Vessel motion shall be controlled and within acceptable limits during onshore tie-in weld between stalks.

10.6.4.4 The curvature of the pipe, peaking and sagging, between the point of departure from the reel and entry into the straighteners shall not exceed the maximum values assumed in design and included in the fracture assessment of the girth welds as per [5.4.8] and validated in the material testing of the girth welded pipes.

10.6.4.5 Anodes should be installed after the pipe has passed through the straightener and tensioner. The electrical connection between anodes and pipe shall meet the specified requirements and shall be verified at regular intervals, see Sec.9.

10.6.5 Towing

10.6.5.1 Tows may be performed as:

— surface or near-surface tows, with the pipestring supported by surface buoys
— mid-depth tows, where the pipestring is towed well clear away from the seabed
— bottom tows, where the pipestring is towed in contact with, or close to, the seabed.

10.6.5.2 For surface tows, all aspects pertaining to the tow are subject to agreement in each case.

10.6.5.3 For bottom or near bottom tows, the pipeline route shall be surveyed prior to the tow and the route shall avoid rough seabed, boulders, rock outcrops and other obstacles that may cause damage to the pipeline, coating or anodes during the tow and installation. During bottom and near bottom tows, adequate monitoring with ROVs and of the pipeline position at critical phases is required. Satisfactory abrasion resistance of the pipeline coating shall be demonstrated. All aspects pertaining to bottom tows are subject to agreement in each case.

10.6.5.4 Launching of pipestrings shall be performed such that the pipestring is safe from damage and damage to the coating and anodes are avoided. If pipestrings are moored inshore awaiting the tow, adequate precautions shall be taken to avoid marine growth influencing pipestring buoyancy, weight and drag.

10.6.5.5 Notification of the tow shall be given to the relevant authorities, operators of subsea installations crossed by the towing route and users of the sea.

10.6.5.6 During the tow a standby vessel shall be present to prevent interference with the tow by third party vessels.

10.6.5.7 Tension in the towing line and the towing depth shall be kept within the specified limits during the tow. If required, ballasting or de-ballasting shall be performed to adjust the towing depth to the specified values.

10.6.5.8 Installation shall be performed by careful ballasting and de-ballasting. Care shall be exercised to prevent over-stressing of the pipestring. The use of drag chains during the installation is recommended. The installation operation shall be monitored by ROV.

10.6.6 Shore pull

10.6.6.1 The requirements of this subsection are applicable to the execution, inspection and testing of shore pull when pipestrings are pulled either from a vessel onto the shore, or vice versa.

10.6.6.2 Detailed requirements for the execution, inspection and testing of shore pull shall be specified, considering the nature of the particular installation site.

10.6.6.3 Cables, pulling heads and other equipment shall be dimensioned for the forces to be applied, including any overloading, friction and dynamic effects that may occur.

10.6.6.4 Measuring devices shall be used to control the integrity of the pipeline during execution of the shore pull. Continuous monitoring of the cable tension and pulling force shall be applied, and these shall be within allowable limits. Monitoring with ROVs may be needed.

10.6.6.5 The winches shall be equipped with wire tension and length indicators and recorders. All measuring equipment shall be calibrated, and an adequate amount of spares to ensure uninterrupted operation shall be provided.

10.6.6.6 It shall be documented that ROVs are able to operate under the seastate expected for the operation in question. The ROVs shall, if used, be equipped as found necessary to perform the work in a safely manner and controlled manner.

10.6.6.7 Satisfactory abrasion resistance of the pipeline coating shall be demonstrated for the installation conditions.

10.6.6.8 Installation of the pulling head shall be made in a manner that does not compromise the integrity of the pipeline and provides a secure connection.

10.6.6.9 Buoyancy aids may be used as a mean to keep pulling tension within allowable limits.

10.6.6.10 During the operation, continuous monitoring of cable tension and pulling force shall be performed. Monitoring with ROVs may be needed.

10.6.7 Buckle detection

10.6.7.1 The consequences of buckles shall be evaluated as part of the HAZID/HAZOP (see [5.1.3] and [10.1.3]), and in agreement between operator and contractor.

Guidance note:

The assessment of the consequences will typically include recovery (e.g. in case wet buckle), availability of repair methods and time frames for repair. The consequences of a buckle not detected during installation will normally require inline repair methods which can have large schedule and cost impact. Detection of buckles during installation will have less schedule and cost impact.

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10.6.7.2 Mitigation measures for consequences of buckles shall be based upon the outcome of the HAZID/HAZOP. Buckle detection in accordance with Table 10-1 should be used.

Guidance note:

Buckle detection may be ensured by a buckle detector or equipment providing similar degree of detection.

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The buckle detector (or equipment providing same degree of detect ability) shall be positioned in such a way that critical areas are monitored (normally a distance after the touch down point). If a buckle detector is used the diameter of the disc shall be chosen with regard to the pipeline diameter and tolerances on ovality, wall thickness, misalignment and internal weld bead.

Table 10-1 Buckle detection

Safety class	*Buckle detection requirement*	*Additional requirements and consequence of buckle*
Low	Buckle detection continuously during laying	
Medium	Buckle detection not required	Improved control of parameters controlling the lay configuration required (e.g. lay tension, touch down point monitoring etc.) and consequence of possible buckle is found acceptable.
High	Buckle detection not required	Improved control of parameters controlling the lay configuration required (e.g. lay tension, touch down point monitoring etc.) and consequence of possible buckle is found unacceptable.

10.6.7.3 In case the parameters controlling the lay configuration indicates that unacceptable configuration is experienced or other indications of buckle events, an inspection shall be performed. The inspection shall be carried out such that it can be confirmed that buckling has not occurred.

10.6.8 Operating limit conditions

10.6.8.1 The installation operation shall be classified as weather restricted operation or unrestricted operation, see [4.3.6]. An unrestricted operation is a temporary condition or permanent condition.

10.6.8.2 For weather restricted operations, operating limit conditions shall be established and agreed.

10.6.8.3 The operating limit conditions shall be based on detailed load effect analyses, vessel station keeping capability, FMEA analysis or HAZOP study data, and shall refer to objective, critical values indicated by measuring devices. The operating limit conditions shall be referred to in the procedure for configuration control. Continuous monitoring and recording of the measuring devices required for control of the operating limit conditions shall be performed during all phases of installation activities.

10.6.8.4 If a systematic deviation between the monitored response and predicted response from a seastate is found this should be accounted for.

10.6.8.5 Start of weather restricted operations is conditional to an acceptable weather forecast. Uncertainty in the weather forecast shall be considered.

10.6.8.6 For weather restricted operations, planning of operation shall be based on an operational reference period. Further, the operational criteria shall account for uncertainties in both weather forecasts and monitoring of environmental conditions. Regular weather forecasts from a recognised meteorological centre shall be available onboard the lay vessel, and shall be supplemented by historical environmental data. See DNVGL-ST-N001.

10.6.8.7 If the critical values are about to be exceeded, preparations for lay-down shall commence. If the critical condition is weather dependent only, and if weather forecasts indicate that the weather condition will subside, the lay-down may be postponed subject to agreement.

10.6.8.8 Decision to recover the pipeline shall be based on comparison of the actual seastate with the limiting seastate, together with weather forecasts.

10.6.9 Spools and other in-line assemblies installed separately from pipeline

10.6.9.1 In-line assemblies to be installed separately from the pipeline shall be sufficiently seafastened to ensure no damage is occurring during transportation.

10.6.9.2 For operating limit conditions for such installations, see [10.6.8].

10.6.9.3 Lifting operations above existing infrastructure on the seabed should be avoided. Safe lifting and installation zones shall be defined.

10.6.9.4 In-line assemblies to be installed separately from pipeline shall be installed inside the pre-defined target areas and also within the pre-defined heading limitations, in all planes.

10.6.9.5 Recommended practice for modelling and analysis of offshore lifting operations are given in DNVGL-RP-N103.

10.7 As-laid survey

10.7.1 General

10.7.1.1 An as-laid survey covering the complete submarine pipeline system shall be performed. This can be done either by continuous touch down point monitoring during pipe laying or by a separate survey. In case continuous touch-down monitoring is used, pipeline positioning shall be confirmed after completion of pipeline installation.

Guidance note:

Continuous touch down monitoring may not identify possible horizontal curve pull-out, and therefore positioning of pipeline have to confirmed after completion of installation activities.

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10.7.1.2 Requirements to survey vessel, survey equipment, the extent of survey, tolerances for the as-laid pipeline, and the maximum acceptable length and gap height of free spans at various locations shall be defined.

10.7.2 Survey requirements

10.7.2.1 The as-laid survey should include the following:

— position and depth of the pipeline, including location of in-line assemblies, anchoring and protective structures, tie-ins, supports etc.
— identification and quantification of any free spans with length and gap height
— determination of position of start-up and lay down heads
— determination of the presence of debris
— video documentation of the submarine pipeline system.

Guidance note:

Where video coverage cannot be obtained due to environmental reasons, alternate methodologies should be utilised to ensure 100% coverage.

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10.7.2.2 The pipeline horizontal position and seabed and pipeline vertical profile/seabed shall as a minimum be reported at intervals defined by the requirement for as-laid pipeline analyses. The data shall be reported in an agreed format.

10.7.3 Survey of corrosion protection systems

10.7.3.1 In the case of damage to coating or anodes, consequences for long-term performance shall be considered. Potential measurements at any bare surfaces should be carried out to confirm adequate corrosion protection. Corrective actions may include retrofitting of anodes and coating repairs. Satisfactory level of corrosion protection shall be documented after the corrective action has been performed.

10.7.3.2 Impressed current cathodic corrosion protection systems shall be inspected, including cables, conduits, anodes and rectifiers. Readings from the corrosion monitoring system shall be verified by independent potential measurements, and adequate electrical insulation from other installations (if applicable) shall be confirmed installed and commissioned according to ISO 15589-2.

If the required protection level is not attained, the causes shall be identified and adequate corrective actions performed. Satisfactory performance shall be documented after the corrective action.

10.8 Post-lay intervention (seabed intervention and pipeline protection)

10.8.1 General

10.8.1.1 The requirements of this subsection are applicable to free span rectification and the protection of pipelines, e.g. by trenching and backfilling, gravel dumping, grout bags, concrete mattresses etc.

10.8.1.2 A specific survey of the work area should be performed, or supplementing, the as-laid survey if:

— significant time has elapsed since the as-laid survey
— a change in seabed conditions is likely
— marine activity is present in the area
— new installations are present in the area
— the as-laid survey does not provide sufficient information.

10.8.1.3 The survey of the work area should as a minimum include:

— a video inspection of the pipeline to identify any areas of damage to pipeline, coating and anodes
— cross profiles of the pipeline and adjacent seabed at regular intervals
— depth profiles along the pipeline and the seabed at both sides of the pipeline
— any existing subsea installations.

The undisturbed seabed level shall be included in the cross profiles.

10.8.2 Span rectification and protection specification

10.8.2.1 The requirements applicable to the specific methods of span rectification and protection regarding execution, monitoring and acceptance criteria shall be documented. Requirements for vessels, survey equipment etc. shall be addressed in the installation and testing specifications and procedures. The extent of procedures to be prepared and qualified shall be specified.

10.8.3 Free span rectification

10.8.3.1 Free span rectification is required for all spans exceeding the specified acceptable length or height for the specific location. Rectification of other spans shall be considered if scour or seabed settlement could enlarge the span length and gap height above maximum acceptable dimensions before the first planned inspection of the pipeline.

10.8.3.2 Adequate rectification of free spans shall be documented by a video survey. All rectified free spans shall be identified and the length, gap and height shall be within the requirements.

10.8.4 Trenching

10.8.4.1 Where trench excavation is performed after pipelaying, the trenching equipment shall be of a type that does not place significant loads on the pipeline and minimises the possibility of damage to the pipeline.

10.8.4.2 Trenching equipment shall be equipped with sufficient instrumentation to ensure that damage and excessive pipe contact is avoided.

10.8.4.3 Special care shall be taken during trenching operations of piggy back/bundle pipelines, so that strapping arrangements will not be disturbed/damaged during trenching.

10.8.4.4 Trenching shall not damage or dismantle the anodes.

10.8.4.5 Where mechanical backfilling is required, it shall be carried out in a manner that minimises the possibility of damage or disturbance to the pipeline.

10.8.4.6 It shall be ensured that the trenching method for the given pipeline submerged weight and soil properties is adequate to avoid pipeline floatation during trenching and backfilling.

10.8.4.7 The trenching equipment monitoring system shall be calibrated and include:

— devices to measure depth of pipe
— a monitoring system and control system preventing horizontal loads on the pipeline or devices to measure and record all vertical and horizontal forces imposed on the pipeline by trenching equipment, and devices to measure the proximity of the trenching equipment to the pipeline, horizontally and vertically relative to the pipeline
— underwater monitoring systems enabling the trenching equipment operator to view the pipeline and seabed profile forward and aft of the trenching equipment
— measuring and recording devices for trenching equipment tow force
— devices monitoring pitch, roll, depth, height and speed of the trenching equipment.

10.8.4.8 Jet sleds shall have a control and monitoring system for the position of the jetting arms and the overhead frame, horizontally and vertically relative to the pipeline. The location of the sled shall not be controlled by the force between sled and pipeline. Devices indicating tension in the tow line and showing the depth of the trench shall be installed.

10.8.4.9 An allowable range of values, indicated by the measuring devices of the trenching equipment, shall be established. The possibility of damage to coating shall be considered. During trenching operations the measuring devices shall be continuously monitored.

10.8.4.10 A post-trenching survey should be performed after the trenching in order to determine if the required depth of trench and/or pipe has been achieved and if any remedial work is required.

10.8.5 Post-installation gravel installation

10.8.5.1 Material used for gravel installation shall meet the specified requirements for specific gravity, composition and grading.

10.8.5.2 Gravel installation shall be performed in a continuous and controlled manner. Existing infrastructure should not be disturbed or interfered with.

10.8.5.3 The gravel installation operation shall ensure rectification of all free spans to meet the specified requirements. Scouring effects shall be considered.

10.8.5.4 If the fall pipe technique is used for gravel installation, minimum clearances shall be specified such that the fall pipe cannot touch the pipeline or any other subsea installation or the seabed. Deployment operations shall be performed well away from the pipeline or any other subsea installation. Before the fall pipe is moved to the installation location, the clearance beneath the fall pipe shall be verified. The clearance shall be continuously monitored during gravel installation.

10.8.5.5 The completed gravel installation shall leave a mound on the seabed with a smooth contour and profile and a slope not steeper than specified.

10.8.5.6 If the gravel installation is performed over cable and pipeline crossings, the gravel mound shall provide the specified depth of cover over both the crossing and the crossed pipeline. During the gravel installation operations inspections shall be performed with a sonar survey system or with video when visibility is restored, to determine the completeness and adequacy of the installation.

10.8.5.7 Upon completion of the gravel installation, a survey shall be performed to confirm compliance with the specified requirements. The survey shall include:

- video of the pipeline length covered
- cross profiles of the mound and adjacent undisturbed seabed at regular intervals
- length profiles of the mound
- confirmation that minimum required buried depth is achieved
- confirmation that maximum burial depth is not exceeded
- any existing installations and their vicinity in order to ensure that the installation(s) have not suffered damage.

10.8.6 Grout bags and concrete mattresses

10.8.6.1 Concrete mattresses and grout bags shall meet the specification with regard to size, shape and flexibility of the material, location of filling points, and the specific gravity, composition and grading of grout.

10.8.6.2 Placing of grout bags and concrete mattresses shall be performed in a controlled manner, such that the bags or mattresses are placed as required. Restrictions on vessel movements during the operation shall be given.

10.8.6.3 During the placing operations, inspections shall be performed with a ROV-mounted video camera to determine the completeness and adequacy of the installation.

10.8.6.4 Upon completion of the placing operation, a survey shall be performed to confirm compliance with the specified requirements. The survey shall as a minimum include:

- video of the completed work
- cross profiles of the placed bags or mattresses and adjacent undisturbed seabed at regular intervals
- length profiles of the placed bags or mattresses and the seabed at both sides of the area.

10.9 Tie-in

10.9.1 General

10.9.1.1 The requirements of this subsection are applicable to tie-in operations using welding or mechanical connectors. The operations can be performed onboard a laying vessel (in which case welding is the preferred method) or underwater.

10.9.1.2 Tie-in operations by means of hot or cold taps are subject to special consideration and agreement.

10.9.1.3 Operating limit conditions with regard to the seastate, current and vessel movements shall be established. Uncertainty in weather forecast shall be considered.

10.9.2 Tie-in operations above water

10.9.2.1 The position of the tie-in shall be verified prior to start of operations. A survey shall be performed to establish that the location is free of obstructions and that the seabed conditions will permit the tie-in to be performed as specified.

10.9.2.2 Lifting and lowering of the pipeline sections shall be analysed to determine the critical parameters and operational criteria for the operation. Critical parameters/operational criteria shall be monitored continuously.

10.9.2.3 Lifting arrangements and equipment shall be designed taking into account the critical parameters and operational criteria for the operations.

10.9.2.4 The operation should be monitored to confirm correct configuration of the pipeline sections from the seabed and onto the vessel.

10.9.2.5 The alignment and position of the tie-in ends shall be within the specified tolerances before completing the tie-in.

10.9.2.6 Installation of mechanical connectors shall be performed in accordance with the manufacturer's procedure. For flanged connections hydraulic bolt tension equipment shall be used. During all handling, lifting and lowering into the final position, open flange faces shall be protected against mechanical damage.

10.9.2.7 A local leak test to an internal pressure not less than the local incidental pressure should be performed for all mechanical connections after make-up. This local leak test is additional to the normal system pressure test.

10.9.2.8 Corrosion protection of the tie-in area shall be performed and inspected in accordance with accepted procedures.

10.9.2.9 After completion of the tie-in, a survey of the pipeline on both sides of the tie-in, and over a length sufficient to ensure that no damage has occurred, should be performed

10.9.2.10 It shall be verified that the position of the tie-in is within the target area prior to departure of the vessel from site. The pipeline stability shall be ensured and adequate protection of pipeline provided.

10.9.2.11 Requirements for dry welding are given in App.C.

10.9.3 Tie-in operations below water

10.9.3.1 In addition to the requirements in [10.9.2], the requirements below are valid for tie-in operations involving underwater activities.

10.9.3.2 Diving and underwater operations shall be performed in accordance with agreed procedures for normal and contingency situations covering applicable requirements.

10.9.3.3 Requirements for underwater hyperbaric dry welding are given in App.C.

10.10 Pre-commissioning

10.10.1 General

10.10.1.1 All work on the submarine pipeline system, including crossings, trenching, gravel installation, artificial backfill, subsea assemblies, riser installation, tie-in etc., should be completed before pre-commissioning activities commences.

10.10.1.2 Disposal of cleaning and test fluids shall be performed in a manner minimising danger to the environment. Any disposal of fluids shall be in compliance with requirements from national authorities.

10.10.1.3 Requirements for equipment, the extent of testing and preparation for operation, performance of tests and preparation for operation and associated acceptance criteria shall be defined. The extent of procedures to be prepared and qualified shall be specified.

10.10.1.4 All operations and tests shall be performed in accordance with agreed procedures.

10.10.1.5 Recommended practice on pre-commissioning is given in DNVGL-RP-F115.

10.10.2 Waterfilling, cleaning and gauging

10.10.2.1 Cleaning and gauging may be combined with the initial flooding of the pipeline, be run as a separate operation, or be combined with the weld sphere removal after completion of hyperbaric tie-in.

10.10.2.2 Appropriate measures shall be taken to ensure that any suspended and dissolved substances in the fluid used for cleaning operation are compatible with the pipe material and internal coating (if applied), and that deposits are not formed within the pipeline.

10.10.2.3 Filling of the submarine pipeline system with water should be performed in a controlled manner, using water behind one or more pigs. The pig(s) shall be capable of providing a positive air/liquid interface. Considerations shall be given to pre-filling valve body cavities with an inert liquid, unless the valves have provision for pressure equalisation across the valve seats. All valves shall be fully open during line filling. A pig tracking system and the use of back-pressure to control the travel speed of the pig shall be considered if steep gradients occur along the pipeline route.

10.10.2.4 Water to be used for flooding should have a minimum quality corresponding to filtration of 50μm, and suspended matters should not have an average content exceeding 20 g/m^3.

10.10.2.5 If water quality or the water source is unknown, water samples shall be analysed and suitable actions shall be taken to remove and/or inhibit harmful substances.

10.10.2.6 If water is to remain in the pipeline for an extended period of time, consideration shall be given to control of bacterial growth and internal corrosion by chemical treatment (see [6.4.3.2]).

10.10.2.7 Added corrosion inhibitors, any chemical additives like oxygen scavengers, biocides, dyes, etc. shall be considered for possible harmful interactions selected to ensure full compatibility and their impact on the environment during and after disposal of the test water shall be considered.

10.10.2.8 The submarine pipeline system shall be cleaned. The pipeline cleaning concept shall consider:

— protection of pipeline components and facilities (e.g. valves) from damage by cleaning fluids and pigs
— testing devices such as isolation spheres etc.
— removal of substances that may contaminate the product to be transported

— particles and residue from testing and mill scale
— organisms and residue resulting from test fluids
— chemical residue and gels
— removal of metallic particles that may affect future inspection activities.

10.10.2.9 Acceptance criteria for cleaning shall be established and agreed.

10.10.2.10 The submarine pipeline system shall be gauged. The main purpose of gauging the submarine pipeline system is to prove that it is unlikely that any damages, dent or buckle exists in the submarine pipeline system, and to provide basis for future operational pigging activities. The purpose is further to document that no excessive dent or ovalisation exceeding the requirements in [5.4.11] and [5.4.12] has taken place. The preferred gauging is by an intelligent gauging tool (calliper pig). As an alternative a running a pig with a metallic gauge plate with a diameter of 95% of the largest nominal inner diameter, or 97% of the minimum inner diameter of the largest nominal inner diameter. In case a gauge plate cannot be used due to internal restrictions (e.g. variations in diameter, valves, bends etc.) an intelligent gauging tool (calliper pig) shall be used. When gauging is carried out with an intelligent tool the tolerances of the diameter measurements should be less than 0.2 mm and the diameter readings should be made minimum each 10mm along the entire pipeline length. The tool shall also be able to report locations of the readings.

Guidance note:

The minimum inner diameter including uncertainties can be established as:

$D_{min,tot} = D_{min}(1\text{-}O_0/2)\text{-}2t_{max}\text{-}2h_{bead}$

Where h_{bead} also allows for possible misalignment.

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10.10.2.11 Cleaning and gauging train design including number and type of pigs, train velocity shall be decided based upon need for chemical cleaning, type and length of pipeline, steep gradients along the pipeline route, type of service, construction method, downstream process, potential cleaning and gauging already performed (see [8.6.5.4] and [8.7.1.1]) or other aspects.

10.10.2.12 For cleaning operations where the acceptance criteria for cleaning are not fulfilled, a rerun of the cleaning pig train should be performed.

10.10.2.13 If cleaning is performed on separate sections of the submarine pipeline system prior to tie-in, a minimum of one cleaning pig should be run through the completed submarine pipeline system prior to, or during, product filling.

10.10.2.14 On completing of all tie-ins, a calliper pig or gauge plate should be run through the submarine pipeline system.

10.10.3 System pressure testing

10.10.3.1 A pipeline system pressure test shall be performed based upon the system test pressure determined according to [5.2.2.2] unless the test is waived as allowed by [5.2.2.3].

10.10.3.2 The submarine pipeline system may be tested as separate sections provided that the tie-in welds between sections fulfil the requirements in [10.5.3.6].

10.10.3.3 The pipeline section under test shall be isolated from other pipelines and facilities. Pressure testing should not be performed against in-line valves, unless possible leakage and damage to the valve is considered, and the valve is designed and tested for the pressure test condition. Blocking off or removal of small-bore branches and instrument tappings, should be considered to avoid possible contamination.

10.10.3.4 Temporary testing equipment such as end closures, temporary pigtraps and manifolds, shall be designed and constructed according to a recognised standards or recommended practices and with design pressure equal to the pipeline design pressure. Such items shall be individually pressure tested to at least the same test pressure as the pipeline.

10.10.3.5 Instruments and test equipment used for the measurement of pressure, volume and temperature shall be calibrated for accuracy, repeatability and sensitivity. All instruments and test equipment shall possess valid calibration certificates, with traceability to reference standards within the 6 months preceding the test. If the instruments and test equipment have been in frequent use, calibration specifically for the test should be performed.

10.10.3.6 Gauges and recorders shall be checked for correct function immediately before each test. All test equipment shall be located in a safe position outside the test boundary area.

10.10.3.7 The test pressure shall be measured using a dead weight tester or a high accuracy pressure transducer, in addition to a high accuracy large diameter pressure gauge. Dead weight testers shall not be used before a stable condition is confirmed, and shall not be used offshore when positioned on a vessel. If a high accuracy pressure transducer is used, it shall have sensitivity that is better than 4 times the target pressure drop, i.e. 0.05%. Time history of the test pressure shall be recorded.

10.10.3.8 The following requirements apply for instruments and test equipment:

— dead weight testers shall have a range of minimum 1.25 times the specified test pressure, and shall have an accuracy better than ±0.1 bar and a sensitivity better than 0.05 bar
— the volume of water added or subtracted during a pressure test shall be measured with equipment having accuracy better than ± 1.0% and sensitivity better than 0.1%
— temperature measuring instruments and recorders shall have an accuracy better than ±1.0°C, and a sensitivity better than 0.1°C
— pressure recorders and temperature recorders shall be used to provide a graphical record of the pressure test continuously for the total duration of the test.

10.10.3.9 A correlation that shows the effect of temperature changes on the test pressure where relevant, shall be developed and accepted prior to starting the test. Temperature measuring devices, if used, shall be positioned close to the pipeline, and the distance between the devices shall be based on temperature gradients along the pipeline route.

10.10.3.10 The test medium should be water meeting the requirements given in [10.10.2].

10.10.3.11 The air content of the test water shall be assessed by constructing a plot of the pressure against volume during the initial filling and pressurisation, until a definite linear relationship is apparent, see Figure 10-1. This should be done at 35% of test pressure, or at maximum 35 bar. The assessed air content should not exceed 0.2% of the calculated total volume of the pipeline under test. If the limit is exceeded, it shall be documented that the amount of air, not will influence the accuracy of the test significantly.

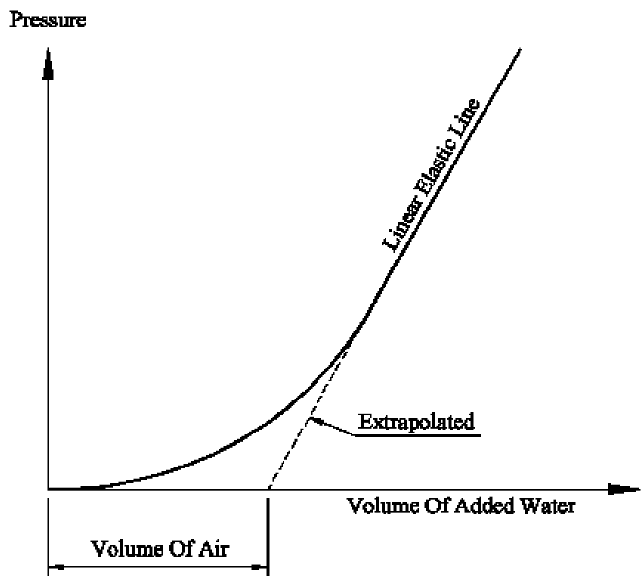

Figure 10-1 Determination of volume of air

10.10.3.12 Pressurisation of the submarine pipeline system shall be performed as a controlled operation with consideration for maximum allowable velocities in the inlet piping. The last 5% up to the test pressure shall be raised at a reduced rate to ensure that the test pressure is not exceeded. Time should be allowed for stabilisation before the test hold period begins, in particular when testing operation occurs directly post flooding/flushing of the pipeline system. Stabilisation time shall be based on the filling water temperature difference with ambient temperature and on the possible presence of thermal insulation.

10.10.3.13 Subject to agreement shorter pressure hold periods may be accepted for pipelines with test volumes less than 5000 m^3. In these cases the principles of [8.7] should apply.

10.10.3.14 The pressure and temperatures where relevant, shall be continuously recorded during the pressurisation, stabilisation and test hold periods.

10.10.3.15 Flanges, mechanical connectors etc. under pressure should be visually inspected for leaks during the pressure test, either directly or by monitors.

10.10.3.16 The pressure test is acceptable if the submarine pipeline system is free from leaks, and the pressure variation is within ± 0.2% of the test pressure.

A pressure variation up to an additional ±0.2% of the test pressure is normally acceptable if the total variation (i.e. ± 0.4%) can be documented to be caused by:

— temperature fluctuations not accounted for or
— tide in case the pressure is measured at a fixed elevation (fixed platform on onshore)
— if pressure variations greater than ± 0.4% of the test pressure are observed, the holding period shall be extended until a hold period with acceptable pressure variations has occurred.

Guidance note:

Corresponding criteria for flexible pipes are often less stringent. For a pipeline system comprising both rigid pipeline and flexible parts (e.g. flexible riser or flexible tail), an equivalent pressure variation criterion should be determined by weighing the criteria for the different parts w.r.t. the volume of water that they contain during the system pressure test.

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10.10.3.17 De-pressurisation of the submarine pipeline system shall be performed as a controlled operation with consideration for maximum allowable velocities in the pipeline and the discharge piping.

10.10.4 De-watering and drying

10.10.4.1 De-watering should be performed before introducing the product fluid into the pipeline. Drying may be required in order to prevent an increase in the corrosion potential or hydrate formation, or if omission of drying is deemed to have an adverse effect on the product transported.

10.10.4.2 In case the product fluid is introduced prior to de-watering the separation pig train between the test medium and the fluid shall be qualified in order to avoid contact between the residual test water and the product.

10.10.4.3 Selection of de-watering and drying methods and chemicals shall include consideration of any effect on valve and seal materials, any internal coating and trapping of fluids in valve cavities, branch piping, instruments etc.

10.10.5 Systems testing

10.10.5.1 Prior to fluid product filling, safety and monitoring systems shall be tested in accordance with accepted procedures. This includes testing of:

— corrosion monitoring systems
— alarm and shutdown systems
— safety systems such and pig trap interlocks, pressure protection systems etc.
— pressure monitoring systems and other monitoring and control systems
— operation of pipeline valves.

10.11 As-built survey

10.11.1 General

10.11.1.1 An as-built survey covering the complete submarine pipeline system shall be performed. The as-built survey shall be performed after all work on the submarine pipeline system, including crossings, trenching, gravel dumping, artificial back-fill, tie-in, riser installation, etc., are completed. The as-built survey of the installed and completed pipeline system is performed to verify that the completed installation work meets the specified requirements, and to document any deviations from the original design. The as-built survey shall include the corrosion protection system where potential damage to the coating and sacrificial anodes shall be documented.

10.11.1.2 The as-built survey should include the following in addition to the requirements for as-laid survey:

— out of straightness measurements as applicable
— depth of cover or trench depth as applicable
— location of areas of damage to pipeline, coating and anodes
— location of any areas with observed scour or erosion along pipeline and adjacent seabed

— verification that the condition of weight coating (or anchoring systems that provide for on-bottom stability) is in accordance with the specification
— description of wreckage, debris or other objects which may affect the cathodic protection system or otherwise impair the pipeline
— video documentation of the submarine pipeline system.

Guidance note:

The survey accuracy should reflect the requirements related to lay corridor, size of lay down target boxes, restrictions in design related to out of straightness (in particular for uneven seabed) or other aspects that may influence pipeline integrity.

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10.12 Documentation

10.12.1 General

10.12.1.1 The documentation of the offshore construction including testing of the submarine pipeline system shall be as a minimum include that given in Sec.12.

10.13 Installation manual

10.13.1 Installation manual

10.13.1.1 Installation manual is defined as a document or collection of documents required for performing the project specific installation work including normal operations and contingency handling/operations and acceptance criteria. In case the installation manual is a collection of documents, a master document shall be prepared.

Guidance note:

The installation manual is prepared in order to demonstrate that methods and equipment used by the contractor will meet specified requirements, and that the results can be verified. The installation manual will hence include all factors that influence quality, reliability and safety of the installation work, including normal and contingency situations, and will address all installation steps, including examinations and check points. The manual will reflect the results of the risk management studies performed for the installation and will state requirements for the parameters to be controlled and the allowable range of parameter variation during the installation.

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10.13.1.2 The installation contractor shall prepare an installation manual. In case several contractors are used, the installation manuals shall be harmonised. A master installation manual may be required

10.13.1.3 The installation manual shall be agreed between contractor and operator, and updated and revised as found necessary.

10.13.1.4 The installation manual shall contain documentation of fulfilment of all requirements in this section.

10.13.1.5 The installation manual shall include the following:

— quality system manual
— mobilisation manual
— construction manual
— health, safety and environment manual
— emergency preparedness manual.

10.13.1.6 The installation manual shall cover:

— organization, communications and reporting
— navigation and positioning, including anchors and anchor handling or dynamic positioning
— installation procedures, see [10.13.2]
— pre-commissioning procedures, see [10.13.3]
— contingency procedures, see [10.13.4]
— spread, including modifications and upgrading, if any
— pipeline configuration monitoring, positioning and control activities, including recording and reporting
— operating limit conditions imposed by environmental loads
— installation analyses including fatigue forming the basis for the operating limit conditions
— installation of in-line assemblies
— operations in areas of particular concern
— limitations imposed by structural strength in accordance with the design
— qualification of personnel
— essential variable including acceptable limits.

Guidance note:

Areas of particular concern may typically include shipping lanes, existing or future subsea installation, shore approach or crossings.

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Guidance note:

For towing operations the installation manualtypically include a description of towing vessel(s) including capacities, equipment and instrumentation.

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10.13.1.7 Essential variables and their acceptable limits shall be established for cases where variations in manner of performance of an activity may give undesirable results. Essential variables shall as minimum be established for:

— allowable variations in configuration control parameters where variations beyond established limits may cause critical conditions during installation
— variations in equipment settings/performance that can cause or aggravate critical conditions
— changes in welding joint design and process parameters beyond that allowed in App.C
— changes in NDT method, NDT equipment and NDT equipment calibration beyond that allowed in App.D and App.E
— weld repair lengths/depths in areas where the pipe is subject to bending moments/axial stress. The maximum length/depth of excavation shall be determined by stress analyses
— field joint coating procedure
— operating limit conditions
— any other requirement due to the nature of the operations.

10.13.1.8 The validity of the installation manual is limited to the lay-vessel/spread where the qualification was performed and to the pipeline or section of pipeline in question.

10.13.2 Installation procedures

10.13.2.1 The installation contractor shall prepare installation procedures. In case several contractors are used, the installation procedures shall be harmonised.

10.13.2.2 The installation procedures shall be agreed between contractor and operator, and updated and revised as found necessary.

10.13.2.3 The installation procedures shall describe the following:

— purpose and scope of the activity
— responsibilities
— materials, equipment and documents to be used
— how the activity is performed in order to meet specified requirements and acceptance criteria
— how the activity is controlled and documented.

10.13.2.4 The installation procedures shall cover all requirements in this section.

10.13.2.5 The following procedures shall be established:

— emergency procedures
— mobilisation procedures
— operational procedures covering all phases of installation work
— verification procedures
— welding and NDT equipment and procedures including repair
— pipe and equipment handling and lifting, hauling, stacking and storage procedures
— pipe tracking procedures
— pre-commissioning and commissioning procedures.

Guidance note:

Operational procedures may typically include configuration and alignment control, anchor handling, field joint coating, tensioning handling, ROV control, anode attachment, control of weight and buoyancy distribution, control of pipe rotations, installation of in-line assemblies, loading and spooling pipe onto the reel, pipe straightening and underwater operations.

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10.13.3 Pre-commissioning procedures

10.13.3.1 The installation contractor shall prepare pre-commissioning procedures. In case several contractors are used, the pre-commissioning procedures shall be harmonised.

10.13.3.2 The pre-commissioning procedures shall be agreed between contractor and operator, and updated and revised as found necessary.

10.13.3.3 The pre-commissioning procedures shall be prepared for the pre-commissioning activities of the submarine pipeline system, covering all testing activities that may be performed. The testing shall be conducted to verify that the submarine pipeline system meet the requirements of this standard. The pre-commissioning procedures shall contain sufficient detail to enable full understanding of testing methods and procedures, including acceptance criteria. It shall also provide references to relevant specifications, test plans and engineering documents applicable for the submarine pipeline system.

10.13.3.4 The pre-commissioning procedures shall state the type and extent of verification, testing, acceptance criteria, records, documentation and certification required for the components of the submarine pipeline system. It shall also provide references to relevant specifications, test plans and engineering documents applicable for the pipeline system.

10.13.4 Contingency procedures

10.13.4.1 The installation contractor shall prepare contingency procedures. In case several contractors are used, the contingency procedures shall be harmonised.

10.13.4.2 The contingency procedures shall be agreed between contractor and operator, and updated and revised as found necessary. For installation methods introducing plastic strains restrictions to potential contingency cyclic plastic loading shall be described.

10.13.4.3 Contingency procedures shall be prepared for all installation activities.

Guidance note:

Contingency procedures may typically include failure of dynamic positioning system, failure of anchors or anchor lines, coating repair, anode repair, failure of tensioning system, ROV breakdown, breakdown of positioning system, weather conditions in excess of operating limit conditions, third party marine activity and critical or emergency situations identified in FMEA or HAZOP studies.

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SECTION 11 OPERATIONS AND ABANDONMENT

11.1 General

11.1.1 Objective

11.1.1.1 This section provides minimum requirements for the safe and reliable operation of submarine pipeline systems for the whole service life with its main focus on the pipeline integrity management system and the pipeline integrity management process.

11.1.1.2 Recommended practice for integrity management of submarine pipeline systems is given in DNVGL-RP-F116.

11.1.1.3 Specific guidance on integrity management on pipe-in-pipe systems is given in [13.6.7].

11.1.2 Scope and application

11.1.2.1 The integrity management system comprises a core integrity management process and a number of support elements (see Figure 11-1 and [11.3.1]).

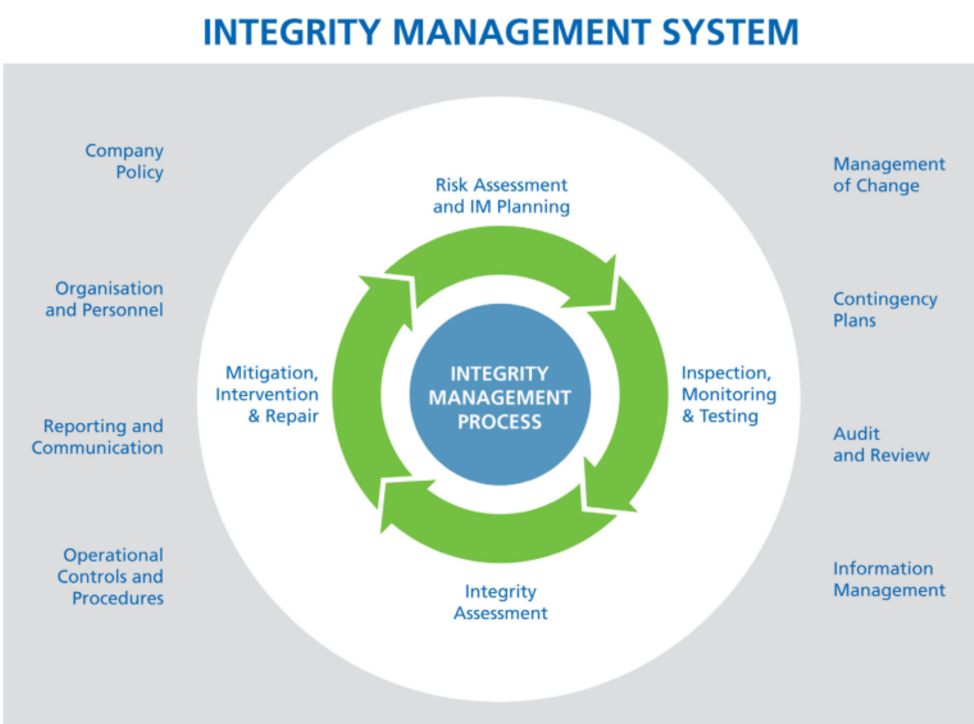

Figure 11-1 Integrity management system

11.1.2.2 The core pipeline integrity management process is the combined process of threat identification, risk assessment, planning, monitoring, inspection, maintenance, etc. to maintain pipeline integrity.

11.1.2.3 Operating safely is interpreted as operating to meet the limit state criteria as established in design and updated through the project phases and service life.

11.1.2.4 The PIM principles and methodology are applicable to pipeline systems in general.

11.1.3 Systematic review of risks

11.1.3.1 The overall requirement to systematic review of risks in Sec.2 is complied with through the risk assessment and integrity management (IM) planning activity that is part of the integrity management process – see [11.1.2.2] and [11.4.2]. The pipeline system threats shall be established (see DNVGL-RP-F116 Table 4-1) and the risk for each threat determined. The risk assessment contributes to ensuring that the safety level premised in the design phase is maintained throughout the original design life of the pipeline system.

11.1.4 Responsibilities

11.1.4.1 Pipeline integrity management is the responsibility of the pipeline operator. The pipeline operator shall ensure that the integrity of the pipeline is not compromised.

11.1.4.2 At all times during the operational life of the pipeline system, responsibilities shall be clearly defined and allocated.

11.1.5 Authority and pipeline operator requirements

11.1.5.1 The relevant national requirements shall be identified and complied with.

11.1.5.2 The relevant company requirements should be complied with when developing, implementing and maintaining the integrity management system.

11.1.6 Safety philosophy

11.1.6.1 The safety philosophy adopted in design shall apply. The original safety philosophy may be modified as a result of company/operator, industry and society developments, improvements and better knowledge of the pipeline system.

A change in the basis for design requires a re-qualification (see [11.5]) and/or a management of change program.

11.1.6.2 It shall be verified that design and operating premises and requirements are fulfilled. If this is not the case, appropriate actions shall be taken to bring the pipeline system back to a safe condition.

11.1.6.3 A risk based pipeline integrity management philosophy, which takes into account both probability of failure and consequence of failure, shall be applied.

11.2 Commissioning

11.2.1 General

11.2.1.1 Commissioning comprises activities associated with the initial filling of the pipeline system with the fluid to be transported, and should be part of the operational phase. Requirements pertaining to documentation and procedures for commissioning are specified in [12.5].

11.2.1.2 This sub-section shall also apply for pipeline re-commissioning.

11.2.2 Fluid filling

11.2.2.1 During fluid filling, care shall be taken to prevent explosive mixtures and, in the case of gas or condensate, to avoid hydrate formation. The injection rate shall be controlled so that pressure and temperature do not exceed allowable limits (as given in design or re-qualification) for the pipeline material or dew point conditions.

11.2.3 Operational verification

11.2.3.1 Following commissioning of the system, it shall be verified that the operational limits are within design conditions. Important issues that may need verification can be:

— flow parameters (pressure, temperature, dew point conditions, hydrate formation sensitivity, sand production, chemical injection, etc.)
— CP-system
— expansion, movement, lateral snaking/buckling, upheaval buckling, free span and exposure.

11.2.3.2 Scheduling of the first inspection of the wall thickness for pipelines designed for inspection pigging shall be evaluated based on the:

— corrosivity of the fluid
— expected operational parameters
— robustness of the internal corrosion protection system (inhibitor system)
— corrosion allowance used in the design
— effectiveness of the QA/QC system applied during fabrication and construction, and
— defect sizing capabilities of the inspection tool that will be used during operation of the pipeline.

11.3 Integrity management system

11.3.1 General

11.3.1.1 The operator shall establish, implement and maintain an integrity management system which includes the following elements as a minimum (see Figure 11-1):

— company policy
— organisation and personnel
— management of change
— operational controls and procedures
— contingency plans
— reporting and communication

— audit and review
— information management
— the integrity management process (see [11.4]).

The integrity management system shall in addition satisfy the requirements from:

— the specific pipeline systems' design documentation and safety philosophy
— the relevant authorities (see [11.1.5]) and the operating company itself
— other relevant external stakeholders.

The core of the integrity management system is the integrity management process. The other elements support this core process.

11.3.1.2 Documents for the operational phase are specified in Sec.12.

11.3.1.3 Specification of work processes should be the basis for establishing procedures.

11.3.1.4 The detailed procedures for operation, inspection and repair shall be established prior to start-up of operation.

11.3.1.5 Procedures covering non-routine or special activities, shall be prepared as required, e.g. for major repairs, modifications, etc.

11.3.2 Pipeline operator policy

11.3.2.1 The pipeline operator policy for pipeline integrity management should set the values and beliefs that the pipeline operator holds, and guide people in how these shall be realized.

11.3.3 Organisation and personnel

11.3.3.1 The roles and responsibilities of personnel involved with integrity management of the pipeline system shall be clearly defined.

11.3.3.2 The interface between the responsibilities of the different organisational units is particularly important. Such interfaces shall be managed and important areas that need to be handled are:

— battery limits
— government regulatory responsibilities and statutory regulations
— emergency response, including contingency planning and responding to emergencies.

11.3.3.3 Training needs shall be identified and training shall be provided for relevant personnel in relation to management of pipeline integrity.

11.3.4 Management of change

11.3.4.1 Modifications of the pipeline system shall be subject to a management of change procedure that shall address the continuing safe operation of the pipeline system. Documentation of changes and communication to those who need to know is essential.

11.3.4.2 If the operating conditions are changed relative to the design premises, a re-qualification of the pipeline system according to [11.5] shall be carried out.

11.3.5 Operational controls and procedures

11.3.5.1 Relevant operational controls and procedures shall be established, implemented and maintained. Typical operational controls and procedures are:

— start-up, operating and shutdown procedures
— procedures for handling non-conformances
— instructions for cleaning and other maintenance activities
— corrosion control activities
— inspection and monitoring activities
— procedures for operating safety equipment and pressure control systems.

11.3.5.2 Measures shall be in place to ensure that critical fluid parameters are kept within the specified design limits. As a minimum, the following parameters should be controlled or monitored:

— pressure and temperature at the inlet and outlet of the pipeline
— dew point for gas lines
— fluid composition, water content, flow rate, density and viscosity.

11.3.5.3 All safety equipment in the pipeline system, including pressure control and over-pressure protection devices, emergency shutdown systems and automatic showdown valves, shall be periodically tested and inspected. The purpose it to verify the integrity of the safety equipment and that the equipment can perform the safety function as specified.

11.3.5.4 Safety equipment in connecting piping systems shall be subject to regular testing and inspection.

11.3.5.5 For pressure control during normal operation, see [3.4.2].

11.3.5.6 Operational control shall ensure that design temperature limits are not exceeded. If the design is based on a constant temperature along the whole route, control of the inlet temperature will be sufficient. If the design is based on a temperature profile for the pipeline, additional measures may be required.

11.3.6 Contingency plans

11.3.6.1 Plans and procedures for emergency situations shall be established and maintained based on a systematic evaluation of possible scenarios. Dependent upon the commercial criticality of the pipeline system, plans and procedures for contingency repair of the pipeline should also be established.

11.3.7 Reporting and communication

11.3.7.1 A plan for reporting and communication to employees, management, authorities, customers, public and others shall be established, implemented and maintained. This covers both regular reporting and communication, and reporting in connection with changes, special findings, emergencies, etc.

11.3.8 Audit and review

11.3.8.1 Audits and reviews of the pipeline integrity management system shall be conducted regularly.

11.3.8.2 Typical focus in the reviews should be on:

— effectiveness and suitability of the system
— improvements to be implemented.

11.3.8.3 Typical focus in the audits should be on:

— compliance with regulatory and pipeline operator requirements
— rectifications to be implemented.

11.3.9 Information management

11.3.9.1 A system for collection of historical data, an in-service file, shall be established and maintained for the whole service life, see [12.1.1.3] and [12.6.2.1]. The in-service file will typically consist of documents, data files and databases.

11.3.9.2 The in-service file, together with the DFI-resume, shall be the basis for future integrity management planning.

11.3.9.3 The in-service file and the DFI-resume shall be easily retrievable in case of an emergency situation.

11.3.9.4 The documents, data and information shall be managed as described in [12.6] and [12.9].

11.4 Integrity management process

11.4.1 General

11.4.1.1 The integrity management process consists of the following steps (see Figure 11-1):

— Risk assessment and IM planning – includes threat identification, risk assessment, long term and short term (annual) planning.
— Inspection, monitoring and testing – includes planning, conducting and documentation of such activities.
— Integrity assessment - carried out using recognized methods and based on design data, operational experience and the results from inspection, monitoring and testing.
— Mitigation, intervention and repair - assess the need for, and the type of, intervention and repair activities and other mitigating actions.

This process shall be performed regularly.

11.4.1.2 The requirements for corrosion inspection and monitoring, and the capability of optional techniques, shall be evaluated at an early stage of the pipeline system design.

Guidance note:
Pipelines manufactured from corrosion resistant alloys (CRA) do not normally require inspection and monitoring of internal corrosion.

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11.4.1.3 Preliminary development of strategies for inspection, monitoring, testing and repair should start during the concept development phase. The strategies should be finalized after construction.

11.4.1.4 All the inspection, monitoring and testing requirements identified during the design phase that affects the safety and reliability during operation shall be covered in the inspection, monitoring and testing program, see [3.4.1] and [5.2.3].

11.4.1.5 A special investigation shall be performed in case of any event which impairs the safety, reliability, strength or stability of the pipeline system. This investigation may initiate further inspections.

11.4.1.6 If mechanical damage or other abnormalities are detected during the periodic inspection, a proper evaluation of the damage shall be performed. This may include additional inspections.

11.4.2 Risk assessment and integrity management planning

11.4.2.1 Different risk assessment methods can be used. Risk can be evaluated using qualitative and/or quantitative methods as most feasible. A levelled approach for assessing risk uses a combination of qualitative and quantitative methods. This levelled approach is described in more detail in DNVGL-RP-F116. The results from the risk assessment shall be used to develop a long term integrity management program. Specific requirements related to the activities in the integrity management program can be found in [11.4.3] to [11.4.5].

11.4.2.2 The risk assessment should be based on:

— data from design and commissioning
— previous risk assessments
— condition assessment results
— operational history (pressure, temperature, flow rate, fluid composition, etc.).

11.4.2.3 Threats shall be systematically identified, assessed and documented throughout the operational lifetime. This shall be carried out for each section along the pipeline and for components. Examples of typical threats are:

— internal corrosion
— external corrosion
— free-spans
— buckles
— impact damage.

A more detailed list of threats and related damage/anomalies can be found in DNVGL-RP-F116.

11.4.2.4 A long term inspection program reflecting the overall safety objective for the pipeline shall be established, and shall be maintained/updated on a regular basis. The long term inspection program shall be based on the risk assessment. In addition the following should be taken into consideration:

— consequence of failure
— likelihood of failure
— strategies for inspection, monitoring, testing and repair
— available inspection, monitoring and testing methods.

11.4.2.5 The long term inspection program shall cover the entire pipeline system according to the operators' equipment scope. This includes the pipeline, protective means ensuring the structural integrity of the pipeline system and all the components according to the definitions [1.8.2], [D.2.1.5] and [5.6].

11.4.3 Inspection, monitoring and testing

11.4.3.1 A pipeline configuration survey is a survey to determine the position, configuration and condition of the pipeline and its components.

11.4.3.2 The start-up external inspections should be completed within one year from start of production, see [11.2.3]. In case of significant increase in temperature, pressure or flow rate after this first inspection, the need for additional inspections should be considered.

11.4.3.3 A detailed external inspection plan including specifications for the inspections shall be prepared for each survey. The detailed inspection plan should be updated based on previous inspections as required.

11.4.3.4 Pipeline systems that are temporarily out of service shall also be subject to periodical survey.

11.4.3.5 External inspections shall be carried out to ensure that the design requirements remain fulfilled and that no damage has occurred. The inspection program should, as a minimum, address:

— exposure and burial depth of buried or covered lines, if required by design, regulations or other specific requirements
— free spans including mapping of length, height and end-support conditions
— condition of artificial supports installed to reduce free spans
— local seabed scour affecting the pipeline integrity or attached structures
— trawl or anchor scars in the seabed close to or, if the pipeline is buried, across the pipeline
— sand wave movements affecting the pipeline integrity
— excessive pipe movements including expansion effects
— identification of areas where upheaval buckling or excessive lateral buckling has taken place
— integrity of mechanical connections and flanges
— integrity of subsea valves including protective structures
— Y- and tee connections including protective structures
— settlement of exposed pipelines, particularly at the valve/tee locations
— the integrity of pipeline protection covers (e.g. mattresses, covers, sand bags, gravel slopes, etc.)
— mechanical damage to pipe, coating and anodes
— major debris on, or close to, the pipeline that may cause damage to the pipeline or the external corrosion protection system
— leakage.

11.4.3.6 The frequency of future external inspections shall be determined based upon an assessment of:

— authority and company requirements
— degradation mechanisms and failure modes
— likelihood and consequences of failure
— results from previous inspections
— changes in the operational parameters
— re-qualification activities and results
— repair and modifications
— subsequent pipelay operation in the vicinity.

11.4.3.7 Critical sections of the pipeline system vulnerable to damage or subject to major changes in the seabed conditions i.e. support and/or burial of the pipeline, shall be inspected externally at short intervals, normally on an annual basis. The remaining sections should also be inspected, ensuring a full coverage of the entire pipeline system within a suitable period determined based on the risk assessment.

11.4.3.8 In the splash zone and atmospheric zone damaged and/or dis-bonded coating can cause severe corrosion damage.

11.4.3.9 In the splash and atmospheric zones, visual examination of the coating shall be performed in order to assess the need for preventive maintenance. Besides visual indications of direct damage to the coating, effects such as rust discoloration and bulging or cracking of the coating are indicative of rust underneath the coating. Coating systems which prevent close inspection of corrosion underneath the coating shall require special consideration.

11.4.3.10 In the submerged zone, coating damage is not critical with respect to external corrosion unless it is combined with a deficiency in the cathodic protection system. For materials susceptible to HISC refer to DNVGL-RP-F112.

11.4.3.11 To a large extent, inspection of external corrosion protection of pipelines with sacrificial anodes can be limited to inspection of the condition of anodes. Excessive anode consumption is indicative of coating deficiencies, except close to platforms, templates and other structures where current drain may lead to premature consumption of adjacent pipe anodes.

11.4.3.12 Potential measurements on anodes, and at any exposed bare pipe metal, may be carried out to verify adequate protection. Electric field gradient measurements in the vicinity of anodes may be used for semi-quantitative assessments of anode current outputs.

11.4.3.13 For pipelines with impressed current cathodic protection systems, measurements of protection potentials shall, as a minimum, be carried out at the locations closest to, and most remote from, the anode(s).

11.4.3.14 A survey of the external corrosion protection system should be carried out within one year of installation.

11.4.3.15 In-line inspection is carried out in order to confirm the integrity of the pipeline system, primarily by means of in situ wall thickness measurements.

Guidance note:

Un-piggable pipelines are subject to separate evaluations and alternative methods.

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11.4.3.16 An in-line inspection should be carried out with a carrier tool (inspection pig) capable of inspecting the internal and external surface of the pipeline along its full circumference and length, or a critical part thereof.

11.4.3.17 The technique for detection of internal and/or external corrosion shall be selected based on considerations of fluid, linepipe material, diameter and wall thickness, expected form of damage, and requirements to detection limits and defect sizing capability. The latter shall be determined based on pipeline design and operational parameters.

11.4.3.18 Candidate operators of inspection tools should be required to document the capability of their systems with respect to detection limits and sizing of relevant corrosion defects (including localised corrosion at girth welds) for the pipe dimensions considered.

11.4.3.19 The frequency of in-line inspections shall be determined based on factors such as:

— authority and pipeline operator requirements
— likelihood and consequences of failure
— potential corrosivity of fluid
— potential for development of external corrosion at hot-spots such as riser(s) and landfall/onshore pipeline sections
— detection limits and accuracy of inspection system
— results from previous surveys and monitoring
— changes in pipeline operational parameters, etc.

See also [11.2.3].

11.4.3.20 Inspection by special internal tools may be used to detect external corrosion of pipelines in all three zones (atmospheric/splash/submerged).

11.4.3.21 The objective of monitoring internal corrosion is to confirm that the fluid remains non-corrosive or, more often, to assess the efficiency of any corrosion preventive measures, and accordingly to identify requirements for inspection of corrosion.

11.4.3.22 Corrosion monitoring as defined above does not normally give any quantitative information of critical loss of wall thickness. Although monitoring may be carried out as actual wall thickness measurements in a selected area, it cannot replace pipeline inspection schemes that cover the pipeline system, or sections thereof, in its full length and circumference. On the other hand, inspection techniques for internal corrosion are not normally sensitive enough to replace monitoring.

11.4.3.23 The following major principles of corrosion monitoring may be applied:

- fluid analyses; i.e. monitoring of fluid physical parameters and sampling of fluid for chemical analysis of corrosive components, corrosion retarding additions or corrosion products
- corrosion probes; i.e. weight loss coupons or other retrievable probes for periodic or on-line determination of corrosion rates
- in-situ wall thickness measurements, i.e. repeated measurements of wall thickness at defined locations using portable or permanently installed equipment.

11.4.3.24 Techniques and equipment for corrosion monitoring shall be selected based upon:

- monitoring objectives, including requirements for accuracy and sensitivity
- fluid corrosivity and the corrosion preventive measures to be applied
- potential corrosion mechanisms.

11.4.3.25 A typical major objective of corrosion monitoring is to detect changes in either intrinsic corrosivity of the fluid, or in the efficiency of the corrosion prevention measures. For pipelines carrying dry (i.e. fully processed) gas, inspection of internal corrosion may be postponed provided that monitoring demonstrates that no corrosive liquids have entered the pipeline, or been formed by condensation downstream of the inlet.

Testing

11.4.3.26 Testing activities may be specified to be carried out during the operational phase. Such activities shall be planned, executed, reviewed and documented. Testing activities may comprise:

- system pressure testing
- hydrostatic testing
- gas or media testing
- shut-in testing.

Recommended practice for testing during operation is given in DNVGL-RP-F116.

11.4.4 Integrity assessment

11.4.4.1 Pipeline systems with unacceptable damage/anomalies may be operated temporarily under the design conditions or reduced operational conditions until the defect has been removed or repair has been carried out. It shall, however, be documented that the pipeline integrity and the specified safety level is maintained, which may include reduced operational conditions and/or temporary precautions.

11.4.4.2 When a potentially unacceptable damage or abnormality is detected, an evaluation shall be carried out including:

- quantify details of the damage/abnormality
- identify the root cause
- evaluate accuracy and uncertainties in the inspection results.

If the damage/abnormality is not acceptable, then further evaluations can include:

- options for continued operation of the pipeline system
- repair methods.

11.4.4.3 In each case a thorough evaluation of the damage/abnormality and the impact on safety and reliability for the operation of the pipeline shall be performed. The requirements given in the following sections regarding necessary actions, e.g. grinding or replacement, may be waived if it can be documented that the specified safety level for the pipeline system is not impaired.

11.4.4.4 Damage or abnormalities that affect the safety or reliability of the pipeline shall either be removed by replacing the damaged section of the pipe or repaired by local reinforcement. Alternatively, the pipeline may be permanently re-qualified to lower operational conditions, see [11.5] and Sec.5, e.g. reduced pressure, which may remove the requirement for repair.

11.4.4.5 Recommended practice for free spanning pipelines is given in DNVGL-RP-F105.

11.4.4.6 If the design is based on controlled global buckling including plastic strains, the pipeline should be verified based on established design limits and conditions (curvatures, strains, bending moment). If unexpected global buckling occurs, utilisation of the pipeline should be evaluated based on relevant failure modes. Recommended practice for global buckling of submarine pipelines is given in DNVGL-RP-F110.

11.4.4.7 Sharp defects like grooves, gouges, and notches should preferably be removed by grinding or other agreed repair methods. For a grinded defect where all the sharp edges are confirmed removed, the defect can be regarded as a smooth metal loss defect, see [11.4.4.8].

11.4.4.8 Metal loss defects caused by e.g. corrosion, erosion, or grind repair shall be checked for capacity. Recommended practice for corroded pipelines is given in DNVGL-RP-F101.

11.4.4.9 A dent is defined as a depression which produces a gross disturbance in the curvature of the pipe wall. For dent acceptance criteria, see [5.4.11].

11.4.5 Mitigation, intervention and repairs

11.4.5.1 Examples of mitigation, intervention and repairs are:

— mitigation:
  — restrictions in operational parameters (pressure, temperature, flow rate, fluid composition, etc.)
  — use of chemical injections
— intervention:
  — rock dumping
  — installation of pipeline protection
  — trenching
— repairs:
  — local reinforcement (clamps, etc.)
  — replacement of pipeline parts.

All mitigation, intervention and repairs shall be documented.

11.4.5.2 Repair and modification shall not reduce the safety level of the pipeline system below the specified safety level.

11.4.5.3 All repairs shall be carried out by qualified personnel in accordance with agreed specifications and procedures, and be up to the standard defined for the pipeline.

11.4.5.4 All repairs shall be tested and inspected by experienced and qualified personnel in accordance with agreed procedures. NDT personnel, equipment, methods, and acceptance criteria shall be agreed upon in accordance with App.D.

11.4.5.5 Depending upon the condition of the damage, a temporary repair may be accepted until the permanent repair can be carried out. If a temporary repair is carried out, it shall be documented that the pipeline integrity and safety level are maintained either by the temporary repair itself or in combination with other precautions.

11.4.5.6 Recommended practice for pipeline repair in general is given in DNVGL-RP-F113.

11.4.5.7 A dent affecting a weld can result in cracks, and removal of the damaged portion of the pipe should be considered. The damaged part can be cut out as a cylinder and replaced. Alternatively it can be repaired by installing a grouted repair clamp, a full encirclement welded split sleeve or bolted clamp which is designed to take the full internal operating pressure.

11.4.5.8 Prior to carrying out a permanent repair of any leak, the cause of the leak shall be established.

11.4.5.9 The most suitable method for repairing a leak in the pipe depends upon e.g. the pipe material, pipe dimensions, location of leak, load conditions, pressure and temperature. The following repair methods may be used:

— The damaged section is cut out of the pipe as a cylinder and a new pipe spool is installed by welding or by the use of a mechanical connector.
— Clamps are installed, and the required tightness is obtained by welding, filler material, friction or other qualified mechanical means.

11.4.5.10 Leaking flanges and couplings may be sealed by installing a seal clamp covering the leaking flange or coupling, increasing the bolt pre-load, or replacing gaskets and seals. Prior to increasing the pre-load in bolts, it shall be documented by calculation that no over-stressing can occur in bolts, flange or gasket/seals. If the pre-load in the bolts is removed, e.g. due to a gasket replacement, new bolts shall be used for the flange connection.

11.4.5.11 All repair clamps, sleeves, pipe spools and mechanical connectors shall be qualified prior to installation and leak tested after installation.

11.4.5.12 Procedures for repair welding, welding equipment and welders shall be qualified as described in App.C.

11.4.5.13 Repair welding above water shall be carried out as described in App.C.

11.4.5.14 Underwater welding shall be carried out in a dry habitat, see App.C.

11.4.5.15 Repair welding may, in special cases, be carried out on pipelines during operation, dependent on the pipe material, pipe wall thickness, fluid type, pressure and temperature. It shall be documented that the safety for carrying out the repair is acceptable, and a safety procedure shall be established and implemented.

11.4.5.16 All repair welds shall be subject to visual inspection and non-destructive testing, see App.D. Following the repair, pressure testing may be required for the repaired section.

11.5 Re-qualification

11.5.1 General

11.5.1.1 The purpose of this section is to define re-qualification and to give requirements for re-qualification of pipeline systems.

11.5.1.2 Re-qualification is a re-assessment of the design under changed design conditions.

11.5.1.3 A re-qualification may be triggered by a change in the original design basis, by not fulfilling the design basis, or by mistakes or shortcomings discovered during normal or abnormal operation. Possible causes may be:

- preference to use a more recent standard, e.g. due to requirements for higher utilisation for existing pipelines
- change of the premises such as:
  - environmental loads
  - deformations
  - scour
- change of operational parameters such as:
  - pressure or temperature
  - fluid composition, water content, H_2S-content
  - operating cycles
- change of flow direction of change of fluid
- deterioration mechanisms having exceeded the original assumptions such as:
  - corrosion rate (internal or external)
  - dynamic responses contributing to fatigue, e.g. VIV, start/stop cycles
- extended design life
- discovered damage such as:
  - dents
  - damage to pipeline protection
  - weld defects
  - corrosion related defects
  - cracks
  - consumption or damage to anodes.

11.5.2 Application

11.5.2.1 Within the original design life, and without essential changes in the manner of employment (repair, etc.), the standard under which the pipeline was built may apply when considering incidents, minor modifications or rectification of design parameters exceeded during operation. Alternatively, this standard and associated DNV GL standards or recommended practices may be used.

11.5.2.2 For major modifications or other instances not covered by the above paragraph this standard shall apply. For lifetime extensions, see also ISO 12747, NORSOK Y-002 and NORSOK U-009.

11.5.2.3 The same safety level shall apply for lifetime extensions of an existing pipeline as would apply for the design of a new pipeline. The reason for requiring use of this standard is in case the original standard used for design is less stringent than necessary to meet the target safety levels specified in this standard.

11.5.3 Safety level

11.5.3.1 A target safety level as defined in [2.3.5] shall apply for a re-qualification assessment.

11.5.3.2 Operational experience, e.g. change of operational conditions, inspection records and modifications, shall be considered in a re-qualification assessment.

11.5.4 System pressure test

11.5.4.1 System pressure testing may be required when:

— the original mill pressure test or system pressure test does not satisfy requirements according to this standard at the new design pressure
— a significant part of the pipeline has not been system pressure tested, e.g. new pipeline section as part of a modification or repair campaign (for omission of system pressure test, see [5.2.2.3]).

11.5.5 Deterioration

11.5.5.1 All relevant deterioration and damage mechanisms shall be evaluated. Typical mechanisms are:

— corrosion:
    — external corrosion
    — internal corrosion
— erosion
— accidental loads
— development of free spans
— fatigue
— settlement.

11.5.5.2 Sufficient reliability or safety measures shall be applied to account for the accuracy and uncertainties in the inspection results.

11.5.5.3 Accumulated damage experienced prior to the re-qualification shall be included in the evaluation.

11.5.6 Design criteria

11.5.6.1 The parameters that trigger the re-qualification and the implication of changes in these parameters on different design conditions shall be clearly identified and documented. For re-design based on these design conditions, see Sec.5.

11.6 De-commissioning

11.6.1 General

11.6.1.1 De-commissioning is the set of activities associated with taking the pipeline temporarily out of service.

11.6.1.2 Pipeline de-commissioning shall be planned and prepared.

11.6.1.3 De-commissioning shall be conducted and documented in such a way that the pipeline can be re-commissioned and put into service again.

11.6.1.4 A de-commissioning evaluation shall at least include the following aspects:

— relevant national regulations
— environment, especially pollution

— obstruction for ship traffic
— obstruction for fishing activities
— corrosion impact on other structures.

11.6.1.5 De-commissioned pipelines shall be preserved to reduce the effect of degradation mechanisms.

11.6.1.6 Sub-section [11.2] shall apply for pipeline re-commissioning.

11.7 Abandonment

11.7.1 General

11.7.1.1 Abandonment of a pipeline system comprises the activities associated with taking the system or part of the system permanently out of operation.

11.7.1.2 An abandoned pipeline is not intended to be returned to operation.

11.7.1.3 Pipeline abandonment shall be planned and prepared.

11.7.1.4 A pipeline abandonment evaluation shall at least include the following aspects:

— relevant national regulations
— health and safety of personnel, if the pipeline shall be removed
— environment, especially pollution
— obstruction for ship traffic
— obstruction for fishing activities
— corrosion impact on other structures.

SECTION 12 DOCUMENTATION

12.1 General

12.1.1 Objective

12.1.1.1 This section specifies the minimum requirements to documentation needed for design, manufacturing/fabrication, installation, operation and abandonment of a pipeline system.

12.1.1.2 A design fabrication installation (DFI) resumé, as described in [12.8], shall be established with the main objective being to provide the operations organisation with a concentrated summary of the most relevant data from the design and construction (incl. pre-commissioning) phases (see [12.2], [12.3] and [12.4]).

12.1.1.3 An in-service file containing all relevant data achieved during the operational phase of the pipeline system and with the main objective to systemise information needed for integrity management and assessment of the pipeline system shall be established and maintained for the whole service life (see [12.6.2]).

12.1.1.4 For the design, fabrication and installation phase, all required documentation shall be reflected in a master document register (MDR).

12.1.1.5 The required documentation for all phases of the pipeline system’s lifetime shall be submitted to the relevant parties for acceptance or information as agreed.

12.1.1.6 Recommended practice for technical documentation required for assemblies, equipment, components and materials that are delivered as part of a subsea (or pipeline) contract is given in DNVGL-RP-O101.

12.2 Design

12.2.1 Structural

12.2.1.1 A design basis for the pipeline system shall be established, including, but not limited to:

- safety objective
- pipeline system description incl. location, general arrangements, battery limits, inlet and outlet conditions
- functional requirements including field development restrictions, e.g. safety barriers and subsea valves
- requirements to repair and replacement of pipeline sections, valves, actuators and fittings
- project plans and schedule, including planned period of the year for installation
- design life including specification of start of design life, e.g. installation, final commissioning, etc.
- transport capacity and pipeline sizing data
- attention to possible code breaks in the pipeline system
- geometrical restrictions such as specifications of constant internal diameter, requirement for fittings, valves, flanges and the use of flexible pipe
- pigging requirements such as bend radius, pipe ovality and distances between various fittings affecting design for pigging applications
- relevant pigging scenarios (inspection and cleaning)
- pigging fluids to be used and handling of pigging fluids in both end of pipeline including impact on process systems
- topographical and bathymetrical conditions along the intended pipeline route

— geotechnical conditions
— environmental conditions
— operational conditions such as pressure, temperature, fluid composition, flow rate, sand production etc. including possible changes during the pipeline system's design life
— principles for strength and in-place analysis
— corrosion control philosophy
— second and third party activities.

12.2.1.2 The purpose of the design documentation is to ensure a reliable pipeline system. The design shall be adequately documented to enable second and/or third party verification. As a minimum, the following items shall be addressed:

— pipeline routing
— physical and chemical characteristics of fluid
— materials selection
— temperature/pressure profile and pipeline expansion
— strength analyses for riser and riser supports
— all relevant strength and in-place stability analyses for pipeline
— relevant pipeline installation analysis
— risk analysis as applicable
— systematic review of threats in order to identify and evaluate the consequences of single failures and series of failures (see [2.2.3])
— corrosion control (internal and external)
— piggability
— installation and commissioning.

12.2.1.3 Drawings shall be provided for the fabrication and installation of the pipeline system, including but not limited to:

— pipeline route drawings including information on, e.g. seabed properties and topology, existing and future platforms, pipelines/cables, subsea well heads, ship lanes, etc.
— alignment sheets
— detailed pipeline crossing drawings
— platform layout drawings with risers, riser protection systems, loading zones, boat landing areas, rescue areas, etc. as applicable
— spool fabrication drawing
— other components within the pipeline system (connectors, pigging loops etc.)
— pipeline protection drawings
— riser and riser clamp fabrication drawings
— land ownership details.

12.2.2 Material selection

12.2.2.1 The selection of materials during conceptual and/or detailed design shall be documented, preferably in a materials selection report in accordance with ISO 21457, section 5.

The documentation shall refer to the requirements and recommendations of Sec.6, including

— use of CRAs,
— corrosion allowance and
— provisions for internal corrosion control.

The design premises for materials selection should be identified, making reference to the design basis and any other relevant project documents, together with the applicable standards and recommended practices.

12.2.2.2 Any requirements and conditions on pipeline fabrication and operational procedures used as the basis for materials selection shall be duly high-lighted in the document to ensure that they are adequately transferred into these phases of the pipeline.

Guidance note:

The internal corrosion control of pipelines carrying potentially corrosive fluids based on chemical treatment is much based on conditions for periodic cleaning, corrosion monitoring and inspection of the integrity of the pipeline which are not always defined in the project design basis and need to be verified by the operator of the pipeline.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

12.2.2.3 The following shall be prepared as separate documents in detailed design:

— specification of line pipe material,
— specification of pipeline components (including fasteners),
— specification of pipe coatings (including line pipe coating, field joint coating and any concrete coating),
— cathodic protection design report
— anode manufacture specification and
— anode installation specification.

12.2.3 Linepipe and pipeline components (including welding)

12.2.3.1 The following documentation shall be established:

— material manufacturing specifications
— welding and NDT specifications
— material take off/data sheets.

12.2.4 Corrosion control systems and weight coating

12.2.4.1 The following documentation shall be established, as applicable:

— cathodic protection design report, see [6.4.5.8]
— anode manufacturing and installation specifications, see. [9.4] and [9.5]
— outline anode drawings
— linepipe coating application specifications
— field joint coating specification(s)
— coating field repair specification(s)
— concrete coating specification (if applicable)
— corrosion monitoring system specification
— material take off/data sheets.

The cathodic protection design report shall pay attention to the landfall section (if any) and possible interaction with the relevant onshore CP-system.

12.2.5 Installation

12.2.5.1 The following documentation shall be established:

— failure mode effect analysis (FMEA) and HAZOP studies (see Sec.10)
— installation and testing specifications and drawings
— welding procedure qualification (WPQ) records.

12.2.6 Operation

12.2.6.1 Decisions and parameters having an impact on the operational phase of the pipeline system such as:

— operation envelope
— external and internal inspection strategies incl. piggability, ROV surveys
— measuring points for in-situ wall thickness measurements, ER-probes, weight loss coupons, fluid monitoring etc.

shall be emphasised and documented in design.

12.2.6.2 As a minimum, the following documentation shall be established:

— pipeline integrity management strategy covering strategies for corrosion control, inspection and maintenance
— emergency response strategy
— emergency repair contingency strategy.

12.2.7 DFI-resumé

12.2.7.1 The design part of the DFI-resumé shall be established and in accordance with the requirements given in [12.8].

12.3 Construction - manufacturing and fabrication

12.3.1 Linepipe and pipeline component

12.3.1.1 The documentation to be submitted for review prior to start or during start-up of manufacturing shall include, but not be limited to:

— quality plan (QP)
— manufacturing procedure specifications (MPS) including test requirements and acceptance criteria
— manufacturing procedure qualification test (MPQT) results
— manufacturing procedures (e.g. hydrostatic testing, dimensional measurements, mechanical and corrosion testing etc.)
— welding procedure specifications (WPS), including procedures for repair welding
— welding procedure qualification (WPQ) records
— non-destructive testing (NDT) procedures
— personnel qualification records (e.g. for welders and NDT operators)
— manufacturer's/fabricator's quality system manual.

12.3.1.2 The as built documentation to be submitted after manufacturing shall include, but not be limited to:

— quality control (QC) procedures
— inspection and test plan (ITP)
— traceability procedure
— material certificates
— manufacturing procedure specifications (MPS) including test requirements and acceptance criteria
— results from MPQT
— test procedures (e.g. hydrostatic testing, dimensional measurements, mechanical and corrosion testing etc.)

- mechanical test reports
- hydrostatic testing report
- weld log records
- consumable batch numbers
- welder certificates
- heat treatment records
- NDT procedures and records
- NDT operator certificates
- dimensional reports
- equipment calibration certificates/reports
- storage procedures
- release certificates
- pipe tally sheet
- complete statistics of chemical composition, mechanical properties and dimensions for the quantity delivered.

12.3.2 Corrosion control system and weight coating

12.3.2.1 The documentation to be submitted for review prior to start of manufacturing shall include, but not be limited to:

- application/manufacturing procedure specification, including inspection/test requirements and acceptance criteria, repairs, documentation, etc.
- documentation of materials and concrete mix design
- procedure qualification trial (PQT) results
- inspection and testing plan (ITP) with referenced procedures for inspection, testing and calibrations
- anode drawings.

12.3.2.2 The as built documentation to be submitted after manufacturing shall include, but not be limited to:

- application/manufacturing procedure specification, including test requirements and acceptance criteria, repairs, personnel qualification records, etc.
- material data sheets and certificates
- daily logs including production test records
- complete statistics of coating dimensions, weight and negative buoyancy for the each joint delivered
- repair log
- electrical resistance test log.

12.3.3 DFI-resumé

12.3.3.1 The manufacturing/fabrication part of the DFI-resumé shall be established and in accordance with the requirements given in [12.8].

12.4 Construction - installation and pre-commissioning

12.4.1 General

12.4.1.1 The documentation to be submitted for review prior to start of installation shall include, but not be limited to:

— installation procedures for pipelines, risers, spools and components including acceptance criteria, test certificates for equipment, qualification records for personnel (e.g. welding, coating), etc.
— installation procedures for protective structures (as mattresses etc.) and pipeline anchoring structures
— installation manuals (IM) procedures
— trenching specification
— intervention procedure
— survey procedure
— hydrotest procedures
— pre-commissioning procedure, incl. procedures for dewatering, cleaning, drying, flooding, mothballing, etc.
— filling of fluid procedures.

12.4.1.2 Documentation produced in connection with the pressure testing of the pipeline system shall include:

— pressure and temperature record charts
— log of pressure and temperatures
— calibration certificates for instruments and test equipment
— calculation of air content
— calculation of pressure and temperature relationship and justification for acceptance
— endorsed test acceptance certificate.

12.4.1.3 The as built documentation to be submitted after installation and pre-commissioning shall include, but not be limited to:

— survey reports
— updated drawings
— intervention reports
— pre-commissioning reports.

12.4.1.4 Records and documentations should include authorisations and permits to operate.

12.4.2 DFI-resumé

12.4.2.1 The Installation (incl. pre-commissioning) part of the DFI-resumé shall be established and in accordance with the requirements given in [12.8].

12.5 Operation - commissioning

12.5.1 General

12.5.1.1 As a part of the commissioning (see [11.2]) the documentation made available shall include, but not be limited to:

- procedure and results from fluid filling operations with special emphasis on design parameters having an impact on the integrity of the pipeline system such as temperature, pressure and dew points
- procedures and results from operational verification activities (i.e. start-up inspection). Important parameters to document are typically:
  - expansion
  - movement
  - global buckling
  - wall thickness/metal loss
- inspection plans covering the future external and internal inspections of the pipeline system.

12.6 Operation

12.6.1 General

12.6.1.1 In order to maintain the integrity of the pipeline system, the documentation made available during the operational phase shall include, but not be limited to:

- organisation chart showing the functions responsible for the operation of the pipeline system
- personnel training and qualifications records
- history of pipeline system operation with reference to events which may have significance to design and safety
- installation condition data as necessary for understanding pipeline system design and configuration, e.g. previous survey reports, as-laid/as-built installation drawings and test reports
- physical and chemical characteristics of transported media including sand data
- inspection and maintenance schedules and their records
- inspection procedure and results covering the inspection aspects described in Sec.11, including supporting records.

12.6.1.2 In case of mechanical damage or other abnormalities that might impair the safety, reliability, strength and stability of the pipeline system, the following documentation shall, but not be limited to, be prepared prior to start-up of the pipeline:

- description of the damage to the pipeline, its systems or components with due reference to location, type, extent of damage and temporary measures, if any
- plans and full particulars of repairs, modifications and replacements, including contingency measures
- further documentation with respect to particular repair, modification and replacement, as agreed upon in line with those for the construction or installation phase.

12.6.1.3 In case of re-qualification of the pipeline system, see [11.5], all information related to the re-assessment process of the original design shall be documented.

12.6.2 In-service file

12.6.2.1 The in-service file, as defined in [11.3.9] shall as a minimum contain documentation regarding:

- results and conclusions from the in-service inspections
- accidental events and damages to the pipeline system
- intervention, repair, and modifications
- operational data (fluid composition, flow rate, pressure, temperature etc.) affecting corrosion and other deterioration mechanisms.

12.7 Abandonment

12.7.1 General

12.7.1.1 Records of abandoned pipelines shall be available and shall include but not be limited to:

— details of abandoned pipelines on land including route maps, the size of the pipeline depth of burial and its location relative to surface features

— details of abandoned offshore pipelines, including navigation charts showing the pipeline route.

12.8 DFI-resumé

12.8.1 General

12.8.1.1 A design fabrication installation (DFI) resumé shall be prepared to provide information for operation of the pipeline system. The DFI resumé shall clearly show the limits of the submarine pipeline system.

12.8.1.2 The DFI-resumé shall reflect the as-built status of the pipeline system and shall provide information for preparation of plans for inspection and maintenance planning.

12.8.1.3 The DFI-resumé shall specify design and operating premises and requirements.

12.8.1.4 The DFI-resumé shall contain all documentation required for normal operation, inspections and maintenance and provide references to the documentation needed for any repair, modification or re-qualification of the pipeline system.

12.8.1.5 The preparation of the DFI-resumé shall be carried out in parallel, and as an integrated part, of the design, fabrication and installation phase of the project.

12.8.2 DFI resumé content

As a minimum, the DFI-resumé shall contain the below listed items:

Table 12-1 DFI resumé content

Considered aspect	*Remark*
System description	Shall include a description of the pipeline system including: — final dimensions — final operational parameters — a table, for planning of future pigging operations, listing all components in the system from pigtrap to pigtrap. Key data like inner diameter (ID), bend radius and wall thickness (WT) should be included, as well as references to additional documentation/drawings.
Document filing system	Shall give an overview of as-built documentation including description of filing system and method.

Considered aspect	*Remark*
Design basis	Shall give a summary of the final design basis, on which engineering, fabrication and installation is based. Design parameters of key importance for the operation of the pipeline system should be emphasised. The following parameters are considered important for the operation of the pipeline system: — design life and limitations — design standards — environmental conditions — tabulated geotechnical parameters as used in design — design pressure and temperature — flow rate — fluid composition — corrosion allowance — depth of cover — material specifications, covering pressure containing equipment and structure — CP-system (i.e. anode details) — coating system — fatigue design assumptions incl. free span criteria — incidental pressure relief system — flow control techniques and requirements.
Design	Shall include a design activity resumé, all engineering assumptions and assessments not listed in the design basis in addition to applicable deviations and non-conformances including a description of possible impact on the operational phase.
Construction - fabrication	Shall include a manufacturing/fabrication activity resumé, reference to specifications, drawings etc., discussion of problem areas and any deviations from specifications and drawings of importance for the operational phase.
Construction - installation	Shall include an installation activity resumé, reference to specifications, drawings etc., discussion of problem areas and any deviations from specifications and drawings of importance for the operational phase.
Construction - pre-commissioning	Shall include a pre-commissioning activity resumé and any results from the pre-commissioning phase. All applicable deviations and non-conformances shall be listed including a description of possible impact on the operational phase.
Certificate and authority approval	Shall include a hierarchical overview of issued certificates, release notes and authority approvals with reference to items and nature of any conditional approvals. The certificates, release notes and authority approvals shall show unambiguous reference to applicable standards and documents, items covered, accepted deviations, certification activities and condition for certificates.
Surveys	Shall give all engineering assumptions and assessments drawn from the route and site surveys in addition to all applicable as-installed route drawings.
Inspection, maintenance and repair	Shall include an overview of: — identified areas deemed to require special attention during normal operation of the pipeline system — operational constraints.

Considered aspect	*Remark*
Deviations and non-conformances	Shall include a complete list of waivers, deviations and non-conformances with special emphasis on identified areas deemed to require special attention during normal operation of the pipeline system.
Selected drawings	Shall include a complete as-built drawing list, including drawings from sub-vendors and contractors, with reference to the as-built filing system. Selected drawings from the design, fabrication and installation phase, as: — drawings of special components — alignment sheets — as-installed route drawings shall be included.

12.9 Filing of documentation

12.9.1 General

12.9.1.1 Maintenance of complete files of all relevant documentation during the life of the pipeline system is the responsibility of the pipeline operator.

12.9.1.2 The DFI-resumé (see [12.8.2]) and all documentation referred to in the DFI-resumé shall by filed for the lifetime of the system. This includes also documentation from possible major repair or re-construction of the pipeline system.

12.9.1.3 The engineering documentation not mentioned in [12.9.1.2] shall be filed by the pipeline operator or by the engineering contractor for a minimum of 10 years.

12.9.1.4 Files to be kept from the operational phase of the pipeline system shall as a minimum include final in-service ([12.6.2]) inspection reports from start-up, periodical and special inspections, condition monitoring records, and final reports of maintenance and repair.

SECTION 13 COMMENTARY (INFORMATIVE)

13.1 General

13.1.1 Objective

This section provides informative:

— background to the requirements in the standard
— guidance to reflecting good engineering practice.

The section is informative and some of the recommendations may be founded on engineering judgement only.

13.2 Safety and design philosophy

13.2.1 Safety class discussion

Safety class shall be specified for each part of the pipeline and for each phase. The classification shall be based on the requirements in Sec.2.

The safety class concept allows the owner some flexibility in terms of risk which is both a reasonable and rational approach, e.g. this allows the owner to differentiate between the design conservatism for a flow line with a 5 year design life and a trunk line with 40 years design life.

The main aspect when determining the safety class is the consequence, typically to people, environment and cost. Note that this consequence not necessarily is limited to failure of the considered pipeline itself, but also to its impact on the total exploration. One such example may be reduction in production if a water injection line or a system for waste water fails which from an isolated point of view could be defined as safety class low.

Another example is differentiation of temporary phases. A failure during installation, normally considered as safety class low, will have a significantly smaller consequence than a failure during a shut-down period of the pipeline, where both pollution and time for repair are significantly more expensive and time consuming. In case a wet buckle occurs during installation and the vessel does not have the capacity to hold or eventually retrieve the pipe, this may have large consequences as another vessel may have to retrieve the pipe, and hence this may call for a higher safety class than low.

However, the total safety may not always be increased by specifying a higher safety class. This may be the case when the most probable cause of failure would be draught of vessel, where the emphasis should be put on operating procedures and back-up. During such circumstances, it may not be required with a higher safety class.

The above clearly illustrates that Table 2-4 is for normal classification only, as stated.

13.2.2 Structural reliability analyses

Structural reliability methods consider structural analysis models in conjunction with available information regarding the involved variables and their associated uncertainties. The reliability as assessed by reliability methods is not an objective physical property of the pipeline itself in the given operational and environmental condition, but rather a nominal measure of the reliability given a particular physical and probabilistic modelling and analysis procedure applied.

Structural reliability analysis is only one part of a total safety concept as gross errors are not included. A gross error is defined as a human mistake during the design, construction or operation of the pipeline that may lead to a safety level far below what is normally aimed for by use of a partial safety factor design format or specific reliability analysis. In the following only natural variability are discussed and the corresponding probabilities are referred to as nominal throughout this standard.

Nominal target reliabilities have to be met in design in order to ensure that certain safety levels are achieved. A probabilistic design check can be performed using the following design format:

$P_{f,calculated} < P_{f,T}$

$P_{f,calculated}$ is the calculated nominal probability of failure evaluated by a recognised (accepted) reliability method and $p_{f,T}$ is a nominal target value that should be fulfilled for a design to be accepted.

Acceptable nominal failure probabilities depend in general on the consequence and nature of failure, the risk of human injury, economic losses, social (political) inconvenience and the expense and effort required to reduce the failure probability. The target values were proposed by Professor Torgeir Moan, see Sotberg (1997) and were based on implied failure probability within different design equations representing different risks as reflected by the safety class.

The target failure probability is express as annual failure probability which has been discussed in the industry. It shall be interpret as *probability that a failure occurs in the period of one year*.

Failure statistics may be used as guidance on relative failure probability levels but only limited information about specific failure probability for SLS, ULS and FLS can be deduced from failure statistics. Structural (nominal) failure probability from a SRA is a nominal value and cannot be interpreted as an expected frequency of failure.

13.2.3 Characteristic values

In a LRFD format, so called characteristic values are used. These are often lower fractiles for strength and resistance, not always however, and upper fractiles for loads. Typical examples of these may be SMYS for the yield stress and 100-year waves for loads.

The characteristic value in the resistance formulas is a lower fractile and the expected yield stress is typically in the order of 8% higher. On commonly overlooked implication of this is that it is not allowed to replace the f_y based upon a certificate or test. Such a replacement requires a thorough reliability assessment.

13.3 Loads

13.3.1 Conversion of pressures

The pressure used in the design criteria is now the incidental pressure. The incidental pressure is normally defined as the pressure with an annual probability of exceedance of 10^{-2}.

The incidental pressure is reflected also in many other standards or recommended practices, referred to as incidental pressure or maximum pressure and allows typically pressures 10% above the design pressure to account for water hammer effect and other not permanent pressures.

The incidental pressure has been used as the characteristic pressure (for extreme functional loads) and is therefore used in all the limit states of this standard. This is in contradiction with many other standards or recommended practices that use the design pressure or the maximum allowable operating pressure. This standard has selected the incidental pressure based on structural reliability arguments; it is a more likely pressure in case of failure.

The ratio between the incidental pressure and design pressure shall be determined based on the pipeline control and safety system tolerances and capabilities to ensure that the local incidental pressure meets the given probability of being exceeded within a year. This will then include simulation of the hydraulics of the medium.

If the pressure cannot exceed the incidental pressure, e.g. full shut-in pressure is used as incidental pressure, the design pressure may be taken as equivalent to the incidental pressure, see Table 3-1.

Different systems may have different definitions of pressures, e.g. between topside and a pipeline system. When converting the defined pressures in one system to pressure in another system, the conversion shall be based on pressure having an annual probability of exceedance less than 10^{-2}. This pressure shall then be defined as the incidental pressure in the pipeline system. Determination of design pressure shall then be made based on the above principles.

For pipeline systems with a two peak annual extreme pressure distribution, special considerations are required. See [13.4.6].

13.4 Design criteria

13.4.1 General

The basis for most of the given limit states have been published as papers or reports that can be ordered, see e.g. Jiao (1996) and Mørk (1997).

The work was incorporated in *DNV Rules for Submarine Pipeline Systems*, 1996 (DNV'96) and modified in order to allow for additional aspects, not necessarily to be considered in a research project. Hence, all limit states may not have identical partial factors as in the above references.

In the 2000 revision of this standard, the LRFD format was modified on the resistance side as described in Sec.5 and the limit states from 1996 version modified correspondingly. The local buckling formulation included some results from the Hotpipe project, allowing a higher utilisation of pressurised pipes, see e.g. Vitali (1999). In the 2007 revision, this was further improved to allow for higher utilisation for pressurised pipes. The characteristic pressure is now incidental pressure for all limit states.

13.4.2 Condition load effect factors

The load condition factor γ_C = 1.07, pipeline resting on uneven seabed refers to the load effect uncertainty due to variation in weight, stiffness, span length or heights. This implies that it is not applicable for the sag bend evaluation during installation on uneven seabed.

A γ_C lower than unity is used in DNVGL-RP-F110 for expansion and global buckling design to represent the degree of displacement control and uncertainties in, primarily, the pipe-soil properties.

13.4.3 Calculation of nominal thickness

The negative fabrication tolerance is normally given as a percentage of the nominal thickness for seamless pipes, and as an absolute measure for welded pipes.

The pressure containment criterion gives a minimum required minimum wall thickness, t_1. Depending on the fabrication tolerance format, the implication of the corrosion allowance will be different. For a fabrication tolerance given as a percentage, % t_{fab}, Equation (13.1) applies.

$$t = \frac{t_1 + t_{corr}}{1 - \%t_{fab}} \tag{13.1}$$

Correspondingly, the nominal thickness based on an absolute fabrication tolerance, t_{fab}, is given by Equation (13.2).

$$t = t_1 + t_{corr} + t_{fab} \tag{13.2}$$

13.4.4 Pressure containment - equivalent format

The format of the pressure containment resistance in Sec.5 is given in a LRFD format. This corresponds to the traditional format, which usually is expressed in terms of allowable hoop stress, is given in Equation (13.3).

$$(p_{li} - p_e)\frac{D - t_1}{2 \cdot t_1} \leq \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC}} \cdot (SMYS - f_{y,temp}) \tag{13.3}$$

The differential pressure is here given as a function of the local incidental pressure. Introducing a load factor, γ_{inc}, reflecting the ratio between the incidental pressure and the design pressure, the formula can be rearranged for the reference point above water, as given in Equation (13.4).

$$p_d \frac{D - t_1}{2 \cdot t_1} \leq \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC} \cdot \gamma_{inc}} \cdot (SMYS - f_{y,temp}) \tag{13.4}$$

Introducing a usage factor as given in Equation (13.5), the criteria can be given as in Equation (13.6) and Equation (13.7).

$$\eta = \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC} \cdot \gamma_{inc}} \tag{13.5}$$

$$p_d \frac{D - t_1}{2 \cdot t_1} \leq \eta \cdot (SMYS - f_{y,temp}) \tag{13.6}$$

$$p_d \frac{D - t_1}{2 \cdot t_1} \leq \frac{\eta}{1.15} \cdot (SMTS - f_{u,temp}) \tag{13.7}$$

The corresponding usage factors for γ_{inc} = 1.10 are given in Table 13-3.

Table 13-1 Usage factors η for pressure containment

Utilisation factor, α_U	*Safety class*			*Pressure test*
	Low	*Medium*	*High*	
1.00	0.847[3)] (0.843)	0.802	0.698[1)]	0.96
0.96	0.813[3)] (0.838)	0.77	0.67[2)]	0.96

1) In location class 1, 0.802 may be used
2) In location class 1, 0.77 may be used
3) Effectively this factor since the pressure test is governing

13.4.5 Pressure containment criterion, design pressure less than 10% below the incidental pressure

The characteristic pressure when determining the wall thickness is the local incidental pressure. The submarine pipeline system shall have a pipeline control and safety system which ensures that there is a probability for exceeding the local incidental pressure at any point in the system less than 10^{-2} within a year. If it can be documented that the ratio between incidental and design pressure, γ_{inc}, can be reduced, a corresponding reduction in wall thickness can be achieved, alternatively a higher design pressure can be used. For hydraulically softer systems like gas trunk lines, a γ_{inc} of 1.05 is often achieved.

13.4.6 High integrity pressure protection system and similar systems

A pipeline is designed for a static pressure without allowing for the pressure loss along the pipe unless the pipeline is sectionised into parts with different design pressure. Hence, the pipeline will always have a pressure during normal operation lower than the design pressure due to the pressure drop caused by the flow of the fluid.

For high pressure wells, this downstream pressure may be reduced on purpose by a choke in order to enable a lower pressure pipeline downstream. This reduced pressure is dependent on a constant flow and will increase to the shut-in pressure in case of blockage downstream.

A high integrity pressure protection system (HIPPS) serve the purpose to protect the downstream pipeline from the shut-in pressure by stopping the flow in case a pressure increase is experience (due to some blocking down-stream). The closer this blockage is to the HIPPS, the faster will the pressure increase occur. Hence, the speed of this HIPPS will determine how long part of the pipeline downstream that not can be protected but designed for the full shut-in pressure. This part is referred to as the fortified zone.

In case of failure of this HIPP system, the downstream pipeline will experience the full shut-in pressure. In order to take advantage of a HIPP system, the annual probability of this to happen shall be less than 10^{-2}.

The resulting annual extreme pressure distribution will then be similar to Figure 13-1, a two peak distribution where the right peak describes the pressure distribution in case of failure of the HIPPS.

From the example in the figure, it is evident that the over pressure scenario will burst the pipeline (a factor 2.5 times the incidental pressure).

For a failure probability less than 10^{-2} this over-pressure may be considered as an accidental limit state and the methodology in [5.4.10] may be used. The wall thickness will then be the larger of the pressure containment criterion based:

— on the choke pressure and
— the accidental scenario of the shut-in pressure.

With the example in Figure 13-1 the accidental scenario will govern the wall thickness design. If the over pressure would have been less than 20-30% above the incidental pressure, the choke pressure may govern the design.

The accidental criterion is:

$$\sum p_{f|Di} \cdot P_{Di} \leq p_{f,T} \tag{13.8}$$

where $p_{f|Di}$ is the failure probability given that the scenario happens and P_{Di} is the probability of the scenario (over pressure) to happen. In the following, it is assumed that the over pressure scenario will be the overall contributing accidental scenario and the summation sign is neglected.

For the HIPPS scenario outlined above, the probability of the scenario, P_{Di}, will be equal to the probability of a blockage to happen times the on-demand-failure of the HIPPS.

$$P_{Di} = P_{blockage} \cdot P_{failure\ on\ demand}(HIPPS) \tag{13.9}$$

The resulting wall thickness for the accidental scenario will then be the wall thickness giving the failure probability required in accordance with Equation (13.8).

Note that the nominal target failure probability in accordance with Sec.2 primarily shall be equal to similar limit states. The nominal failure probability of the pressure containment criterion is at least one order of magnitude less than the other limit states target values in Table 2-5.

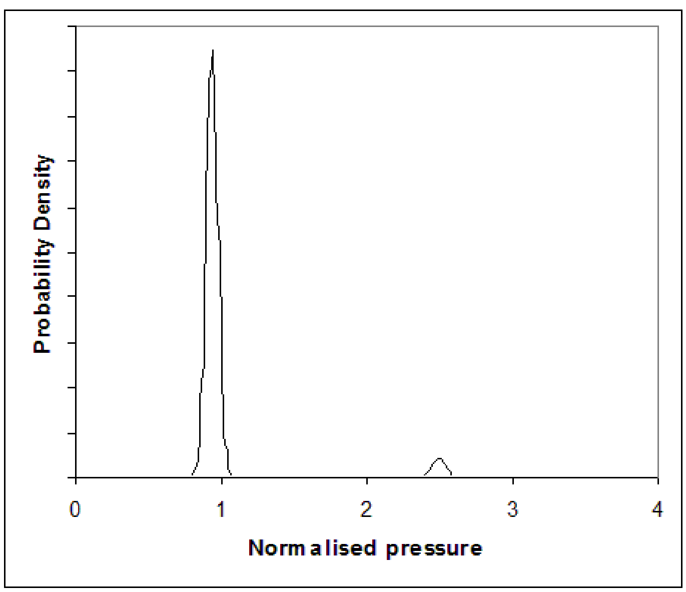

Figure 13-1 Pressure distribution

13.4.7 Local buckling - collapse

The collapse pressure, p_c, is a function of the:

— elastic capacity
— plastic capacity

— the ovality.

The formulation adopted in this standard is identical as in BS8010, apart from the safety margin. The formula is given in Equation (13.10) with the defined elastic and plastic capacities in Equation (13.11) and Equation (13.12).

$$\left[p_c(t) - p_{el}(t)\right]\left[p_c(t)^2 - p_p(t)^2\right] = p_c(t) \cdot p_{el}(t) \cdot p_p(t) \cdot O_0 \cdot \frac{D}{t} \tag{13.10}$$

$$p_{el}(t) = \frac{2 \cdot E \cdot \left(\frac{t}{D}\right)^3}{1 - \nu^2} \tag{13.11}$$

$$p_p(t) = f_y \cdot \alpha_{fab} \cdot \frac{2 \cdot t}{D} \tag{13.12}$$

This third degree polynomial has the following analytical solution:

$$p_c = y - \frac{1}{3}b \tag{13.13}$$

where:

$$b = -p_{el}(t)$$

$$c = -\left[p_p(t)^2 + p_p(t) \cdot p_{el}(t) \cdot O_0 \cdot \frac{D}{t}\right]$$

$$d = p_{el}(t)\, p_p(t)^2$$

$$u = \frac{1}{3}\left(-\frac{1}{3}b^2 + c\right)$$

$$v = \frac{1}{2}\left(\frac{2}{27}b^3 - \frac{1}{3}bc + d\right)$$

$$\Phi = \cos^{-1}\left(\frac{-v}{\sqrt{-u^3}}\right)$$

$$y = -2\sqrt{-u}\cos\left(\frac{\Phi}{3} + \frac{60\pi}{180}\right)$$

13.4.8 Buckle arrestor

The buckle arrestor formula in Sec.5 is taken from Torselletti (2003).

13.4.9 Local buckling - moment

The given formula is valid for 15 < D/t_2 < 60 for yielding and ovalisation failure modes. Up to D/t_2 equal to 45, these failure modes will occur prior to other failure modes, e.g. elastic buckling, and hence do not need to be checked.

For D/t_2 above 45, elastic buckling has to be checked separately, typically through FE analysis, with D/t_2 a sufficient safety margin above the actual D/t_2 in order to account for both uncertainty as well as natural thickness variations.

In addition to check for elastic buckling, a thinner pipe becomes more susceptible to imperfections. Special considerations shall be made to

— girth welds and mismatch at girth welds, and
— point loads, e.g. point supports.

If both the elastic buckling has been documented to occur beyond the valid range and the implications of imperfections has found to be acceptable, the criteria may be extended to D/t_2 = 60. Derrivation and comparison of the local buckling criterion see Collberg (2016) and Fyriliev (2016).

13.4.10 Local buckling - girth weld factor

Research on buckling of pipes including girth welds has shown that the girth weld has a significant impact on the compressive strain capacity, see Ghodsi (1994). A reduction in the order of 40% was found for D/t_2 = 60. There are no other known experiments on the impact from girth welds for lower D/t_2.

It is assumed that the detrimental effect is due to on-set of buckling due to imperfections at the weld on the compressive side. If this is true, this effect will be more pronounced for higher D/t_2's. The girth weld factor should be established by test and/or FE-calculations.

If no other information exists and given that the reduction is due to the misalignment on the compressive side, the reduction is expected to be negligible at D/t_2 = 20. A linear interpolation is then proposed up to D/t_2 = 60.

If no other information exists then the girth weld factor in Figure 13-2 is proposed.

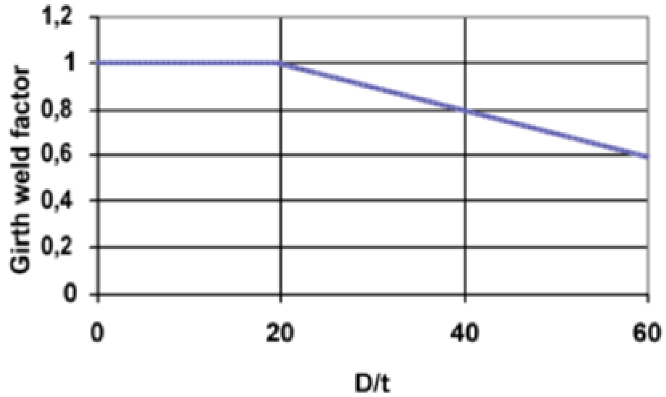

Figure 13-2 Proposed girth weld factors

13.4.11 Ovalisation

Pipe ovalisation is mentioned in three different places within this standard:

[5.4.12], where the maximum allowable ovalisation O_0 = 3%. This applies for the pipeline as installed condition. This limitation is due to the given resistance formulations which not includes the ovality explicitly, as well as other functional aspects as stated in the paragraph.

[5.4.4], where the minimum ovalisation O_0 = 0.5% to be accounted for in the system collapse check; and the combined loading. The collapse formula includes the ovality explicitly giving a lower resistance for a larger ovality, hence a minimum ovality is prescribed.

Table 7-17, dimensional requirements, where the maximum allowable out of roundness to be delivered from manufacturer is specified.

The ovality of a pipe exposed to bending strain may be estimated by Equation (13.14). This is a characteristic formula without any safety factors.

$$O_0' = \frac{O_0 + \left[0.030\left(1 + \frac{D}{120 \cdot t}\right)\left(2\epsilon_c \frac{D}{t}\right)^2\right]}{1 - \frac{p_e}{p_c}} \tag{13.14}$$

For further information, see Murphey (1985).

13.5 API material grades

13.5.1 API material grades

The API requirements to the grades X42 through X80 are listed in Table 13-2. For full details see the *API Specification for Line Pipe (API Specification 5L)*. The SMYS and SMTS values given in MPa in the table below are converted from the API specification (in ksi), and differ slightly from the mechanical properties in Table 7-5, which apply for this standard.

Table 13-2 API material grades

API Grade	*SMYS*		*SMTS*	
	ksi	MPa	ksi	MPa
X42	42	289	60	413
X46	46	317	63	434
X52	52	358	66	455
X56	56	386	71	489
X60	60	413	75	517
X65	65	448	77	530
X70	70	482	82	565
X80	80	551	90	620
ksi = 6.895 MPa; 1 MPa = 0.145 ksi; ksi = 1000 psi (lb f/in2)				

13.6 Pipe-in-pipe

13.6.1 General

Objective

This informative section provides guidance on pipe-in-pipe design and integrity management based on the criteria given in this standard. It focuses on the general aspects of PiP systems. As new ideas develop these general aspects may have to be further developed and detailed on a project to project basis.

Pipe-in-pipe systems

Pipe-in-pipe systems are built up of an inner pipe (also called the flowline), carrying the fluid, inside a larger outer pipe also called carrier, or jacket, pipe. The annulus is dry and normally not pressurised which allows the use of high performance insulation. This may be a good alternative to expensive wet insulation for deep water pipelines or for very high temperatures. The annulus can be fully or partially filled by the insulation material. In case of being partially filled, centralizers spaced at regular predetermined intervals are provided to protect the insulation from mechanical loading and damage during installation and operation, and to prevent buckling of the inner pipe inside the outer pipe. PiP systems are increasingly considered as a robust solution to combat these flow assurance challenges, ensuring that a very low OHTC can be achieved. In addition, pipe-in-pipe systems are increasingly considered as an additional protective layer against loss of containment or to withstand the impact force due to third party or trawl/fishing gear interaction. PiP systems are also used in onshore arctic field developments to safeguard against spillage into the environment due to mechanical failure of inner pipe. The primary objective for selecting a PiP system is the high thermal insulation potential. This makes it the preferred solution for challenging flow assurance flowlines. In addition to the good thermal insulation, secondary advantages are:

— High submerged weight. This may increase the on-set to global buckling due to the high lateral pipe-soil resistance.
— Axial transfer of forces between the outer and inner pipe. This may reduce the overall expansion of high pressure/high temperature pipelines.
— High resistance to external impacts. This may also be an advantage in arctic water where the outer pipe constitutes a second barrier to containment.
— Dry annulus. This may allow different types of instrumentation (e.g. leakage) as well as heating systems (e.g. water circulation).

The pipe-in-pipe systems are often project specific and vary in design but can be differentiated by the load transfer between inner and outer pipe and split into:

— Fully bonded systems, i.e. entire annulus is filled with insulation material.
— Sliding systems, i.e. insulation is achieved by wrapping standard size insulation pads onto the inner pipe.
— Regular multiple (double, quad, etc.) pipe-in-pipe joints with discrete bulkheads.

It is important that the load effect analyses reflect the actual load transfer between the outer and inner pipe. At the ends of a PiP section, a transition is required from a double wall of a PiP system to a single wall of the connection system (e.g. to a PLET, PLEM, tie-in spools). This is achieved by using end bulkheads which act as stress distribution diaphragms within a PiP system. The end bulkheads are generally made of forged, heat treated material and machined to the required tolerance. At the double wall end, they are welded to the inner and outer pipes and at the single wall end to the hub flange or spool piece. Thus, end bulkheads have a conical shape in order to seal the annulus, maintain the concentricity of the system and transfer installation and operational (expansion) loads between the inner and outer pipes.

As the end bulkheads act as a permanent means of the load transfer between the two parts, they are classed as pipeline components and are designed in accordance with recognized PVC. However, there are a number of PVCs that can be used for design and their selection and implementation are at the discretion of the pipeline operator and designer.

Other components are also included in pipe-in-pipe to achieve specific functionalities, most notably thermal insulation but also spacers, water stops, heating wires, etc.

Typical elements in pipe-in-pipe systems, in addition to inner and outer pipe, and their purpose are:

— Insulation, as well as insulating the inner pipe, the mechanical strength of the insulation material may be used for the design of the pipeline if its material properties can be documented. Typical examples of its use for other properties than thermal are as a spacer to keep inner and outer pipes from contacting or as a shock absorber against external impact loads.
— Spacers, with the purpose of centralising the inner pipe, preventing buckling of the same, and ensuring an even space in the annulus. This may be done by the insulation itself or by specific centralisers.
— Water stops, with the purpose of avoiding ingress of water to move along the pipeline annulus, impacting the insulation properties. This has limited axial structural capacity. Although not their intended purpose, project experience suggest water stops can also serve as an installation aid in PiP fit-up.
— Bulkheads, with the objective to avoid ingress of water to move along the pipeline annulus and to transfer the axial loads between the inner and outer pipes. Intermediate bulkheads can also be used during installation (in deep water conditions) to reduce the compression forces locked-in in the inner pipe.
— Field joints connecting sections of PiP. Different field joint types can affect the behaviour of other elements in the PiP system. Examples of different types of field joints include:
    — standard girth welds in sliding systems
    — welded half-shells with the objective to connect outer pipe sections after welding of inner pipe.
    — sliding sleeves
    — swaged ends, where the outer pipe is swaged to touch the inner pipe. These often have resin adhered single- and double-sleeves elements over swaged outer pipe ends.
— Pipelay elements present in the system as an aide to installation. This include forgings such as J-Lay collars and inner pipe pull-out collars, as well as stiffened pipe sections from ILTA and FTA structures if they are part of the pipelay string.

The interactions of these elements with the pipes (inner and outer) and with each other should be carefully assessed, in particular to assess stress and strain concentrations in the vicinity of the area where they interact with the line pipes. Typical examples are strain concentrations in the vicinity of bulkheads, waterstops and spacers. The distance between the bulkheads are typically governed by the structural response, including the degree of sliding, and the installation method. Further, tie-ins and potential hot-taps should be considered. The design of the bulkheads should also assess consequence assessments related to damage of the bulkheads. Distance between water stops should be based upon consequence evaluations Special attention shall be given to construction and welding details and different field joint types, buckle arrestors etc. Field joint fit-up tolerances and strength variability between pipe joints, sleeves and half shells as potential sources of stress/strain concentration should be considered. PiP systems are inherently difficult to fabricate, hence the manufacturing process (e.g. welding) is often chosen to minimize potential delays. Likewise, NDT shall be planned and allowed for, requiring sufficient space. The different installation methods for PiP systems impose different requirements to axial transfer between the pipes and continuity in bending moment capacity and thereby guide the Pipe-in-Pipe concept selection. Installation methods introducing plastic strain during installation will require special attention to straightening and residual straightness of the pipe after installation. For pipe-in-pipe installed by reeling, functionality of the components after installation need to be assessed including possible knockdown effects on thermal performance due to compression of insulation and movement of spacers etc.

Design premises

The pipe-in-pipe concept selection process shall include formulation of design premises with primary and secondary purpose of the different pipe-in-pipe system elements. This will constitute important input for safety class selection, design including progressive failure evaluations and integrity management planning of the pipeline system.

The data and description should include the following items specific to PiP systems, as applicable:

— Safety class selection for inner and outer pipe.
— Installation method and the consequences for the selection and design of the PiP concept.
— Expected life history e.g. fabrication, installation, commissioning, operation etc.
— Flow assurance – insulation requirements, average and maximum local OHTC, cool down time, bulkhead/waterstop spacing, arrival temperature requirements, inner and outer pipe temperature profiles, expected location of low temperature. An operating/shutdown philosophy should be developed as necessary to safeguard the pipeline from wax and hydrate formations during cool-down below the wax appearance temperature (WAT).
— Attention to possible code breaks in the pipeline system.
— Bulkhead design.
— Details/properties of components (spacers/water stops).
— Field joint system.
— Axial and bending continuity.

13.6.2 Safety class

A pipe-in-pipe or bundle system is more complex than a conventional pipeline. Different design configurations may result in the same probabilities of failure and satisfy the same overall safety class. The designer shall decide how to satisfy the overall safety class through design of the different components. Safety class should be determined with respect to the functions the inner/outer pipe is expected to perform. A risk assessment or consequence analyses may be a helpful tool in this selection process that also shall include progressive failures. The consequences shall not be limited to structural failures only but also functional failures. The safety class is normally given by the location and contents of the pipeline. The safety class for a conventional (single) pipeline is thereby the same for a pipe-in-pipe with the same location and contents. This could (for example) be described as the nominal pipe-in-pipe safety class. In many loading cases, the resistance of both pipes is needed to withstand the applied loading safely. In this case there is no redundancy and both inner and outer pipes shall have the same (nominal) safety class. Most of the time, the outer pipe is used for insulation purposes only, whereas the inner pipe acts as primary barrier to pressure containment and hence has to be designed, manufactured and fabricated to suit more stringent requirements. For some loading cases, the design may have evolved to give the system an element of redundancy. If there is some redundancy, and this can be demonstrated by carefully considering each relevant failure mechanism, then the safety class of one or both pipes (typically the outer pipe) may be reduced provided that the combined safety class is equivalent to, or exceeds, the nominal safety class, and that the consequences of taking advantage of such redundancy and related issues are fully understood. In most cases, if the thought process is thoroughly gone through, the safety class of the inner pipe often remains unchanged. In general, it is not recommended to reduce safety class for the inner pipe, even if there are apparent redundancies to take advantage of, e.g. collapse in deep waters. That said, sometimes a thinner inner pipe can be attractive, e.g. to reduce compressive force when designing against upheaval buckling. The challenge is to then consider all the failure modes in enough detail, ensure that the mechanisms, consequences and level of redundancy are understood. Changing the safety class could also have implications further down the life cycle, e.g. during operation.

Another example of progressive failure is bursting limit state close to a change in location class, e.g. when entering the safe zone. A containment release of the inner pipe may then travel along the annulus. If the outer pipe has the same wall thickness in both location class 1 and 2, containment release from the outer pipe is equal likely in both location classes. Solutions to this could be either to have a thicker outer pipe in the location class 2 or design a bulkhead that may resist containment release into the annulus.

13.6.3 Global system behaviour

Load effect

Load effect calculation requires knowledge about the actual layout of system, this is a main challenge compared to a single pipe system. Load effect calculation may therefore have additional uncertainties compared to single pipe systems, and examples may include:

— Initial condition following installation, such as axial loadings in the individual pipes and residual moment.
— A pipe-in-pipe system that expands (as axial or lateral motions) will influence the axial loads in both inner- and outer pipe:
  — Inner pipe in compression (equal or higher compared to single pipe)
  — Outer pipe in tension (higher tension compared to single pipe).
— Axial friction and sliding in between the inner and outer pipe (note that there is no buoyancy on inner pipe resulting in that even if the friction factor is lower compared to between outer pipe and soil, the friction force could be large)
— Bending interaction between inner and outer pipe, plasticity in the different pipes, differences in curvature of the two pipes and load transfer shall be taken into account, see Goplen (2011)
— Temperature difference and different sources of heating
— Influence of spacers, bulkhead and field joint design, position and tolerances

A load effect analysis is required to determine both the global system behaviour as well as the load effect of each individual pipe for limit state design purposes. For pipe-in-pipe systems the following concerns apply:

— Installation by Reel-lay, J-lay or S-lay
  — Holding of inner and outer pipe
  — Potential residual curvature
  — Residual axial forces
— Installation by reel lay method
  — Straightening and residual curvature
— Global buckling
  — Global response and axial sliding
  — Degree of displacement control for buried pipes
  — Sources of localised stress/strain concentration and bending moments
  — Bending stiffness continuity, e.g. due to presence of field joint or bulkhead

System behaviour

The DNVGL-RP-F110 covering global buckling can be applied for a pipe-in-pipe in case the pipeline can be considered to be fully bonded in the axial and radial direction. Bonding is here related to no movement, including axial sliding, between the inner and outer pipe. Hence a bonded pipe will have equal displacement pattern for both inner and outer pipe. An un- bonded pipe-in-pipe will face larger uncertainties and higher degree of randomness in the initiation of global buckles and post buckling behaviour. This shall be reflected in the design approach and in the applied safety factors. The friction between the pipes is related to mechanical properties of spacers, insulation, rollers etc. that is used in the annulus. The friction is influenced by curvature in the pipe and the operational conditions of the pipe. The higher pressure and temperature, the higher friction is obtained. Further, the bending strain capacity of the outer thinner pipe may be lower and hence influence on the total bending strain capacity of the pipe-in-pipe system.

Restrained force

The effective axial restrained force of a bonded pipe-in-pipe system where there are no axial displacements between the pipes is given by Equation (13.15).

$$S_0 = H - \sum_{j=1}^{n} \left(\Delta p_{ij} \cdot A_{ij} \left(1 - 2 \cdot v \right) - E \cdot A_{sj} \cdot \alpha \cdot \Delta T_j \right) \tag{13.15}$$

Reeled pipe-in-pipe systems

A conventional reeled pipe-in-pipe (PiP) consists of the inner and outer pipes, insulation, and a number of uniformly distributed spacers (or centralisers) which maintain the separation and transfer loads between the two pipes and protect the insulation. Detailed knowledge of the response of the PiP system during reeling is a key requirement for installation engineering purposes. The main objectives of the installation engineering analyses are to check straightener settings, estimate loads on equipment, and to determine a suitable spacer pitch which avoids crushing of the insulation in the annulus. The reeling installation method can have an effect on the subsequent in-service behaviour, due to the residual stresses, strains and deformations imparted on the pipe. Of particular interest are the self-equilibrating residual moments in the inner and outer pipe and the residual deformation in the inner pipe. A representative moment-curvature plot of the outer and inner pipes during installation are shown in Figure 13-3. The plot shows the moment and curvature in the plane of reeling. The plot shows two strain cycles, corresponding to i) spooling on and off the reel, and ii) passing over the aligner and through the straightener. The greatest curvature in the outer pipe, on the reel and aligner, is geometrically defined by the reel and aligner radii and is independent of the spacer location. In contrast, the inner pipe curvature on the reel and aligner depends on the discrete radial loads transmitted through the spacers, and therefore varies with spacer location. There are two residual moment-curvature effects at the end of the reeling process. Firstly, the inner pipe has a residual curvature which varies along the PiP axis at the spacer pitch. The residual curvature changes sign between the spacers, and is greatest in magnitude at each spacer. (A similar but reversed effect occurs in the outer pipe but is smaller because the equal and opposing spacer force has less influence on the bending of the outer pipe). Secondly, the inner and outer pipes have residual moments which are equal in magnitude but of opposite sign, such that the combined residual moment in the PiP is zero. These moments are constant and do not vary with the spacer pitch. The reeling process also results in near-yield magnitude residual stresses in parts of the cross-section. The axial stress distributions are complex and depend on the distance from the pipe neutral axis and the cyclic elastic-plastic response of the pipe material. This elastic-plastic response is influenced by strain-hardening and the Bauschinger effect, where the elastic limit is modified by the plastic strain history. The same effects occur in a conventional reeled pipeline, but are much more complex in a PiP due to the additional interaction between the inner and outer pipes. The full variation in moment as shown in Figure 13-3) and stress distribution are normally calculated by non-linear FE analysis. The overall effect is that the response of a reeled PiP will depend on the direction of loading with respect to the plane of reeling, and on the pitch and position of the spacers. The response of a reeled PiP under operational loads will be different from that of a non-reeled PiP. The difference is relatively small, however, and is normally neglected during conceptual design and FEED. However these effects may justify more detailed analysis during detailed design.

Guidance on modelling

Screening of bonded pipe-in-pipe systems can be achieved by considering an equivalent single pipe with the combined stiffness of the inner and outer pipe, provided plasticity is not predicted in either pipeline. Movement of the inner pipe relative to the outer pipe mean that this approach is not necessarily conservative for an unbonded pipe-in-pipe system. The issues associated with movement of the inner pipe relative to outer pipe include

— Sliding between inner and outer pipes affecting effective force in system and leading to potential axial localisation effects, e.g. axial load wrinkling

- — The friction between the pipes is related to mechanical properties of spacers, insulation, and rollers etc. that are used in the annulus. The friction is also influenced by curvature in the pipe and the operational conditions of the pipe. The higher pressure and temperature, the higher friction is obtained.

— Bending stiffness of system is not the sum of the inner and outer pipes as they need not have the same curvature.

— Potential for increased local radius in inner pipe leading to higher buckling resistance being needed than predicted from the curvature of the outer pipe and hence greater likelihood of global buckling.

— Snaking/helical buckling of inner pipe in outer pipe and hence relief of axial load.

— Response to cyclic loading, potentially larger stress ranges in inner pipe than predicted from equivalent single pipe.

Miscellaneous

Pipe-in-pipe has a high on-bottom stability level due to the high submerged weight, however, the potential for sinking into soil, particular fluidized sand or soft clay can be high and should be considered for both the installation and the operational phase. Anode design will normally be equal to a single pipe.

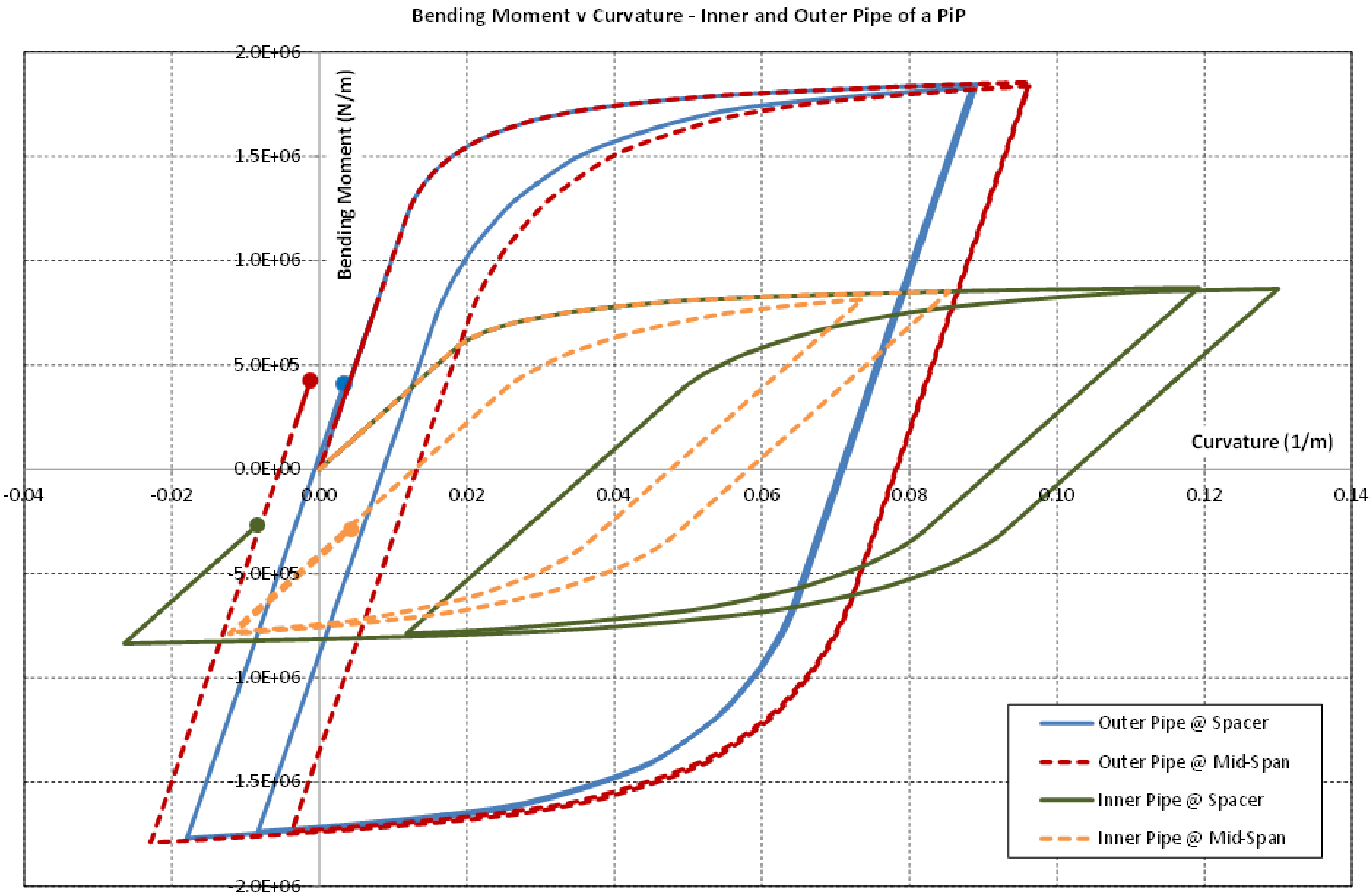

Figure 13-3 Moment - curvature of the inner and outer pipe during installation (at spacer and between spacer locations). Note that the finishing point in the figure not is in equilibrium, i.e. it will spring back slightly when pipe is released.

13.6.4 Limit states

Most of the limit states listed in Sec.5 will apply to one or both pipes in the pipe-in-pipe system.

Failure modes and PiP specific limit states

A limit state is a state beyond which the structure no longer satisfies the requirements, this means failure mode in some sense. The limit states are grouped into different limit states categories dependent on the how severe that failure mode is and includes:

— Ultimate limit state (ULS) category failure is defined as a condition which, if exceeded, compromises the integrity of the pipeline. Examples of such may be bursting, collapse, buckling and fatigue limit state (FLS) category and accidental limit state (ALS) category are two sub-categories of the ULS. An ULS failure often implies release of content.

- Serviceability limit state (SLS) category failure is defined as a condition which, if exceeded, renders the pipeline unsuitable for normal operations. Exceedance of a serviceability limit state category shall be evaluated as an accidental limit state.

Re-assessment of a failure consequences shall be reflected in the safety class, not by changing limit state category. It is difficult to summarize PiP limit states into clearly defined context due to complexity. Some PiP system limit states are same as those for a single pipe, but many are associated with insulation performances. Also, it is unclear whether an individual flooded section is acceptable, and whether dents are acceptable as they may not affect insulation but can reduce fatigue life and structural performance. The intention is to try and capture this complexity in the standards or recommended practices so that guidance is provided to inexperienced engineers. It is important that the design premises sub-section reflects operational aspects so that they feed into failure mode and limit state considerations. Failure modes for PiP systems may be summarised as follows:

- Outer pipe collapse without breach: ULS (including FLS which requires caution in application, rigorous engineering shall be demonstrated); failure modes include:
  - damaged cables/fibres
  - reduced resistance to bending (progressive failure may cause buckling of the complete PiP system)
  - reduced U value
  - ovalization of outer pipe (SLS).
- Outer pipe breach –ULS/SLS. Failure modes include:
  - flooded annulus
  - loss of U-value
  - inner pipe collapse
  - corrosion in annulus.
- Inner pipe breach/loss of inner pipe containment – ULS/SLS. Failure modes include:
  - damaged insulation, cables, fibre optic cables (FOCs), etc.
  - outer pipe burst - escape to environment
  - corrosion of annulus.
- Loss of insulation due to failure of field joint or component – SLS, loss of insulation.
- Failures due to fatigue (FLS), e.g. installation fatigue damage, operational high cycle low stress (VIV or slug flow pulsations) or low cycle high strain events (lateral buckles and local strain concentrations).
- Loss of flow assurance – SLS.
- Other failure modes:
  - local corrosion
  - local buckling of inner/outer pipe
  - crushed insulation
  - water stops for sliding PiP systems
  - gas permeation into the annulus.

  Description of failure modes and limit states should account for project-specific considerations, e.g. for pipelines in the arctic regions, the outer pipe need to perform pressure containment should the inner pipe fails. Limit states of the inner pipe should be considered as a single pipe in the absence of more rigorous engineering. Design of the PiP system should capture induced/progressive failure modes, interaction between/amongst multiple limit states, and the possibility that combinations/interactions of SLSs may lead to a more critical limit state for the PiP systems. Limit state criteria in Sec.5 are valid for each of the pipes. The residual loading from installation should be considered in the analysis. Compared to a single pipe solution the close to zero pressure in the annulus may imply higher wall thickness in the inner pipe caused by the pressure containment requirement (burst). Collapse is an issue throughout life time of the outer pipe as the pressure in the annulus often is close to zero and will be unchanged during lifetime. In case beneficial combined effect of insulation, spacers etc. in annulus between inner pipe and outer pipe shall be considered, such as in collapse or propagating buckling, this shall be documented (e.g. collapse). Progressive failure mechanisms need to be considered. During design for FLS of PiP systems, S-N curves and Stress Concentration Factors (SCFs) shall be chosen appropriately. Relevant considerations include: the inner and outer pipe fit-up, out of roundness, weak/strong inner and outer pipe strength mismatch, offshore and on-shore field joint criteria in regard to double, quad or hex joints and field joint systems, KDF, pipelay forgings, PUPs, connectors, collars, J-Lay forgings bulkhead interfaces, and stiffener pieces to ITA/FTA structures. In addition, localised deformations and fatigue resulting from helical movements of compressed inner pipe within the PiP annulus may be an additional consideration for certain PiP systems without centraliser.

Local buckling – combined loading; displacement or load control

Local buckling - combined loading criteria differentiates between:

— load controlled condition (LC condition)
— displacement controlled condition (DC condition).

A load-controlled condition is one in which the structural response is primarily governed by the imposed loads while a displacement-controlled condition is one in which the structural response is primarily governed by imposed geometric displacements. The question on if a condition is load controlled or displacement controlled is wrong. The question should be; how can one take partial benefit of that a condition is partially displacement controlled? On a general basis this needs sensitivity analyses. In any sensitivity study the system effect is also important to consider. A uniform moment/curvature cannot be applied to the whole pipeline at once but will typically occur as a peak moment moving along the pipeline. This applies to sag bend, stinger and reeling. Local buckling – combined loading will then be governed by the maximum moment capacity variation along the pipe. This will occur a small distance (typically in the order of a diameter) into the weak part, when the peak moment moves from strong to weak section. For such applications, more detailed assessment can be based on a weak link evaluation, where this weak link is the extreme variation from one joint to another. Pipe-in-pipe systems typically have numerous stress/strain concentration sites within them capable of serving as weak links along the production flowline system. Such sites usually associated with half shells, J-lay forgings, sliding single or double sleeves all have strength, wall thickness and pipe-in-pipe fit-up variability within them. Loss of integrity from at a critical field joint girth weld during pipelay or through-life operation may result in progressive failure of the PiP system through water ingress, loss of insulation, movement of the high P&T loaded inner pipe and a developing cold spot within the production system during operation. All this can be aided by inadequate field joint welds, missing spacers or water stops. [5.4.6.4] states that a load controlled design criterion can always be applied in place of a displacement controlled design criterion. For a single pipe the requirements can be summarised as follows:

— buried pipes – DCC
— exposed pipe on seabed – LCC with adjusted safety factors
— spans, including buckling at spans – LCC
— sag bend during installation – LCC
— over bend during installation – LCC
— reeling during installation – (partially) DCC.

For a PiP system, the outer pipe may generally be treated to be the same as a single pipe. The inner pipe may for some concepts have a similarity with pipe on stinger, as discussed in guidance note of [5.4.6.4], where the moment is imposed by discrete spacer points. LCC would always be acceptable, but it is permitted to go for DCC if demonstrated sufficiently, e.g. when inner pipe movement is restrained by the outer pipe and the limiting strains can be documented and demonstrated as acceptable for both inner and outer pipes. It is key that the correct loadings are applied. Loadings will be determined by nominal or average properties. Resistance, and the highest expected strains, will be determined in sections with minimum properties. For PiP systems, both system checks and inner/outer pipe checks need to be performed. Inner and outer pipe should be modelled separately, and force distribution at components. need to be considered carefully due to possible localization effects.

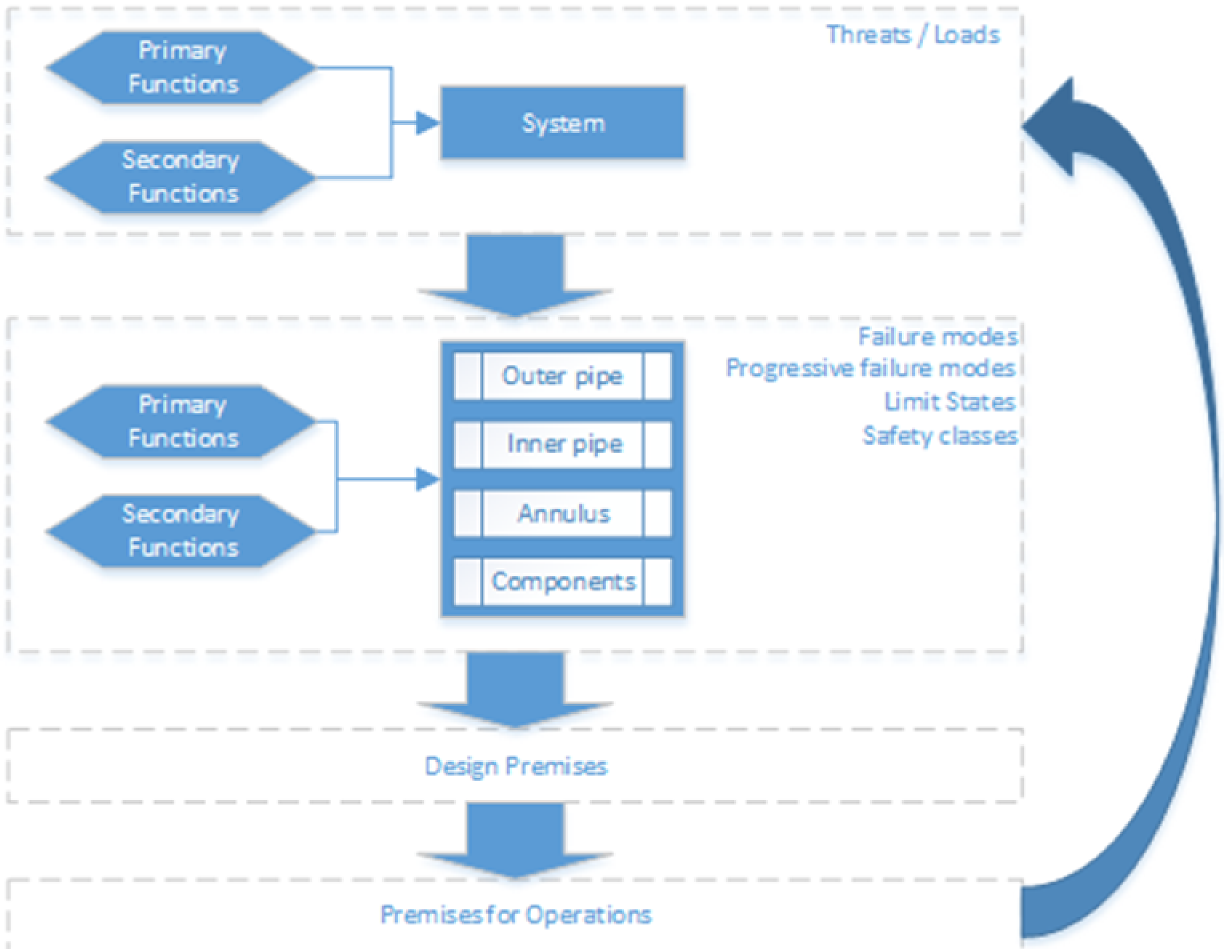

Figure 13-4 Illustration of derivation of relevant limit states

13.6.5 In-line components

Pipe-in-pipe bulkheads

Pipe-in-pipe and bundles may include a number of structural load-bearing components, including bulkhead(s), flanges, collars etc. For some of these components, such as flanges and collars, the design considerations are the same as for the same component in a conventional pipeline. However bulkheads are key components which are unique for pipe-in-pipe and bundles. The design of bulkheads for pipe-in-pipe is discussed below. This also provides relevant guidance for the design of bundle bulkheads.

There are two generic types of bulkhead; end bulkheads and midline bulkheads.

End bulkheads are used in every pipe-in-pipe system. At the ends of a pipe-in-pipe section, a transition is required from a double wall of a pipe-in-pipe system to a single wall of the connecting piping (to a PLET, PLEM, tie-in spool etc.). At the double wall side, the bulkhead is connected to the inner and outer pipes. At the single wall side, the bulkhead is typically connected to a hub flange or spool piece. The bulkhead seals the annulus, maintains the concentricity of the system and transfers the axial loads between the inner and outer pipes. The bulkhead design usually adopts a conical shape for effective transfer of high axial loads between the different components.

Midline bulkheads are used to connect one section of the pipe-in-pipe system to another section of the same pipe-in-pipe system. The bulkhead isolates the different sections of the pipe-in-pipe and transfers axial forces between the inner and outer pipes. The midline bulkhead may be used to transfer forces between the two pipes during installation or operation, or to provide an annular seal to minimise the extent of damage in the event of inner or outer pipe failure.

Examples of typical end and midline bulkheads are shown in Figure 13-5 and Figure 13-6. More complex (and proprietary) designs have also been used, but satisfy the same generic functionality.

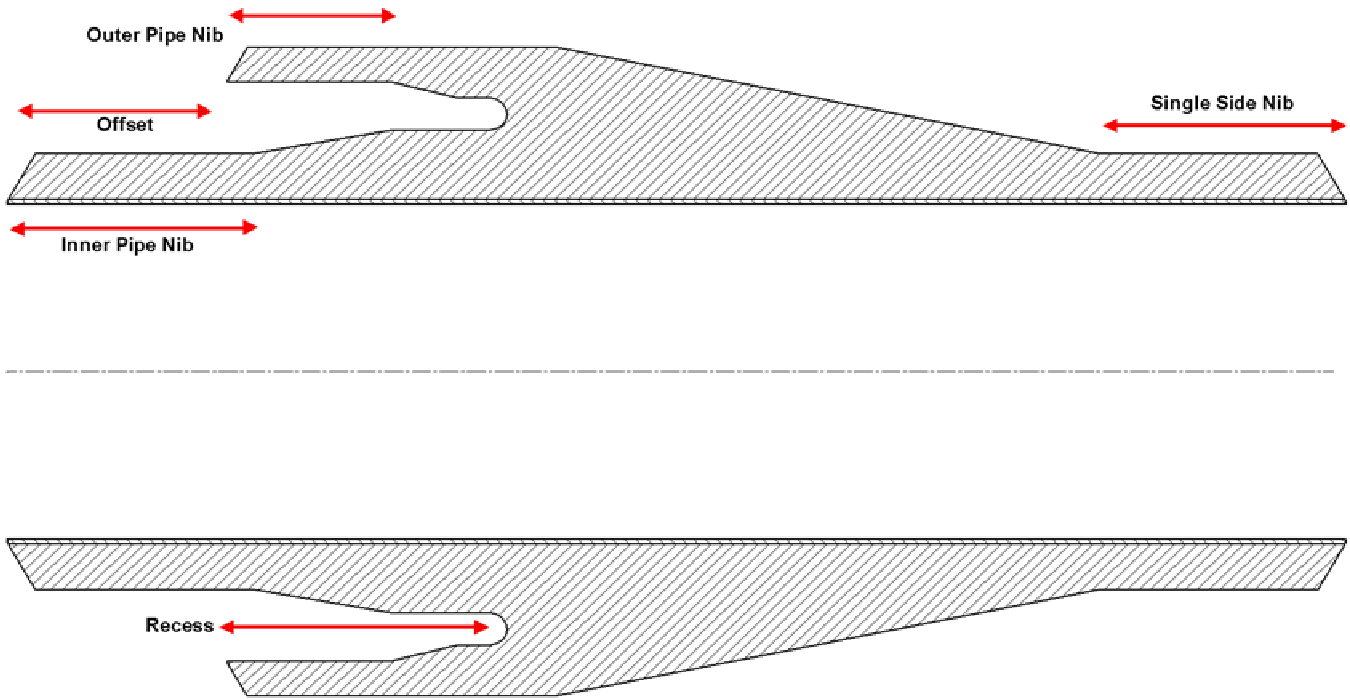

Figure 13-5 Example of end bulkhead

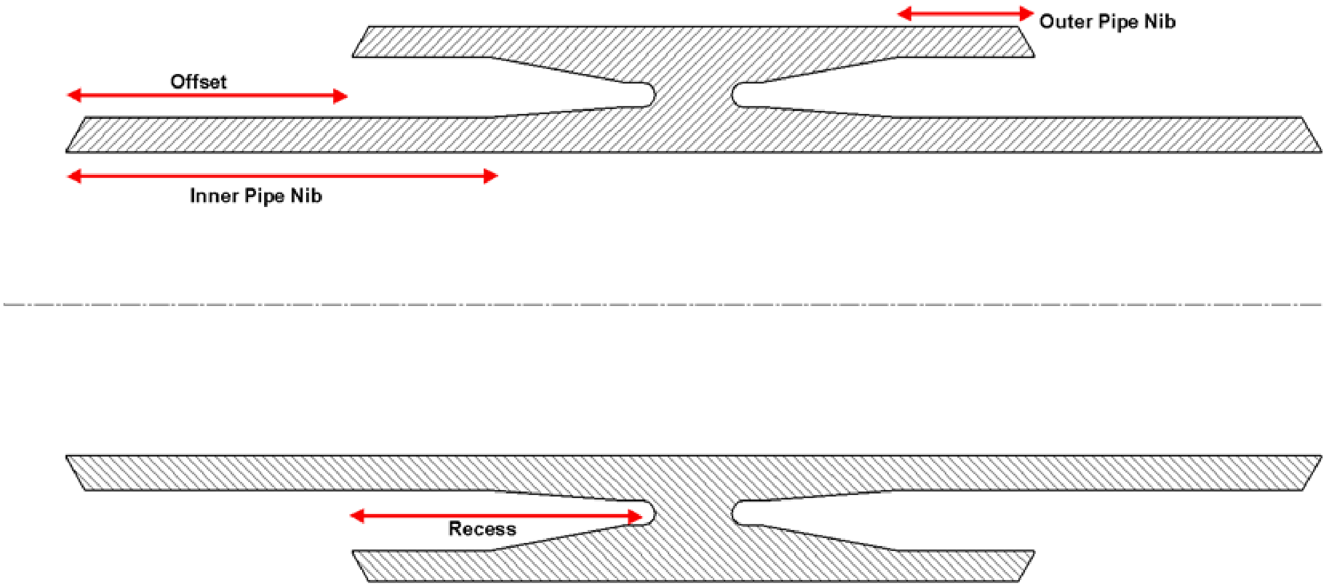

Figure 13-6 Example of midline bulkhead

Design of bulkheads

Bulkhead design should follow the requirements set in [E.8.8.7]. The requirements of a recognised pressure vessel code should be followed. The codes require FE analysis of the bulkhead. There are three methods of FE analysis that can be adopted:

— Elastic stress analysis: The analysis is based on elastic material properties only, and can be used where the bulkhead does not experience any form of plasticity. Stresses associated with different loadings are categorised as primary and secondary stresses. Different stress limits should be satisfied. This method requires stress linearization techniques.
— Elastic-perfectly plastic stress analysis. The analysis takes the elastic-perfectly plastic response of the material (i.e. without any strain hardening) into consideration. The concept of load and resistance factor design (LRFD) is used where factored loads are compared with the resistance of the component. A global plastic collapse load is established in the FE model, equal to the load that causes overall structural instability in the bulkhead. This method provides a more economic design than elastic analysis but it is not suitable for reeled bulkheads for which an elastic-plastic stress analysis is required.
— Elastic-plastic stress analysis. The analysis follows the same approach as an elastic-perfectly plastic stress analysis, but takes into consideration the actual post-yield response of the material (i.e. with strain hardening). This method is used for the design of highly loaded components (with gross plasticity) such as reeled bulkheads.

The pressure vessel codes identified in Table 5-13 generally adopt two or more of the three methods listed above.

Pressure vessel codes classify the type of load into several categories and assign load factors for each category. In the assessment of pipeline components, the loads should be classified carefully as the load categories in pressure vessel codes are not necessarily representative of the loads experienced by subsea pipelines.

In the development of FE models, geometrical variability between the different components, including dimensional variation and misalignment, should be considered. Similarly, for the elastic-plastic analyses, the effect of variation in material properties should be considered. Sensitivity studies should be performed to investigate all possible combinations (lower bound, best estimate and upper bound) of material properties and dimensions. The critical case is usually a combination of upper and lower bounds.

The use of a pressure vessel code requires a specific code break between this standard and the *Pressure Vessel Code*, e.g. ASME VIII Division 2. See [5.6.1]. The code break location has to ensure that the overall level of safety is maintained.

The component is generally more rigid than the pipeline. The presence of the component may introduce stress or strain concentrations in the adjacent linepipe and the intermediate girth weld. The selection of the code break location should take into account the following:

— All possible limit states or failure modes;

— Differences in material properties, including the manufacturing process;

— The effect of the component on the overall integrity of the pipeline

The current guidance in [5.6.1.7] states that *the standard or recommended practice for [the] pipeline component shall include pipe sections affected by the presence of the component*. The pipe sections affected by the component are assessed using a pressure vessel code, and the remaining sections unaffected by the presence of the component are assessed using the pipeline standard or recommended practice. Given that the presence of the component extends into the adjacent linepipe, these linepipe sections shall be assessed against the (generally more conservative) pressure vessel code. It can be difficult to identify a satisfactory design. The designer may be forced to change the code break location for different loading condition, with acknowledgement that this is in disagreement with the concept in this standard of code breaks at a fixed location for all loading scenarios.

This guidance on the extent of the component has therefore been removed. The modified Figure 5-3 shows the two main options for defining the code break location.

Figure 5-3 (a) illustrates a code break at the material transition between the parts manufactured in accordance with this standard requirements (i.e. linepipe) and the component.

This material-based code break allows the designer to take credit for different material properties and different partial safety factors between this standard and the pressure vessel codes. The designer may also consider the differences in manufacture of forgings for pressure vessels and forgings for subsea applications.

The pressure vessel code often requires a greater wall thickness than the linepipe standard. This means that a wall thickness transition is required. This generally requires the manufacture of a machined transition piece and additional girth weld.

Figure 5-3 (b) illustrates a code break within the component. The code break is placed at a location on the component side of the wall thickness transition. This geometry-based code break avoids the need for an additional transition piece. However part of the component now comes under this standard. The designer should ensure that material specification for this section also satisfies the material requirements of this standard.

The geometry-based code break illustrates an example where the manufacturing process and material specification should meet the appropriate material requirements for more than one standard or recommended practice. The manufacturing process includes fabrication and installation. For example, the swaging process used for some proprietary pipe-in-pipe bulkheads imposes a specific geometry by deformation of the inner or outer pipes, and may modify the material properties. Similarly, large plastic strains may modify the material properties of a reeled pipe-in-pipe. The material properties after all manufacturing, fabrication and installation activities should remain within the requirements of the relevant standard or recommended practicee.

Pressure vessel codes are based on limit states and are therefore conceptually compatible with design standards or recommende practices for subsea pipelines, such as this standard. In practice, however, the levels of safety in pressure vessel and pipeline standards or recommended practices are inconsistent. The partial safety factors prescribed in the pressure vessel codes are not necessarily valid for components in subsea pipelines. The load factors in pressure vessel codes are intended for any component under any loading condition, but were not derived for the load conditions typically experienced within pipelines. In particular, the displacement controlled condition commonly used in the design of subsea pipelines cannot be fully considered in pressure vessel codes. Similarly, the factors on material properties do not account for the more stringent methods used to manufacture components for subsea pipelines.

Within this standard, there is a clear provision to perform a problem specific reliability based analysis. This route can be used to reduce the conservatism in the partial safety factors used in the pressure vessel codes.

In the future, this approach could be developed further to derive generic partial safety factors for the design of pipeline components. This may remove the need for artificial code breaks and achieve consistent levels of safety across the pipeline and its components.

Reeled bulkheads

Bulkheads in reeled pipe-in-pipe have traditionally been welded into the pipeline on the lay vessel ramp during installation. Welding the bulkhead into the pipeline at the spoolbase and reeling the bulkhead onto the reel is more cost effective than offshore welding.

The reel lay method induces gross plastic deformation in the pipeline. Bulkheads are generally much stiffer than the pipeline; the reeling of a bulkhead does not normally induce significant strains in the body of the bulkhead, but can introduce very high strains in the bulkhead nibs and adjacent linepipe.

Design of reelable pipe-in-pipe bulkheads requires a design by analysis approach using non-linear FE analysis to predict the strains during installation. The high strains mean that a full elastic-plastic stress analysis (including the actual post-yield response of the material, with strain hardening) is required. The pressure vessel code approach to the analysis may be adopted, but the absence of pressure during reeling, and the very high level of strain, mean that the pressure vessel code criteria are not appropriate. In addition, most pressure vessel codes (e.g. ASME VIII Division 2) have serviceability criteria which require that the component (in this case the reeled bulkhead) to have satisfactory performance following application of a load (in this case reeling). The implementation of this criterion is under the discretion of the designer. The analysis determines the maximum strains that occur in the weaker nibs and linepipe. The designer uses the analysis to develop a bulkhead design which provides an adequate margin of safety against collapse during reeling.

For a number of bulkheads in the pipeline, load combination a, Table 4-4 is appropriate with a functional load effect factor of 1.2, and a condition load factor of 0.82 in Table 4-5. A reduction in condition load factor may be allowed if demonstrated by FE analysis.

A low safety class in Table 2-5 with annual probability of failure less than 10^{-2} (equivalent to a safety index, β of 2.32) can be used to assess the serviceability limit state during the reeling and unreeling phase provided that the repair of potential damage is feasible and may be performed during laying.

A lower probability of failure may be appropriate if the above criteria are not satisfied.

Geometric and material variability has a significant influence on the maximum strain during reeling. This should be considered in the analysis. The most onerous combination of upper and lower bounds may govern the design. In this case, load combination b in Table 4-4 may be used.

The probability of buckling may be reduced by placing pipe joints which closely match the actual bulkhead dimensions and yield stress on either side of the bulkhead. Fracture assessment of the girth welds shall be performed as per DNVGL-RP-F108.

13.6.6 Construction

Requirements to manufacture, testing and documentation of inner pipe and outer pipe should follow relevant requirements given in Sec.7.

Relevant requirements to manufacture, testing and inspection of pipe-in-pipe bulkhead that typically is a forged component are given in [8.3] through [8.5].

Applicable requirements to assembly welding of pipe-in-pipe are given in App.C.

For pipe-in-pipe and bundles the inner pipe and outer pipe should have equal requirements to manufacture of linepipe, welding and connection. However, some differences to requirements may be considered depending on project specific requirements, e.g. in case of H_2S service, it could relevant only to specify Suppl. Req. S for the inner pipe. Temperature should be monitored in the individual pipes during construction. Tolerances related to distance keepers (spacers, foam etc.) to be established and documented. Measure sliding between inner and outer pipe during construction of stalks

The installation process will impact in service pipe-in-pipe system design in terms of:

— acceptable stress/strain limits from ECA weld defect criteria

— presence of SCF and SnCF from installation fit up tolerances

- strength mismatches between sleeve half shell and J-Lay forgings
- residual reel lay moments
- post installation inner and outer pipe tensions
- possible presence of FTA/ILTA structures along the pipelay string
- level of pipelay induced fatigue damage at key sites along the route.

The effect of the installation by reeling on the various parts of the pipe-in-pipe system should be accounted for including straightening of inner and outer pipe during off-reeling, see Endal (1998). For installation by S-lay or J-lay sliding of the inner pipe shall be evaluated.

Leak testing of the annulus can be carried out to increase confidence in the construction and installation of the pipeline, e.g. pressure testing of the annulus.

During system pressure test there will be no external pressure on inner pipe, and this may affect the wall thickness sizing of the inner pipe.

13.6.7 Operation

The principles of integrity management are described in Sec.11, and guidance is given in DNVGL-RP-F116*Integrity management of submarine pipeline systems*. Specific considerations for PiP systems wrt integrity management are given here. There are two main structural failure modes for pipelines:

- loss of containment – leakage or rupture
- gross deformation of the pipe cross-section.

Other known failure modes from past pipe-in-pipe project experience include:

- corrosion
- blockage of flow (loss of pipeline function) due to, e.g. insulation defects and hydrate formation
- failure of carrier pipe and/or field joint, leading to fatigue failure of inner pipe
- stuck PIG
- anchor dragging.

As for single pipe, the premises for operations are set in the design phase and will be governing for the operations phase. The design philosophy for a PiP system will include:

- function of pipe-in-pipe elements (incl. handling of progressive failure)
- inspection and monitoring
- contingency and repair.

This includes primary and (possibly) secondary functions for outer pipe, inner pipe, annulus and components, e.g. inner pipe collapse, outer pipe burst, acceptability of limited outer pipe local damage. An example of a progressive failure may be leak into annulus, followed by damaged insulation and blockage of flow. A PiP system is more complex compared to a single pipe system, however, it may be regarded as a robust system due to the double wall. Table 13-4 gives and overview of specific considerations for PiP systems with respect to integrity management: A risk assessment scheme may be used to map this in more detail (see example in Table 13-5). In the design phase, the purpose of having such a matrix is to increase awareness of Pipeline Integrity Management (PIM). Documentation of the integrity in the operation phase may be limited for a pipe-in-pipe compared to a single pipe. This will again affect the life-time extension and re-assessment of the pipeline.

Table 13-3 Integrity consideration for PiP systems

Aspect	*Comment*
Condition of annulus and insulation	Detection of leaks into annulus (from internal or external fluids) may not be easily identified and the associated environment in the annulus cannot be fully controlled or reversed.
Inspection capabilities	Inspection possibilities are more limited for pipe-in-pipe, and hence detection of corrosion in annulus and external corrosion is challenging. As it stands, there is no single inspection system or technique that is capable of inspecting both the inner and the outer pipe simultaneously.
Repair and intervention methods	Limited opportunities and more complicated compared to single pipe.

Table 13-4 Risk assessment scheme example

Red = Limited possibilities

GENERIC FAILURE RESPONSE MATRIX										PROJECT-SPECIFIC RISK ASSESSMENT				
THREAT	CAUSE		CONSEQUENCE			RISK REDUCING MEASURES				SEVERITY			LIKELIHOOD	RISK
Threat Categories	Failure Mechanism		System Element Affected Inner Pipe (IP) Outer Pipe (OP) Annulus (A) Component (C)	Failure Mode	Progressive Failure Mode	Preventive Response Remove the Threat or Mitigate the Consequence	Predictive Response Detect & Confirm Threat Likelihood, Location & Characteristics	Corrective Response Address Detected Threat prior to Failure	Reactive Response Contain Consequence following a Failure	Safety	Environ ment	Business	Probability of Occurrence	Develop Risk Matrix
Time Dependent Threat (Evolutionary Threat)	Corrosion	Internal	IP, A	Metal loss	Loss of containment (LOC), Annulus Flooding	Chemistry, Routine Pigging	Direct Assessment, InLine Inspection, Progressive Integrity Evaluation	Repair, Cut-out	Leak Detection SCADA Strike Detection Notification EPRS	To be completed by the project				
		external	OP	Metal loss	LOC, Flooding	Design, CP	DA	Repair, Cut-out						
	Material fatigue	VIV stress	OP, IP	Deformation	LOC	Design, Route selection	Data loggers	Strakes						
		Free span	OP, IP	Deformation	LOC	Design, Route selection	ROV inspection	Span supports						
	Operations	Wax, hydrates	IP	Flow impediment	Blockage	Operating conditions	Survey, Monitoring	Intervention, Cut out						
		Thermal Buckling	IP, OP	Deformation	Blockage	Operating conditions	ROV inspection, ILI	Cut-out						
Resident Threat (Binary Threat)	Fabrication Defect	Latent defects	IP, OP		LOC	Specs, QA	Audit, ILI, PIE	Replace						
	Construction Defect	Weld Defect	IP, OP		LOC	Specs, QA	Geo ILI, PIE	Repair						
	Faulty Accessory	Clamps, connectors, valves	C		LOC	Prev. Maintenance	Direct Examination	Replace						
Time Independent Threat (Event-led Threat)	Unintentional Damage	Fire / explosion, Impact by Anchor, Dropped Object, Ships, trawls	Whole System	Deformation	LOC, Flooding	Detection, Route selection	Susceptibility Analysis	Replace, Repair						
	Intentional Damage	Sabotage	Whole System	Deformation	LOC	Detection	Susceptibility Analysis	Replace, Repair						
	Incorrect Operations	Sand erosion	IP	Metal loss	LOC	Operating conditions	Survey, Monitoring	Intervention, Cut out						
		Stuck pig	IP		Blockage	Competency Assessment	Audit	Intervention, Cut out						
	Defect During Construction	Wet buckle	IP, OP	Deformation	Flooding	Lay procedures, Flood barrier	Susceptibility Analysis	Repair during construction						
	Climatic / Nature Forces	Natural hazard, storm, hurricane, mud slide	System	Deformation	LOC	Route selection	Susceptibility Analysis	Stabilise, Repair						

13.7 Installation

13.7.1 Safety class definition

Installation of pipeline and pipeline components is normally defined as safety class low. However, if the installation activity impose a higher risk to personnel, environment or the assets, a higher safety class should be used. Such activities may typically be repair, where the system is shut down, but the production medium is still within the system, modifications to existing system or installation operations where failure may lead to extensive economic loss, see also [13.2.1].

13.7.2 Coating

In case no other data is available the following criterion should be used. The mean overbend strain:

$$\varepsilon_{mean} = -\frac{D}{2R} + \varepsilon_{axial} \tag{13.16}$$

should satisfy:

$$\gamma_{cc}\,\varepsilon_{mean} \geq \varepsilon_{cc} \tag{13.17}$$

where:

D	= outer steel diameter
R	= stinger radius
ε_{mean}	= calculated mean overbend strain
ε_{axial}	= axial strain contribution
γ_{cc}	= 1.05 safety factor for concrete crushing
ε_{cc}	= limit mean strain giving crushing of the concrete. Positive strain denotes tensile strain. Note the sign convention is that compressive is negative in the above criterion.

The mean overbend strain at which concrete crushing first occurs depends on the pipe stiffness, the concrete strength and thickness, the axial force and the shear resistance of the corrosion coating. Crushing occurs at lower mean overbend strains for lower concrete strength, lower axial force, higher pipe stiffness and higher shear resistance. If no other information is available, concrete crushing may be assumed to occur when the strain in the concrete (at the compressive fibre in the middle of the concrete thickness) reaches (-)0.2%.

For concrete coating of 40 mm thickness or more, together with asphalt corrosion coating, a conservative estimate of ε_{cc} is (-)0.22% for 42" pipelines and (-)0.24% for 16" pipelines, with linear interpolation in between.

See Endal (1995) or Ness (1995).

13.7.3 Simplified laying criteria

This simplified laying criteria may be used as a preliminary simplified criterion of the local buckling check during early design stages. It does not supersede any of the failure mode checks as given in the normative part of the standard.

In addition to the simplified stress criteria given below, the limit states for concrete crushing ([13.7.2]), fatigue ([5.4.8]) and rotation ([5.8.3]) shall be satisfied. Reference is further made to Endal et. al. (1995) for discussion on the rotation limit state.

For static loading at the overbend the calculated strain shall satisfy criterion I in Table 13-5. The strain shall include effects of bending, axial force and local roller loads. Effects due to varying stiffness (e.g. strain concentration at field joints or buckle arrestors) need not be included.

For static plus dynamic loading the calculated strain shall satisfy criterion II in Table 13-5. The strain shall include all effects, including varying stiffness due to field joints or buckle arrestors.

For combined static and dynamic loads in the sagbend the equivalent stress in the sagbend and at the stinger tip shall be less than

$$\sigma_{eq} < 0.87 \text{ times } f_y \qquad (13.17)$$

with all load effect factors set to unity.

Effects due to varying stiffness or residual strain from the overbend may be ignored.

For the sagbend in deeper water, where collapse is a potential problem, the normative buckling criteria in the standard shall also be satisfied.

The following calculation requirements to the lay analysis apply both when using Limit State Criteria and Simplified Criteria:

— The analysis shall be conducted using a realistic non-linear stress-strain (or moment-curvature) representation of the material (or cross-section).
— For calculation of strain concentration at field joints, non-linear material properties of the steel, the concrete and the corrosion coating shall be considered.
— The characteristic environmental load during installation is to be taken as the most probable largest value for the sea-state (H_s, T_p) considered with appropriate current and wind conditions. The sea-state duration considered is not to be less than 3 hrs.
— If the dynamic lay analysis is based on regular waves, it shall be documented that the choice of wave heights and periods conservatively represents the irregular sea-state (H_s, T_p).

Table 13-5 Simplified criteria, overbend

Criterion	*X70*	*X65*	*X60*	*X52*
I	0.270%	0.250%	0.230%	0.205%
II	0.325%	0.305%	0.290%	0.260%

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APPENDIX A FRACTURE LIMIT STATE OF GIRTH WELDS

This appendix is intentionally left empty.

Content of this appendix from previous editions has been implemented in DNVGL-RP-F108.

APPENDIX B MECHANICAL TESTING AND CORROSION TESTING

B.1 General

B.1.1 Objective

B.1.1.1 This appendix addresses methods for mechanical testing, chemical analysis and corrosion testing of materials and products.

B.1.2 Application

B.1.2.1 This appendix is applicable for the testing of all types of materials with testing requirements as referred to in this standard.

B.1.2.2 Test laboratories shall meet the requirements of ISO 17025 or an accepted equivalent.

B.2 Mechanical testing and chemical analysis

B.2.1 General requirements to selection and preparation of samples and test pieces

B.2.1.1 Selection of samples and preparation of test pieces shall as far as applicable be in accordance with the general conditions of ISO 377. In addition the following requirements apply.

B.2.1.2 For any of the mechanical tests, any test piece that shows material imperfections unrelated to the intent of the particular mechanical test, whether observed before or after testing, may be discarded and replaced by another test piece from the same pipe. If the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample shall be replaced by a correctly prepared sample from the same pipe and a new test performed.

B.2.1.3 For tensile tests, CVN impact tests, DWT tests, guided-bend tests, and flattening tests of linepipe, the samples shall be taken, and the corresponding test pieces prepared, in accordance with the applicable reference standard.

B.2.1.4 Samples and test pieces for the various test types for linepipe shall be taken from alternating pipe ends in the locations as shown in Figure 5 and Figure 6 in ISO 3183 and as given in Table 7-9, and the details stated below. Sampling from alternating pipe ends over the course of a reasonable time period (e.g. shift, day, week) shall be reviewed, and during this period an approximately equal number of front and tail ends shall be tested.

B.2.1.5 The location of samples and test pieces from components should be according to [8.5].

B.2.1.6 For induction bends and bolts the location of samples and test pieces shall be according to the recognised standard or specification used for manufacture, as specified for the relevant component in Sec.8.

B.2.1.7 For welds not performed as part of linepipe fabrication, including girth welds, samples shall be taken in accordance Figure C-1 and Figure C-2.

B.2.2 Chemical analysis

B.2.2.1 Samples for heat and product analyses shall be taken and prepared in accordance with ISO 14284. Methods and procedures for chemical analysis shall be according to recognised industry standards, of acceptable uncertainty. Results from chemical analyses shall be given with the same number of digits (or more) as given in the specification of the product and/or in this standard.

Guidance note:

ISO/TR 9769 gives a list of available international standards providing chemical analysis methods, with information on the application and precision of the various methods.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.2.2 The chemical composition of the weld overlay shall be obtained at the surface of the overlay after machining of the overlay such that the minimum distance from the surface to the fusion line is either 3 mm or the minimum thickness specified for the finished component, whichever is the lesser.

B.2.3 Tensile testing

B.2.3.1 Tensile testing shall be carried out in accordance with the requirements in this appendix and ISO 6892 or ASTM A370. The test piece configuration and possible test piece flattening shall be the same for all the delivered items. The extensometer shall be attached to a machined surface. Double sided extensometers should be used.

Guidance note:

The elongation requirements in Table 7-5 are based on a formula identical with API 5L and ISO 3183. The formula is calibrated for use with tensile test specimens prepared according to ASTM A370 (i.e. API test specimens). It should be noted that the same material tested with specimens based on ASTM A370 and ISO 6892 can give different elongation results due to the different specimen geometries.

In general it should be considered to use ASTM A370 specimens for normal tensile testing, since this would give the best correspondence with the requirements in Table 7-5.

Tensile specimens based on ISO 6892 can be used, but then the acceptance criteria should be reviewed. Some options are (i) use the values from Table 7-5, (ii) during qualification perform a number of tests on both types of specimens to establish an empirical correspondence for the specific material or (iii) define elongation criteria based on relevant testing experience and existing documentation.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.3.2 Base material tensile properties may be determined using rectangular or round test pieces at the manufacturers discretion, see [B.2.3.3] and [B.2.3.4], respectively.

B.2.3.3 Rectangular test pieces shall represent the full wall thickness. Longitudinal/axial test pieces shall not be flattened. Transverse/tangential test pieces shall be flattened. Test piece grip ends may be flattened or machined to fit the test machine's grips. Weld beads may be ground flush and local imperfections may be removed.

B.2.3.4 Round test pieces shall be obtained from non-flattened samples. For longitudinal/axial tensile tests when $t \geq 19.0$ mm, such test pieces shall be 12.7 mm in diameter, or largest obtainable diameter if 12.7 mm is not possible. For transverse or tangential tensile tests the diameter of such test pieces shall be as given in Table 21 in ISO 3183, except that the next larger diameter may be used at the option of the manufacturer.

B.2.3.5 For testing when $D < 219.1$ mm full-section longitudinal/axial test pieces may be used at the option of the manufacturer.

B.2.3.6 If agreed, ring expansion test pieces may be used for the determination of transverse yield strength.

B.2.3.7 All weld tensile tests shall be carried out using round test pieces.

Guidance note:

All-weld tensile specimens are not required to conform to the sizes in Table 21 in ISO 3183, see [B.2.3.4] above. The all-weld tensile specimen shall be as large as possible when considering that the gauge length material shall be only weld metal.

Note that the grip area of the tensile specimens can contain material from the HAZ and also base metal. This will not influence the results for the weld metal on the gauge length.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.3.8 For pipes to be tested according to supplementary requirement P and when ECA is to be performed, specimens should be of proportional type with gauge length:

$$L_{gau} = 5.65\sqrt{S_o} \quad \text{(B.1)}$$

where S_0 is the cross-section area of the specimen. If the test results shall be used as basis for ECA, the whole stress-strain curve shall be reported.

Guidance note:

For supplementary requirement P additional tensile testing is required, and of particular interest is the elongation. The industry experience and qualification testing is primarily based on proportional specimens according to ISO 6892. Consequently the criteria have been established for such tensile specimens, and it is not relevant to use specimens based on ASTM A370 for supplementary requirement P.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.3.9 Test pieces for transverse weld (cross weld) tensile shall be rectangular and in accordance with [B.2.3.3]. The weld reinforcement shall be removed on the face and root sides by machining or grinding. The tensile strength shall be determined (yield stress and elongation is not required).

B.2.3.10 Transverse weld tensile test pieces of clad or lined linepipe shall be performed on the full thickness of the carbon steel, after removal of the CRA, taking care not to reduce the C-Mn steel wall thickness.

All-weld tensile testing of load bearing weld overlay

B.2.3.11 Test pieces shall be round with maximum obtainable diameter. The test pieces shall be machined from the weld overlay transverse to the welding direction.

Tensile testing of girth welds relevant for ECA

B.2.3.12 Full stress-strain curves shall be established from the testing. If possible, the test specimens shall either be all-weld specimens (recommended) or transverse all-weld specimens as follows:

— All-weld tensile specimens: The specimens shall be round and of proportional type
— Transverse all-weld specimens: The recommended geometry is as indicated in Figure B-13. If the weld metal portion of the specimen is instrumented with strain gauges, three strain gauges are recommended around the circumference. The width of the weld metal should be minimum 6mm. For narrow bevels, it is recommended that the positioning of the test specimen is validated by polishing and etching to ensure that the reduced section of the specimen contains 100% weld metal. Possible yield plateau may be difficult to discover using this specimen type and the tensile stress-strain curve is typically 5% higher compared with results using traditional round specimens. Hence, if this specimen is used as input to FE analyses or for demonstrating weld metal strength, over-match the engineering stress shall be lowered 5%

If the weld and pipe geometry is such that it is difficult to establish stress-strain curves representing the weld metal, one of the following solutions shall be followed:

- Dedicated special specimens may be tested if possible, similar specimen geometry shall then be fabricated also from the parent pipe material
- Weld strength over-match with sufficient confidence may be demonstrated by cross-weld tensile testing
- If none of the above is possible and an ECA is required full-scale testing of representative worst case girth welds (i.e. geometry, material properties and weld defect) shall be tested to the worst case loading to demonstrate the fracture integrity

B.2.4 Charpy V-notch impact testing

B.2.4.1 The test pieces shall be prepared in accordance with ASTM A370 without any prior flattening of the material. Testing according to ISO 148-1 is acceptable if agreed and the required striking radius (2 or 8 mm) is specified. Each set shall consist of three specimens taken from the same test coupon. Full size test pieces shall be used whenever possible.

B.2.4.2 The size, orientation and source of the test pieces from linepipe shall be as given in Table 22 in ISO 3183, except that the next smaller test piece size may be used if the absorbed energy is expected to exceed 80% of the full-scale capacity of the impact testing machine. Additional sets of HAZ test pieces shall be sampled compared to ISO 3183, see Table 7-7 and Table 7-8. The notch locations shall be according to [B.2.4.8] - [D.2.1.5].

Guidance note:

It is not necessary to impact-test linepipe with combinations of specified outside diameter and specified wall thickness not covered by Table 22 in ISO 3183.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.4.3 For seamless pipe with t > 25 mm and delivered in the quenched and tempered condition, one additional set of transverse direction CNV test pieces shall be sampled 2 mm above the internal surface during MPQT.

B.2.4.4 The locations of test pieces taken from components shall be according to [8.5].

B.2.4.5 The locations of test pieces taken from girth welds shall be according to Figure C-2.

B.2.4.6 Whenever possible, and apart for testing of the root of double sided welds, the test pieces shall be sampled 2 mm below the external surface. A smaller distance than 2 mm shall be used if necessary (due to the dimensions of the material) to make specimens with the largest possible cross section. The axis of the notch shall be perpendicular to the surface.

B.2.4.7 For weld metal and HAZ tests, each test piece shall be etched prior to notching in order to enable proper placement of the notch.

B.2.4.8 For production welds other than HFW pipe the axis of the notch of the weld metal sample shall be located on, or as close as practical to, the centreline of the outside weld bead.

B.2.4.9 For test pieces taken in the weld of HFW pipe, the axis of the notch shall be located on, or as close as practical to the weld line.

B.2.4.10 The HAZ notch positions comprise the fusion line (FL), the FL+2 mm and the FL+5 mm test pieces shall be sampled in the positions given in Figure B-3 to Figure B-8, with the notch positions as applicable. FL test pieces shall always be located such that 50% of weld metal and 50% of HAZ is sampled.

B.2.4.11 Impact testing of clad/lined pipes shall be performed in the carbon steel portion of the material.

B.2.4.12 When dissimilar materials are welded, both sides of the weld shall be tested.

B.2.4.13 For weld overlay material contributing to the transfer of load across the base material/weld overlay fusion line, impact testing of the weld overlay and HAZ shall be performed (i.e. when the overlay is a part of a butt joint or acts as a transition between a corrosion resistant alloy and a carbon steel). The longitudinal axis of the specimen shall be perpendicular to the fusion line and the notch parallel to the fusion line.

B.2.5 Bend testing

B.2.5.1 The test pieces for guided-bend testing of the seam weld of welded pipe shall be prepared in accordance with ISO 7438 or ASTM A370, and Figure 8 in ISO 3183.

B.2.5.2 For pipe with t > 19.0 mm, the test pieces may be machined to provide a rectangular cross-section having a thickness of 18.0 mm. For pipe with t ≤ 19.0 mm, the test pieces shall be full wall thickness curved-section test pieces.

B.2.5.3 For SAW pipes, the weld reinforcement shall be removed from both faces.

B.2.5.4 The guided-bend test shall be carried out in accordance with ISO 7438. The mandrel dimension shall not be larger than that determined using the following equation, with the result rounded to the nearest 1 mm:

$$A_{gb} = \frac{1.15(D-2t)}{(e\frac{D}{t}-2e-1)} - t \tag{B.2}$$

where:

A_{gb} = the mandrel dimension, expressed in millimetres (inches)
D = the specified outside diameter, expressed in millimetres (inches)
t = the specified wall thickness, expressed in millimetres (inches
e = the strain, as given in Table 23 of ISO 3183
1.15 = the peaking factor.

B.2.5.5 Both test pieces shall be bent 180° in a jig as shown in Figure 9 in ISO 3183. One test piece shall have the root of the weld directly in contact with the mandrel; the other test piece shall have the face of the weld directly in contact with the mandrel.

B.2.5.6 Clad pipes shall be subjected to bend testing (the longitudinal weldment shall not be included). Specimens shall be of full thickness, including the full thickness of the clad layer. The width of the specimens shall be approximately 25 mm. The edges may be rounded to a radius of 1/10 of the thickness.

The specimens shall be bent 180° around a former with a diameter 5x the pipe wall thickness.

B.2.5.7 Longitudinal weld root bend test shall include the corrosion resistant alloy.

— The longitudinal axis of the weld shall be parallel to the specimen, which is bent so that the root surface is in tension.
— The width of the longitudinal root bend specimen shall be at least twice the width of the internal weld reinforcement or maximum 25 mm. The edges may be rounded to a radius of 1/10 of the thickness.
— The internal and external weld reinforcement shall be removed flush with the original surfaces.
— The thickness of the specimen shall be equal to the base material thickness or a maximum of 10 mm, as shown in Figure B-2.

— The specimen shall be bent to an angle of 180° using a former with diameter 90 mm.

Bend testing for WPQT according to App.C

B.2.5.8 Bend testing shall be performed in accordance with ISO 5173. Bend test specimens shall have full wall thickness. The width of root and face bend specimens shall be approximately 25 mm. The width of side bend specimens shall be 10 mm. The edges may be rounded to a radius of 1/10 of the thickness.

B.2.5.9 Bend test of clad pipes shall be performed on full thickness of the pipe, including the corrosion resistant alloy.

B.2.5.10 The weld reinforcement on both faces shall be removed flush with the original surfaces, as shown in Figure B-1. The weld shall be located in the centre of each specimen.

B.2.5.11 The specimens shall be bent to an angle of 180° using a former with diameter depending on the specified minimum yield stress SMYS for the parent material. For materials with SMYS up to 415 MPa, the former diameter shall be 4x thickness of the test specimen. For materials with SMYS equal to or exceeding 415 MPa, the former diameter shall be 5× thickness of the test specimen.

B.2.5.12 If necessary, e.g. if one of the materials to be joined has a lower yield stress than the other, guided bend testing in accordance with ISO 5173 may be applied, using the same roller diameter as for the conventional bend testing.

B.2.5.13 After bending, the welded joint shall be completely within the tensioned region.

B.2.5.14 Side bend test specimens shall be used for bend testing of weld overlay. The test specimens shall be sampled perpendicular to the welding direction.

— For pipes, the test specimens shall sample the full thickness of the weld overlay and the base material. For heavy section components, the thickness of the base material in the specimen shall be at least equal to 5x the thickness of the overlay.
— The thickness of side bend specimens shall be 10 mm. The edges may be rounded to a radius of 1/10 of the thickness. The central portion of the bend test specimen shall include an overlap area.
— The specimens shall be bent to an angle of 180°. For base materials with SMYS up to 415 MPa the former diameter shall be 4x thickness of the test specimen. For base materials with SMYS equal to or exceeding 415 MPa the former diameter shall be 5x thickness of the test specimen.

B.2.6 Flattening test

B.2.6.1 The test pieces shall be taken in accordance with ISO 8492, except that the length of each test piece shall be ≥ 60 mm. Minor surface imperfections may be removed by grinding.

B.2.6.2 The flattening test shall be carried out in accordance with ISO 8492. As shown in Figure 6 in ISO 3183, one of the two test pieces taken from both end-of-coil locations shall be tested with the weld at the 6 or 12 o’clock position, whereas the remaining two test pieces shall be tested at the 3 or 9 o’clock position. Test pieces taken from crop ends at weld stops shall be tested at the 3 or 9 o’clock position only.

B.2.7 Drop weight tear test

B.2.7.1 Drop weight tear test shall be carried out in accordance with API RP 5L3.

B.2.7.2 Full thickness specimens shall be used where possible. Reduced thickness specimens may be used subject to purchaser agreement. The testing temperature reduction given in API RP 5L3 shall apply.

The specimens shall be taken transverse to the rolling direction or pipe axis, with the notch perpendicular to the surface.

For high toughness steels ductile crack initiation from the notch tip shall be acceptable (contrary to API RP 5L3, Clause 7.1).

B.2.8 Fracture toughness testing

B.2.8.1 For qualification testing of linepipe weld metal, see [B.2.8.4] and [B.2.8.13] to [B.2.8.15]:

— for qualification testing of girth welds, see [B.2.8.16] to [B.2.8.20].

B.2.8.2 The fracture toughness testing applicable to this standard is:

— Fracture toughness testing, J or CTOD (δ), a minimum of 3 specimens is required for each notch position.
— Fracture toughness resistance curve testing, J-Δa (J R-curve) or δ-Δa (δ R-curve), a minimum of 6 specimens is required for each notch position.

B.2.8.3 Fracture toughness testing should be performed using one of the following type of specimens:

— single edge notched tension (SENT), or
— single edge notched bend (SENB) specimen.

Pipeline walls are predominately loaded in tension independent of the loading mode. The specimen for such conditions should be the SENT specimen, as shown in Figure B-12. See also to BS 8571 for further guidance.

Guidance note:

Commonly used testing standards describe methods for determining the fracture resistance from deeply notched SENB (Single Edge Notched Bend) or CT (Compact Tension) specimens. These specimens, both predominantly loaded in bending, have high crack tip constraint and will hence give lower bound estimates for the fracture resistance that can be used for conservative fracture assessments for a large range of engineering structures. The SENB specimen can also be used but this is likely to result in unnecessarily conservative fracture toughness.

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B.2.8.4 Fracture toughness testing as required in Sec.7 for weld metal shall be CTOD testing of SENB specimens.

B.2.8.5 Other test specimen configurations may be used for deriving the fracture toughness for use in an ECA provided that the fracture toughness can be derived from experimental measurement, e.g. load vs. clip gauge displacement and that it is justified that the crack tip constraint of the test specimen is not smaller than for the most severe pipeline weld defect assessed in the ECA.

B.2.8.6 Testing of SENB specimens shall be carried out in compliance with the latest revisions of ISO 12135 and ISO 15653 or an equivalent standard.

All SENT testing shall be performed in accordance with BS 8571.

B.2.8.7 Post-test metallography shall be applied to the specimens designated for FL/HAZ testing in order to establish if the crack tip has been successfully located in the target microstructure.

The specimen is considered qualified if:

— the pre-crack tip is not more than 0.5 mm from fusion line
— grain coarsened heat affected zone (GCHAZ) micro-structure is present within a region confined by a plane perpendicular to the crack plane through the crack tip and a parallel plane 0.5 mm ahead of the crack tip.

B.2.8.8 Testing of SENB specimens are acceptable, see [B.2.8.3], also with reduced notch length. However, for use in an ECA the specimen notch length shall not be chosen shorter than the height of the most severe weld defect assessed in the ECA.

The fracture toughness for SENB test specimens can be derived from the load vs. clip gauge displacement record according to the following formulae:

$$J = \frac{K^2(1-\nu^2)}{E} + \frac{\eta_{pl} \cdot A_{pl}}{B(W-a_o)\left(1+\frac{\Delta a}{3(W-a_o)}\right)} \tag{B.3}$$

where:

$$\eta_{pl} = 3.667 - 2.199\left(\frac{a_o}{W}\right) + 0.437\left(\frac{a_o}{W}\right)^2 \tag{B.4}$$

where A_{pl} is the area under the load vs. crack mouth displacement (CMOD) curve. For definitions of the other parameters it is referred to BS 7448, ISO 12135 and ASTM E1820 and Δa is the crack extension after testing.

B.2.8.9 If the total displacement, V_g, is measured at a distance z ≤ 0.2a from the physical crack mouth then the CMOD can be calculated from:

$$CMOD = \frac{V_g}{1 + \frac{z}{0.8a + 0.2W}} \tag{B.5}$$

B.2.8.10 The CTOD-value, δ, can be calculated from J according DNVGL-RP-F108.

B.2.8.11 The following information shall be reported from J/CTOD testing:

— load vs. crack mouth opening displacement curves of all tests
— crack measurements (a_0)
— j or δ results
— test temperature
— material condition (possible pre-straining and aging history)
— welding procedure and weld metal designation
— parent pipe designation.

B.2.8.12 The following information shall be reported from J R-curve or δ R- curve testing:

— load vs. crack mouth opening displacement curves of all tests
— crack measurements (a_0 and Δa)
— J-Δa or δ-Δa results
— test temperature
— material condition (possible pre-straining and aging history)
— welding procedure and weld metal designation

— parent pipe designation.

B.2.8.13 The following applies to fracture toughness testing of linepipe as required during MPQT:

δ fracture toughness testing of the weld metal shall be performed using SENB specimens.

B.2.8.14 Testing shall be conducted on through thickness notched specimens with the specimen orientated transverse to the weld direction (the corresponding notation used by ISO 15653 is NP). The notch shall be located in the weld metal centre line.

B.2.8.15 The number of valid CTOD or J tests for each location shall be minimum 3. The characteristic CTOD or critical J value shall be taken as the lowest from 3 valid tests or selected in accordance with BS 7910. Only specimens that are qualified with respect to crack tip location by post-test metallographic examination shall be considered valid.

B.2.8.16 The specimen for fracture toughness testing of girth welds should be the SENT (single edge notched tension) specimen. The calculation and performance of SENT testing shall be according to DNVGL-RP-F108.

B.2.8.17 The SENT specimens shall be designed with a Surface Notch (SN), since this is the relevant orientation for defects in the welds.

B.2.8.18 The notch positions and welding procedures to be tested shall be agreed. The notch may be introduced either from the outer surface or from the inner surface. Typically the main line procedure(s), the through thickness procedure(s) and the partial repair procedure(s) shall be tested as illustrated in Figure B-9 and specified in DNVGL-RP-F108.

Guidance note:

The FL/HAZ should be notched from the outer surface. Such notching is empirically more successful because the crack growth tends to grow towards the base material. Hence, a crack tip at the FL boundary is typically growing through the HAZ if it is notched from the outer surface.

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B.2.8.19 For situations involving plastic deformation and possibility of unstable fracture caused by tearing, crack resistance curve testing (preferably J R-curve) shall be performed of the girth weld. If the SENT specimen is tested, which is recommended, the testing shall be in accordance with DNVGL-RP-F108.

B.2.8.20 In case segment testing will be performed referece is given to DNVGL-RP-F108. The level of testing and the test procedure shall be adjusted accoring to the loading considered.

B.2.9 Specific tests for clad and lined linepipe

B.2.9.1 Shear testing shall be performed in accordance with ASTM A264 (*Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate, Sheet and Strip*) or ASTM A265 (*Standard Specification for Nickel and Nickel-Base Alloy-Clad Steel Plate*), whichever is relevant.

B.2.9.2 Gripping force of lined pipe shall be measured by the residual compressive stress test, in accordance with Clause 7.3 b of API 5LD.

B.2.10 Metallographic examination and hardness testing

B.2.10.1 Macro examination shall be performed at 5× to 10× magnifications (for HFW the examination shall be performed at minimum 40× and be documented at 10× to 20× magnification). Macro examination shall be conducted on specimens given in Figure B-10 and Figure B-11, as applicable. The macro section shall include the whole weld deposit and in addition include at least 15 mm of base material on each side measured from any point of the fusion line. The macro-section shall be prepared by grinding, polishing, and etched on one side to clearly reveal the fusion line and HAZ.

The macro examination of weld overlay shall be sampled transverse to the welding direction. The width of the macro section shall be minimum 40 mm. The face exposed by sectioning shall be prepared by grinding, polishing and etched by a suitable etchant to clearly reveal the weld and heat affected zone.

B.2.10.2 Samples for optical metallography shall be prepared using standard procedures, and further etched using a suitable etchant in order to reveal the microstructure.

Micro examination of duplex stainless steels shall be performed and documented at a minimum magnification of 400X.

The ferrite content of the base material and weld metal shall be measured according to ASTM E562.

B.2.10.3 Hardness testing of base material and weld cross-section samples shall be carried out using the Vickers HV10 method according to ISO 6507-1.

B.2.10.4 For pipe base material tests, individual hardness readings exceeding the applicable acceptance limit may be considered acceptable if the average of a minimum of three and maximum of six additional readings taken within close proximity does not exceed the applicable acceptance limit and if no such individual reading exceeds the acceptance limit by more than 10 HV10 units.

B.2.10.5 Hardness test locations for SMLS pipe shall be as shown in Figure B-10 a), except that:

— when t < 4.0 mm, it is only necessary to carry out the mid-thickness traverse
— for pipe with 4.0 mm ≤ t < 6 mm, it is only necessary to carry out the inside and outside surface traverses.

B.2.10.6 Hardness testing of welds shall be performed on the specimens used for macro examination, and as shown in Figure B-10 b) and c), and Figure B-11. The hardness test indentations should be documented on images of macro specimens and attached to the WPQR.

B.2.10.7 For SAW, HFW and MWP the following applies:

— for pipe with t < 4.0 mm, it is only necessary to carry out the mid-thickness traverse
— for pipe with 4.0 mm ≤ t < 6 mm, it is only necessary to carry out the inside and outside surface traverses.

B.2.10.8 In the weld metal of SAW and MWP welds, a minimum of 3 indentations equally spaced along each traverse shall be made. In the HAZ, indentations shall be made along the traverses for each 0.5 - 1.0 mm (as close as possible but provided indentation is made into unaffected material). The first indentation in the HAZ shall be placed as close to the fusion line as possible and with a maximum distance of 0.5 mm between the centrepoint of the indentation and the fusion line, according to Figure B-10.

Guidance note:

Testing should be carried out to ensure that the highest and lowest level of hardness of both parent metal and weld metal is determined.

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B.2.10.9 Hardness testing of clad/lined pipes shall have one additional hardness traverse located in the thickness centre of the CRA material. See Figure B-11.

B.2.10.10 For hardness testing of weld overlay hardness testing shall be performed at a minimum of 3 test locations: in the base material, in the HAZ and in each layer of overlay up to a maximum of 2 layers.

B.2.10.11 Surface hardness testing, e.g. of suspected hard spots detected by visual inspection, shall be carried out in accordance with ISO 6506, ISO 6507, ISO 6508 or ASTM A370 using portable hardness test equipment. Depending on the method used the equipment shall comply with ASTM A956, ASTM A1038 or ASTM E110.

B.2.11 Straining and ageing

B.2.11.1 Th strain ageing test is applicable if the cold forming during pipe manufacture of C-Mn and clad/lined steels exceeds 5% strain and for Supplementary requirement F. This test does not apply to linepipe delivered with a final heat treatment (e.g. normalising or quench and tempering).

A test coupon shall be machined from the pipe material and aged at 250°C for one hour. Thereafter, the specified number of Charpy V-notch specimens shall be machined from the middle of the coupon. The orientation of the specimens shall be longitudinal to the coupon centreline, with the notch perpendicular to the surface of the test coupon.

B.2.11.2 Pre-straining is applicable to:

— Linepipe material to be qualified in accordance with supplementary requirement P.
— Girth welds to be qualified in accordance with DNVGL-RP-F108 (ECA) if subjected to plastic deformation.

B.2.11.3 Pre-straining can be carried out as full scale (reversed) bending of whole pipes sections or as tension/compression straining of material cut from the pipe wall (segment specimens).

B.2.11.4 When full scale bending is applied whole pipes sections they shall be instrumented with strain gauges on the outside of the pipe wall in the 12 and 6 o'clock positions, see Figure B-14 a). A sufficient number of strain gauges shall be fitted along the length of the test section to ensure an efficient monitoring of the strain along the whole test section. If reeling installation is simulated it is recommended to bend the pipe against formers with the correct radiuses.

B.2.11.5 When pre-straining cut material such material shall be fitted with strain gauges on each of the opposite sides with respect to the smallest measure on the cross-section, see Figure B-14. A sufficient number of strain gauges shall be fitted along the length of the test section to ensure an efficient monitoring of the strain along the whole test section. If the test machine is not sufficiently rigid, strain gauges shall also be fitted either sides along the long cross-section.

B.2.11.6 The strain gauges shall be logged with sufficient frequency during the straining cycle to ensure efficient monitoring of the cycle.

B.2.11.7 The pre-straining shall be carried out in such a way that the characteristic strain (see below) reaches at least the strain levels to be simulated.

B.2.11.8 The characteristic strain shall for cut material (segments or strip specimens) be defined as the mean value of the strains measured on the outside and inside of the pipe side with the highest strain. For full scale bending of spool pieces/pipe sections the characteristic strain should be achieved by bending against a former with the actual radius. If a former is not used the material which will be used for later material testing shall at least reach the target strain (characteristic strain), where the strain is measured at the outer curvature.

B.2.11.9 The differences between strain gauges may be large due to buckling of the segment/strip specimens during compression. If fracture toughness testing of the FL shall be performed from a strained specimen the FL against the parent pipe with strain level equal to the target strain shall be tested.

B.2.11.10 After straining for supplementary requirement P, the samples shall be artificially aged at 250°C for one hour before testing. Regarding artificial ageing for ECA, see DNVGL-RP-F108.

B.2.12 Testing of pin brazings and aluminothermic welds

B.2.12.1 2 test specimens shall the sectioned transverse to the anode lead and 2 test specimens parallel with the anode lead for copper penetration test. The specimens shall be prepared and etched for metallographic examination. The examination shall be performed at a magnification of 50X. The fusion line of the weld/brazing shall at any point not be more than 1.0 mm below the base material surface. Intergranular copper penetration of the base material shall not at any point extend beyond 0.5 mm from the fusion line.

B.2.12.2 HV10 hardness tests shall be made on each of the specimens for copper penetration measurements. A traverse shall be made across the weld/brazing zone. The traverse shall consist of minimum 10 indentations; two in the heat affected zone (HAZ) on each side of the weld/brazing, two in the HAZ under the weld/brazing and two in the base material on each side of the weld/brazing. The HAZ indentations shall be made as close to the fusion line as possible.

B.2.12.3 The maximum hardness shall not exceed the limits given in App.C as applicable for the intended service and type of material.

B.2.12.4 The test specimen for the pull test shall be mounted in a tensile testing machine and secured in the cable in one end and the base material in the other end. Force shall be applied until the specimen breaks. The specimen shall break in the cable.

B.3 Corrosion testing

B.3.1 General

B.3.1.1 For certain material and fluid combinations where improper manufacture or fabrication can cause susceptibility to corrosion related damage, the need for corrosion testing during qualification and/or production of materials shall be assessed. Certain corrosion tests are further applicable to verify adequate microstructure affecting toughness in addition to corrosion resistance. This subsection describes test requirements and methods for corrosion testing.

B.3.2 Pitting corrosion test

B.3.2.1 This test is applicable to verify CRAs' resistance to pitting and crevice corrosion by oxidising and chloride containing fluids, e.g. raw seawater and other water containing fluids (including treated seawater) with high residual contents of oxygen and/or active chlorine. For duplex stainless steels, this test is further applicable to verify adequate microstructure after manufacturing or fabrication.

B.3.2.2 Testing shall be carried out according to ASTM G48, Method A.

B.3.2.3 Location of specimens is given in Figure C-1 and Figure C-2.

B.3.2.4 The minimum recommended size of test specimens is 25 mm wide by 50 mm long by full material thickness (except as allowed by [B.3.2.5]). For welds, at least 15 mm of the base material on each side of the weld shall be included in the test specimen.

B.3.2.5 Test specimens from clad/lined pipe shall be machined to remove the carbon steel portion and shall contain the full weld and any heat affected zone in the corrosion resistant alloy. The specimen thickness shall as a minimum be 1 mm where one of the surfaces is representing the inside of the pipe.

B.3.2.6 Rolled surfaces shall be tested as-received, i.e. without mechanical preparation. The root and the cap side of the welds are only to be prepared with the intention of removing loose material that will interfere with weighing prior to and after testing. Cut faces shall be ground (500 grid) and sharp edges smoothed off. The specimen shall subsequently be pickled to reduce the susceptibility of cut surfaces to end-grain attack. For duplex stainless steels and austenitic grades with PRE > 30, 20% nitric acid + 5% hydrofluoric acid, 5 minutes at 60°C is adequate.

B.3.2.7 The test solution shall be prepared according to the referenced standard.

B.3.2.8 Specimens for corrosion testing of the weld overlay shall be machined from the base material side. The remaining surface of the specimen shall be representative for the weld overlay at the minimum distance from the fusion line (equal to 3 mm or the minimum weld overlay thickness specified for the finished machined component, whichever is the lesser). The opposite surface of the specimen shall be machined such that the thickness of the specimen is 2 mm. The size of the specimen shall be 25 × 25 mm in length and width.

B.3.3 Hydrogen induced cracking test

B.3.3.1 Testing for Hydrogen Induced Cracking (HIC), also referred to as StepWise Cracking (SWC), as defined in ISO 15156 is applicable to rolled C-Mn steel linepipe and pipeline components. Testing shall be according to ISO 15156-2, B.5 (referring to NACE TM0284).

B.3.3.2 Tests should be conducted in a medium complying with NACE TM0284, Solution A.

If agreed, tests may be conducted:

- in 5% mass fraction NaCl + 0.4 mass fraction CH_3COONa and pH adjusted to required value using HCl or NaOH (see ISO 15156-2:2003, Table B.3)
- with a partial pressure of H_2S appropriate to the intended application
- with acceptance criteria that are equal to or more stringent than those specified in [7.9.1.10].

Values of crack length ratio, crack thickness ratio, and crack sensitivity ratio shall be reported. If agreed, photographs of any reportable crack shall be provided with the report.

B.3.4 Sulphide stress cracking test

B.3.4.1 For qualification of new materials (i.e. not listed for H_2S service in ISO 15156-2/3), testing shall be conducted on specimens from at least 3 heats of material. Qualification testing shall include testing of simulated girth welds and for welded pipe also seam welds, in addition to longitudinal samples of the base material. Specimen preparation, testing procedures and acceptance criteria shall comply with ISO 15156, using triplicate specimens for each testing condition (i.e. heat of material and environment).

B.3.4.2 Materials listed for H_2S service in ISO 15156 but not meeting the requirements in [7.9.1], (e.g. maximum hardness or contents of alloying or impurity elements) may be qualified by testing for resistance to Sulphide Stress Cracking (SSC) as specified in [B.3.4.1], except that testing shall be carried out on material representing the worst case conditions to be qualified (e.g. max. hardness or max. sulphur content).

B.3.4.3 As an option to purchaser, SSC testing may be carried out for qualification of pipe manufacturing. One longitudinal base material sample shall be taken from each test pipe.

B.3.4.4 For welded linepipe, testing shall include one additional sample transverse to the weld direction (samples W or WS according to Figure 5 in ISO 3183) and shall contain a section of the longitudinal or helical seam weld at its centre.

B.3.4.5 Three test pieces shall be taken from each sample. Test pieces for four-point bending SSC tests should be ≥ 115 mm long × 15 mm wide × 5 mm thick. Samples may be flattened prior to machining test pieces from the inside surface of the pipe.

B.3.4.6 Tests should be performed in accordance with NACE TM0177, using Test Solution A. A four-point bend test piece in accordance with ISO 7539-2 shall be used and the test duration shall be 720 h. The test pieces shall be stressed to a fraction of AYS appropriate for the pipeline design, however minimum 80% of the material AYS.

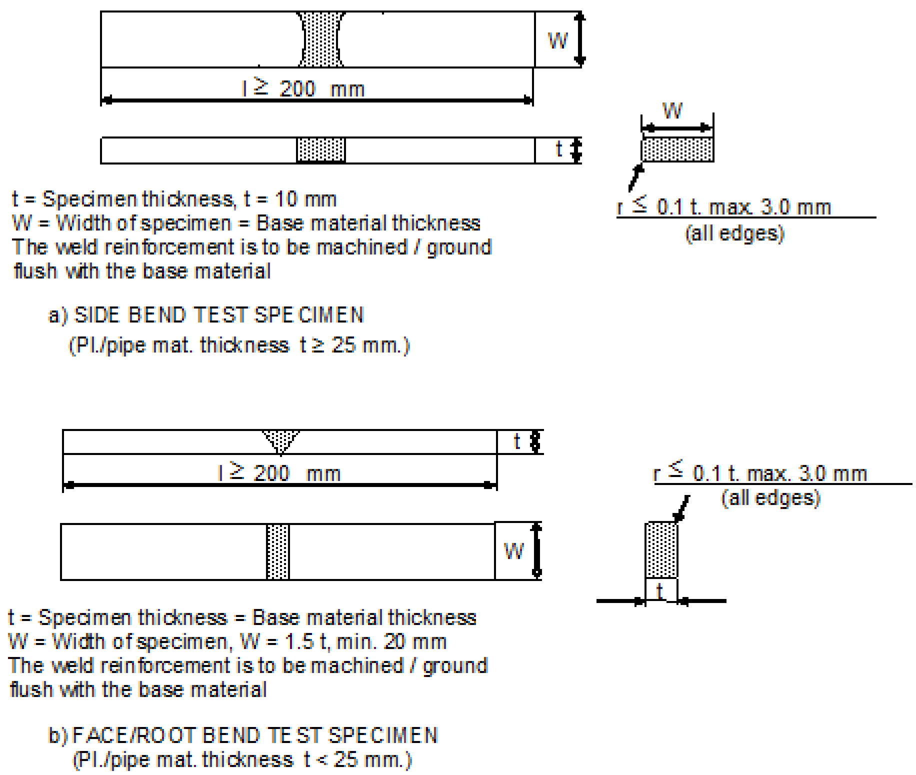


Figure B-1 Bend test specimens

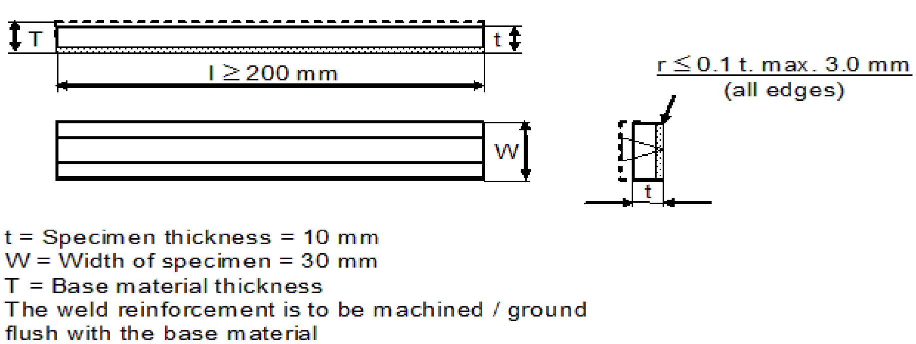
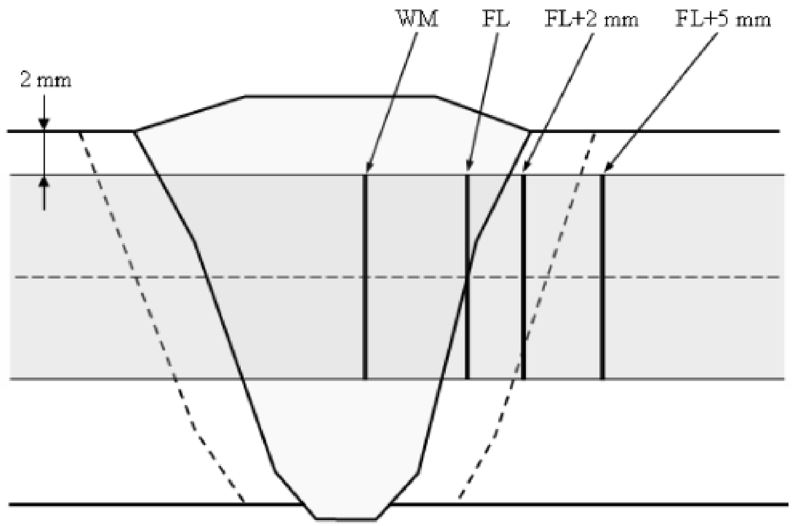
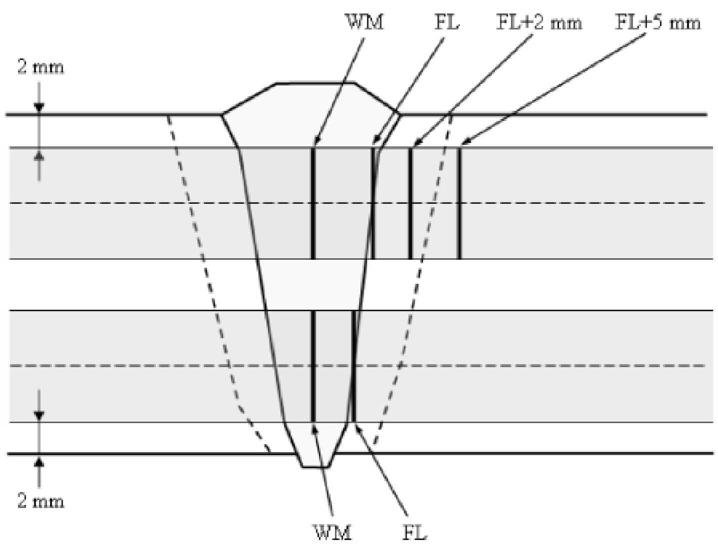


Figure B-2 Longitudinal root bend test specimens



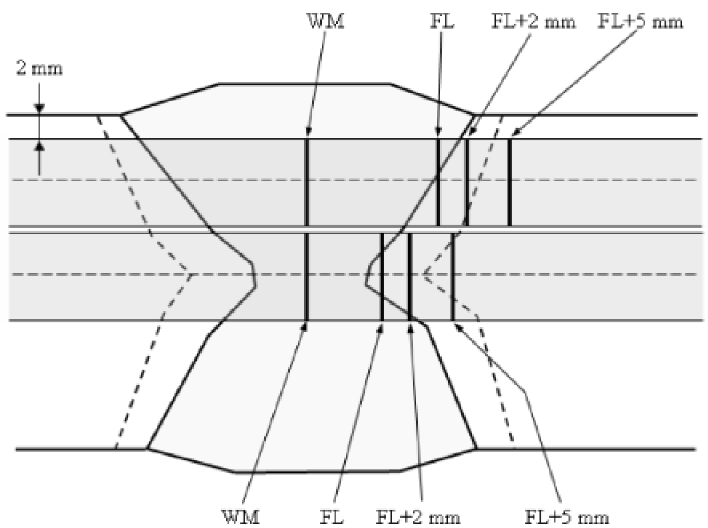
— The FL specimen shall sample 50% WM and 50% HAZ.
— The FL+5 mm sample is applicable to WPQT only.

Figure B-3 Charpy V-notch impact testing specimen positions for single sided welds with t ≤ 25 mm



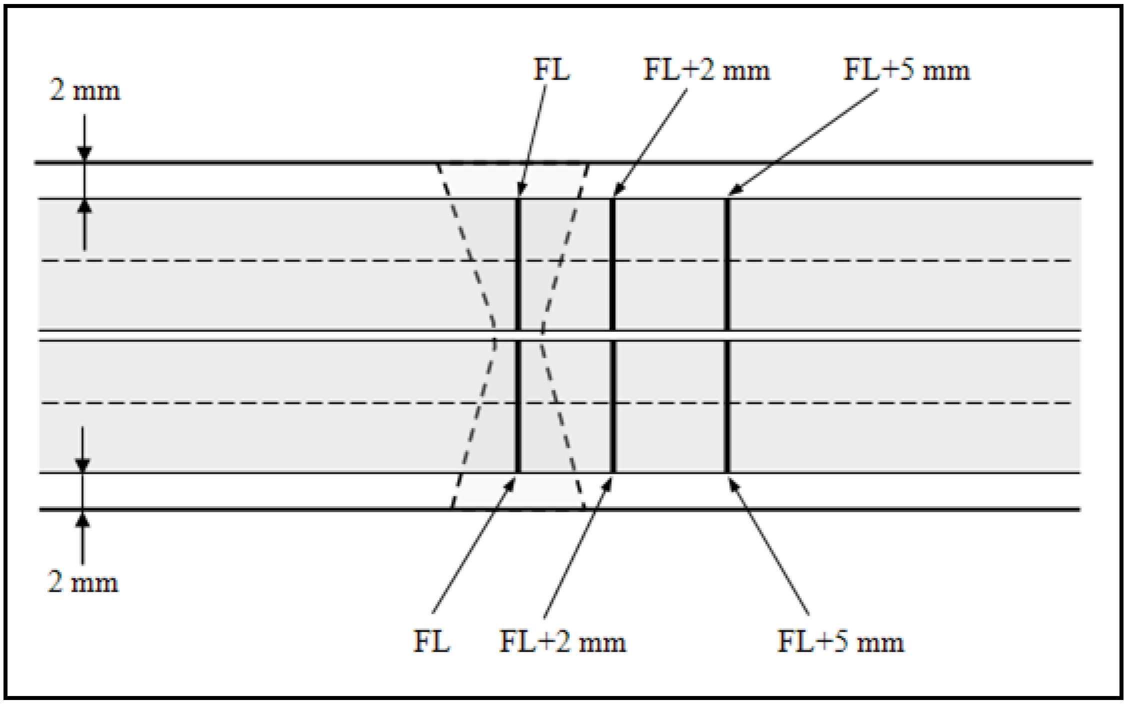
— The FL specimen shall sample 50% WM and 50% HAZ.
— The FL+ 5 mm sample is applicable to WPQT only.

Figure B-4 Charpy V-notch impact test specimen positions for single sided welds with t > 25 mm



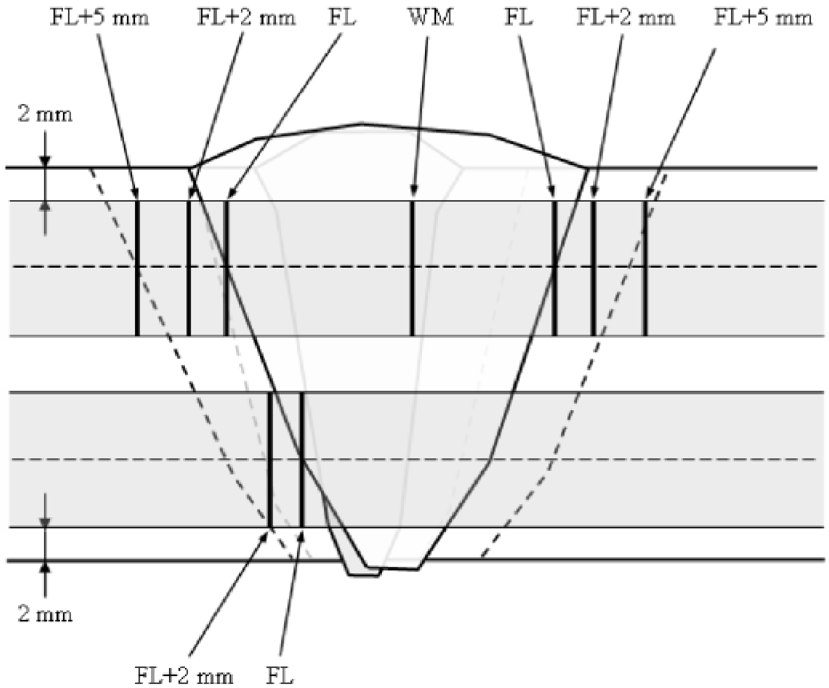
— The specimens indicated in the root area are only applicable when t > 25 mm).
— For t > 25 mm, sampling shall be from both ID and OD of longitudinal seam during pipe mill MPQT.
— The FL specimen shall sample 50% WM and 50% HAZ.
— The FL+5 mm samples are applicable to WPQT only (not at pipe mill).

Figure B-5 Charpy V-notch impact test specimen positions for double sided welds



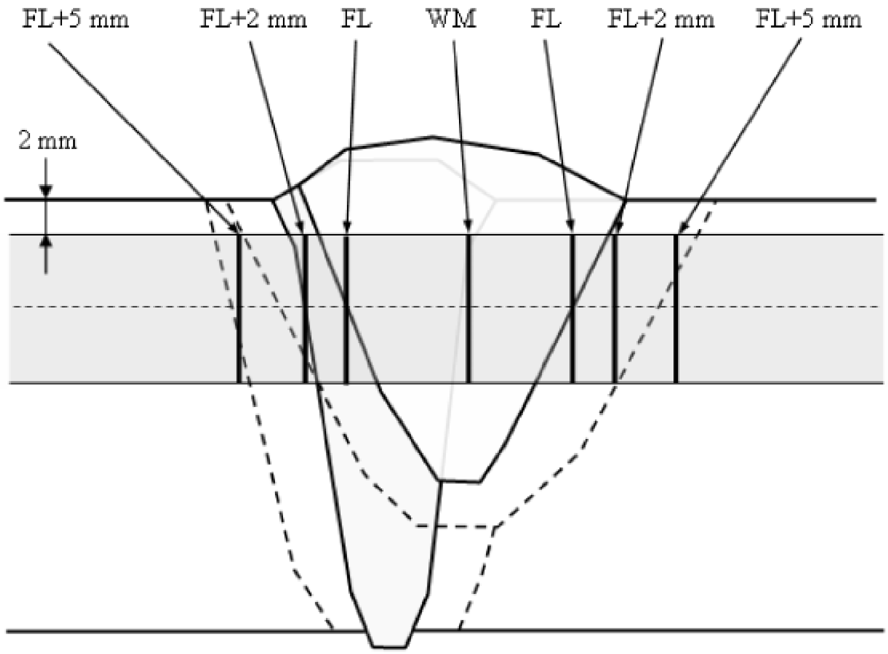
— The specimens indicated in the root area are only applicable when t > 25 mm).

Figure B-6 Charpy V-notch impact test specimen positions for HF welds



— The FL specimen shall sample 50% WM and 50% HAZ.
— The FL+5 mm sample is applicable to WPQT only.

Figure B-7 Charpy V-notch impact test specimen positions for full thickness repair welding of narrow gap welds



— The FL specimen shall sample 50% WM and 50% HAZ.
— The FL+5 mm sample is applicable to WPQT only.

Figure B-8 Charpy V-notch impact test specimen positions for partial thickness repair welding

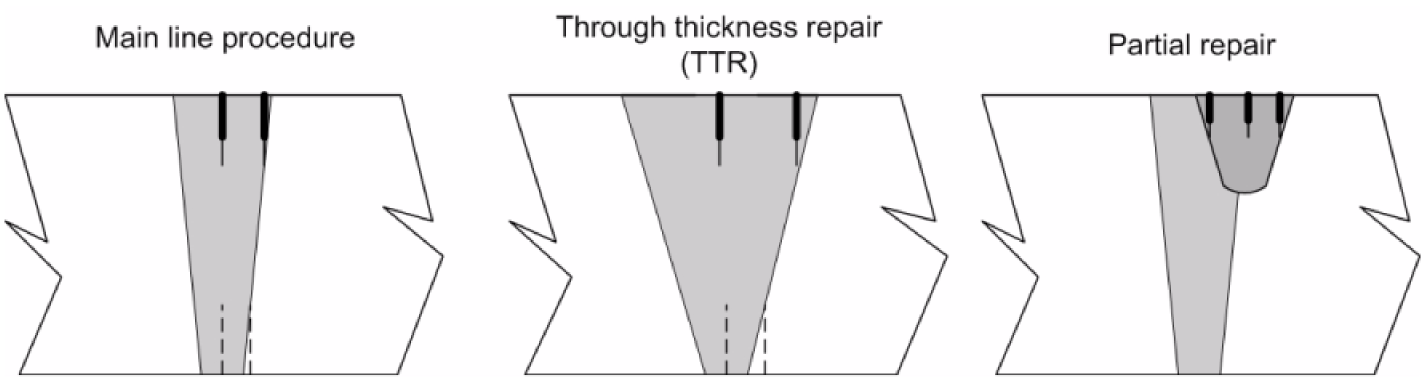


Figure B-9 Illustration of typical notch positions for fracture toughness testing of girth welds

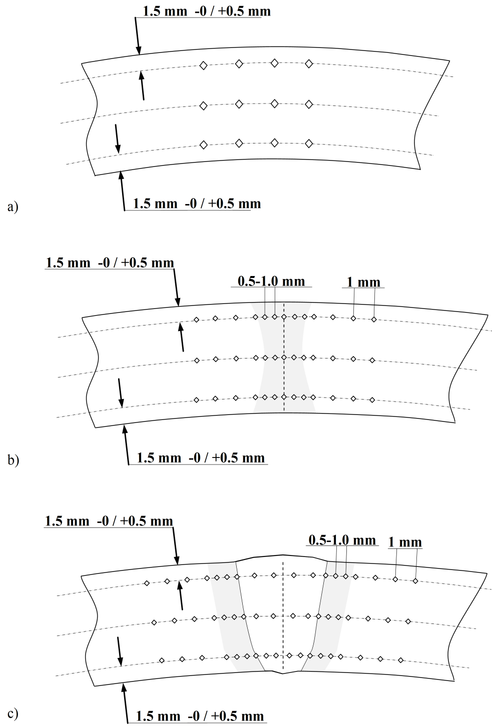


Figure B-10 Hardness locations in a) seamless pipes, b) HFW pipe, and c) fusion welded joints.

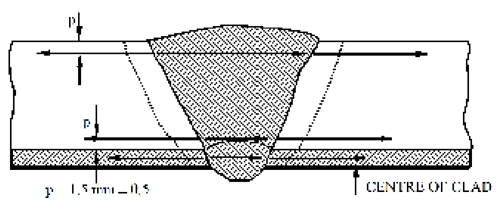


Figure B-11 Hardness locations clad materials

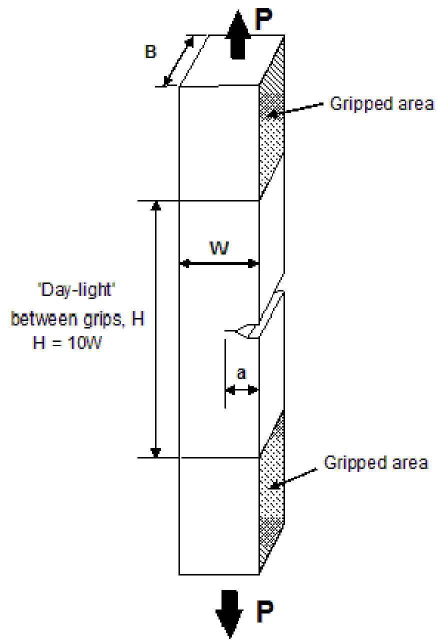


Figure B-12 The clamped SENT (Single Edge Notched Tension) specimen

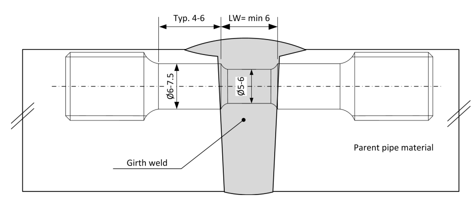


Figure B-13 Tensile specimen for determination of stress/strain curves of weld metals in the weld transverse direction

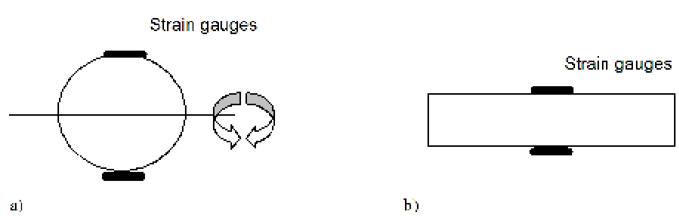


Figure B-14 Instrumentation of pipe section of samples for pre-straining of materials

APPENDIX C WELDING

C.1 General

C.1.1 Objective

C.1.1.1 This appendix gives requirements to all welding on submarine pipeline systems with exception of longitudinal seam welding in pipe mills that is given in Sec.7.

C.1.2 Application

C.1.2.1 This appendix applies to all fabrication involving shop-, site- or field welding including post weld heat treatment.

C.1.2.2 The base materials covered by this appendix are:

— C-Mn and low alloy steels
— corrosion resistant alloys (CRA) including ferritic austenitic (duplex) steel, austenitic stainless steels, martensitic stainless steels (13Cr), other stainless steels and nickel based alloys
— clad and lined steels.

The base material requirements are specified in Sec.7 and Sec.8.

C.1.2.3 Welding may be performed with the following processes (see ISO 4063) unless otherwise specified:

— Shielded Metal Arc Welding, SMAW (Process ISO 4063-111).
— Flux Cored Arc Welding with active gas shield, G-FCAW (Process ISO 4063-136).
— Flux Cored Arc Welding with inert gas shield, G-FCAW (Process ISO 4063-137).
— Gas Metal Arc Welding with inert gas shield, GMAW (Process ISO 4063-131).
— Gas Metal Arc Welding with active gas shield, GMAW (Process ISO 4063-135).
— Tungsten Inert Gas Arc Welding, GTAW (Process ISO 4063-141).
— Submerged Arc Welding, SAW (Process ISO 4063-12).
— Plasma arc welding, PAW (Process ISO 4063-15) may be used for specific applications.

Guidance note:

GMAW and FCAW (downhill only) are regarded as methods with high potential for non-fusing type defects.

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C.1.2.4 The following processes (see ISO 4063) may be used for specific applications subject to agreement:

— Laser beam welding, LBW (Process ISO 4063-52).
— Electron beam welding, EBW (Process ISO 4063-51).
— Electro slag welding.
— Plasma transferred arc welding, PTA.

C.1.2.5 Mechanised and automatic welding systems where previous experience is limited, or where the system will be used under new conditions, shall be subject to a more extensive pre-qualification programme or documentation before they may be used. The extent and the contents of a pre-qualification programme for such mechanised welding systems shall be agreed before start up. The contractor shall prove and document that the welding systems are reliable and that the process can be continuously monitored and controlled.

C.1.3 Definitions

C.1.3.1 The following definitions are used in this appendix:

Term	*Description*
welder	person who performs the welding
manual welder	welder who holds and manipulates the electrode holder, welding gun, torch or blowpipe by hand
welding operator	welder who operates welding equipment with partly mechanised relative movement between the electrode holder, welding gun, torch or blowpipe and the work piece.
manual welding	welding where the welding parameters and torch guidance are controlled by the welder
partly-mechanised welding	welding where the welding parameters and torch guidance are controlled by the welder, but where the equipment incorporates wire feeding
mechanised welding	welding where the welding parameters and torch guidance are fully controlled mechanically or electronically but where minor manual adjustments can be performed during welding to maintain the required welding conditions
automatic welding	welding where the welding parameters and torch guidance are fully controlled mechanically or electronically and where manual adjustment of welding variables during welding is not possible and where the task of the welding operator is limited to preset, start and stop the welding operation

C.2 Welding equipment, tools and personnel

C.2.1 Welding equipment and tools

C.2.1.1 Inspection of the workshop, site or vessel prior to start of welding shall be required. This shall include verification of calibration and testing of all tools and welding equipment used during qualification/ production welding.

Guidance note:

ISO 3834-2 gives quality requirements for welding both in workshops, sites or vessels that may be applicable for submarine pipeline systems.

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C.2.1.2 Welding equipment shall be of a capacity and type suitable for the work. The equipment shall be calibrated and maintained in good working condition.

C.2.1.3 The control software for mechanised and automatic welding systems shall be documented. The name and unique version number of control software and the executable programme in use shall be clearly visible, e.g. on displays and/or printouts. For mechanized welding, a welding system which displays the instantaneous heat input on screen with outputs for recording various parameters should be used.

C.2.1.4 All welding equipment shall have a unique marking for identification.

C.2.1.5 Calibration status and the validity of welding, monitoring and inspection equipment shall be summarised giving reference to the type of equipment, calibration certificate and expiry date.

C.2.1.6 Welding return cables shall have sufficient cross-section area to prevent concentration of current and shall be securely attached to prevent arc burns.

C.2.2 Personnel

C.2.2.1 All personnel involved in welding related tasks shall have adequate qualifications and understanding of welding technology. The qualification level shall reflect the tasks and responsibilities of each person in order to obtain the specified quality level.

Welding co-ordinator

C.2.2.2 The organisation responsible for welding shall nominate at least one authorised welding co-ordinator in accordance with ISO 14731 to be present at the location where welding is performed. The welding co-ordinator shall have comprehensive technical knowledge according to ISO 14731, paragraph 6.2.a.

Welding operators and welders

C.2.2.3 Through training and practise prior to qualification testing, the welding personnel shall have an understanding of (see Annex D of ISO 9606-1):

— fundamental welding techniques
— welding procedure specifications
— relevant methods for non-destructive testing
— acceptance criteria.

C.2.2.4 Welding operators performing automatic welding shall be qualified according to ISO 14732.

C.2.2.5 Welders performing manual, partly-mechanised welding and mechanised welding shall be qualified for single side butt welds of pipes or plates in the required principal position in accordance with ISO 9606-1 or other relevant and recognised standards, for the respective positions, material grades and welding processes. These requirements are also applicable for welders performing temporary welds and tack welds.

C.2.2.6 Welders shall be qualified for single side butt welding of pipes in the required principal position. Welders may be qualified for part of the weld, root, fillers or cap by agreement. Repair welders will be qualified for all types of repair after successfully being tested on full penetration repair providing the welding processes are the same for the particular section. Minimum repair length shall be 300 mm, and the repair shall be performed in the most difficult position expected (normally 6 o'clock position).

C.2.2.7 The qualification test shall be carried out with the same or equivalent equipment to be used during production welding, and should be at the actual premises, i.e. work shop, yard, and vessel. Use of other premises shall be specially agreed.

C.2.2.8 Qualification NDT shall be 100% visual examination, 100% radiographic or ultrasonic testing, and 100% magnetic particle or liquid penetrant testing. Test requirements and acceptance criteria shall be in accordance with [D.2].

C.2.2.9 When using processes which have high potential for non-fusing type defects, including G-FCAW , bend testing shall be performed with the number of bend tests according to ISO 9606-1. Bend testing may be omitted in situations where AUT is applied during welder qualification.

C.2.2.10 A welder or welding operator who has produced a complete and acceptable welding procedure qualification is thereby qualified.

Retesting

C.2.2.11 A welder may produce additional test pieces if it is demonstrated that the failure of a test piece is due to metallurgical or other causes outside the control of the welder/welding operator.

C.2.2.12 If it is determined that the failure of a test is due to welder's lack of skill, retesting shall only be performed after the welder has received further training.

Period of validity

C.2.2.13 The period of validity of a welder qualification shall be in accordance with the standard used for qualification. A qualification can be cancelled if the welder/welding operator show inadequate skill, knowledge and performance.

C.2.2.14 When a qualification testing of recent date is transferred to a new project, the welding personnel shall be informed about particular project requirements for which their welding performance will be especially important.

Identification of welders

C.2.2.15 Each qualified welder shall be assigned an identifying number, letter or symbol to identify the work of that welder.

C.2.2.16 Qualified welders shall be issued with and be carrying an ID card displaying the identifying number, letter or symbol.

C.2.2.17 The Welding Coordinator shall maintain a list of welders ID stating the qualification range for each welder.

Thermal cutters and air-arc gougers

C.2.2.18 Personnel to perform air-arc gouging shall be trained and experienced with the actual equipment. Qualification testing may be required.

Operators for pin brazing and aluminothermic welding

C.2.2.19 Operators that have performed a qualified procedure test are thereby qualified.

C.2.2.20 Other operators shall each complete three test pieces made in accordance with the procedure specification prior to carrying out operation work. Each test piece shall pass the test for electrical resistance and mechanical strength according to Table C-6.

C.2.3 Qualification and testing of welding personnel for hyperbaric dry welding

C.2.3.1 Requirements for qualification and testing of welding personnel for hyperbaric dry welding are given in [C.9].

C.3 Welding consumables

C.3.1 General

C.3.1.1 Welding consumables shall be suitable for their intended application, giving a weld with the required properties and corrosion resistance in the finally installed condition.

C.3.1.2 Welding consumables for arc welding shall be classified according to recognised classification schemes.

C.3.1.3 Welding consumables and welding processes shall give a diffusible hydrogen content of maximum 5 ml/100g weld metal unless other requirements are given for specific applications in this appendix. Hydrogen testing shall be performed in accordance with ISO 3690.

C.3.1.4 For the FCAW welding processes it shall be documented that the hydrogen content of the deposited weld metal will be below 5 ml diffusible hydrogen per 100 g weld metal under conditions that realistically can be expected for production welding.

C.3.1.5 Welding consumables for processes other than manual or mechanised arc welding may require special consideration with respect to certification, handling and storage.

C.3.1.6 Depletion of alloying elements during welding performed with shielding gases other than 99.99% argon shall be considered.

C.3.1.7 All welding consumables shall be individually marked and supplied with an inspection certificate type 3.1 according to EN 10204 or equivalent. Certificate type 2.2 is sufficient for SAW flux.

Cellulose coated electrodes

C.3.1.8 Cellulose coated electrodes may be used only subject to agreement for welding of pipeline girth welds in C-Mn linepipe with SMYS ≤ 450 MPa. If used, see additional requirements in [C.5.1.8].

C.3.1.9 Use of cellulose coated electrodes is not permitted for:

— repair welding of pipeline girth welds
— welding of pipeline girth welds in C-Mn linepipe with SMYS > 450 MPa.

Data Sheet

C.3.1.10 Each batch of welding consumables shall be delivered in accordance with a manufacturer's data sheet, which shall state:

— guaranteed maximum value for diffusible hydrogen in the deposited weld metal
— the guaranteed minimum and maximum levels of C, alloying elements and any other intentionally added elements
— guaranteed mechanical properties (tensile and impact)
— determined under defined reference conditions. The data sheet shall, when relevant, also give recommendations for handling/recycling of the welding consumables in order to meet the guaranteed maximum value for diffusible hydrogen in the deposited weld metal.

Guidance note:

The contractor responsible for the welding and the welding consumable manufacturer should agree on the content and the specified limits in the data sheets.

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C.3.2 Chemical composition

C.3.2.1 All welding consumables shall be delivered in accordance with manufacturer's data sheets, which shall state the minimum and maximum levels of C, Mn, Si, P, S, micro-alloying elements and any other intentionally added elements.

C.3.2.2 For solid wire and metal powders, the chemical analysis shall represent the product itself. The analysis shall include all elements specified in the relevant classification standard and the relevant data sheet.

C.3.2.3 For coated electrodes and cored wires, the analysis shall represent the weld metal, deposited according to ISO 6847. The analysis shall include all elements specified in the relevant classification standard and the relevant data sheet

C.3.2.4 When H_2S service is specified, the chemical composition of the deposited weld metal shall comply with ISO 15156. The Ni-content in welding consumables for girth welds in C-Mn steel may be increased up to

2% Ni, provided that other requirements in ISO 15156 are fulfilled, and that the welding procedure has been tested for resistance to SSC.

C.3.2.5 The chemical composition of the weld overlay materials shall comply with the material requirements specified for the applicable type of overlay material or with a project specification.

C.3.3 Mechanical properties

Pipeline girth welds

C.3.3.1 Weld metal in pipeline girth welds shall, as a minimum have strength, ductility and toughness meeting the requirements of the base material.

C.3.3.2 For girth welds exposed to strain $\varepsilon_{l,nom}$< 0.4%, the yield stress ($R_{t0.5}$) of the weld metal should be minimum 80 MPa above SMYS of the base material. If two grades are joined, the requirement applies to the SMYS of the lower strength base material.

C.3.3.3 For girth welds exposed to strain $\varepsilon_{l,nom}$ ≥ 0.4%,the minimum required weld metalyield strength shall be 20 MPa less than the specified max YS of base material.

ECA shall be conducted for all girth welds exposed to a strain $\varepsilon_{l,nom}$ ≥ 0.4% (see DNVGL-RP-F108).

C.3.3.4 Whenever an ECA is performed, the tensile properties of the weld metal shall at least be equal to the properties used as input to the ECA. If the properties of the weld metal do not meet these requirements, it shall be validated that the assumptions made during design and/or the ECA have not been jeopardised.

C.3.3.5 Whenever an ECA is performed or for steels with SMYS ≥ 450 MPa, any batch intended for use in production welding that was not qualified during welding procedure qualification, shall be qualified according to [C.3.4].

C.3.3.6 For girth welds, all batches of consumables used in production including possible wire/flux combinations should be qualified by testing during welding procedure qualification.

C.3.3.7 Batch testing is not required for steels with SMYS < 450 MPa and when ECA is not performed providing the tensile and impact properties stated on the material/supplier certificates are above 90% of the values on the material/supplier certificates for the batch used during welding procedure qualification.

Pipeline components

C.3.3.8 For welds in pipeline components the weld metal shall, as a minimum, have ductility and toughness meeting the requirements of the base material and the actual yield stress (Rt0.5) of the deposited weld metal should be minimum 80 MPa above SMYS of the base material. If two grades are joined, the requirement applies to the SMYS of the lower strength base material.

C.3.4 Batch testing of welding consumables for pipeline girth welds

C.3.4.1 A consumable batch is defined as the volume of product identified by the supplier under one unique batch/lot number, manufactured in one continuous run from batch/lot controlled raw materials. For solid wire welding consumables, a batch may be defined as originating from the same heat of controlled raw materials, and not necessarily manufactured in one continuous run.

C.3.4.2 Batch testing shall be conducted to verify that consumables not tested during qualification of the welding procedure will give a deposited weld metal nominally equivalent to those batches used for welding procedure qualification, with respect to chemistry and mechanical properties.

C.3.4.3 The batch testing shall be performed for all welding consumables, including possible wire/flux combinations. Consumable batches and combinations used during WPQ are considered tested.

C.3.4.4 Each individual product (brand name and dimensions) shall be tested once per batch/lot, except for solid wire originating from the same heat, where one diameter may represent all. SAW fluxes do not require individual testing but SAW wires shall be tested in combination with a selected, nominal batch of flux of the same classification as used for the welding of the girth welds.

Mechanical testing

C.3.4.5 The testing shall be performed on samples taken from girth welds welded according to the welding procedure to be used in production. Samples shall be removed from same clock positions as for the WPQT. The testing shall be performed as required in App.B, and include:

— 1 all-weld metal tensile test.
— 1 macro section with hardness test of weld metal (HV10) as per Figure B-10, with only indentations towards the centre line of the weld, spaced by 1 mm.
— 1 set of Charpy V-notch test at weld centre line. Test temperature shall be the same as for qualification of the relevant welding procedure.

C.3.4.6 If an ECA is not performed, the mechanical properties shall meet the specified minimum requirements.

C.3.4.7 If an ECA is used as basis for establishing acceptance criteria for pipeline girth welds (see DNVGL-RP-F108), fracture toughness testing shall be performed with the same type of specimens and test conditions as for qualification of the relevant welding procedure, whenever:

— average impact test values are not within 80% of the average value obtained during WPQT
— all weld metal yield stress is not within 90% of the value obtained during WPQT

In case of fracture toughness testing, the results shall as a minimum meet the values that have been used as the basis for the ECA.

Chemical analysis

C.3.4.8 For solid wire and metal powders the analysis shall represent the product itself. For coated electrodes and cored wires, the analysis shall represent the weld metal, deposited according to EN 26847 (ISO 6847). The analysis, made by manufacturer or contractor, shall include:

— all elements specified in the relevant classification standard and the relevant data sheet, see [C.3.2.1]
— the N content.

C.3.4.9 The chemical analysis shall be in accordance with the composition ranges stated in the manufacturer's data sheets, see [C.3.2.1].

C.3.5 Shielding, backing and plasma gases

C.3.5.1 The classification and designation and purity of shielding, backing and plasma gases shall be in compliance with ISO 14175.

C.3.5.2 Gases shall be delivered with a certificate stating the classification, designation, purity and dewpoint of the delivered gas.

C.3.5.3 The gas supply/distribution system shall be designed and maintained such that the purity and dewpoint is maintained up to the point of use.

C.3.5.4 Shielding, backing and plasma gases shall be stored in the containers in which they are supplied. Gases shall not be intermixed in their containers.

C.3.5.5 If gas mixing unit systems are used, the delivered gas composition shall be verified and regularly checked.

C.3.6 Handling and storage of welding consumables

C.3.6.1 A detailed procedure for storage, handling, recycling and re-baking of welding consumables to ensure that the hydrogen diffusible content of weld metal is maintained at less than 5 ml per 100 g weld metal shall be prepared. The procedure shall, as a minimum, be in accordance with the manufacturer's recommendations. The procedure shall be reviewed and agreed prior to start of the production.

C.3.6.2 The manufacturer's recommendations may be adapted for conditions at the location of welding provided the following requirements are met:

— solid and flux cored wire shall be treated with care in order to avoid contamination, moisture pick-up and rusting, and shall be stored under controlled dry conditions. Ranges of temperature and relative humidity for storage shall be stated
— if vacuum packed low hydrogen SMAW welding consumables are not used, low hydrogen SMAW consumables shall be stored, baked, handled and re-baked in accordance with the manufacturer’s recommendation. Re-baking more than once should not be permitted
— flux shall be delivered in moisture proof containers/bags. The moisture proof integrity of bags shall be verified upon delivery and when retrieving bags for use. The flux shall only be taken from undamaged containers/bags directly into a hopper or storage container
— the temperature ranges for heated hoppers, holding boxes and storage containers shall be in accordance with the flux manufacturer’s recommendations
— whenever recycling of flux is applied, the recycling process shall ensure a near constant ratio of new/recycled flux and the ratio of new/recycled flux shall be suitable to prevent any detrimental degradation of the flux operating characteristics, e.g. moisture pick-up, excessive build-up of fines and change of grain size balance.

C.4 Welding procedures

C.4.1 General

C.4.1.1 Detailed welding procedure specifications shall be prepared for all welding covered by this appendix.

C.4.1.2 All welding shall be based on welding consumables, welding processes and welding techniques proven to be suitable for the type of material and type of fabrication in question.

C.4.2 Previously qualified welding procedures

General

C.4.2.1 A qualified welding procedure of a particular manufacturer is valid for welding only in workshops or sites under the operational technical and quality control of that manufacturer.

C.4.2.2 For welding procedures developed, qualified and kept on file for contingency situations such as hyperbaric welding procedures intended for pipeline repair and other contingency situations, the restrictions below shall not apply.

Pipeline girth welds

C.4.2.3 Previously qualified welding procedures shall not be used for:

— welding of girth welds when the SMYS of C-Mn linepipe is > 450 MPa

— welding of girth welds in clad or lined, duplex stainless steel or 13Cr martensitic stainless steel linepipe.

C.4.2.4 Except as limited by [C.4.2.3] above, a WPS for new production may be based on a previously qualified WPQR. The type and extent of testing and test results for the previously qualified WPQR shall meet the requirements of this appendix. A WPS for the new production shall be specified within the essential variables of this appendix.

C.4.2.5 For WPQRs older than 5 years the validity shall be documented through production tests.

Pipeline components

C.4.2.6 Previously qualified welding procedures shall not be used for welding of steels with SMYS > 450 MPa. A WPS for new production may otherwise be based on a previously qualified WPQR. The type and extent of testing and test results for the previously qualified WPQR shall meet the requirements of this appendix and a WPS for the new production shall, based the previously qualified WPQR, be specified within the essential variables of this appendix.

C.4.2.7 For a WPQR where the actual qualification is more than 5 years old, it shall be documented through production tests that a WPS based on the qualifying WPQR have been capable of producing welds of acceptable quality over a period of time. Alternatively a limited confirmation welding may be performed to demonstrate that the WPS is workable and producing welds of acceptable quality.

C.4.3 Preliminary welding procedure specification

C.4.3.1 A preliminary Welding Procedure Specification (pWPS) shall be prepared for each new welding procedure qualification. The pWPS shall contain the relevant information required for making a weld for the intended application when using the applicable welding processes, including tack welds.

C.4.4 Welding procedure qualification record

C.4.4.1 The Welding Procedure Qualification Record (WPQR) shall be a record of the materials, consumables, parameters and any heat treatment used during qualification welding and the subsequent non-destructive, destructive and corrosion test results. All essential variables used during qualification welding that are relevant for the final application of the WPQR shall be documented and the welding parameters recorded in relevant positions for each pass.

C.4.5 Welding procedure specification

C.4.5.1 A Welding Procedure Specification (WPS) is a specification based on one or more accepted WPQRs. One or more WPSs may be prepared based on the data of one or more WPQRs provided the essential variables are kept within the acceptable limits and other requirements of this appendix are met. A WPS may include one or a combination of welding processes, consumables or other variables.

All limits and ranges for the applicable essential variables for the welding to be performed shall be stated in the WPS. Grouping of passes, e.g. fill and cap passes, may be allowed subject to agreement.

C.4.5.2 The WPS shall be submitted together with the referenced supporting WPQR(s) for review and acceptance prior to start of production.

C.4.6 Welding procedure specification for repair welding

C.4.6.1 Repair welding procedure specifications shall be prepared in line with the type of repair weld qualifications required in [C.5.3.7].

C.4.7 Contents of preliminary welding procedure specification

C.4.7.1 The preliminary welding procedure specification (pWPS) shall contain the relevant information required for the applicable welding processes, including any tack welds. A pWPS for production welding shall include the information given in Table C-1 and [C.4.7.2], as relevant for the welding to be performed.

Table C-1 Contents of preliminary welding procedure specification

Manufacturer	*Identification of manufacturer*
pWPS	Identification of the pWPS.
Welding process	Welding process and for multiple processes; the order of processes used. Manual, partly-mechanised, mechanised and automatic welding.
Welding equipment	Type and model of welding equipment. Number of wires.
Base materials	Material grade(s), supply condition, chemical composition and manufacturing process. For steels with SMYS > 450 MPa; Steel supplier and For CRAs; UNS and PRE numbers.
Material thickness and diameter	Material thickness of test piece. Nominal ID of pipe.
Groove configuration	Groove design/configuration; dimensions and tolerances of angles, root face, root gap and when applicable; diameters. Backing and backing material.
Alignment and tack welding	Tack welding (removal of tack welds or integration of tack welds in the weld). Type of line-up clamp. Stage for removal of line-up clamp.
Welding consumables	Electrode or filler metal diameter or cross-section area. Type, classification and trade name. Manufacturer consumable data sheet shall be attached.
Shielding, backing and plasma gases	Designation, classification and purity according to ISO 14175. Nominal composition of other gases and gas mixtures. Gas flow rate.
Electrical characteristics and pulsing data	Polarity. Type of current (AC, DC or pulsed current). Pulse welding details (machine settings and/or programme selection).
Arc Characteristics	Spray arc, globular arc, pulsating arc or short circuiting arc.
Welding techniques	Welding position according to ISO 6947. Welding direction. Stringer/weave beads. Sequence of deposition of different consumables. Number of passes to be completed before cooling to below preheat temperature. Accelerated weld cooling (method and medium). Time lapse between completion of root pass and start of hot pass and number of welders on each side. Time lapse between completion of root pass and start of hot pass. For double sided welding: Sequence of sides welded first and last and number of passes welded from each side.
Preheating	Method of preheat and minimum preheat temperature. Minimum initial temperature when preheat is not used.
Interpass temperature	Maximum and minimum interpass temperature.
Heat input	Heat input range for each pass.
Post weld heat treatment	Method, time and temperature for post heating for hydrogen release Method of post weld heat treatment (holding time and heating and cooling rates).

Manufacturer	*Identification of manufacturer*
Specific for the SMAW welding process	Run-out length of electrode or travel speed.
Specific for the SAW welding process	Number and configuration of wire electrodes. Flux, designation, manufacturer and trade name. Additional filler metal. Contact tip - work piece distance. Arc voltage range.
Specific for the FCAW welding process	Mode of metal transfer (short circuiting, spray or globular transfer).
Specific for the GMAW welding process	Shielding and backing gas flow rate. Additional filler metal. Contact tip - work piece distance. Arc voltage range.
Specific for the GTAW welding process	Shielding and backing gas flow rate. Nozzle diameter. Diameter and codification of tungsten electrode (ISO 6848). Hot or cold wire.
Specific for the PAW welding process	Shielding, backing and plasma gas flow rate. Nozzle diameter. Type of torch. Contact tip - work piece distance. Hot or cold wire.
Specific for mechanized welding processes (general)	Control software (programme and/or software version. List of welding parameters that can be adjusted by the welders. Minimum number of welders for each pass.
Specific for mechanized GMAW welding process	Wire feed. Oscillation width and frequency. Side wall dwell time.
Specific for mechanized GTAW/PAW welding processes	Programmed arc voltage. Wire feed including pulsing pattern and timing diagram. Oscillation width and frequency. Side wall dwell time. Shielding gas timing diagrams and pulse pattern.

C.4.7.2 A pWPS for repair welding shall in addition to the requirements applicable for a pWPS for production welding include the following information:

— type of repair (see Table C-7)
— method of removal of the defect, preparation and design of the repair weld excavation
— minimum repair depth and length
— minimum ligament
— visual examination and NDT to be performed of the excavated area according to [D.2] to confirm complete removal of defect before welding as well as visual examination and NDT of the final repaired weld.
— In cases when through thickness or partial thickness repeated repairs are permitted or agreed (see Table C-7) the location of additional Charpy V-notch tests, in addition to the tests required by Table C-4, shall be shown on sketches in the pWPS.

C.4.8 Essential variables for welding procedures

C.4.8.1 A qualified welding procedure remains valid as long as the essential variables are kept within the limits specified in Table C-2.

C.4.8.2 For special welding processes as stated in [C.1.2.4] and welding systems using these processes other essential parameters and acceptable variations need to be applied and shall be subject to agreement.

C.4.8.3 The limits and ranges for essential variables for a WPS shall be based on the on documented records in one or more WPQRs.

C.4.8.4 The essential variables given in Table C-2 shall, when applicable, be supplemented with the requirements in [C.4.8.5] through [C.4.8.12] below.

C.4.8.5 If two different materials are used in one test piece, the essential variables shall apply to each of the materials joined. A WPQR qualified for a dissimilar material joint will also qualify each material welded to itself, provided the applicable essential variables are complied with.

C.4.8.6 Multiple test pieces may be required to qualify a pWPS where the size of a single test piece will not allow extraction of sufficient number of test specimens according to Figure C-2. In such cases the heat input for the same weld regions and passes between the test pieces should be as similar as possible. Maximum allowed heat input variations between the different test pieces are:

— 15% for mechanised and automated welding
— 30% for manual and partly-mechanised welding

An average heat input shall be calculated in line with [C.5.1.7].

Hardness and impact testing shall be taken as follows:

— hardness test specimens from the test piece and position welded with the lowest heat input
— impact test specimens from the test piece and position welded with the highest heat input.

C.4.8.7 When it is intended to qualify a pWPS with an extended heat input range (larger difference between high and low heat input) , the maximum difference between lowest and highest average heat input shall not exceed 30%. In the production WPS it is allowed to add the heat input tolerances as given in Table C-2. All required mechanical testing shall be performed on test pieces welded with both high and low heat input.

C.4.8.8 The minimum preheat or work piece temperature to be stated in the WPS shall not be below that of the test piece with the recorded highest preheat.

C.4.8.9 The maximum interpass temperature of any pass to be stated in the WPS shall not be higher than the recorded highest interpass temperature during qualification of the procedure. It is not allowed to boost the interpass temperature for one pass only. The maximum interpass temperature shall reflect the maximum interpass temperature that is expected during production.

Guidance note:

The all weld tensile test sample should be taken as close as possible to the location were the highest interpass temperature to be stated in the WPS is measured.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

C.4.8.10 When multiple filler metals are used in a test joint, the qualified thickness for each deposited filler metal shall be between 0.75 to 1.5 times the deposited thickness of that filler material during qualification.

To document the properties of each filler material, the test sample should at least contain 30% of the specimen cross-section for the filler material to be tested. If the mechanical properties of each filler material will not be documented by the original welding procedure qualification, separate welds with each consumable should be made to allow testing of AWT and WM/FL Charpy V-notch specimens.

C.4.8.11 If welders have been working on opposite sides of a test piece, the maximum difference in heat input between the welders shall not exceed the following:

— 15% for mechanised and automated welding.
— 30% for manual and partly-mechanised welding.

The allowable variation in heat input shall be based on the average of the heat inputs used by the welders.

Table C-2 Essential variables for welding of pipeline girth welds and component longitudinal welds

Variable		*Changes requiring re-qualification*
1 Manufacturer		
Manufacturer	a	Any change in responsibility for operational, technical and quality control.
2 Welding process		
The process(es) used	a	Any change.
The order of processes used	b	Any change when multiple processes are used.
Manual, partly-mechanised, mechanised or automatic welding	c	Any change between manual, partly-mechanised, mechanised and automatic welding.
3 Welding equipment		
Welding	a	Any change in make, type and model for partly-mechanised, mechanised and automatic welding.
Welding equipment	b	Any change in type for manual welding.
Number of wires	c	Change from single wire to multiple wire system and vice versa (e.g. going from tandem/twin to single wire). This does not apply to multiple torch systems where the wires feed into separate weld pools.
4 Base materials		
Material grade	a	A change from a lower to a higher strength grade but not vice versa.
Supply condition	b	A change in the supply condition (TMCP, Q/T or normalised).
Steel supplier	c	For SMYS ≥ 450 MPa; a change in base material origin (steel/plate/pipe mills) (linepipe to linepipe girth welds only – e.g. not for components).
Chemical composition	d	An increase in Pcm of more than 0.020, CE of more than 0.030 and C content of more than 0.02% for C-Mn and low alloy steel.
Manufacturing process	e	A change in manufacturing process (rolled, seamless, forged, cast).
UNS numbers.	f	A change in the UNS number for CRAs.
5 Material thickness and diameter		

Variable		*Changes requiring re-qualification*
Material thickness (t = nominal thickness of test joint.)	a	For non-H_2S service: — t ≤ 25 mm: A change outside 0.75 t to 1.5 t — t > 25 mm: A change outside 0.75 t to 1.25 t For H_2S service: — A change outside the thickness interval 0.75 t to 1.25 t.
Nominal ID of pipe	b	— t ≤ 25 mm: A change of pipe ID outside the range 0.5 ID to 2 ID — t > 25 mm: A change of pipe ID outside the range 0.5 ID to ∞.
6 Groove configuration		
Groove design/configuration.	a	Any change in groove dimensions outside the tolerances specified in the agreed WPS (all dimensions shall have tolerances).
Backing and backing material.	b	Addition or deletion of backing or change of backing material (e.g. from copper to ceramic).
7 Alignment and tack welding		
Tack welding	a	Any change in removal of tack welds or integration of tack welds in the weld.
Line-up clamp	b	Omission of a line-up clamp and a change between external and internal line-up clamp.
Removal of line-up clamp	c	Any reduction in length of each section of root pass welded; the spacing of sections, number of sections and percentage of circumference welded for external line-up clamp.
	d	Any decrease in number of completed passes and length of passes for internal line-up clamp.
8 Welding consumables		
Electrode or filler metal	a	Any change of diameter or cross-section area.
	b	Any change of type classification and brand (brand not applicable for bare wire).
	c	Any use of a non tested welding consumables batch when batch testing is required.

Variable		*Changes requiring re-qualification*
	d	Any use of a welding consumables batch with a reduction in tensile or impact properties of more than −10% (average values) from the batch used for WPQR when batch testing is not required.
Flux	e	Any change of type, classification and brand.
	f	Any increase in the ratio of recycled to new flux.
9 Shielding, backing and plasma gases		
Gases according to ISO 14175	a	Any change in designation, classification and purity according to ISO 14175.
Other gases and gas mixtures	b	Any change in nominal composition, purity and dew point.
Oxygen content of backing gas	c	Any increase.
Shielding gas flow rate	d	For processes 131, 135 136, 137 and 141 (see ISO 4063): Any change in flow rate beyond ± 10%.
10 Electrical characteristics and pulsing data		
Polarity	a	Any change in polarity.
AC, DC or pulsed current	b	Any change in type of current and a change from normal to pulsed current and vice versa.
Pulse frequency range in pulsed manual welding	c	Any change in: Pulse frequency for background and peak current exceeding ± 10% and pulse duration range exceeding ± 10%.
11 Arc Characteristics		
Mode of metal transfer	a	A change from spray arc, globular arc or pulsating arc to short circuiting arc and vice versa.
12 Welding techniques		
Angle of pipe axis to the horizontal	a	A change of more than ± 15°from the position welded. The L045 position qualifies for all positions provided all other essential variables are fulfilled.
Welding direction	b	A change from upwards to downwards welding and vice versa.
Stringer/weave	c	A change from stringer to weave of more than 3X electrode/wire diameter or vice versa.

Variable		*Changes requiring re-qualification*
Sequence of deposition of different consumables	d	Any change in the sequence.
Sequence of sides welded first and last (double sided welds)	e	Any change in the sequence.
Passes welded from each side	f	Change from single to multi pass welding and vice versa.
Number of welders	g	Any decrease in number of welders for welding of root and hot pass for cellulose coated electrodes.
Time lapse between completion of root pass and start of hot pass	h	Any increase above maximum time qualified.
Weld completion	i	Any reduction in the number of passes completed before cooling to below preheat temperature.
Accelerated weld cooling	j	Any change in method and medium and any increase in maximum temperature of the weld at start of cooling.
13 Preheating		
Preheat temperature	a	Any reduction.
Initial temperature when preheat is not used	b	Any reduction.
14 Interpass temperature		
Maximum and minimum interpass temperature	a	Any increase for CRAs, C-Mn and low alloy steel. Any reduction below the preheat temperature.
15 Heat input		
Heat input range for each pass	a	For C-Mn and low alloy steels with SMYS ≤ 450 MPa in non-H_2S service: Any change exceeding ± 15%.
	b	For C-Mn and low alloy steels with SMYS > 450 MPa and C-Mn and low alloy steels in H_2S service: Any change exceeding ± 10%.
	c	For CRAs: Any change exceeding ± 10%.
16 Post weld heat treatment		
Post heating; hydrogen release	a	Any reduction in the time and temperature and deletion but not addition of post heating.

Variable		*Changes requiring re-qualification*
Post weld heat treatment	b	Addition or deletion of post weld heat treatment. Any change in holding temperature exceeding ± 20°C. Any change in heating and cooling rates outside ± 5%.
Holding time	c	Any change in holding time outside below formula (± 5%): *holding time = (actual thickness/qualified thickness) × qualified holding time.*
17 Specific for the SAW welding process		
Wire electrode configuration.	a	Each variant of process 12 (121 to 125) shall be qualified separately.
Flux	b	Any change of type, classification and brand.
Arc voltage range.	c	Any change beyond ± 10%.
18 Specific for the FCAW welding process		
Mode of metal transfer	a	A change from short circuiting transfer to spray or globular transfer. Qualification with spray or globular transfer qualifies both spray or globular transfer.
19 Specific for the GMAW welding process		
Arc voltage range	a	Any change beyond ± 10%.
20 Specific for the GTAW welding process		
Diameter and codification of tungsten electrode (ISO 6848)	a	Any change.
Hot or cold wire.	b	A change from hot to cold wire and vice versa.
21 Specific for the PAW welding process		
Hot or cold wire	a	A change from hot to cold wire and vice versa.
22 Specific for automatic welding of pipeline girth welds		
Control software	a	Any change.
Pre-set parameters	b	Any change (applies to parameters that can not be adjusted by the welder).
23 Specific for mechanised welding of pipeline girth welds		
Control software	a	Any change.
24 Specific for repair welding		

Variable		*Changes requiring re-qualification*
Welding techniques	a	A change from internal to external repairs and vice versa for pipeline girth welds.
	b	A change from single to multi pass repairs and vice versa.
	c	A change from cold to thermal method for removal of the defect but not vice versa.
	d	Any increase above 20% in the depth of excavation for partial thickness repairs.

C.4.8.12 If CRA or clad welds are subject to solution annealing heat treatment after welding a slight variation in welding parameters outside those in Table C-2, Items 10 through 15 may be agreed.

C.5 Qualification of welding procedures

C.5.1 General

C.5.1.1 Qualification welding shall be performed based upon the accepted pWPS, using the type of welding equipment to be used during production welding, and under conditions that are representative of the actual working environment for the work shop, site, or vessel where the production welding will be performed. The configuration of the test joint shall be representative of the actual weld to be performed during production.

C.5.1.2 The number of test joints shall be sufficient to obtain the required number of specimens from the required locations given in Figure C-1 and Figure C-2. Allowance for re-testing should be considered when deciding the number of test joints to be welded.

C.5.1.3 The test joints for qualification welding shall be of sufficient size to give realistic restraint during welding.

C.5.1.4 The base material selected for the qualification testing should be representative of the upper range of the specified chemical composition for C-Mn and low alloy steels, and of the nominal range of the specified chemical composition for corrosion resistant alloys.

C.5.1.5 The material thickness shall be the same for both pipes/components/plates to be welded, except to qualify joining of two base materials with unequal thickness and for fillet end T-joint test pieces.

Qualification welding

C.5.1.6 Certificates for materials and consumables, including shielding, backing and plasma gases, shall be verified, and validity and traceability to the actual materials shall be established prior to start of qualification welding. The records from qualification welding shall include all information needed to establish a WPS for the intended application within the essential variables and their allowable ranges.

C.5.1.7 The following requirements apply:

— the welding qualification test shall be representative for the production welding with respect to welding positions, interpass temperature, application of preheat (propane will also qualify for induction coil preheating), heat conduction, etc.
— if multiple welding arcs are combined in a single welding head the parameters for each welding arc shall be recorded
— the direction of plate rolling (when relevant) and the 12 o'clock position (for fixed pipe positions) shall be marked on the test piece

- when more than one welding process or filler metal is used to weld a test piece, the parameters used and the approximate thickness of the weld metal deposited shall be recorded for each welding process and filler metal
- if tack welds are to be fused into the final joint during production welding, they shall be included when welding the test piece
- backing gas oxygen content and the duration of backing gas application before, during and after welding shall be recorded
- each test piece shall be uniquely identified by hard stamping or indelible marking adjacent to the weld and the records made during test welding, non-destructive testing and mechanical testing shall be traceable to each test piece
- average heat input shall be calculated and should be based on averages of each parameter (V, A, travel speed).

Pipeline girth welds

- the welding qualification test shall be representative for the production welding with respect to angle of pipe axis., interpass temperature, application of preheat, heat conduction, etc.
- for girth welds in welded pipe in all positions, except 1G (PA) and 2G (PC), it is recommended that one of the pipes used for the welding procedure qualification test be fixed with the longitudinal weld in the 6 or 12 o'clock position
- for welding of pipe with diameter ≥ 20” in fixed positions, the weld circumference shall be divided in appropriate sectors around the circumference. The welding parameters shall be recorded for each pass in each sector and for each welding arc. For each sector an average heat input shall be determined for each pass. For manual welding, the heat input for a sector shall be recorded as average of all the average heat inputs for the run-out lengths in each pass in that sector
- for welding of pipe with diameter < 20” the average heat input shall be recorded for each pass. For manual welding, the heat input for each pass shall be recorded as average of all the average heat inputs for the run-out lengths in each pass in the pipe circumference
- the heat input range to be stated on the WPS for the full circumference shall be based on the highest and lowest circumferential or sectoral average heat input, as relevant, with tolerances as given in Table C-2. Grouping of passes, e.g. fill and cap passes, may be allowed subject to agreement
- the release of external line-up clamps shall be simulated during qualification welding. Clamps should not be released until the completed sections of the root pass covers a minimum of 50% of the circumference with even spacing. The length of each section, the spacing of the sections, the number of sections welded and the percentage of welded sections of the circumference shall be recorded
- if it is expected that the interpass temperature will drop below preheat temperature during installation welding, this scenario shall be simulated during qualification welding. The number of passes completed before cooling to below preheat temperature shall be recorded
- accelerated cooling of the weld shall be performed during qualification welding if accelerated weld cooling, e.g. for AUT will be performed in production. The cooling method and the weld temperature at the start of the cooling shall be recorded. A macro and hardness shall be taken at cooling start point.

C.5.1.8 If the use of cellulose covered electrodes has been agreed, the following additional requirements shall apply:

- preheat shall be minimum 100°C
- delay between completion of the root pass and the start of depositing the hot pass shall be minimum 6 minutes
- immediately upon completion of welding during welding procedure qualification the test pieces shall be water quenched as soon as the temperature of the test piece is below 300°C
- non destructive testing of the test piece shall be by Automated Ultrasonic Testing (AUT) or Radiographic testing and Manual Ultrasonic Testing.

C.5.2 Repair welding procedures

C.5.2.1 Repair welding shall be qualified by a separate weld repair qualification test.

C.5.2.2 Preheat for repair welding should be minimum 50°C above minimum specified preheat for production welding.

C.5.2.3 When a heat treated pipe or component is repaired by welding, a new heat treatment may have to be included in the qualification of the weld repair procedure, depending on the effect of the weld repair on the properties and microstructure of the existing weld and base material.

C.5.2.4 Qualification of repair welding procedures shall be made by excavating a groove in an original weld welded in accordance with a qualified welding procedure.

C.5.2.5 The excavated groove shall be of sufficient length to obtain the required number of test specimens + 50 mm at each end.

Repeated repairs

C.5.2.6 If repeated weld repairs are permitted or agreed, these shall be qualified separately.

C.5.2.7 In case of repeated repairs, the test piece shall contain a repair weld of a repaired original weld. For repeated in-process root repair, single pass cap repair and/or single pass root sealing repairs the repair weld shall be removed prior to re-repair. A repeated repair qualification may qualify a repair WPS providing it is ensured that the HAZ has been exposed to two heat treatment cycles, i.e. the second excavation is performed exactly on the same location as the first excavation.

C.5.2.8 The qualification test shall be made in a manner realistically simulating the repair situation to be qualified.

C.5.2.9 Qualification welding shall be performed in accordance with [C.5.1.1] through [C.5.1.8].

C.5.2.10 For pipeline girth welds the repair qualification welding shall be performed in the overhead through vertical positions.

C.5.2.11 For roll welding the length of the repair weld may be centred at the 12 o'clock location for external repairs and at the 6 o'clock location for internal repairs, in which case repair welding is qualified for repair welding in these locations only.

C.5.3 Qualification of girth butt welds and component longitudinal welds welding procedures

C.5.3.1 Qualification of welding procedures for pipeline system girth welds and welds in pipeline components may be performed by any of the arc welding processes specified in [C.1.2].

C.5.3.2 The WPS shall be qualified and approved by all parties prior to start of any production welding.

C.5.3.3 The type and number of destructive tests for welding procedure qualification are given in Table C-3, with methods and acceptance criteria as specified in [C.6].

C.5.3.4 For pipeline girth welds exposed to strain ≥ 0.4%, testing should be performed to determine the properties of weld metal in the strained and aged condition after deformation cycles and also at elevated temperature. See DNVGL-RP-F108.

Qualification of repair welding procedures

Table C-3 Qualification of welding procedures for girth butt welds including component longitudinal welds

Test joint Minimum number of each specified test											
Wall thickness (mm)	D *(mm)*	*Transverse weld Tensile*	*Transverse all-weld Tensile* 1)	*All-weld tensile* 1)	*Root bend* 9)	*Face bend* 9)	*Side bend*)	*Charpy V-notch sets* 3, 4,5,6,7)	*Macro and hardness* 10)	*Other tests*	*Fracture toughness*
≤ 25	≤ 300 > 300	2 2	2 2	2 2	2 2) 4 2)	2 2) 4 2)	0 0	4 4	2 2	11) 11)	12) 12)
> 25	all	2	2	2	0	0	4	6	2	11)	12, 13)

Notes:

1) The strength mismatch between the girth weld and the parent material shall be evaluated when ECA is required. All-weld tensile specimens are recommended when ECA is performed, however, transverse all-weld specimens are acceptable. In case of ECA, full stress-strain curves shall be established as far as possible, see also DNVGL-RP-F108. If it is impossible to prepare test samples due to size limitations, weld metal properties shall be documented based on the weld consumables material certificates provided by the supplier (i.e. to document that the yield and ultimate tensile weld metal strength are above the base metal values).
2) For welding processes GMAW, GTAW, FCAW and SMAW side bend tests shall be performed instead of root and face bend tests. For t > 12 mm side bend test is an acceptable alternative to root and face bend tests.
3) Impact testing is not required for t < 6 mm.
4) Each Charpy V-notch set consists of 3 specimens.
5) The notch shall be located in the weld metal, the fusion line (FL) sampling 50% of HAZ, FL+2 mm and FL+5 mm, see App.B, Figure B-3 through Figure B-5.
6) For double sided welds on C-Mn and low alloy steels, four additional sets of Charpy V-notch test specimens shall be sampled from the weld metal, FL (sampling 50% of HAZ), FL+2 mm and FL+5 mm in the root area, see Figure B-5.
7) If several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions, even if the region tested cannot be considered representative for the complete weld.
8) When the wall thickness exceeds 25 mm for single sided welds, two additional sets of Charpy V-notch test specimens shall be sampled from the weld metal root and FL in the root area.
9) Bend tests on clad/lined pipes shall be performed as side bend tests. 4 side bend tests shall be performed (for all wall thicknesses).
10) For girth welds in welded pipe, one macro and hardness shall include an intersection between a longitudinal/girth weld.
11) Requirements for corrosion tests, chemical analysis and microstructure examination are specified in [C.6].
12) Fracture toughness testing is only required when a generic or full ECA is performed for pipeline girth butt welds. Extent of testing shall be in accordance with DNVGL-RP-F108.
13) For nominal wall thickness above 50 mm in C-Mn and low alloy steels fracture toughness testing is required unless PWHT is performed.

C.5.3.5 Qualification of repair welding procedures for pipeline system girth welds and welds in pipeline components may be performed by any of the arc welding processes specified in [C.1.2].

C.5.3.6 The WPS for repair welding shall be qualified prior to start of any production repair welding.

C.5.3.7 The following types of repairs should be qualified to the extent that such repairs are feasible and applicable for the repair situation considering the size of pipe or component:

— through thickness repair
— partial thickness repair
— in-process root repair
— single pass cap repair
— single pass root sealing repair.

C.5.3.8 The type and number of destructive tests for qualification or repair welding procedure are given in Table C-4, with methods and acceptance criteria as specified in [C.6] below.

Repeated repairs

C.5.3.9 If it has been agreed to permit through thickness or partial thickness repeated repairs (see Table C-7), and a HAZ is introduced in the weld metal from the first repair, then additional Charpy V-notch sets (in addition to the tests required by Table C-4) shall be located in the re-repair weld metal and in FL, FL+2 mm and FL+5 mm of the weld metal from the first repair and/or the base material as applicable and as shown in the accepted pWPS, see [C.4.7.2].

C.5.3.10 If it has been agreed to permit repeated in-process root repair, single pass cap repair and/or single pass root sealing repair, see Table C-7, the extent of testing shall be as tests required by Table C-4.

Table C-4 Qualification of repair welding procedures for girth butt welds including components longitudinal welds

Test joint	*Minimum number of each specified test*									
Type of repair	*Transverse weld tensile*	*Transverse all-weld tensile* 1)	*All-weld tensile* 1), 2)	*Root bend*	*Face bend*	*Side bend*	*Charpy V-notch sets*	*Macro and hardness*	*Other tests*	*Fracture toughness*
Through thickness repair	1	1	1	1 2)	1 2)	2 3)	9 4, 5, 6)	1	7)	8, 9)
Partial thickness repair	1	1	1	1 2)	1 2)	2 3)	7 4, 5, 6)	1	7)	8, 9)
In-process root repair				1				1	7)	
Single pass cap repair					1			1	7)	
Single pass root sealing repair				1				1	7)	

Notes:

1) The strength mismatch between the girth weld and the parent material shall be evaluated when ECA for repair weld is required. All-weld tensile specimens are recommended when ECA is performed, however, transverse all-weld specimens are acceptable. In case of ECA, full stress-strain curves shall be established as far as possible, see also DNVGL-RP-F108. If it is impossible to prepare test samples due to size limitations, weld metal properties shall be documented based on the weld consumables material certificates provided by the supplier (i.e. to document that the yield and ultimate tensile weld metal strength are above the base metal values).
2) 1 root and 1 face bend test for $t \leq 25$ mm. For $t > 12$ mm side bend test is an acceptable alternative to root and face bend tests.
3) For welding processes GMAW, GTAW, FCAW and SMAW, for clad/lined pipes and for all pipes when $t > 25$ mm, side bend tests shall be performed instead of root and face bend tests.
4) For partial penetration and through thickness repairs where a new HAZ is introduced in the original weld metal, Charpy V-notch sets of 3 specimens shall be located according to App.B, Figure B-7 and Figure B-8.
5) The notch shall be located in the repair weld metal, the fusion line (FL) sampling 50% of HAZ, FL+2 mm and FL+5 mm of both the base material and the original weld.
6) If several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions, even if the region tested cannot be considered representative for the complete weld.
7) Requirements for corrosion tests, chemical analysis and microstructure examination are specified in [C.6].
8) Fracture toughness testing of repairs is only required when a generic or full ECA is performed for the original pipeline girth butt welds. Extent of testing shall be in accordance with DNVGL-RP-F108.
9) For nominal wall thickness above 50 mm in C-Mn and low alloy steels fracture toughness testing is required unless PWHT is performed

C.5.4 Qualification of welding procedures for corrosion resistant overlay welding

Qualification of welding procedures

C.5.4.1 Qualification of welding procedures for corrosion resistant overlay welding shall be performed with GMAW or pulsed GTAW. Other methods may be used subject to agreement.

C.5.4.2 The chemical composition of test pieces shall be representative for the production conditions.

C.5.4.3 Qualification of weld overlay shall be performed on a test sample which is representative for the size and thickness of the production base material, e.g. tolerance ranges in ISO 15614-7 may be considered acceptable. The minimum weld overlay thickness used for the production welding shall be used for the welding procedure qualification test.

C.5.4.4 The dimensions of, or the number of test pieces shall be sufficient to obtain all required tests.

C.5.4.5 The test pieces used shall be relevant for the intended application of the weld overlay:

— forging or casting for overlay welding of ring grooves
— pipe with the overlay welding performed externally or internally, or
— plate or pipe with a prepared welding groove for qualification of buttering and when the weld overlay strength is utilised in the design.

C.5.4.6 If a buffer layer will be used in production welding, it shall also be used in welding the test piece.

C.5.4.7 The WPS shall be qualified prior to start of any production welding.

C.5.4.8 The type and number of destructive tests for welding procedure qualification are given in Table C-5 with methods and acceptance criteria specified in [C.6].

Qualification of repair welding procedures

Table C-5 Qualification of corrosion resistant overlay welding procedures

Test joint	*Minimum number of each specified test*					
Thickness of base material	*Side bend*	*Macro and hardness tests*	*Chemical analysis*	*All-weld tensile*	*Charpy V-notch Impact tests*	*Other tests*
All	4 [1)]	1	1	2 [2)]	[2,3,4,5)]	[6)]

Notes:

1) Side bend specimens shall be taken transverse to the welding direction.
2) Only required when the weld overlay strength is utilised in the design of the welded joint (e.g. load bearing weld overlay).
3) Only required when the weld overlay is load bearing across the overlay/base material fusion line.
4) Sets shall be tested with the notch in the overlay weld metal, Fl, and FL+2 mm and FL+5 mm in the base material.
5) If several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions if the region otherwise required to be tested cannot be considered representative for the complete weld.
6) Requirements for corrosion tests and microstructure examination are specified in [C.6].

C.5.4.9 Unless the production welding procedure can be applied, the repair welding procedure shall be qualified. Weld repair performed on weld overlay machined to the final thickness shall be separately qualified.

C.5.4.10 The type and number of destructive tests for qualification of repair welding procedure are given in Table C-5. In cases when qualification is performed using a pipe, component or plate with a prepared welding groove, and a new HAZ is introduced in the original weld metal, additional Charpy V-notch impact sets shall be located according to Figure B-7 and Figure B-8.

C.5.5 Qualification of procedures for pin brazing and aluminothermic welding of anode leads

Qualification of procedures

C.5.5.1 Attachment of anode leads shall be by pin brazing or aluminothermic welding methods. Other methods may be used subject to agreement. Full details of the technique used and associated equipment shall be available prior to qualification of procedures.

C.5.5.2 The chemical composition of test pieces shall be representative for the production conditions and be selected in the upper range of the chemical composition.

C.5.5.3 Qualification for brazing/welding of anode leads shall be performed on test samples which is representative for the size and thickness of the production base material and the number of test pieces shall be minimum 4 and sufficient to obtain all required tests.

C.5.5.4 The WPS shall be qualified prior to start of any production.

Table C-6 Qualification of pin brazing and aluminothermic welding procedures

Test joint	*Minimum number of each specified test* [1)]				
Thickness of base material	*Electrical resistance*	*Mechanical strength*	*Copper penetration* [2)]	*Hardness* [3)]	*Pull test*
All	4	4	4	4	4

Notes

1) The number of tests refers to the total number of tests from all pieces.

2) 2 test specimens shall the sectioned transverse to the anode lead and 2 test specimens parallel with the anode lead.

3) The hardness tests shall be made on the specimens for copper penetration measurements.

C.5.5.5 The type and number of destructive tests for procedure qualification are given in Table C-6 with methods and acceptance criteria specified in [C.6] below.

C.5.6 Qualification of welding procedures for temporary and permanent attachments and branch welding fittings to linepipe

Qualification of welding procedures

C.5.6.1 Qualification of welding procedures for temporary and permanent attachments and branch welding fittings to linepipe may be performed by any of the arc welding processes specified in [C.1.2], but use of cellulose coated electrodes is not permitted.

C.5.6.2 The WPS shall be qualified prior to start of any production welding.

C.5.6.3 The type and number of destructive tests for welding procedure qualification are given in [C.5.6.4] to [C.5.6.14] with methods and acceptance criteria as specified in [C.6].

Longitudinal welds in doubler sleeves

C.5.6.4 Longitudinal welds in doubler sleeves shall be made with backing strips and qualified as required in [C.5.3] and Table C-3, but with the extent of testing limited to:

— transverse weld tensile
— Charpy V-notch impact testing
— macro and hardness testing.

Fillet welds in doubler sleeves and anode pads

C.5.6.5 The fillet weld qualification test shall comprise two test pieces welded in the PD and PF plate positions to qualify the welding procedure for welding in all positions.

C.5.6.6 The extent of testing for each test piece shall be 3 macro and hardness specimens taken from the start, end and middle of each test weld with methods and acceptance criteria as specified in [C.6].

Branch welding fittings

C.5.6.7 The branch fitting qualification test welds shall be welded in the PF and PD pipe positions to qualify welding in all positions.

C.5.6.8 The extent of testing shall be 4 macro and hardness specimens taken from the 12, 3, 6 and 9 o'clock locations of each test weld. A procedure qualified as a butt weld may be used.

C.5.6.9 Charpy V-notch impact testing with the notch in the weld metal, FL, FL+2 mm and FL+5 mm using full size or reduced size specimens shall always be performed whenever the material thickness allows. Charpy V-notch specimens shall be taken from both test welds.

Qualification of repair welding procedures for longitudinal welds in doubler sleeves

C.5.6.10 Repair welding procedures for longitudinal welds in doubler sleeves shall be qualified as required in [C.5.3] and Table C-4, but with the extent of testing modified according to [C.5.6.4].

Qualification of repair welding procedures for fillet welds

C.5.6.11 Qualification welding shall be performed in the PD and PF plate positions. The extent of qualification of repair welding procedures shall at as a minimum consist of:

— through thickness repair
— single pass repair against the pipe material
— single pass repair against the sleeve material.

C.5.6.12 Methods of testing and acceptance criteria shall be as specified in [C.6].

Qualification of repair welding procedures for branch welding fittings

C.5.6.13 Qualification welding shall be performed in the PD and PF pipe positions. The extent of qualification of repair welding procedures shall at as a minimum consist of:

— through thickness repair
— single pass cap repair against the fitting
— single pass cap repair against the pipe.

C.5.6.14 Methods of testing and acceptance criteria shall be as specified in [C.6].

C.5.7 Qualification of welding procedures for structural components

C.5.7.1 Welding procedures for structural components, supplied as a part of the pipeline systems, shall be qualified in accordance with ISO 15614-1. The requirements shall be appropriate for the structural categorisation of the members and stresses in the structure. The extent of tensile, hardness and impact testing and the testing conditions should be in compliance with this appendix.

C.5.8 Qualification of welding procedures for hyperbaric dry welding

C.5.8.1 Requirements for qualification of welding procedures for hyperbaric dry welding are given in [C.9].

C.6 Examination and testing for welding procedure qualification

C.6.1 General

C.6.1.1 All visual examination, non-destructive testing, mechanical testing and corrosion testing of test pieces shall be performed in the as welded or post weld heat treated condition, whatever is applicable for the final product.

Visual examination and non-destructive testing

C.6.1.2 Visual examination and non-destructive testing shall be performed no earlier than 24 hours after the completion of welding of each test piece. Original welds intended for repair welding qualification may be examined and tested when temperature of test piece allows for it.

C.6.1.3 If a test piece does not meet the acceptance criteria for visual examination and NDT, one further test piece shall be welded and subjected to the same examination. If this additional test piece does not meet the requirements, the WPQ is not acceptable.

Destructive testing

C.6.1.4 The type and number of mechanical tests and microstructure evaluations for qualification tests are given in [C.5.3] to [C.5.7].

C.6.1.5 Test specimens shall be taken from the positions shown in Figure C-1 and Figure C-2 for longitudinal welds and girth welds respectively.

Re-testing

C.6.1.6 A destructive test failing to meet the specified requirements may be re-tested. The reason for the failure shall be investigated and reported preferably before any re-testing is performed. If the investigation reveals that the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample and specimen (as relevant) shall be replaced by a correctly prepared sample or specimen and a new test performed.

C.6.1.7 A destructive test failing to meet the specified requirements shall be rejected if the reason for failure can not be related to improper sampling, machining, preparation, treatment or testing of specimens.

C.6.1.8 Re-testing of a test failing to meet the specified requirements should only be performed subject to agreement. This re-testing shall consist of at least two further test specimens/sets of test specimens. If both re-tests meet the requirements, the test may be regarded as acceptable. All test results, including the failed tests, shall be reported.

C.6.1.9 If there are single hardness values in the different test zones (weld metal, HAZ, base material) that do not meet the requirement, retesting shall be carried out on the reverse side of the tested specimen or after grinding and re-preparation of the tested surface. None of these additional hardness values shall exceed the maximum value.

C.6.1.10 For Charpy V-notch impact testing the following requirements shall apply:

— in order to consider a set as approved, the average requirement has to be met and only one test specimen out of the three may have a value between the average and the single minimum requirement.
— subject to agreement, retest may be performed with two test specimen sets.

Note 1: For pipeline girth welds, if applicable, one macro and hardness specimen shall include a pipe longitudinal seam weld.

Note 2: The indicated location of the test specimens are not required for qualification of welding in the PA (1G rotated) where sampling positions are optional.

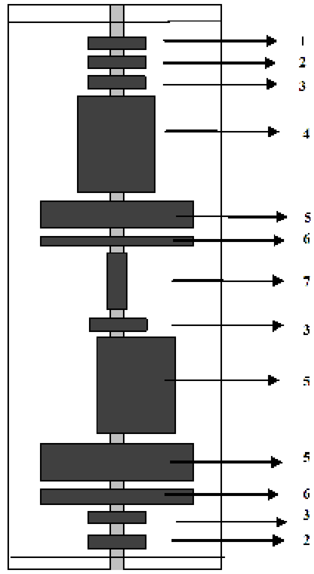

Figure C-1 Welding procedure qualification test - sampling of test specimens for longitudinal butt welds.

Note: The indicated location of the test specimens are not required for qualification of welding in the PA (1G) and PC (2G) positions, where sampling positions are optional.

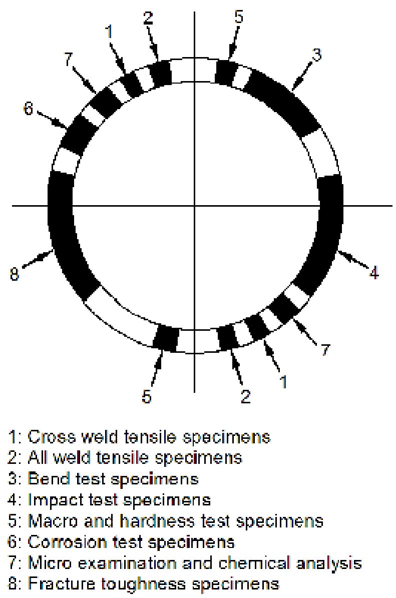

Figure C-2 Welding procedure qualification test - typical sampling of test specimens for girth butt welds.

Note 1: For pipeline girth welds, if applicable, one macro and hardness specimen shall include a pipe longitudinal seam weld.

Note 2: The indicated location of the test specimens are not required for qualification of welding in the PA (1G rotated) where sampling positions are optional.

C.6.2 Visual examination and non-destructive testing requirements

C.6.2.1 Each test weld shall undergo 100% visual examination and 100% ultrasonic and 100% radiographic testing and 100% magnetic particle or liquid penetrant testing. Testing shall be in accordance with [D.2]. AUT in line with production inspection as required in App.E may be used instead of manual UT + RT.

C.6.2.2 Acceptance criteria for visual examination and non-destructive testing shall be in accordance with [D.2.9] for welds exposed to strains < 0.4%. For welds exposed to strains ≥ 0.4%, the acceptance criteria shall be as for the production welding or according to [D.2.9], whichever is the more stringent.

Guidance note:

When results from ECA are not available, it is recommended to consider relevant historical data compared with workmanship criteria [D.2.9] as basis for acceptance criteria.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

C.6.2.3 Weld overlay shall be non-destructively tested according to [D.3.3] with acceptance criteria according to [D.3.6]. The surface and weld thickness shall be representative for the production welding, i.e. after machining of the overlay thickness or the thickness representative for the thickness on the finished component.

C.6.3 Testing of butt welds

C.6.3.1 All testing shall be performed in accordance with App.B.

Transverse weld tensile testing

C.6.3.2 For longitudinal welds and girth welds exposed to strain $\varepsilon_{l,nom}$ ≥ 0.4% the fracture shall not be located in the weld metal, while for longitudinal welds and girth welds exposed to strain $\varepsilon_{l,nom}$ <0.4% and where no ECA is performed the fracture should not be in the weld metal. The ultimate tensile strength shall be at least equal to the SMTS for the base material. When different material grades are joined, the ultimate tensile strength of the joint shall be at least equal to the SMTS for the lower grade.

All-weld tensile testing

C.6.3.3 For longitudinal welds and girth welds exposed to strain $\varepsilon_{l,nom}$ <0.4% and where no ECA is performed, the upper yield or the $R_{t0.5}$ of the deposited weld metal should be 80 MPa above SMYS of the base material and the elongation not less than 18%. If two grades are joined the requirement applies to the lower strength material.

Transverse all-weld tensile testing

C.6.3.4 For pipeline girth welds where generic ECA acceptance criteria (see DNVGL-RP-F108) are applied, the upper yield or the $R_{t0.5}$ of the deposited weld metal shall as a minimum exceed or be equal to a value 20 MPa below the specified maximum base material yield strength. The elongation shall as a minimum be 18%.When different material grades are joined, the yield stress requirements applies to the lower grade.

C.6.3.5 For pipeline girth welds exposed to strain $\varepsilon_{l,nom}$ ≥ 0.4% and where full ECA acceptance criteria shall be applied, the upper yield or the $R_{t0.5}$ of the deposited weld metal shall as a minimum exceed or be equal to a value 20 MPa below the specified maximum base material yield strength, or the assumptions made during design and/or the ECA. The elongation shall as a minimum be 18%.

Bend testing

C.6.3.6 The end tests shall not disclose any open defects in any direction exceeding 3 mm. Minor ductile tears less than 6 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

Charpy V-notch impact testing

C.6.3.7 The average and single Charpy V-notch toughness at each position shall not be less than specified for the base material in the transverse direction (KVT values). Requirement for fracture arrest properties does not apply.

— C-Mn and low alloy steels shall meet the requirements given in [7.2.4].
— Duplex and martensitic stainless steels shall meet the requirements given in [7.3.4].
— The C-Mn steel backing material in clad and lined linepipe shall meet the requirements given in [7.2.4].

C.6.3.8 When different steel grades are joined, the required impact tests shall be performed on both sides of the weld. The weld metal shall meet the less stringent energy requirement.

Macro section

C.6.3.9 The macro section shall be documented by photographs (magnification of at least 5×).

C.6.3.10 The macro section shall show a sound weld merging smoothly into the base material and meeting Quality level C of ISO 5817.

C.6.3.11 For girth welds in welded pipe, one macro section shall include a longitudinal weld.

Hardness testing

C.6.3.12 The maximum hardness in the HAZ and weld metal is:

— 325 HV10 for C-Mn and low alloy steels in non-H_2S service (also applies to backing steel in clad or lined material).
— 250 HV10 for C-Mn and low alloy steels in H_2S service (for weld caps not exposed to the H_2S media, maximum hardness of 275 HV10 may be agreed for base material thickness >9 mm) unless a higher hardness has been qualified according to [6.2.2.2] and [B.3.4].
— 350 HV10 for 13Cr martensitic stainless steels
— 350 HV10 for duplex stainless steels
— 345 HV10 for Ni-based alloys in clad or lined material in non-H_2S service. For explosion welded clad material the requirement of maximum 40 HRC in accordance with API 5LD applies.
— 300 HV10 for austenitic stainless steels in clad or lined material in non-H_2S service
— 275 HV10 for anode pads.

For clad or lined materials in H_2S service special considerations are required, see ISO 15156.

C.6.3.13 Subject to agreement, additional hardness measurements shall be taken in the start/stop area for repair weld qualification.

C.6.3.14 For girth welds in welded pipe, one hardness test specimen shall include a longitudinal weld.

Corrosion testing

C.6.3.15 Sulphide stress cracking testing (SSC) is only required for C-Mn and low alloy steels with SMYS > 450 MPa, 13Cr martensitic stainless steels and other materials not listed for H_2S service in ISO 15156.

Acceptance criteria shall be according to ISO 15156.

C.6.3.16 Pitting corrosion test according to ASTM G48 is only required for 25Cr duplex stainless steel (see [6.2.3.2]). The maximum weight loss shall be 4.0 g/m^2 when tested at 40°C for 24 hours and there shall be no pitting at 20 X magnification.

C.6.3.17 Welds in duplex stainless steel materials, CRA materials and clad/lined materials shall be subject to microstructure examination. The material shall be essentially free from grain boundary carbides, nitrides and intermetallic phases. Essentially free implies that occasional strings of detrimental phases along the centreline of the base material is acceptable given that the phase content within one field of vision (at 400X magnification) is < 1.0% (max. 0.5% intermetallic phases).

For duplex steel the ferrite content of the weld metal shall be within the range 35 to 65%.

The ferrite content of austenitic stainless steel weld deposit shall be within the range 5 to 13%.

Micro cracking at the fusion line is not permitted.

Chemical analysis

C.6.3.18 For welds in clad or lined materials, a chemical analysis shall be performed. The analysis shall be representative of the CRA composition at a point at the centreline of the root pass 0.5 mm below the surface. The chemical composition shall be within the specification limits according to the UNS number for the specified cladding/lining material or, if the weld metal is of a different composition than the cladding/liner, within the limits of chemical composition specified for the welding consumable.

Fracture toughness testing

C.6.3.19 Fracture toughness testing shall be performed for both girth welds and repair welds when acceptance criteria for girth welds are established by an ECA. The extent of testing shall be in accordance with DNVGL-RP-F108.

C.6.3.20 For nominal wall thickness above 50 mm in C-Mn and low alloy steels fracture toughness testing is required unless PWHT is performed.

C-Mn and low alloy steels shall meet the requirements given in [7.2.4.15].

Duplex and martensitic stainless steels shall meet the requirements given in [7.3.4.3].

C.6.4 Testing of weld overlay

C.6.4.1 When the weld overlay is not contributing to strength (e.g. not load bearing), tensile testing and Charpy V-notch testing of the weld overlay material are not required. When the weld overlay strength is considered as a part of the design, such mechanical testing of the weld overlay material is required (see [C.6.4.12] to [C.6.4.17]).

C.6.4.2 The base material shall retain the minimum specified mechanical properties after any post weld heat treatment. The base material properties in the post weld heat treated condition shall then be documented by additional testing and recorded as a part of the welding procedure qualification.

C.6.4.3 The testing in [C.6.4.4] through [C.6.4.11] shall, as a minimum, be performed when the overlay material is not considered as part of the design and when the base material has not been affected by any post weld heat treatment. When the overlay material is considered to be part of design, the testing in [C.6.4.12] through [C.6.4.17] shall be performed in addition to the testing in [C.6.4.4] through [C.6.4.11].

Bend testing of weld overlay

C.6.4.4 The bend testing shall be performed in accordance with [B.2.5.14]. The bend tests shall disclose no defects exceeding 1.6 mm. Minor ductile tears less than 3 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

Macro examination of weld overlay

C.6.4.5 The macro sections shall be documented by photographs (magnification of at least 5X). The macro section shall show a sound weld merging smoothly into the base material and meeting Quality level C of ISO 5817.

Hardness testing of weld overlay

C.6.4.6 The maximum hardness for base material and HAZ shall not exceed the limits given in [C.6.3.12] above as applicable for the intended service and type of material. The maximum hardness for the overlay material should not exceed any limit given in ISO 15156 for H_2S service.

Chemical analysis of weld overlay

C.6.4.7 The chemical composition shall be obtained in accordance with App.B. Specimens for chemical analysis shall either be performed directly on the as welded or machined surface or by taking specimen or filings/chips from:

— the as welded surface
— a machined surface
— from a horizontal drilled cavity.

The location for the chemical analysis shall be considered as the minimum qualified thickness to be left after any machining of the corrosion resistant weld overlay.

C.6.4.8 The chemical composition of overlay shall be shall be within the specification limits according to the UNS for the specified overlay material. The iron content of alloy UNS N06625 overlay shall be < 10%.

Microstructure examination of weld overlay

C.6.4.9 The surface to be used for microstructure examination shall be representative of a weld overlay thickness of 3 mm or the minimum overlay thickness specified for the finished machined component, whichever is less. Microstructure examination shall be performed after any final heat treatment.

C.6.4.10 Metallographic examination at a magnification of 400X of the CRA weld metal HAZ and the base material shall be performed. Micro cracking at the CRA to the C-Mn/low alloy steel interface is not permitted. The material shall be essentially free from grain boundary carbides, nitrides and inter-metallic phases in the final condition (as-welded or heat treated as applicable).

C.6.4.11 The ferrite content of austenitic stainless steel weld overlay deposit shall be within the range 5-13%. The ferrite content of duplex stainless steel weld overlay in the weld metal and HAZ shall be within the range 35-65%.

All-weld tensile testing of load bearing weld overlay

C.6.4.12 All-weld tensile testing shall be performed in accordance with [B.2.3].

C.6.4.13 The yield stress and ultimate tensile strength of the weld deposit shall be at least equal to the material tensile properties used in the design.

Charpy V-notch impact testing of load bearing weld overlay

C.6.4.14 When the weld overlay material is designed to transfer the load across the base material/weld overlay fusion line, impact testing of the weld overlay and HAZ shall be performed (i.e. when the overlay is a part of a butt joint or acts as a transition between a corrosion resistant alloy and a C-Mn/low alloy steel).

C.6.4.15 Testing shall be with the notch in the overlay weld metal, FL, FL+2 mm and FL+5 mm in the base material.

C.6.4.16 The average and single Charpy V-notch toughness at each position shall not be less than specified for the base material. When different steel grades are joined, a series of impact tests shall be considered in the HAZ on each side of the joint. The weld metal shall meet the more stringent energy requirement.

Corrosion testing of weld overlay

C.6.4.17 Corrosion testing and microstructure examination of stainless steel and nickel base weld overlay materials shall be considered.

C.6.5 Testing of pin brazing and aluminothermic welds

Electrical resistance

C.6.5.1 The electrical resistance of each test weld/brazing shall not exceed 0.1 Ohm.

Mechanical strength

C.6.5.2 Each test weld/brazing shall be securely fixed and tested with a sharp blow from a 1.0 kg hammer. The weld/brazing shall withstand the hammer blow and remain firmly attached to the base material and show no sign of tearing or cracking.

Copper penetration

C.6.5.3 2 test specimens shall the sectioned transverse to the anode lead and 2 test specimens parallel with the anode lead. The fusion line of the weld/brazing shall at any point not be more than 1.0 mm below the base material surface. Intergranular copper penetration of the base material shall not at any point extend beyond 0.5 mm from the fusion line.

Hardness

C.6.5.4 HV10 hardness tests shall be made on each of the specimens for copper penetration measurements.

C.6.5.5 The maximum hardness shall not exceed the limits given in [C.6.3.12] as applicable for the intended service and type of material.

Pull test

C.6.5.6 The specimen shall break in the cable.

C.6.6 Testing of welds for temporary and permanent attachments and branch outlet fittings to linepipe

C.6.6.1 Welds shall be tested to the extent required in [C.5.6] and meet the relevant requirements given in [C.6.3] above.

C.7 Welding and post weld heath treatment requirements

C.7.1 General

C.7.1.1 All welding shall be performed using the type of welding equipment and under the conditions that are representative for the working environment during procedure qualification welding.

C.7.1.2 Pre-qualification testing shall be performed for welding systems where the contractor has limited previous experience, or where the system will be used under new conditions. All welding equipment shall be maintained in good condition in order to ensure the quality of the weldment.

C.7.1.3 All welding shall be performed under controlled conditions with adequate protection from detrimental environmental influence such as humidity, dust, draught and large temperature variations.

C.7.1.4 All instruments shall have valid calibration certificates and the adequacy of any control software shall be documented.

C.7.1.5 Welding and welding supervision shall be carried out by personnel qualified in accordance with the requirements given in [C.2.2].

C.7.2 Production welding, general requirements

C.7.2.1 All welding shall be carried out strictly in accordance with the accepted welding procedure specification and the requirements in this subsection. If any parameter is changed outside the limits of the essential variables, the welding procedure shall be re-specified and re-qualified. Essential variables and variation limits are specified in [C.4.8].

C.7.2.2 The preparation of bevel faces shall be performed by agreed methods. The final groove configuration shall be as specified in the WPS and within the tolerances in the WPS.

C.7.2.3 After cutting of pipe or plate material for new bevel preparation, a new lamination check by ultrasonic and magnetic particle/dye penetrant testing should be performed. Procedures for ultrasonic and magnetic particle/dye penetrant testing and acceptance criteria shall be in accordance with App.D.

C.7.2.4 For welding processes using shielding, backing and plasma gases, the gas classification moisture content and dew point shall be checked prior to start of welding. Gases in damaged containers or of questionable composition, purity and dew point shall not be used. All gas supply lines shall be inspected for damage on a daily basis. All gas supply lines shall be purged before the welding is started.

C.7.2.5 The weld bevel shall be free from moisture, oil, grease, rust, carbonised material, coating etc., which may affect the weld quality.

C.7.2.6 The alignment of the abutting ends shall be adjusted to minimise misalignment. Misalignment shall not exceed the tolerances in the WPS.

C.7.2.7 The weld area shall be heated to the minimum preheat temperature specified in the WPS. Pre-heating shall also be performed whenever moisture is present or may condense in the weld area and/or when the ambient temperature or material temperature is below 5°C. Welding below 20°C should not be performed.

C.7.2.8 When pre-heating is applied prior to welding, including tack welding, the pre-heating temperature shall be measured at a distance of minimum 75 mm from the edges of the groove at the opposite side of the heating source when practically possible. If this is not possible, the adequacy of the performed measurement shall be demonstrated.

C.7.2.9 Tack welding shall only be performed if qualified during welding procedure qualification. The minimum tack weld length is 2t or 100 mm, whichever is larger. For small pipe diameters, shorter tack lengths may be agreed. Temporary tack welds using bridging or bullets shall only be performed using materials equivalent to the base material and using a WPS based on a qualified welding procedure. All such tack welds and any spacer wedges shall be removed from the final weldment. Tack welds to be fused into the weld shall be made in the weld groove only and the ends of the tack welds shall have their ends ground and feathered and examined for cracks by an adequate NDT method. Defective tack welds shall be removed or repaired prior to production welding.

C.7.2.10 Removal of tack welds shall be by grinding and cleaning followed by examination of the ground area by visual inspection. Where temporary tack welds are removed, the bevel configuration and root gaps specified in the WPS shall be maintained for the subsequent pass and the groove visually inspected prior to resuming welding of the root pass.

C.7.2.11 The interpass temperature shall be measured at the edge of the groove immediately prior to starting the following pass. For multi torch bugs, the interpass temperature is defined as the temperature in front of the first wire on each bug.

C.7.2.12 Earth connections shall be securely attached to avoid arc burns and excessive resistance heating. Welding of earth connections to the work piece is not permitted.

C.7.2.13 The number of welders and the weld sequence shall be selected in order to cause minimum distortion of the pipeline or the components.

C.7.2.14 Start and stop points shall be distributed over a length of weld and not stacked in the same area.

C.7.2.15 Welding arcs shall be struck on the fusion faces only. Weld repair of base material affected by stray arcs is not permitted.

C.7.2.16 Arc burns shall be repaired by mechanical removal of affected base material followed by NDT to verify absence of cracks and ultrasonic wall thickness measurements to verify that the remaining material thickness is not below the minimum allowed.

C.7.2.17 Surface slag clusters, surface porosity and high points shall be removed by grinding and the weld visually inspected prior to deposition of the next weld pass.

C.7.2.18 After weld completion, all spatter, scales, slag, porosity, irregularities and extraneous matter on the weld and the adjacent area shall be removed. The cleaned area shall be sufficient for the subsequent NDT. Peening is not permitted.

C.7.2.19 Welding shall not be interrupted before the joint has sufficient strength to avoid plastic yielding and cracking during handling. Prior to restart after an interruption, preheating to the minimum interpass temperature of the pass in question shall be applied.

C.7.2.20 Welds shall only be left un-completed if unavoidable. Welding of fittings shall always be completed without interruption. If welding is interrupted due to production restraints, the minimum number of passes specified in the WPS shall be completed before stopping welding. If the WPS does not specify a minimum number of passes, at least 3 passes or half the thickness of the joint should be completed before the welding is interrupted. When interruption of welding is imposed by production restraints, interrupted welds shall be wrapped in dry insulating material and allowed to cool in a slow and uniform manner. Before restarting welding of an interrupted weld, the joint shall be reheated to the interpass temperature recorded during qualification of the welding procedure.

C.7.2.21 Maximum root gap for fillet welds should be 2 mm. Where the root gap is > 2 mm but ≤ 5 mm, this shall be compensated by increasing the throat thickness on the fillet weld by 0.7 mm for each mm beyond 2 mm gap. Welding of fillet welds with root gap > 5 mm is subject to repair based on an agreed procedure.

C.7.3 Repair welding, general requirements

C.7.3.1 The allowable repairs and re-repairs are given in Table C-7 and are limited to one repair in the same area. Repeated repairs shall be subject to agreement and are limited to one repeated repair of a previously repaired area.

Table C-7 Types of weld repairs

Type of repair	*Type of material*			
	C-Mn and low alloy steel	*13Cr MSS*	*Clad/lined*	*CRA/Duplex SS 1)*
Through thickness repair	Permitted	Permitted	If agreed	If agreed
Partial thickness repair	Permitted	Permitted	Permitted	Permitted
In-process root repair	Permitted	Permitted	Permitted	Permitted

Single pass cap repair	Permitted	Permitted	Permitted	Permitted
Single pass root sealing repair	If agreed	If agreed	If agreed	If agreed
Through thickness repeated repair	If agreed	Not permitted	Not permitted	Not permitted
Partial thickness repeated repair	If agreed	Not permitted	Not permitted	Not permitted
In-process root repeated repair	Not permitted	Not permitted	Not permitted	Not permitted
Single pass cap repeated repair	Not permitted	Not permitted	Not permitted	Not permitted
Single pass root sealing repeated repair	Not permitted	Not permitted	Not permitted	Not permitted
Note 1) Provided solution annealing is performed after welding, all repairs are allowed.				

C.7.3.2 Repair welding procedures shall be qualified to the extent that such repairs are feasible and applicable for the repair situation in question. Qualification of repair welding procedures denoted if agreed, need only be done if performing such repairs is agreed and are feasible for the repair situation in question.

C.7.3.3 Cellulosic coated electrodes shall not be used for repair welding.

C.7.3.4 Repair welding of cracks is not permitted unless the cause of cracking by technical evaluation has been established not to be a systematic welding error (cracks in the weld is cause for rejection).

C.7.3.5 Defects in the base material shall be repaired by grinding only.

C.7.3.6 Defective welds that cannot be repaired with grinding only may be repaired locally by welding. Repair welding shall be performed in accordance with a qualified repair welding procedure. For welding processes applying large weld pools, e.g. multi-arc welding systems, any unintended arc-stops shall be considered as defects.

C.7.3.7 Weld seams may only be repaired twice in the same area, if agreed. Repeated repairs of the root in single sided welds are not permitted, unless specifically qualified and accepted in each case. Weld repairs shall be ground to merge smoothly into the original weld contour.

C.7.3.8 Repairs of the root pass in a single-sided joint for material meeting H_2S service requirements shall be carried out under constant supervision.

C.7.3.9 A local weld repair shall be at least 50 mm long or 4 times the excavation depth, whichever is longest. The length of the excavation measured at the bottom of the groove shall be minimum 50 mm.

C.7.3.10 The excavated portion of the weld shall be large enough to ensure complete removal of the defect, and the ends and sides of the excavation shall have a gradual taper from the bottom of the excavation to the surface. Defects can be removed by grinding, machining or air-arc gouging. Air-arc gouging shall be controlled by a documented procedure including the allowed variables according to AWS C5.3. If air-arc gouging is used, the last 3 mm through the root of the weld shall be removed by mechanical means and the whole excavated area shall be ground to remove any carbon enriched zones. The width and the profile of the excavation shall be sufficient to ensure adequate access for re-welding. Complete removal of the defect shall be confirmed by magnetic particle testing, or by dye penetrant testing for non ferromagnetic materials. Residuals from the NDT shall be removed prior to re-welding.

C.7.3.11 Weld repairs shall be ground to merge smoothly into the original weld contour.

C.7.3.12 Repair by welding after final heat treatment is not permitted.

C.7.3.13 For partial thickness repair the minimum ligament should be 6 mm. Subject to agreement, a lower ligament may be qualified, but never smaller than 3 mm.

C.7.4 Post weld heat treatment

C.7.4.1 Welds shall be subjected to PWHT as specified in the pWPS or WPS and to a documented procedure.

C.7.4.2 Post weld heat treatment shall be performed for welded joints of C-Mn and low alloy steel having a nominal wall thickness above 50 mm, unless fracture toughness testing shows acceptable values in the as welded condition. In cases where the minimum design temperature is less than -10°C, the thickness limit shall be specially determined.

C.7.4.3 If post weld heat treatment is used to obtain adequate resistance of welded joints against sulphide stress cracking, this shall be performed for all thicknesses.

C.7.4.4 Whenever possible, PWHT shall be carried out by placing the welded assembly in an enclosed furnace. Requirements to PWHT in an enclosed furnace are given in [8.4.5].

C.7.4.5 If PWHT in an enclosed furnace is not practical, local PWHT shall be performed by means of electric resistance heating mats or other methods as agreed or specified. The PWHT shall cover a band over the entire length of the weld. The band shall be centred on the weld and the width of the heated band shall not be less than 5 times the thickness of the thicker component in the assembly.

C.7.4.6 Temperatures should be measured by thermocouples in effective contact with the material and at a number of locations to monitor that the whole length of the weld is heated within the specified temperature range. In addition temperature measurements shall be made to confirm that undesired temperature gradients do not occur.

C.7.4.7 Insulation shall be provided if necessary to ensure that the temperature of the weld and the HAZ is not less than the temperature specified in the pWPS or WPS. The width of the insulation shall be sufficient to ensure that the material temperature at the edge of the insulation is less than 300°C.

C.7.4.8 The rate of heating for C-Mn and low alloy steels above 300°C shall not exceed $5500/t$ °C · h^1 and the rate of cooling while above 300°C shall not exceed $6875/t$ °C · h^1 with t expressed in mm. During heating and cooling at temperatures above 300°C the temperature variation shall not exceed 35°C in any weld length of 1000 mm.

The holding time at temperature should be minimum 30 minutes +2.5 minutes per mm thickness. Below 300°C the cooling may take place in still air.

C.7.4.9 The holding temperature for C-Mn low alloy steels should be within 580°C to 620°C unless otherwise specified or recommended by the material/welding consumable supplier. The maximum PWHT temperature for quenched and tempered low alloy steels shall be 25°C less than the tempering temperature of the material as stated in the material certificate.

C.7.4.10 The heat treatment temperature cycle charts shall be available for verification if requested.

C.7.4.11 For materials other than C-Mn and low alloy steels the PWHT heating and cooling rates, temperature, and holding time shall be as recommended by the material manufacturer.

C.7.5 Welding of pipeline girth welds

Production welding

C.7.5.1 These requirements apply to welding of girth welds in pipelines regardless of whether the welds are made onboard a laying vessel or at other locations, onshore or offshore. Girth welds in expansion loops, pipe strings for reeling or towing and tie-in welds are considered as pipeline girth welds.

C.7.5.2 The type of welding equipment and the welding procedure shall be qualified prior to installation welding.

C.7.5.3 In addition to the requirements given in [C.7.1] and [C.7.2], the requirements below shall apply for production welding of pipeline girth welds.

C.7.5.4 Bevels shall be prepared by machining. Bevelling by thermal cutting shall be performed only when bevelling by machining is not feasible e.g. for tie-in and similar situations. Bevels prepared by thermal cutting shall be dressed to obtain the final configuration. The bevelling operator shall check the bevel configuration for compliance with suitable tools or gauges at regular intervals.

C.7.5.5 When welds are to be examined by manual or automated ultrasonic testing, reference marking shall be made on both sides of the joint as a scribed line around the pipe circumference. The reference marking shall be at a uniform and known distance from the root face of the bevel preparation. The distance from the root face and the tolerances shall be established, See also [E.2.1.4] and [E.2.10].

C.7.5.6 All pipes shall be cleaned on the inside to remove any and all foreign matters and deposits in accordance with a documented procedure.

C.7.5.7 The longitudinal welds shall be staggered at least 50 mm. This is primarily to avoid a running fracture along the weldseam over several linepipe joints. If agreed with end-user, it may be accepted to line up the longitudinal welds of two consecutive linepipes given that there are sufficient amount of girth welds with staggered longitudinal weld seams between such instances. Girth welds should be separated at least 1.5 pipe diameters or 500 mm, whichever is larger. Whenever possible girth welds shall be separated by the maximum possible distance.

Guidance note:

The location of longitudinal welds along the circumference of the pipeline has no influence for pipeline integrity, however, for S-lay welding it could be considered to locate the longitudinal weld in the top quadrant for inspection purposes.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

C.7.5.8 Excessive misalignment may be corrected by hydraulic or screw type clamps. Hammering or heating for correction of misalignment is not permitted. Root gaps shall be even around the circumference. The final fit-up shall be checked with spacer tools prior to engaging line-up clamps or tack welding.

C.7.5.9 The use of mitre welds to correct angular misalignment of more than 2 degrees between the axis of two adjoining pipes is not permitted and a series of purpose made misalignment are not allowed to constitute a bend, see [5.2.1.9].

C.7.5.10 Power operated internal line-up clamps shall be used whenever possible.

Internal line-up clamps shall not be released unless the pipe is fully supported on each side of the joint.

External line-up clamps shall not be removed unless the pipe is fully supported on each side of the joint and not before the completed parts of the root pass meet the requirements to length of each section, the spacing of the sections, the number of sections and the percentage of circumference required by the WPS.

C.7.5.11 Line-up clamps should not be removed before the first two passes are completed. For spool base welding the internal line up clamps may be removed after completing root pass when pipe is supported by rollers to ensure a smooth transfer from station to station. See [10.5.2.3] regarding moving of pipe during installation welding.

C.7.5.12 If cables are present inside the pipeline, e.g. buckle detector cables, and radiographic testing is used, the starts and stops shall be made away from the six o’clock position to avoid masking of starts and stops on radiographs.

C.7.5.13 Copper contact tips and backing strips shall be checked on a regular basis for damage that could introduce copper contamination in welds. Damaged contact tips and backing strips shall be replaced.

C.7.5.14 Procedures shall be established for pre-cleaning, in process cleaning and post cleaning of welds.

C.7.5.15 If a pipe is to be cut for any reason, the cut shall be at a minimum distance of 25 mm from the weld toe. It is acceptable to cut less than 25 mm providing it can be documented by macrograph that the entire HAZ has been removed.

C.7.5.16 The root and the first filler pass shall be completed at the first welding station before moving the pipe. Moving the pipe at an earlier stage may be permitted if an analysis demonstrates that the pipe can be moved without any risk of introducing damage to the deposited weld metal. For spool base welding the pipe may be moved after completing root pass when pipe is supported by rollers to ensure a smooth transfer from station to station. See [10.5.2.3].

Repair welding

C.7.5.17 In addition to the requirements given in [C.7.3] the below requirements shall apply for repair welding of pipeline girth welds.

C.7.5.18 For through thickness repairs where the defects to be repaired are less than 100 mm apart, they shall be considered and repaired as one continuous defect.

C.7.5.19 The location of repair of burn through and other in process root repairs shall be marked on the outside of the pipe to inform NDT personnel that a root repair has been made.

C.7.5.20 If the pipe and the area of repair is not exposed to bending and/or axial stresses at the repair location when performing a repair, the length of a repair excavation shall not exceed 30% of the pipe circumference for partial penetration repairs and 20% of the pipe circumference for through thickness repairs.

C.7.5.21 Long defects may require repair in several steps to avoid yielding and cracking. The maximum length of allowable repair steps shall be calculated based on the maximum stresses present in the joint during the repair operation, and shall not exceed 80% of SMYS.

C.7.5.22 If the repair is performed at a location where the pipe and the area of repair is exposed to bending and axial stresses the allowable length of the repair excavation shall be determined by calculations, see [10.5.2.2] and [10.5.2.3].

C.7.5.23 If repairs can not be executed according to the requirements above, or are not performed successfully, the weld shall be cut out.

C.7.5.24 Full records of all repairs, including in-process root repairs, shall be maintained.

Production tests

C.7.5.25 Production tests shall be performed in a manner which, as far as possible, reproduces the actual welding, and covers the welding of a sufficient large pipe section in the relevant position. All welding stations on the production line shall be used to produce the production test weld. Production welds cut out due to NDT failure may be used.

C.7.5.26 Production tests should be performed for each welding procedure specification (WPS) used for welding of the pipeline girth welds. All welding stations/productions lines shall be covered. Production tests should be performed as early as possible in the construction phase, e.g. within the first 100 welds.

Guidance note:

Production tests also applies to welding onshore for e.g. installation by reeling. Production tests may also be performed on the vessel prior to start installation welding, e.g. when the vessel is moving to the pipelaying start destination.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

C.7.5.27 Production tests should not be required for welding procedures qualified specifically for tie-in welds, flange welds, Tee-piece welds etc.

C.7.5.28 The extent of production tests shall be expanded if:

— the contractor has limited previous experience with the welding equipment and welding methods used
— the welding inspection performed is found to be inadequate
— severe defects occur repeatedly
— any other incident indicates inadequate welding performance
— the installed pipeline is not subjected to system pressure testing, see [5.2.2.3].

C.7.5.29 The extent of production testing shall be consistent with the inspection and test regime and philosophy of the pipeline project.

C.7.5.30 Production tests shall be subject to the non-destructive, macro, hardness, all-weld tensile and Charpy V-notch impact testing as required in this appendix for welding procedure qualification testing (WPQT).

C.7.5.31 If production tests show unacceptable results, appropriate corrective and preventative actions shall be initiated and the extent of production testing shall be increased.

C.7.6 Welding and post weld heath treatment of pipeline components

C.7.6.1 The manufacturer shall be capable of producing pipeline components of the required quality.

C.7.6.2 Welding and PWHT shall be performed in accordance with [C.7.1] through [C.7.4] above.

C.7.6.3 Production tests shall be performed in a manner which, as far as possible, reproduces the actual welding, and covers the welding of a sufficient large test section in the relevant position. All welding stations on the production line shall be used to produce the production test weld. Production welds cut out due to NDT failure may be used.

C.8 Material and process specific requirements

C.8.1 Internally clad/lined carbon steel and duplex stainless steel

WPS

C.8.1.1 In addition to the applicable data given in Table C-1, the WPS shall specify the following, as recorded during the welding procedure qualification:

— the minimum time period of backing gas application prior to start of welding
— the minimum time period of backing gas application during welding
— the minimum time period of backing gas application after welding
— description of the back-purge dam type and method.

Essential variables

C.8.1.2 The following essential variables shall apply in addition to those in Table C-2:

— any reduction of the time of backing gas application prior to start of welding
— any reduction in the number of passes completed before stopping back-purging.

Welding consumables for clad/lined carbon steel

C.8.1.3 For single sided (field) joints, the same type of welding consumable should be used for all passes needed to complete the joint. Alternative welding consumables may be considered for fill and capping passes after depositing a weld thickness not less than 2 times thickness of the cladding/lining. The alternative welding consumables shall be documented to be compatible with the welding consumables used for the root area, the base material and the applicable service conditions. Welding consumables for clad/lining shall be segregated from consumables for C-Mn steel.

Welding consumables for duplex steel

C.8.1.4 Welding consumables with enhanced nickel and nitrogen content shall be used unless full heat treatment after welding is performed. Sufficient addition of material from the welding consumables is essential for welding of the root pass and the two subsequent passes. Welding consumables shall be segregated from consumables for C-Mn steel.

C.8.1.5 Backing and shielding gases shall not contain hydrogen and shall have a dew point not higher than -30°C. Some particular cases may exempt from this requirement (i.e. plasma shielding gas used for welding of austenitic materials). The oxygen content of the backing gas should be less than 0.1% during welding of the root pass. Backing gas shall be used for welding of root and hot pass as a minimum to avoid oxidation of the CRA. (Exception from this requirement may be tie-in welds when stick electrodes are used for root bead welding, subject to agreement.)

Production

C.8.1.6 Welding of clad/lined carbon steel and duplex stainless steel may be performed by the welding processes listed in [C.1.2]. The welding shall be double sided whenever possible. Welding of the root pass in single sided joints will generally require welding with Gas Tungsten Arc Welding (GTAW/141) or Gas Metal Arc Welding (GMAW/135).

C.8.1.7 Onshore fabrication of clad/lined carbon steel and duplex stainless steel shall be performed in a workshop, or part thereof, which is reserved exclusively for this type of material. During all stages of manufacturing, contamination of CRA and duplex steel with carbon steel and zinc shall be avoided. Direct contact of the CRA with carbon steel or galvanised handling equipment (e.g. hooks, belts, rolls, etc.) shall be avoided. Tools such as earthing clamps, brushes etc, shall be stainless steel suitable for working on type of material in question and not previously used for carbon steel. Contamination of weld bevels and surrounding areas with iron and low melting point metals such as copper, zinc, etc. is not acceptable. The grinding wheels shall not have previously been used for carbon steel, unless it can be documented that no contamination will occur. Parts of internal line-up clamps that come in contact with the material shall be non-metallic or of a similar alloy as the internal pipe surface. Thermal cutting shall be limited to plasma arc cutting.

C.8.1.8 The weld bevel shall be prepared by milling or other agreed machining methods. The weld bevel and the internal and external pipe surface up to a distance of at least 25 mm from the bevels shall be thoroughly cleaned with an organic solvent.

C.8.1.9 Welding consumables shall be segregated from consumables for C-Mn/low alloy steels.

C.8.1.10 The backing gas composition shall be monitored using an oxygen analyser immediately prior to starting or re-starting welding. The flow rate of the back purge gas shall be adjusted to prevent gas turbulence and possible air entrainment through open weld seams.

C.8.1.11 Inter-run cleaning shall be by grinding to bright, defect free material for all passes.

C.8.1.12 Welds shall be multipass and performed in a continuous operation.

C.8.1.13 The interpass temperature shall be measured directly where a weld run will start and terminate. The weld zone shall be kept below the maximum interpass temperature before a welding run is started. Unless post weld heat treatment is performed, the maximum interpass temperature shall not exceed 150°C for welding of all solid CRA and in root and hot pass for lined/clad carbon steel.

C.8.1.14 When clad/lined C-Mn linepipe is cut and/or re-bevelled a lamination check by through thickness ultrasonic testing and dye penetrant testing on the bevel face shall be performed. If a laminar discontinuity is detected on the bevel face the cladding/liner shall be removed and a seal weld shall be overlay welded at the pipe end.

Additional for welding of duplex steel

C.8.1.15 The heat input shall be controlled to avoid detrimental weld cooling rates. For optimum control of the heat input faster welding speeds and associated higher welding current should be used. Stringer beads shall be used to ensure a constant heat input, and any weaving of the weld bead should be limited to maximum 3X filler wire/electrode diameter. For girth welds the heat input should be kept within the range 0.5 - 1.8 kJ/mm and avoiding the higher heat input for small wall thicknesses. For wall thickness > 25 mm and provided post weld heat treatment (solution annealing) is performed a maximum heat input of 2.4 kJ/mm is acceptable. For the root pass the heat input shall be higher than for second pass. For SAW welding small diameter wire and modest welding parameters (high travel speed and low arc energy) shall be used. The depth to width ratio of the weld deposit shall be less than 1.0.

C.8.1.16 Solution annealing post weld heat treatment shall be performed in accordance with qualified heat treatment procedure.

C.8.1.17 Excavation of repair grooves shall be by chipping, grinding or machining. Air-arc gouging shall not be used. Entire welds shall be removed by plasma cutting or machining. Repeated repairs are not permitted.

C.8.1.18 All operations during welding shall be carried out with adequate equipment and/or in a protected environment to avoid carbon steel contamination of the corrosion resistant material. Procedures for examination of surfaces and removal of any contamination shall be prepared.

C.8.2 13Cr Martensitic stainless steel

WPS and essential variables

C.8.2.1 The additional data for the WPS and the essential variables given in [C.8.1.1] and [C.8.1.2] also applies to 13Cr martensitic stainless steels.

Welding consumables

C.8.2.2 The requirements to backing and shielding gases in [C.8.1.5] also apply to 13Cr MSS.

Production

C.8.2.3 Welding of 13Cr MSS may be performed by the welding processes listed in [C.1.2], except active gas shielded methods. The welding shall be double sided whenever possible.

C.8.2.4 During all stages contamination of 13Cr MSS with carbon steel and zinc shall be avoided. Direct contact with carbon steel or galvanised handling equipment (e.g. hooks, belts, rolls, etc.) shall be avoided. Tools such as earthing clamps, brushes etc., shall be stainless steel suitable for working on type of material in question and not previously used for carbon steel. Contamination of weld bevels and surrounding areas with iron and low melting point metals such as copper, zinc, etc. is not acceptable. The grinding shall not have previously been used for carbon steel. Parts of internal line-up clamps that come in contact with the material shall be non-metallic or of a similar alloy as the internal pipe surface. Thermal cutting shall be limited to plasma arc cutting.

C.8.2.5 The weld bevel shall be prepared by milling or other agreed machining methods. The weld bevel and the internal and external pipe surface up to a distance of at least 25 mm from the bevels shall be thoroughly cleaned with an organic solvent.

C.8.2.6 Welding consumables shall be segregated from consumables for C-Mn steel.

C.8.2.7 The backing gas composition shall be monitored using an oxygen analyser immediately prior to starting or re-starting welding. Care shall be taken to adjust the flow rate of the back purge gas to prevent gas turbulence and possible air entrainment through open weld seams.

C.8.2.8 The interpass temperature shall be measured directly at the points where a welding run will start and terminate. The weld zone shall be below the maximum interpass temperature before a welding run is started. The maximum interpass temperature shall not exceed 150^{o}C.

C.8.2.9 PWHT (e.g.≈ 5 minutes at≈ 630^{o}C) should be performed in accordance with the PWHT procedure qualified during welding qualification.

C.8.2.10 Excavation of repair grooves shall be by chipping, grinding or machining. Air-arc gouging shall not be used. Entire welds shall be removed by plasma cutting or machining.

C.8.2.11 All operations during welding shall be carried out with adequate equipment and/or in a protected environment to avoid carbon steel contamination of the corrosion resistant material. Procedures for examination of surfaces and removal of any contamination shall be prepared.

C.8.3 Pin brazing and aluminothermic welding

C.8.3.1 Anode leads may be attached by pin brazing or aluminothermic welding according to qualified procedures including full details of the technique used and associated equipment.

Qualification of operators

C.8.3.2 Operators that have performed a qualified procedure test are thereby qualified.

C.8.3.3 Other operators shall prior to carrying out operation work, each complete three test pieces made in accordance with the procedure specification under realistic conditions. Each test piece shall pass the test for electrical resistance and mechanical strength according to Table C-6 and [C.6.5].

Essential variables

C.8.3.4 Essential variables for pin brazing and aluminothermic welding shall be:

Base material grade and chemical composition:

- a change in grade
- a change in the supply condition (TMCP, Q/T or normalised)
- any increase in P_{cm} of more than 0.02, CE of more than 0.03 and C content of more than 0.02% for C-Mn linepipe.

For both methods a change in:

- cable dimension
- process (brazing or aluminothermic welding)
- make, type and model of equipment
- method for cleaning and preparation of cable ends and cable attachment area.

For aluminothermic welding a change in:

- type, classification and brand of start and welding powder
- type, make and model of other consumables
- volume (cartridge, packaging type) and type of start and welding powder that will change the heat input by more than ± 15%.

For pin brazing a change in:

- type, composition, make and model of pin for pin brazing
- the minimum preheat or working temperature
- range of equipment settings for pin brazing
- the equipment earth connection area.

Production requirements for welding/brazing of anode leads

C.8.3.5 The anode cable attachments shall be located at least 150 mm away from any weld.

C.8.3.6 For cable preparation cable cutters shall be used. The insulation shall be stripped for the last 50 mm of the cable to be attached. The conductor core shall be clean, bright and dry. Greasy and oily conductor cores shall be cleaned with residue free solvent or dipped in molten solder. Corroded conductor cores shall be cleaned to bright metal with brush or other means. Wet conductor cores shall be dried by rapid drying residue free solvent, alcohol or hand torch.

C.8.3.7 The cable attachment area, and for pin brazing also the equipment earth connection area, shall be cleaned for an area of minimum 50 mm × 550 mm. All mill scale, rust, grease, paint, primer, corrosion coating, and dirt shall be removed and the surface prepared to finishing degree St 3 according to ISO 8501-1. The surface shall be bright, clean and dry when welding/brazing is started.

Production testing

C.8.3.8 Each welded/brazed anode lead shall be subjected to electrical resistance test and mechanical strength test according to Table C-6 with acceptance criteria according to [C.6.5].

Repair of welded/brazed anode leads

C.8.3.9 Welded/brazed anode leads not meeting the requirements in [C.6.5] shall be removed and the affected area shall be removed by grinding.

C.8.3.10 For welded/brazed anode leads that are attached directly onto pressure containing parts the ground areas shall blend smoothly into the surrounding material. Complete removal of defects shall be verified by local visual inspection and polishing and etching to confirm removal of copper penetration. The remaining wall thickness in the ground area shall be checked by ultrasonic wall thickness measurements to verify that the thickness of the remaining material is more than the specified minimum. Imperfections that encroach on the minimum permissible wall thickness shall be classified as defects.

C.9 Hyperbaric dry welding

C.9.1 General

C.9.1.1 Underwater welding on pressure containing components for hydrocarbons shall be carried out utilising a low hydrogen process, in a chamber (habitat) where the water has been displaced. Other methods can be used on non-pressure containing components subject to special acceptance by purchaser.

C.9.1.2 All relevant welding parameters shall be monitored and recorded at the surface control station under supervision by a welding co-ordinator. The welding area shall have continuous communication with the control station. All operations including welding shall be monitored by a video system that can be remotely controlled from the control station.

C.9.2 Qualification and testing of welding personnel for hyperbaric dry welding

Hyperbaric welding co-ordinator

C.9.2.1 The welding co-ordinator for hyperbaric dry welding shall have adequate experience with welding procedure qualification and offshore operations for the hyperbaric welding and welding related system used.

C.9.2.2 The welding co-ordinator shall, when applicable, have completed the training programme required for mechanised welding required in [C.9.2.4] to [C.9.2.6].

Welders for hyperbaric welding

C.9.2.3 Prior to qualification testing for underwater (hyperbaric) dry welding of girth welds, welders shall have passed a welding test for pipeline girth welds as specified in [C.2.2].

Training programme

C.9.2.4 The hyperbaric welders shall be informed on all aspects of the work related to the welding operation, the qualified welding procedures, the applicable technical specifications and layout of the welding and habitat system.

C.9.2.5 Hyperbaric welders shall receive a training programme and pass an examination upon completion of the programme. The training programme shall be structured according to Annex B of ISO 15618-2.

C.9.2.6 In addition, for mechanised welding the training programme shall include:

— software structure of welding programme and loading of any welding programme prior to start of welding
— perform a complete butt weld, from programming of the welding parameters to welding of the cap passes
— repair welding
— daily maintenance of the welding equipment
— knowledge about the functions of the welding heads and how to replace consumables such as welding wire, contact tubes, gas nozzles and tungsten electrodes.

Test welding

C.9.2.7 The hyperbaric welders shall perform a qualification test using welding equipment identical or equal in function to the hyperbaric welding equipment used for production welding.

C.9.2.8 The qualification welding for hyperbaric welding shall be performed in accordance with ISO 15618-2.

Qualification testing of welders

C.9.2.9 For welder qualification for dry hyperbaric welding of girth welds and other butt weld configurations the test pieces shall be subject to same the testing and acceptance criteria as for pipeline girth welds in [C.2.2].

C.9.2.10 A welder is deemed qualified for the applicable ranges of approval stated in Clause 6 of ISO 15618-2 when the following requirements for inspection and testing of test pieces, as applicable, are met:

— 100% visual examination and 100% ultrasonic testing with test requirements and acceptance criteria in accordance with App.D
— macro-examination according to App.B. The specimen shall meet the requirements of ISO 15618-2, Chapter 8

— if 100% radiographic testing with test requirements and acceptance criteria in accordance with App.D is performed in lieu of 100% ultrasonic testing, bend testing as required in ISO 9606 shall be performed for all welding processes.

Retesting

C.9.2.11 See ISO 15618-2, Chapter 9.

Period of validity and prolongation

C.9.2.12 The period of validity shall be 6 months, and the prolongation in accordance with ISO 15618-2, paragraph 10.2.

C.9.3 Welding processes for hyperbaric dry welding

C.9.3.1 The allowable welding processes are (see ISO 4063):

— SMAW (Process ISO 4063-111)
— G-FCAW (Process ISO 4063-137)
— GMAW (Process ISO 4063-131)
— GTAW (Process ISO 4063-141).

C.9.4 Welding consumables for hyperbaric dry welding

C.9.4.1 In addition to the requirements given in [C.3.1] to [C.3.4] the following shall apply:

— consumables should be of a type that is tested or developed for dry hyperbaric welding with respect to arc stability and metal transfer behaviour and mechanical properties
— procedures for transfer of consumables to the hyperbaric chamber and for consumable handling in the chamber, including disposal of unused exposed consumables. The procedure shall particularly consider the maximum humidity expected during production welding
— all consumables for qualification of the welding procedure shall be from the same batch, a consumable batch being defined as the volume of product identified by the supplier under one unique batch/lot number, manufactured in one continuous run from batch/lot controlled raw materials.

C.9.5 Shielding and backing gases for hyperbaric dry welding

C.9.5.1 In addition to the requirements given in [C.3.5] the following shall apply:

— the purity of shielding and backing gases shall be 99.995 for Ar and 99.997% for He. The maximum allowable moisture content in the gas used in the actual welding is governed by the moisture content of the gas used during the qualification welding.

Guidance note:

The dew point temperature at atmospheric pressure (1 bar) is often used to specify the upper level acceptance criteria for the moisture content in shielding gases. However, for hyperbaric conditions, even a low dew-point temperature (e.g. -30°C for an Argon gas) can result in condensation of water at the relevant working depth/pressure and temperature (e.g. at 165 m at 5°C). This means that the gas is saturated with water when used at this depth and condensed water will be present at greater depths.

In general the acceptance level for the water content in the shield gas should be specified precisely. The use of "ppm" alone is not sufficient. It should be related either to volume or weight of the gas.

It is the water concentration in the gas at the working depth/pressure which is essential. This can be specified as weight of the water per volume unit (mg H_2O/m3) or partial pressure of the H_2O (millibar H_2O).

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C.9.6 Welding equipment and systems for hyperbaric dry welding

C.9.6.1 In addition to the requirements given in [C.2.1] the following shall apply unless the voltage is measured at the arc during both qualification and production welding:

— Welding cables shall have the same dimension and approximately the same resistance during the welding procedure qualification and production welding. If necessary artificial resistance to simulate the full cable length used in production should be used during qualification welding.

C.9.7 Welding procedures for hyperbaric dry welding

Contents of pWPS

C.9.7.1 A pWPS shall be prepared for each welding and repair welding procedure that will be qualified for use during welding of pipeline girth welds.

C.9.7.2 The pWPS shall contain the information required for the applicable welding processes, including any tack welds and shall be prepared in accordance with Table C-1 and shall propose limits and ranges for the applicable essential variables for welding and repair welding procedures given in Table C-2 and Table C-8.

C.9.7.3 In addition the pWPS shall address the following:

— vent hole, number of runs to be deposited before closing the root and methods for closing the root
— conditions for release of external line-up clamps including the percentage of the circumference for the welded root sections, the length of each section and spacing of the sections
— water depth (minimum/maximum)
— pressure inside the chamber
— gas composition inside the chamber
— humidity, maximum level
— temperature inside the chamber (minimum/maximum)
— length, type and size of the welding umbilical
— position for voltage measurements
— welding equipment.

C.9.7.4 The welding procedures for closing possible vent holes shall also be qualified. This qualification test should as a minimum include impact testing of weld metal, FL, FL+2, FL+5,macro/hardness testing and for CRA also metallographic examination. The qualification may be performed as a buttering test providing considerations are made to start/stop and that access limitations for the actual production welding is simulated.

Essential variables

C.9.7.5 The essential variables for hyperbaric dry welding shall be according to Table C-2 with additional requirements according to Table C-8 below.

Table C-8 Additional essential variables for hyperbaric dry welding

A qualified water depth for SMAW and GTAW 1)		
Water depth (WD) in metres:	1	WD ≤ 200 m: Any increase in excess of + 20% or 10 m or whichever is greater.
	2	200 m < WD ≤ 300 m: ± 10%
	3	300 m < WD ≤ 500 m: ± 10%
B Habitat environment		

Gas composition (argon, heliox, air or nitrox), and humidity	1	For water depth ≤ 200 m: A change from argon or heliox to air or nitrox but not vice versa
	2	For water depth > 200 m: Any change in gas composition
	3	Any increase in relative humidity for SMAW and G-FCAW flux based welding processes otherwise any increase in excess of + 10%
C Monitoring of electrical parameters		
Method and point of monitoring	1	Any change
Note 1) For other processes the depth of qualification shall be agreed.		

C.9.8 Qualification welding for hyperbaric dry welding

C.9.8.1 Qualification welding shall be performed in the habitat at a water depth selected in accordance with the intended range of qualification, or under appropriately simulated conditions. The qualification test program shall consist of a minimum of one completed joint for manual welding, and a minimum of three joints for mechanised welding systems.

C.9.8.2 Qualification welding shall comply with [C.5.1] and the following additions:

— for SMAW welding shall be performed at the maximum expected humidity in the chamber during production welding
— the power source and the technical specification for the welding system shall be equivalent to the production system
— the pipes shall be rigidly fixed to simulate restraint during welding
— method and position/point for monitoring of electrical parameters shall be as for production welding
— with increasing pressure the voltage gradient will increase. Accordingly may small changes in arc length and or operating depth result in considerable changes in the monitored values of arc voltage. For calculations of the heat input, the arc voltage shall be recorded at the position/point of welding during qualification of the welding procedure and the difference between these values and remote monitored values recorded for use during production welding.

Repair welding procedures

C.9.8.3 Qualification welding shall be performed in compliance with the requirements given in [C.5.2].

C.9.9 Qualification of welding procedures for hyperbaric dry welding

C.9.9.1 The requirements given in [C.5.3] shall apply.

C.9.10 Examination and testing

C.9.10.1 Examination and testing shall be in accordance with [C.6.1], [C.6.2] and [C.6.3].

C.9.11 Production welding requirements for dry hyperbaric welding

C.9.11.1 In addition to the applicable requirements given in [C.7], [C.8.1] and [C.8.2], the requirements below shall apply for dry hyperbaric production welding:

C.9.11.2 The habitat shall be of adequate size to allow access for welding and for all necessary welding, safety and life support equipment. Further the habitat shall be lighted and be fitted with remote cameras for surveillance. Welding fumes shall not prevent the use of the remote cameras in the welding area.

C.9.11.3 A function test of the habitat, habitat equipment and the monitoring and communication equipment shall be performed to a written and agreed procedure, and accepted before lowering the habitat to the working position. The function test shall also include verification of that the welding parameters are applied correctly on the actual equipment.

C.9.11.4 If used, shielding and/or backing gas shall be of qualified purity including moisture limit. Gas purity and composition in all containers shall be certified and traceable to the gas storage containers. The gas purity and moisture content shall be verified after purging the gas supply system prior to start of welding. The moisture content of the shielding gas shall be monitored at/near the torch during welding operation.

C.9.11.5 Pup pieces shall be bevelled, checked for correct length, laminations at cut ends and the bevel profile.

C.9.11.6 At completion of positioning of the two pipe sections to be welded, the following information, as a minimum, shall be reported to the surface:

— pipe sections to be connected (pipe number, heat number if possible)
— approximate distance from the girth weld to the pipe extremity
— position of the longitudinal welds.

C.9.11.7 If the requirement for staggering of longitudinal welds can not be met, any reduction in the separation of welds shall be limited to two pipe lengths.

C.9.11.8 All operations including welding shall be monitored by a video system that can be remotely controlled from the control station and the welding area shall have continuous communication with the control station. All relevant data shall be monitored and recorded at the surface control station under supervision by the welding co-ordinator, including:

— environmental conditions (humidity, temperature, atmosphere composition)
— welding parameters (mechanised and automatic welding)
— gas moisture content
— preheat and interpass temperature
— information transmitted by the welders.

C.9.11.9 The following records shall be presented as part of the documentation:

— chart recordings of welding current, arc voltage, filler wire speed, welding speed
— video recording from the weld observation cameras.

Weld repair

C.9.11.10 The applicable requirements given Table C-7 shall apply. In addition repairs exceeding 30% of pipe D shall be performed only if agreed.

APPENDIX D NON-DESTRUCTIVE TESTING (NDT)

D.1 General

D.1.1 Objective

D.1.1.1 This appendix specifies the requirements for methods, equipment, procedures, acceptance criteria and the qualification and certification of personnel for visual examination and non-destructive testing (NDT) of C-Mn steels, low alloy steels, duplex steels, other stainless steels and clad steel materials and weldments for use in pipeline systems.

D.1.1.2 This appendix does not cover automated ultrasonic testing (AUT) of girth welds. Specific requirements pertaining to AUT of girth welds are given in App.E.

D.1.1.3 Requirements for NDT and visual examination of other materials shall be specified and be in general agreement with the requirements of this appendix.

D.1.2 Application

D.1.2.1 The requirements in this appendix are given in several subsections with each subsection dealing with the non-destructive testing of specific objects.

D.1.2.2 The requirements given in [D.1] are applicable for the whole of this appendix.

D.1.2.3 The requirements given within the other subsections are applicable only to the scope of the subsection as indicated in the title of the subsection, unless specific references to other subsections are made.

D.1.3 Quality assurance

D.1.3.1 In addition to the general requirements to quality assurance of Sec.2, NDT contractors and organisations shall as a minimum supplement this with the requirements given in ASTM E1212.

D.1.4 Non-destructive testing methods

D.1.4.1 Methods of NDT shall be chosen with due regard to the conditions influencing the sensitivity of the methods. The ability to detect imperfections shall be considered for the material, joint geometry and welding process used.

D.1.4.2 As the NDT methods differ in their limitations and/or sensitivities, combination of two or more methods shall be considered since this is often required in order to ensure optimum probability of detection of harmful defects.

D.1.4.3 Magnetic particle, eddy current or magnetic flux leakage testing is preferred for detection of surface imperfections in ferromagnetic materials. For detection of surface imperfections in non-magnetic materials, either liquid penetrant testing or eddy current testing shall be preferred.

D.1.4.4 Ultrasonic and/or radiographic testing shall be used for detection of internal imperfections. It may be necessary to supplement ultrasonic testing by radiographic testing or vice versa, in order to enhance the probability of detection or characterisation/sizing of the type of flaws that can be expected, as specified in [10.5.3].

Radiographic testing is preferred for detection of volumetric imperfections. For material thicknesses above 25 mm radiographic testing should always be supplemented by ultrasonic testing.

Ultrasonic testing shall be preferred for detection of planar imperfections: Whenever determination of the imperfection height and depth is necessary, e.g. as a result of an ECA, automated ultrasonic testing is required. The sizing accuracy and POD has to be documented to be adequate for use with the applicable ECA derived acceptance criteria.

Guidance note:

The detectability of cracks with radiographic testing depends on the crack height, the presence of branching parts of the crack, the direction if the X-ray beam to the orientation of the crack and radiographic technique parameters. Reliable detection of cracks is therefore limited.

Lack of sidewall fusion will probably not be detected unless it is associated with volumetric imperfections or if X-ray beam is in the direction of the side-wall.

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D.1.4.5 When manual non-destructive testing in special cases is used as a substitute for automated ultrasonic testing for pipeline girth welds, both radiographic and ultrasonic testing of the girth weld shall be performed.

D.1.4.6 Alternative methods or combination of methods for detection of imperfections may be used if the methods are demonstrated as capable of detecting imperfections with an acceptable equivalence to the preferred methods.

D.1.5 Personnel qualifications

Manual or semi-automatic NDT

D.1.5.1 Personnel performing manual or semi-automated NDT and interpretation of test results shall be certified to Level 2 by a Certification Body or Authorised Qualifying Body in accordance with ISO 9712 or the ASNT Central Certification Program (ACCP). Personnel qualification to an employer based qualification scheme as SNT-TC-1A may be accepted if the employer's written practice is reviewed and found acceptable and the Level 3 is ASNT Level III or ACCP Professional or ISO 9712 Level III and certified in the applicable method. Company appointed Level 3 is not accepted.

Personnel performing testing of welds with duplex, other stainless steels and nickel alloy steel weld deposits shall have documented adequate experience or having sustained a documented dedicated training for this type of ultrasonic testing.

Automated NDT, general

D.1.5.2 Personnel calibrating equipment and interpreting results from automated equipment for NDT shall be certified to an appropriate level according to a certification scheme meeting the requirements of [D.1.5.1]. In addition, they shall be able to document adequate training and experience with the equipment in question, and shall be able to demonstrate their capabilities with regard to calibrating the equipment, performing an operational test under production/site/field conditions, and evaluating size and location of imperfections.

Automated NDT, linepipe manufacture

D.1.5.3 Personnel operating automated equipment for NDT during manufacture of linepipe shall be certified according to ISO 11484 or equivalent certification scheme.

Preparation of NDT procedures

D.1.5.4 Preparation of NDT procedures and execution of all NDT shall be carried out under the responsibility of Level 3 personnel. Any tasks involving calibration of the equipment, data acquisition and interpretation of the results, shall include personnel qualified to at least Level 2 of applicable NDT method.

Visual examination

D.1.5.5 Personnel performing visual examination of the whole welding process shall have documented training and qualifications according to NS 477, minimum CSWIP3.1 (Level 2) or minimum IWI-S or equivalent certification scheme. Personnel performing visual examination of other objects shall have training and examination according to a documented in-house standard. Personnel performing visual testing of finished, welded joints shall be qualified according to an independent certification scheme as NS 477, minimum CSWIP3.1 (Level 2) or minimum IWI-S or equivalent or in accordance with ISO 9712, VT level 2, or equivalent.

Visual acuity

D.1.5.6 Personnel interpreting radiographs, performing ultrasonic testing, interpreting results of magnetic particle and liquid penetrant testing and performing visual examination shall have passed a visual acuity test such as required by ISO 9712 or a Jaeger J-w test at 300 mm, within the previous 12 months.

D.1.6 Timing of non-desctructive testing

D.1.6.1 Whenever possible, NDT of welds shall not be performed until 24 hours has elapsed since completion of welding.

D.1.6.2 If welding processes ensuring a diffusible hydrogen content of maximum 5 ml/100 g of weld metal are used, adequate handling of welding consumables is verified, shielding gas content of H_2 is controlled, or measures (such as post heating of the weldment) are taken to reduce the contents of hydrogen, the time in [D.1.6.1] above can be reduced, subject to agreement.

D.1.6.3 NDT of pipeline installation girth welds and longitudinal welds in linepipe can be performed as soon as the welds have cooled sufficiently to allow the NDT to be performed.

D.2 Manual non-destructive testing and visual examination of welds

D.2.1 General

D.2.1.1 Non-destructive testing shall be performed in accordance with written procedures that, as a minimum, give information on the following aspects:

— applicable standards or recommended practices
— welding method (when relevant)
— joint geometries and dimensions
— material(s)
— method
— technique
— equipment main and auxiliary
— consumables (including brand name)
— sensitivity
— calibration techniques and calibration references
— testing parameters and variables
— assessment of imperfections
— reporting and documentation of results
— reference to applicable welding procedure(s)
— example of reporting forms
— acceptance criteria.

— testing parameters and variables.

D.2.1.2 If alternative methods or combinations of methods are used for detection of imperfections, the procedures shall be prepared in accordance with an agreed standard or recommended practice. The need for procedure qualification shall be considered in each case based on the method's sensitivity in detecting and characterising imperfections and the size and type of defects to be detected.

D.2.1.3 All non-destructive testing procedures shall be signed by the responsible Level III person.

Reporting

D.2.1.4 All NDT shall be documented such that the tested areas may be easily identified and such that the performed testing can be duplicated. The reports shall identify the defects present in the weld area and state if the weld satisfies the acceptance criteria or not.

D.2.1.5 The report shall include the reporting requirements of the applicable standard, NDT procedure and acceptance criteria.

At least the following minimum information shall be given:

— name of the company and operator carrying out the testing including certification level of the operator
— object and drawing references
— place and date of testing
— material type and dimensions
— post weld heat treatment, if required
— location of examined areas, type of joint
— welding process used
— surface conditions
— temperature of the object
— number of repairs if specific area repaired twice or more
— contract requirements e.g. order no., specifications, special agreements etc.
— example of reporting forms
— sketch showing location and information regarding detected defects
— extent of testing
— test equipment used
— description of the parameters used for each method
— description and location of all recordable indications
— testing results with reference to acceptance level
— other information related to the specific method may be listed under each method.

D.2.2 Radiographic testing of welds

D.2.2.1 Radiographic testing shall be performed in compliance with ISO 17636-1 and as required below. Digital radiographic testing shall be in accordance with ISO 17636-2 and as required below, and if relevant: EN 13068 and EN14784. Digital radiographic testing of weld seam of welded steel tubes shall be according to ISO 10893-7.

D.2.2.2 Radiographic testing shall be performed by use of X-ray according to accepted procedures. Use of radiographic isotopes (gamma rays) may be required in some situations and is subject to agreement in each case.

Radiographic testing procedures

D.2.2.3 Radiographic testing procedures shall be according to [D.2.1.1] through [D.2.1.3] and include:

— radiographic technique class
— radiation source
— technique
— geometric relationships
— film type
— intensifying screens
— exposure conditions
— processing
— image quality indicator sensitivities in percent of the wall thickness, based on source and film side indicators respectively
— backscatter detection method
— density
— film side image quality indicator (IQI) identification method
— film coverage
— weld identification system.

Classification of radiographic techniques

D.2.2.4 The radiographic techniques used shall be according to class B and the requirements below.

D.2.2.5 Class B techniques should also be used when using gamma ray sources.

If, for technical reasons, it is not possible to meet one of the conditions specified for class B, the note to Chapter 5 of ISO 17636-1 shall apply.

Image quality indicators

D.2.2.6 Image quality indicators (IQIs) shall meet the requirements given in ISO 19232.

The wire material shall have a coefficient of absorption as close as possible to the material tested. If the absorption coefficients of the IQI material and the material tested differ by more than 20%, an experimental evaluation according to ISO 19232-4 shall be performed to establish the acceptable image quality values, or IQIs according to ASTM E 747 having material characteristics similar to the item to be tested can be used. For the latter option, absorption coefficient difference between IQI and material has to be less than 20% and it shall be documented that the IQI ensures at least the same sensitivity as with ISO 19232.

Sensitivity

D.2.2.7 The sensitivities obtained during production radiography shall at least meet the requirements of ISO 17636-1, Annex A except for double wall techniques with the IQI on the film side. For this technique, the sensitivity of the film side IQI from the procedure qualification shall be used as acceptance criterion for film sensitivity.

Radiographic procedure qualification

D.2.2.8 Each radiographic procedure and the consumables used shall be qualified by making radiographic exposures of a welded joint or base material with the same or typical configuration and dimensions, and of material equivalent to that which shall be used in production radiography.

For procedures using source side IQIs, the sensitivity shall meet the applicable criterion in ISO 17636-1, Annex A and the average density at the sound weld metal image shall be minimum 2.0. The maximum density allowed shall be according to the capabilities of the available viewing equipment, but not more than 4.0.

D.2.2.9 For procedures using film side IQIs, the IQIs shall for radiographic procedure qualification purposes be placed on both the film side and the source side.

The sensitivity of the source and film side IQIs shall both satisfy the applicable criteria in ISO 17636-1, Annex A and the density shall meet the requirements of [D.2.2.8].

If the sensitivity of the film side IQI is better than required by the applicable criterion in ISO 17636-1, Annex A the film side sensitivity obtained during procedure qualification shall be recorded and be acceptance criterion for the sensitivity of the film side IQI during production radiography.

Processing and storage

D.2.2.10 Processing of radiographs shall conform to ISO 17636-1. Storage shall be such that the radiographs maintain their quality for a minimum of 5 years without deterioration. Thiosulphate tests shall be performed at regular intervals.

If radiograph storage time in excess of 5 years is required, the radiographs should be digitised using methods giving adequate resolution and stored in electronic media in an agreed manner.

Reporting

D.2.2.11 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5]. In addition to the items listed in ISO 17636-1 the following shall be included in the radiographic testing report:

— radiographic procedure reference
— geometric unsharpness, at minimum all information required for calculation of it.

Specific requirements to radiography of installation girth welds

D.2.2.12 For radiography the following additional requirements shall apply for installation girth welds:

— Panoramic (single wall single image) exposures shall be used whenever possible
— Fluormetallic screens may be used in combination with X-ray based on a satisfactory procedure qualification test where all requirements to sensitivity are met. Films used with fluormetallic screens shall be designed for use with this screen type
— For pipe with internal diameter < 250 mm gamma ray and panoramic (single wall single image) exposures may be used. The gamma ray source should be Se 75 used with a film system class better than C4 according to ISO 17636, Table 3. Other types of radiation sources may be used for small wall thicknesses in combination with other film types. The use of gamma ray sources shall always be based on a satisfactory procedure qualification test where all requirements to sensitivity are met
— Where no internal access is possible, a double wall technique shall be applied
— For the double wall double image technique x-ray shall be used. Fluormetallic screens may be used based on a satisfactory procedure qualification test where all requirements to sensitivity are met. Films for use with fluormetallic screens shall be suitable for this screen type
— For the double wall single image technique both X-ray and gamma ray may be used. The choice of radiation source, film and screen types shall be based on a satisfactory procedure qualification test where all requirements to sensitivity are met.

D.2.3 Manual ultrasonic testing of welds in C-Mn/low alloy steel with C-Mn/low alloy steel weld deposits

D.2.3.1 Ultrasonic testing shall be performed in compliance with ISO 17640 and as required below.

D.2.3.2 Ultrasonic testing shall be performed according to accepted procedures and DNVGL-CG-0051.

Ultrasonic testing procedures

D.2.3.3 Ultrasonic testing procedures shall be according to [D.2.1.1] through [D.2.1.5], and include:

— type of instrument
— type and dimensions of probes
— range of probe frequencies
— description of reference block
— calibration details, range and sensitivity

— surface requirements, including maximum temperature
— type of coupling medium
— scanning techniques supplemented with sketches, showing the probes used and area covered
— recording details.

D.2.3.4 Typical applications, which require specific UT procedures, are:

— ultrasonic examination of welds in austenitic stainless steel
— ferritic-austenitic (duplex) stainless steels
— detection of corrosion and/or thickness measurement
— phased array ultrasonic testing
— automated ultrasonic testing, AUT
— for special application during in-service inspection
— estimation of defect size (height) using conventional beam spread diagram (20 dB drop), time-of-flight-diffraction (TOFD) technique or the back diffraction technique
— testing of objects with temperature outside the range 0°C to 40°C.

The ultrasonic testing procedure shall be submitted for acceptance.

D.2.3.5 No special procedure qualification test should be required when manual methods are used.

Ultrasonic testing techniques

D.2.3.6 Ultrasonic testing techniques shall be in accordance with ISO 17640, and the requirements below.

Guidance note:

Manual or semi- automated ultrasonic phased array systems may be used provided it is qualified that such systems will give the same sensitivity, resolution and detection ability as conventional ultrasonic testing performed according to the requirements given in [D.2.3] and that specific ultrasonic testing procedures are developed and accepted.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Manual ultrasonic testing equipment

D.2.3.7 Manual ultrasonic testing equipment shall:

— be applicable for the pulse echo technique and for the double probe technique
— cover as a minimum the frequency range from 1 to 6 MHz
— have a calibrated gain regulator with maximum 2 dB per step over a range of at least 60 dB
— have a flat screen accessible from the front for direct plotting of reference curves or be equipped with digital DAC- display presentation of user-defined curves
— allow echoes with amplitudes of 5% of full screen height to be clearly detectable under test conditions.

D.2.3.8 Calibration of ultrasonic equipment shall be undertaken yearly according to procedures established according to a recognised standard or recommended practice, e.g. EN 12668-1-2-3 or ASME V. Verification of Screen Height Linearity and Amplitude Linearity shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less). Calibration records shall be made available upon request.

Semi-automated ultrasonic testing equipment

D.2.3.9 Semi-automated ultrasonic testing equipment shall follow the examination requirements of ASME V, Article 4, Mandatory Appendix VI.

Time-of-flight-diffraction

D.2.3.10 Time-of-flight diffraction inspection shall be according to ISO 10863, testing level C.

Phased array ultrasonic testing

D.2.3.11 Phased array based inspection techniques shall be according to ISO 13588, testing level C, as far as applicable for manual UT.

Probes

D.2.3.12 Probes used for testing of welds with C-Mn steel weld deposits shall be characterised as required by ISO 10375 and ISO 12715.

Angle beam shear-wave probes shall be available in angles allowing effective testing of the actual weld connections. For testing of girth welds or welds in plate probe angles of 45°, 60° and 70° will normally be sufficient but additional probes of 35° and 55° are recommended. Other applications may require probes covering the range of 35° to 80° to allow effective testing.

Straight beam probes shall be single or twin crystal probes. Twin crystal probes shall be used when testing is performed on material with nominal thickness $t < 60$ mm. Single crystal probes may be used when testing is performed on material with nominal thickness $t \geq 60$ mm.

Probes shall, if necessary, be suitable for use on hot surfaces (100 to 150°C).

D.2.3.13 Additional probes for time-of-flight diffraction (ToFD) and double probe techniques are recommended.

D.2.3.14 Probe frequencies shall be selected according to ISO 17640.

Guidance note:

The nominal angle of probes used are normally valid for C-Mn steels with compression wave velocity of approximately 5900 m/s and shear wave velocity of approximately 3200 m/s at 20°C.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Coupling medium

D.2.3.15 The same coupling medium as used for calibration and setting of gains and amplification shall be used during testing.

Calibration of range scale and angle determination

D.2.3.16 The IIW or ISO calibration blocks (K1 – K2) according to ISO 2400 or ISO 7963 respectively, shall be used for calibration of range scale and for angle determination. These calibration blocks shall, as near as practicable, have the same acoustic properties as the material to be tested.

Reference blocks for setting of reference levels

D.2.3.17 For testing of welds reference blocks shall be used for gain calibration and construction of the reference curves. The reference block shall be manufactured from the actual material to be examined. Reference blocks manufactured from other materials may be acceptable provided that the material is documented to have acoustic properties similar to the actual material to be examined or, alternatively, a transfer correction to accommodate for attenuation differences shall be performed, considering the requirements in [D.2.3.19] and [D.2.3.25]. The reference block shall have length and width dimensions suitable for the sound beam path for all probe types and the material dimension(s) to be tested.

For testing of welds in plate and similar geometries a reference block with side drilled holes shall be used. The thickness of the reference block, diameter and position of the drilled holes shall be as shown in Figure D-1 and Table D-1.

For testing of welds in pipe when testing can be performed from one side only, and the DAC reference signals can only be obtained from the side where the inspection shall be performed, i.e. the D side, the reference blocks shall have side drilled holes at T/4, T/2 and 3/4T.

When ultrasonic testing is to be performed on TMCP steel reference blocks shall, when required, be produced perpendicular to and/or parallel to the direction of rolling. The rolling direction shall be clearly identified.

D.2.3.18 For testing of longitudinal welds in pipe and similar geometries the reference block shall in addition to the features required above, have a curvature equal to the pipe to be tested.

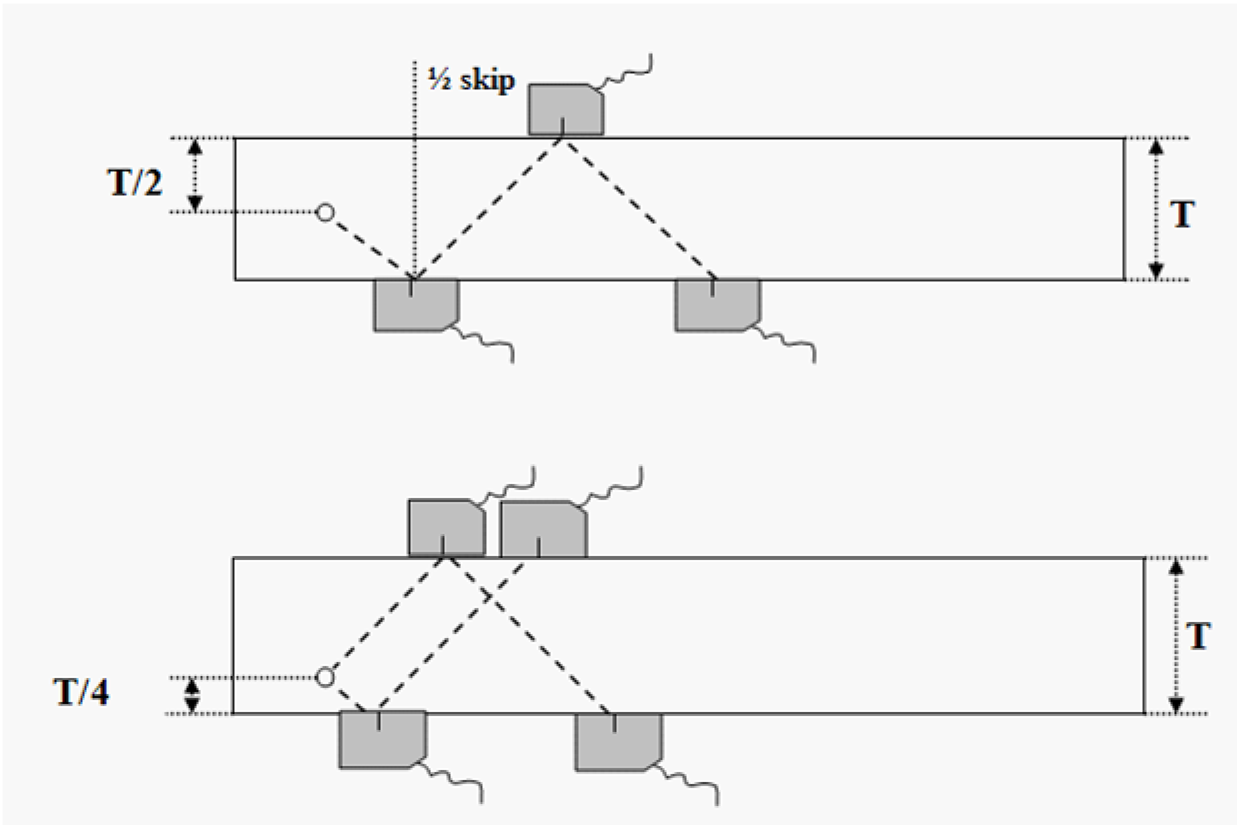

Figure D-1 Reference block dimensions

Table D-1 Reference block dimensions

Material thickness (t)	*Thickness of reference block (T)*	*Diameter of side drilled hole (mm)*	*Position of side drilled hole*	*Note*
T < 15 mm	15 mm or t	2.4 ± 0.2	T/2	Additional holes are required for testing of pipe when the DAC can be constructed from one side only. Additional holes are generally allowed and recommended
15 mm ≤ t < 35 mm	20 mm or t	3.0 ± 0.2		
35 mm ≤ t < 50 mm	38 mm or t			
50 mm ≤ t < 100 mm	75 mm or t	3.0 ± 0.2	T/4	
100 mm ≤ t < 150 mm	125 mm or t			

D.2.3.19 All reference blocks shall be marked with an identification that relates to the specific application of each block

Gain calibration

D.2.3.20 The DAC- curve shall be constructed using reference blocks with side-drilled holes as described in [D.2.3.16].

D.2.3.21 Reference blocks not made from the actual material to be tested shall be checked for variation in acoustic properties between the reference block and the actual material. The variation can be checked by calibrating the range scale on the ISO 2400 block with a normal probe and subsequently measure a known material thickness with this calibration.

D.2.3.22 Whenever ultrasonic testing of welds in TMCP steel is performed, the difference in attenuation between transverse and longitudinal rolling direction shall be checked when the scanning direction changes between transverse and parallel to the rolling direction. This requires DAC constructed by use of calibration blocks taken from transverse and parallel to the rolling direction. Difference in gain setting shall be noted and taken into consideration when evaluation of indications is performed.

D.2.3.23 When testing is carried out of welds in TMCP steel the actual beam angle shall be determined. The angle can be calculated using trigonometric functions as long as the distance and depth to the reflectors in the TMCP steel reference block is known. Alternatively the method described in [E.11] can be used.

Construction of the reference curves (DAC)

D.2.3.24 The echo reflected from the drilled hole in the calibration block shall be maximised and the amplitude set at 80% of full screen height.

D.2.3.25 The first point of DAC shall be selected such that the distance in sound path from the probe index to the drilled hole is not less than 0.6 N where N is the near field length of the relevant probe. The DAC shall be constructed by obtaining at least 3 points on the curve. The gain setting shall be recorded and comprises the primary gain.

The recorded gain following all corrections for surface condition and attenuation is the corrected primary gain. Alternatively, a Time Corrected Gain calibration can be used if the ultrasonic apparatus is fitted with a time corrected gain (TCG) correction. The echo amplitude reflected from the drilled hole in the calibration can be adjusted to 80% of full screen height over the whole range in question. DAC will thus be a horizontal line.

Periodical checks of equipment, re-calibration and re-examination

D.2.3.26 At approximately four-hourly intervals and at the end of testing, the range scale, probe angle and primary gain shall be checked and confirmed.

If deviation is found to be larger than 2% of range scale, or 4 dB of primary gain setting or 2° of nominal probe angle, the equipment shall be re-calibrated and the testing carried out with the equipment over the previous period shall be repeated.

Re-calibration shall be performed whenever the equipment has been out function for any reason including on-off and whenever there is any doubt concerning proper function of the equipment.

Contact surface

D.2.3.27 For ultrasonic testing the contact surface shall be clean and smooth, i.e. free from dirt, scale, rust, welding spatter, etc. which may influence the result of the testing. Correction for differences in surface conditions and attenuation between the reference block and the actual work piece shall be performed according to the following:

—if the difference is less than 2 dB, correction is not required

—if the difference is greater than 2 dB but smaller than 6 dB for flat surfaces and 12 dB for curved surfaces, it shall be compensated for

— if transfer loss exceeds the limits above, the reason shall be determined and further preparation of the scanning surfaces shall be carried out.

Transfer correction

D.2.3.28 Transfer correction from reference block to the weld piece shall be evaluated on a portion of the item to be tested without any discontinuity.

Transfer correction shall be performed using two of the same angle beam probes on the calibration block that shall be used to construct a specific transfer DAC curve with 2 points, i.e. full skip or more, on the item to be examined. One of the probes shall work as transmitter while the other as receiver. For the item to be examined, the orientation of the probe pair upon transfer correction shall be the same as the scanning direction. The difference in dB required to achieve an 80% FSH level on the calibration block and item to be examined for the same pair of angle beam probes shall be recorded.

In case of difference in thickness between the reference block and the item to be inspected a specific transfer correction to account for the different sound path shall be performed.

Testing levels

D.2.3.29 The testing level shall be in accordance with ISO 17640, chapter 11, testing level B and the requirements below.

Probe selection

D.2.3.30 In addition to straight beam probe minimum number of angle probes to be applied shall be in accordance with ISO 17640, see the guidance given in Table D-2. It is emphasised that this table is for guidance and that the actual choice of angle probes shall be made carefully and depending on material thickness, weld bevel and type of defects likely to occur with the welding method used.

Table D-2 Parent material thickness and related Probe angle

Parent material thickness, T	*Probe angle*
<15 mm	60° and 70°
15 to 40 mm	45°, 60° and 70°
T > 40 mm	45°, 60° and 70° (70° when ½ V or K groove)

D.2.3.31 The choice of optimum probe angle for initial full scanning of the weld shall be chosen such that incident angle of the sound beam centre is perpendicular to the side of the weld bevel. If this angle does not comply with any standard probe angle, the nearest larger probe angle shall be selected.

D.2.3.32 These additional probes shall have a larger and smaller angle than the probe used for initial scanning. The differences in angle shall be more than 10^{o}.

D.2.3.33 If only one additional probe can be used the angle for this probe should be:

— ≥ 10° different
— Larger than the initial probe if the sound beam centre of the initial probe is perpendicular to the side of the weld bevel
— Smaller than the initial probe if the nearest larger probe angle was selected for the initial probe

Testing of welds

D.2.3.34 When scanning, the gain shall be increased by a minimum of 6 dB above the corrected primary gain. Testing of welds shall be performed in accordance with ISO 17640.

D.2.3.35 The scanning zone for angle probes in the base material shall be examined with straight beam (normal) probes for features that might influence the angle beam testing. The scanning zone is defined as 1.5 × full skip distance. Features interfering with the scanning shall be reported.

D.2.3.36 The welds shall whenever feasible be tested from both sides on the same surface and include scanning for both transverse and longitudinal indications. For T-joints and plate thickness above 70 mm, scanning from both surfaces and all accessible sides shall be performed.

Evaluation of indications

D.2.3.37 For evaluation of indications the gain shall be reduced by the increased dB level used during scanning.

D.2.3.38 All indications equal to or exceeding 20% of the reference curve (evaluation level) shall be evaluated. The indications shall be investigated by maximising the echoes by rotating the probes and by using different angle probes with DAC established according to [D.2.3.23] and [D.2.3.24].

D.2.3.39 The length of an indication shall be determined by the 6 dB drop method.

D.2.3.40 The final evaluation against the acceptance criteria shall be based on the echo amplitude and length measured with the probe angle giving the maximum response.

Reporting

D.2.3.41 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5]. In addition to the items listed in ISO 17640 the following shall be included in the ultrasonic testing report:

— identification of the ultrasonic testing procedure used
— the length of acceptable indications with amplitude exceeding 50% of the reference curve.

D.2.4 Manual ultrasonic testing of welds with corrosion resistance alloy (duplex, other stainless steels and nickel alloy steel) weld deposits

General

D.2.4.1 Ultrasonic testing shall be performed in compliance with [D.2.3], ISO 22825, ISO 17640, and as required below.

D.2.4.2 Weld deposits in duplex, austenitic stainless steels and nickel alloys have a coarse grain structure with variations in grain size and structure resulting in unpredictable fluctuations in attenuation and ultrasonic beam patterns. Duplex and austenitic stainless steel base materials, in particular forgings and castings, will have the same characteristics.

Ultrasonic testing of welds with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will in order to achieve an adequate detection of imperfections require that special calibration blocks and probes are used for testing of welds in these materials. Angle probes generating compression waves shall be used, but alternative waveforms may be employed providing procedure techniques have been demonstrated and provide equivalent detection capabilities.

Ultrasonic testing procedures

D.2.4.3 Specific ultrasonic testing procedures shall be developed for this testing in compliance with this chapter and including the information required in [D.2.1.1] and [D.2.3.3]. The procedure shall be submitted for acceptance prior to start of testing.

Personnel qualifications

D.2.4.4 In addition to the requirements given in [D.1.5] personnel performing testing of welds with duplex, other stainless steels and nickel alloy steel weld deposits shall be qualified for or document adequate experience and training for this type of ultrasonic testing.

Manual ultrasonic testing equipment

D.2.4.5 The requirements given in [D.2.3.7] and [D.2.3.8] shall apply

Probes

D.2.4.6 In addition to the requirements given in [D.2.3.9], [D.2.3.10], [D.2.3.11] and [D.2.3.12], the requirements below shall apply.

D.2.4.7 Probes used for testing should be straight beam transducers and twin crystal (transmitter/receiver) compression wave probes of 45°, 60° and 70°. In addition shear-wave angle probes shall be used, if found suitable through demonstration of adequate signal to noise ratio for inspection at the area of interest.

D.2.4.8 In general, a combination of shear and compression wave angle probes should be used since the detection of open to surface imperfections on the opposite surface of the scanning surface, e.g. incomplete penetration or lack of fusion, may increase by using shear wave probes. It shall, however, be verified by using calibration blocks with actual weld connections, see [D.2.4.18] below, that angle shear wave probes are suitable.

D.2.4.9 Creep wave probes shall be used for inspection of surface area, unless testing can be performed from opposite sides.

Reference blocks for setting of reference levels

D.2.4.10 In addition to the reference blocks as described in [D.2.3.17], [D.2.3.18] and [D.2.3.19], reference blocks prepared from the actual test material and containing welds produced in accordance with the actual WPS shall be used for establishing the DAC. These reference blocks shall have the weld ground flush and the surface condition of the calibration blocks shall be typical of the condition of the parent material(s) in the scanning areas.

D.2.4.11 The reference block for construction of DAC shall have side drilled holes with dimensions according to Table D-3 and located as shown in Figure D-2. The length and width of the reference blocks shall be sufficient to allow the scanning needed for construction of the DAC.

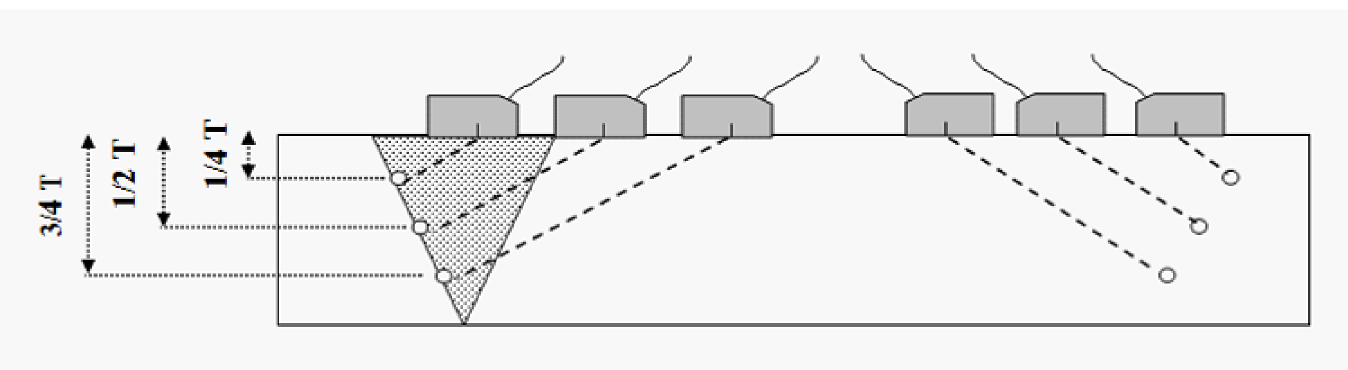

Figure D-2 Reference block for construction of DAC, dimensions

Notes:

1) Side drilled holes shall be drilled in the fusion line and in the base material. Holes in the base material shall be in the same relative position as the fusion line holes.
2) Holes shall be drilled in both fusion lines and base material when two dissimilar materials are welded to each other.
3) For double sided welds, side drilled holes shall be located in the fusion line for the full thickness of the weld.

4) For hole positions when t ≥ 50 mm, see Table D-3.

Table D-3 Reference block dimensions

Material thickness (t)	*Thickness of reference block (T) in*	*Diameter of side drilled hole in mm*	*Position of side drilled holes*
T < 15 mm	15 mm or t	2.4 ± 0.2	T/4, T/2 and T3/4
15 mm ≤ t < 35 mm	25 mm or t	3.0 ± 0.2	
35 mm ≤ t < 50 mm	45 mm or t		
50 mm ≤ t < 100 mm	75 mm or t	3.0 ± 0.2	The distance between the two outer holes and the nearest surface shall not exceed 12 mm.
100 mm ≤ t < 150 mm	125 mm or t		

D.2.4.12 The reference block for sensitivity setting for creep wave probes shall have 0.5, 1.0 and 2.0 mm spark eroded notches with a minimum length of 20 mm as shown in Figure D-3. The location of notches shall allow setting against each individual notch.

Construction of the reference curves (DAC) for angle compression wave probes

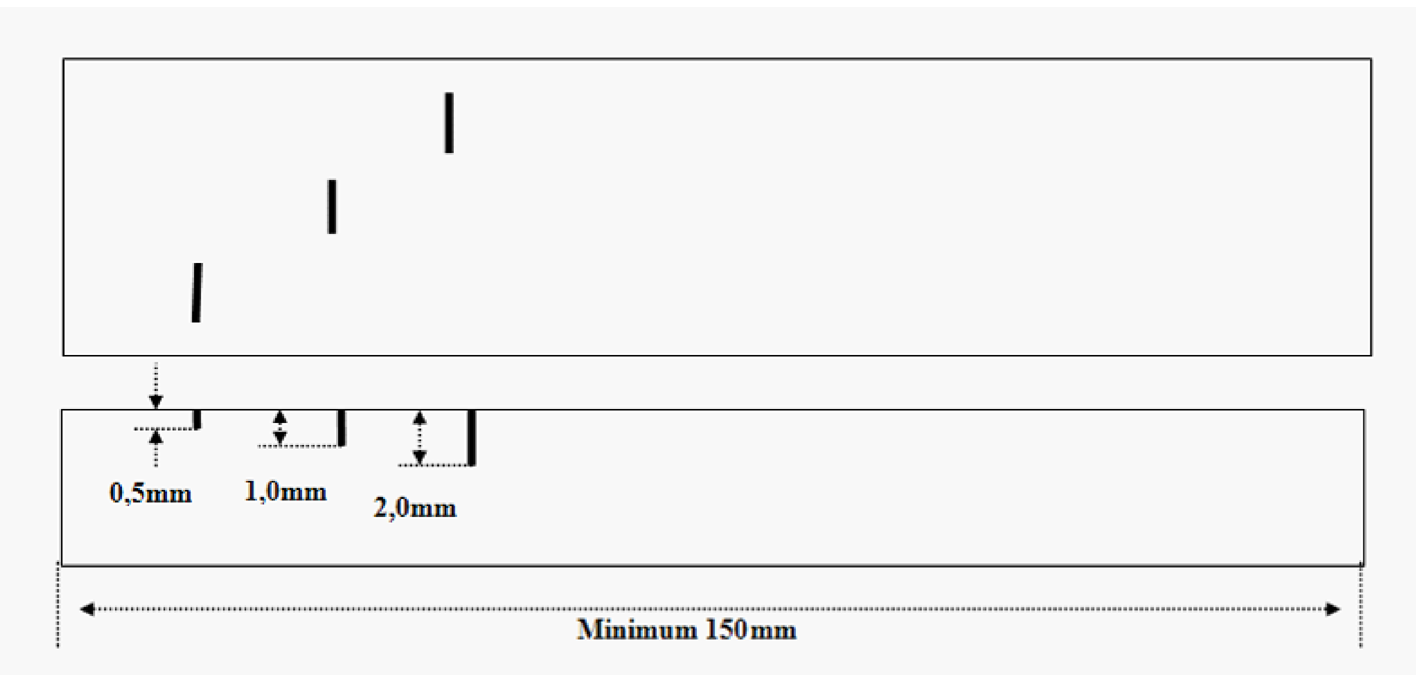

Figure D-3 Reference block for sensitivity setting for creep wave probes, dimensions

D.2.4.13 Angle compression wave probes shall and can only be used for scanning without skipping. The construction of the DAC curves using angle compression wave probe shall be performed according to:

— when the ultrasonic beam is passing through the parent metal only
— when ultrasonic beam is passing through the weld metal.

D.2.4.14 When the ultrasonic beam is passing through the parent metal only the DAC curve shall be constructed from the drilled holes in the parent material of the calibration blocks, see Figure D-2. Next, a maximum response shall be obtained from the holes in the weld fusion line and if necessary, the gain setting shall be adjusted such that this response reach the DAC constructed against drilled holes in the parent material. This shall be the primary gain to be used when locating indications on the fusion line on the side of the weld nearest to the scanning side.

D.2.4.15 When the ultrasonic beam is passing through the weld metal, the DAC curve shall be constructed from the holes drilled in the fusion line on the side of the weld opposite to the scanning side. See Figure D-2. This DAC shall be verified against the holes drilled in the base material. Any variations shall be noted so that echoes reflected from indications within the weld zone can be evaluated for amplitude response.

Transfer correction

D.2.4.16 Since compression wave angle probes can only be used without skipping, transfer correction can not be performed. The calibration blocks shall therefore have a surface finish similar to the production material.

Sensitivity setting for creep wave probes

D.2.4.17 The reference block shown in Figure D-3 shall be used for sensitivity setting for creep wave probes. The echo response from the 1.0 mm notch shall be set to 75% of FSH.

Shear wave angle probes

D.2.4.18 If shear wave angle probes are considered for skipped scanning or in the root area of single sided welds, it shall be verified on the reference blocks with welds, see Figure D-2, if it is possible to obtain a DAC with a shear wave angle probe that is comparable to the DAC obtained with an angle compression wave probe.

Preparation of weld and scanning surfaces for testing

D.2.4.19 Prior to starting the testing the external weld cap shall be ground flush with the adjacent base material. The surface finish of the weld and the scanning areas shall be as that on the reference blocks to be used or better.

Probe selection

D.2.4.20 In addition to the straight beam probe minimum two angle probes shall be used for the testing, see the guidance given in Table D-2 and [D.2.3.20] through [D.2.3.34].

D.2.4.21 Where the weld configuration or adjacent parts of the object are such that scanning from both sides is not possible, two additional probes shall always be used.

D.2.5 Manual magnetic particle testing of welds

General

D.2.5.1 Magnetic particle testing shall be performed in compliance with ISO 17638 and as required below.

D.2.5.2 Magnetic particle testing shall be performed according to accepted procedures.

Magnetic particle testing procedures

D.2.5.3 Magnetic particle testing procedures shall be according to [D.2.1.1] through [D.2.1.3] and include:

— type of magnetisation
— type of equipment

— surface preparation
— wet or dry method
— make and type of magnetic particles and contrast paint
— magnetising current (for prod magnetising, the prod type and spacing shall be stated)
— demagnetisation
— description of the testing technique.

D.2.5.4 No special procedure qualification tests is required.

Magnetising equipment

D.2.5.5 The equipment shall be tested at maximum 6 months interval to verify that the required field strength is established at the maximum pole distance/prod spacing to be used. The results shall be recorded.

D.2.5.6 Prods shall be soft tipped with lead or similar. Sparks between the prods and the material tested shall be avoided.

D.2.5.7 Electromagnetic AC yokes shall develop a minimum lifting force of 4.5 kg at maximum pole distance on a block with equivalent magnetic properties as the object to be tested. The lifting force shall be checked prior to start of any testing and at regular intervals during testing.

D.2.5.8 Use of permanent magnets and DC yokes may only be used for specific applications if required by national regulations and subject to agreement.

Application techniques

D.2.5.9 Magnetic particle testing shall not be performed on parts with surface temperatures exceeding 300°C. Between 60°C and 300°C, only dry magnetic particle testing shall be used.

Detection media

D.2.5.10 For both wet or dry particles, they shall provide adequate contrast with the background or the surface being tested.

Viewing conditions

D.2.5.11 Testing with fluorescent magnetic particles shall be conducted in a darkened area with maximum 20 lux background light, using filtered ultraviolet light with wave lengths in the range of 3200 to 3900 Å. The minimum UV light intensity shall be 1000 μW/cm^2. Operators/interpreters shall allow sufficient time for eyesight to adjust to the dark surroundings. Interpreters shall not wear photo-chromatic viewing aids.

For color contrast technique, the minimum viewing conditions shall be 1000 lx white light at the area of interest.

Reporting

D.2.5.12 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5]. In addition to the items listed in ISO 17638 the following shall be included in the testing report:

— Identification of the testing procedure used.

D.2.6 Manual liquid penetrant testing of welds

General

D.2.6.1 Liquid penetrant testing shall be performed in compliance with ISO 3452 and as required below

D.2.6.2 Liquid penetrant testing should only be used on non-ferromagnetic materials or materials with great variation in magnetic permeability.

D.2.6.3 Liquid penetrant testing shall be performed according to accepted procedures. Viewing conditions shall be minimum 1000 lx at the area of interest.

Procedures

D.2.6.4 Liquid penetrant testing procedures shall be according to [D.2.1.1] through [D.2.1.3] and include:

— surface preparation
— make and type of penetrant, remover, emulsifier and developer
— details of pre-testing cleaning and drying, including materials used and time allowed for drying
— details of penetrant application: the time the penetrant remains on the surface, the temperature of the surface and penetrant during the testing (if not within the 15°C to 35°C range)
— details of developer application, and developing time before evaluation
— method for post-test cleaning.

Application techniques

D.2.6.5 The penetration and developing times shall be long enough to allow effective detection of the smallest indications allowed. The penetration time shall comply with the manufacturers recommendation, minimum 15 minutes. Development time should be at least equal to the penetration time. The inspection area shall be monitored during developing time. Demonstration of adequate detection shall be performed for short penetration times.

D.2.6.6 When the temperature of the surface and the penetrant is within the range 10°C to 50°C, no special procedure qualification tests should be required.

Outside the temperature range 10°C to 50°C, the procedure shall be qualified and a suitable comparator block shall be used to compare indications from surface defects tested within and outside the range during the procedure qualification.

Reporting

D.2.6.7 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5].

D.2.7 Manual eddy current testing of welds

General

D.2.7.1 Eddy current testing shall be performed in compliance with ISO 17643. The limitations given in ISO 17643, paragraph 6.3, notes 1 and 2 shall apply.

D.2.7.2 Eddy current testing shall be performed according to accepted procedures.

Procedure

D.2.7.3 Eddy current testing procedures shall contain the information in [D.2.1.1] and:

— type of instrument
— type of probe
— frequency setting
— calibration blocks and calibration details
— surface condition requirements
— scanning details
— recording details.

Equipment

D.2.7.4 Eddy current equipment, including probes and cables, shall be calibrated at maximum 6 months intervals and shall have calibration certification pertaining to the characteristics of the equipment.

D.2.7.5 Functional checks of the eddy current equipment shall be carried out whenever it has been out of function for any reason including on/off, and whenever there is any doubt concerning proper functioning of the equipment.

D.2.7.6 All calibration blocks shall be marked with an identification that relates to the specific application of each block.

Surface conditions

D.2.7.7 Excess weld spatter, scale, rust and loose paint shall be removed before the inspection.

Application techniques

D.2.7.8 ISO 17643 shall apply.

Reporting

D.2.7.9 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5]. In addition to the items listed in ISO 17643 the following shall be included in the testing report:

— Identification of the testing procedure used.

D.2.8 Visual examination of welds

General

D.2.8.1 Visual examination of welds shall be performed in accordance with ISO 17637 and accepted procedures.

D.2.8.2 Reports shall be in accordance with ISO 17637. In addition to the items listed in ISO 17637 the following shall be included in the testing report:

— Identification of the testing procedure used.

D.2.9 Acceptance criteria for manual non-destructive testing of welds not considered to be fatigue sensitive and with $\varepsilon_{l,nom}$ < 0.4%

General

D.2.9.1 The acceptance criteria given in Table D-4, Table D-5, Table D-6 and Table D-7 are applicable for non-destructive testing of welds exposed to nominal strains < 0.4%.

D.2.9.2 The acceptance criteria use the term defect to define an imperfection/indication that has exceeded given dimensions and thus is deemed unacceptable.

D.2.9.3 The acceptance criteria given in Table D-5 assume that multi-pass welds are used and that the height of defects will not exceed 0.25 t or the height of a welding pass. The height of the welding pass shall be assumed not to be more than 3 mm.

Pipeline girth welds

D.2.9.4 The acceptance criteria given in Table D-4, Table D-5 and Table D-6 are generally applicable for manual non-destructive testing of pipeline girth welds exposed to total nominal strains < 0.4%.

D.2.9.5 Acceptance criteria applicable for automated ultrasonic testing (AUT) of pipeline girth welds exposed to total nominal strains < 0.4% are given in Table E-1 and Table E-2.

D.2.9.6 If the allowable defect sizes are established by an ECA for pipeline girth welds exposed to total nominal strains ≥ 0.4%, the provisions according to [D.2.10] shall apply.

Welds in pipeline components

D.2.9.7 The acceptance criteria given in Table D-4, Table D-5 and Table D-6 are generally applicable for manual non-destructive testing of welds in pipeline components. For girth welds connecting a component to the pipeline or for pup-pieces welded to the component, the acceptance criteria for pipeline girth welds shall apply, unless other acceptance criteria are given in the design, manufacture and testing data for the component.

D.2.9.8 For welds exposed to total nominal strains ≥ 0.4%, the allowable defect sizes shall be established by an ECA and the provisions according to [D.2.10] shall apply.

D.2.9.9 Automated NDT-procedures to be used with the acceptance criteria provided in Table D-4, Table D-5, Table D-6 and Table D-7 shall be qualified in accordance with [D.6] in order to document the function of the equipment. It should be noted that the acceptance criteria in this section in principle assumes manual NDT in accordance with the respective requirements in this section. The qualification shall therefore document that the required sensitivity for manual techniques, in addition to inspection coverage of the areas of interest are maintained for the automated procedure.

D.2.10 ECA based non-destructive testing acceptance criteria for pipeline girth welds

General

D.2.10.1 Acceptance criteria for pipeline girth welds can be based on an Engineering Critical Assessment (ECA).

D.2.10.2 Whenever acceptance criteria for NDT are established by an ECA, the ECA shall be performed in accordance with the requirements given in [5.4.8].

D.2.10.3 If acceptance criteria for weld defects are based on an ECA and hence involves sizing of indication height and lengths, manual ultrasonic testing or automated ultrasonic testing shall be performed.

D.2.10.4 Sizing of indication height and length by manual or automated ultrasonic testing will have inherent inaccuracies. The allowable defect sizes derived from an ECA shall accordingly be corrected for the ultrasonic testing uncertainty (sizing error) as follows:

— If the ECA gives the allowable defect size the sizing error shall be subtracted from the calculated allowable defect height and length to establish the acceptance criteria for non-destructive testing.
— If the ECA gives the material properties and stresses/strains allowed to tolerate a given defect size the sizing error shall be added to the defect height and length used as input into the ECA to establish the acceptance criteria for non-destructive testing.

D.2.10.5 If an embedded defect is located close to a surface, such that the ligament height is less than half the defect height, the ligament height between the defect and the surface shall be included in the defect height.

Automated ultrasonic testing uncertainty data

D.2.10.6 If automated ultrasonic testing (AUT) is used for testing of pipeline girth welds, the uncertainty data used shall be obtained from the qualification testing of the automated ultrasonic testing system required in App.E.

Manual ultrasonic testing uncertainty data

D.2.10.7 For manual ultrasonic testing the data used for quantitative estimates of uncertainty performance and reliability in the sizing of indication length and height, shall preferably be of the measured response versus actual flaw size type. The estimates shall be based on published results from comprehensive studies into the reliability of manual ultrasonic testing. It has to be documented that the critical defect sizes of the relevant types, i.e. with regards to orientation, location and shape, can be detected with a response above the evaluation level.

D.2.10.8 If adequate data for manual ultrasonic testing are not available, the sizing error shall not be taken as less than 2.5 mm.

Acceptance criteria based on ECA assessment

D.2.10.9 [5.4.8] gives requirements for establishing allowable flaw sizes based on an ECA assessment.

D.2.10.10

Acceptance criteria shall be established by correcting the allowable defect sizes derived from the ECA with the ultrasonic testing uncertainty in accordance with [D.2.10.5] or [D.2.10.6] and [D.2.10.7].

Guidance note:

Acceptance criteria based on ECA will frequently allow significantly larger indications than workmanship based acceptance criteria. In order to maintain a high standard of welding ECA based allowable defect sizes may be used as a weld repair criterion rather than as acceptance criterion. Criteria that are more restrictive are then used as a measure of the welding standard obtained. If these more restrictive criteria are exceeded, it should be required that preventative or corrective actions are performed to maintain the required welding standard.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.2.10.11 Alternative NDT methods to AUT in accordance with requirements in this appendix should be regarded as acceptable for pipes with wall thickness < 8.0 mm if it is considered that efficient AUT is prevented by the pipe configurations. The alternative NDT process shall be technically justified to provide sufficient inspection performance for the expected imperfections for the applied welding procedure. Alternative NDT process can be inspection by one NDT method or consist of a combination of several NDT methods. In case radiographic testing is used, acceptance criteria shall be in accordance with Table D-5, except that linear indications shall not be acceptable.

Guidance note:

Girth welds of small diameter and/or thin wall thickness pipes can provide limitations for efficient inspection with AUT, and UT inspection in general. In particular, low wall thickness configurations with corresponding acceptance criteria can be challenging for AUT with regards to accurate height sizing and depth positioning.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table D-4 Acceptance criteria for visual examination and surface method testing of welds 1) 2)

Visual examination		
External profile (not relevant for SAWL in pipe mills)	Welds shall have a regular finish and merge smoothly into the base material and shall not extend beyond the original joint preparation by more than 5 mm (8 mm for SAW welds). Fillet welds shall be of specified dimensions and regular in form.	
Cap and root reinforcement height (Longitudinal welds)	External welds: For t < 13 mm: max. 3.0 mm. For t ≥ 13 mm: max. 4.0 mm Internal welds: max. 3.5 mm For ground areas at pipe ends: max. 0.5 mm.	The radial offset of HFW and SAWL linepipe shall not reduce the thickness to weld to less than t_{min}.
Weld flash (HFW pipe longitudinal welds only)	The external flash shall be trimmed essentially flush with the pipe surface, with no noticeable radial step. The internal flash shall not extend above the contour of the pipe by more than 0.3 mm + 0.05 t). The trimming shall not reduce the wall thickness to below t_{min}, and the groove resulting from the trimming shall have a smooth transition to the base material without notches and the depth shall be max. 0.05 t. (see ISO 3183 Table 15)	
Cap and root reinforcement height(Double sided girth welds)	Height < 0.2 t, but max. 4.0 mm	
Cap reinforcement (Single sided welds)	Height < 0.2 t, but max. 4.0 mm	
Root penetration (Single sided welds)	Height < 0.2 t, but max. 3.0 mm. Length of excess penetration: max 25 mm	
Weld interpenetration (double-sided SAW in pipe mills)	Option 1) minimum 1.0 mm overlap in the radial direction Option 2) Width of overlap to be measured with a straight line perpendicular to the radial direction. The length shall be minimum 20% of nominal WT or 5 mm, whichever is less.	
Cap concavity	Not permitted.	
Root concavity	At no point shall the weld thickness be less than t_{min}	
Offset of strip/plate edges(Longitudinal welds)	For t ≤ 15 mm max. 1.3 mm For 15 mm < t ≤ 25 mm max. 0.1 t For t > 25 mm max. 2.0 mm	Additional requirements for clad/lined pipes: The offset shall not reduce the thickness of the CRA below the specified thickness.
High/low on root side of single sided girth welds 3)	For t ≤ 13 mm max. 1.3 mm For 13 mm < t ≤ 20 mm max. 0.1 t For t > 20 mm max. 2.0 mm	Additional requirements for clad/lined pipes: Max. internal high/low shall not exceed 1.0 mm unless otherwise qualified or if the applied high/low does not reduce the thickness of the CRA barrier below the specified thickness.

Visual examination			
Transverse misalignment of weld beads for double sided welds	max. 3.0 mm for t ≤ 20 mm max. 4.0 mm for t > 20 mm		
Deviation of weld toe from a straight line (double-sided SAW in pipe mills)	The weld toe shall run parallel to the weld longitudinal axis. The maximum deviation within any section of 300 mm length is 0.20 t, but not more than 4.0 mm. A straight line shall be oriented parallel to the longitudinal axis of the weld (e.g. the longitudinal axis of the pipe). The distance from this line to the weld toe shall be determined, and the difference between the point closest and farthest from the line shall not exceed the acceptance criteria. (COMMENT: the intention is to determine the presence of both waving bead/dog-leg and widening/narrowing of the weld cap - both of which indicates unstable welding process. This should not be a reason to reject the pipe, since the cap can be ground. But an inspector shall be informed before any grinding, and measures to improve the welding practice shall be implemented)		
Undercut	Individual undercuts		Accumulated length of undercuts in any 300 mm length of weld:
	Depth d	Permitted length	
	d > 1.0 mm	Not permitted	None
	1.0 mm ≥ d > 0.5 mm	50 mm	< 4 t, max. 100 mm.
	0.5 mm ≥ d > 0.2 mm	100 mm	
	d < 0.2 mm	unlimited	unlimited
Cracks, Arc burns, Start/stop craters/ poor restart, Surface porosity	Not permitted.		
Lack of penetration/lack of fusion	Not permitted in the root of welds in CRAs and clad/lined steel. Individual acceptable length: t, max. 25 mm. Accumulated length in any 300 mm length of weld: t, max. 50 mm.		
Systematic imperfections	Imperfections that are distributed at regular distances over the length of the weld are not permitted even if the size of any single imperfection meets the requirements above		
Burn through	Not permitted for welds in duplex stainless steel, CRAs and clad/lined steel. Acceptable for welds in C-Mn and low alloy steels provided that weld thickness at no point is less than t and: — Individual length/width: t/4, max. 4 mm in any dimension. — Accumulated length in any 300 mm length of weld: t/2, max. 8 mm.		
Surface testing (MT, PT and ET)			
Linear indication	Type of indication		
	Number	Dimension	

Visual examination		
Number of indications in any part of inspection area	2	2.0 mm
Linear indication evaluated as incomplete fusion	2	25 mm
Rounded indication	2	4.0 mm
Notes: 1) Any two imperfections separated by a distance smaller than the major dimension of the smaller imperfection shall be considered as a single imperfection. 2) Detectable imperfections are not permitted in any intersection of welds. 3) For t > 25 mm an increased high/low could be accepted based on an engineering judgment including as a minimum SCF calculations and AUT validation.		

Table D-5 Acceptance criteria for radiographic testing of welds

Type of defect	*Acceptance criteria* [1,2,3,10,11]	
	Individual discontinuities	*Maximum accumulated size of in any 300 mm weld length for each type of discontinuity*
Porosity[1,2] Scattered Cluster [5] Wormhole Hollow bead Isolated [6] On-line [7]	Diameter: < t/4, but max. 3 mm Individual pore: <2 mm, cluster diameter max. 12 mm Length: t/2, but max. 12 mm, Width: t/10, but max. 3 mm Length: t, but max. 25 mm, Width: max. 1.5 mm Diameter: < t/4, max 3 mm Diameter: <2 mm group length: 2t, but max. 50 mm, Clad/ lined steel: Individual pore <2 mm	See note 4. One cluster or total length < 12 mm 2 wormholes or total length < 12 mm Length 2 t, but max. 50 mm -Length 2 t, but max. 50 mm
Slag [1,2,3,8] Isolated Single lines Parallel lines	Width < 3 mm Width: max 1.5 Individual width: max 1.5	Length 12 mm, but max. 4 off separated by min 50 mm Length 2 t, but max. 50 mm Length 2 t, but max. 25 mm
Inclusions Tungsten Copper, wire	Diameter < 0.5 t, but max. 3 mm Not permitted	Max 2 off separated by min 50 mm -
Lack of penetration [1,2,3,8] Root Embedded [9]	Not permitted for welds with CRA weld overlay and/or for clad/lined steel	-
	Length: t, but max. 25 mm Length: 2t, but max. 50 mm	Length t, but max. 25 mm Length 2 t, but max. 50 mm
Lack of fusion[1,2,3,8] Surface Embedded	Not permitted in CRA layer of weld overlay and/or for clad/lined steel	-
	Length: t, but max. 25 mm Length: 2 t, but max. 50 mm	Length t, but max. 25 mm Length 2 t, but max. 50 mm
Cracks	Not permitted	-
Shrinkage cavities and crater pipes	Not permitted	-
Root concavity	Length: 2t, but max. 50 mm	Length: 2 t, but max. 50 mm
Root undercut Excess penetration Burn through	See Table D-4	See Table D-4
Total accumulation of discontinuities (excluding porosity) — Maximum accumulation of discontinuities in any 300 mm weld length 3 t, max 100 mm. — Maximum accumulation of discontinuities: 12% of total weld length. — Any accumulation of discontinuities in any cross sections of weld that may constitute a leak path or may reduce the effective weld thickness with more than t/3 is not acceptable.		

Type of defect	*Acceptance criteria* [1) 2) 3)10)11)]	
	Individual discontinuities	*Maximum accumulated size of in any 300 mm weld length for each type of discontinuity*

Notes:

1) Refer to the additional requirements in [D.2.9.3] for welding methods that produce welding passes exceeding 0.25 t.
2) Volumetric imperfections separated by less than the length of the smallest defect or defect group shall be considered as one imperfection.
3) Elongated imperfection situated in a line and separated by less than the length of the shortest defect shall be considered as one imperfection.
4) For single layer welds: 1.5% of projected area, for multi layer welds with $t < 15$ mm 2% of projected area, for multi layer welds with $t \geq 15$ mm 3% of projected area.
5) Maximum 10% porosity in cluster area.
6) Isolated pores are separated by more than 5 times the diameter of the largest pore.
7) Pores are in a line if not isolated and if 4 or more pores are touched by a line drawn through the outer pores and parallel to the weld. On-line pores shall be checked by ultrasonic testing. If ultrasonic testing indicates a continuous defect, the criteria for lack of fusion defect shall apply.
8) Detectable imperfections are not permitted in any intersection of welds.
9) Applicable to double sided welding where the root is within the middle t/3 only.
10) Acceptance criteria of Table D-4 shall also be satisfied.
11) Systematic imperfections that are distributed at regular distances over the length of the weld are not permitted even if the size of any single imperfection meets the requirements above.

Table D-6 Acceptance criteria for manual ultrasonic testing of welds 1) 2) 3) 4) 5) 6) 7)

Base material thickness 8 mm ≤ t < 15 mm		*Base material thickness 15 mm ≤ t ≤ 150 mm*	
Max. echo amplitude	Corresponding acceptable indication length, L (mm)	Max. echo amplitude	Corresponding acceptable indication length, L (mm)
Reference level (DAC)	L ≤ t (but max. 8 mm)	DAC + 4 dB	L ≤ 0.5t (but max. 12.5 mm)
DAC – 6 dB	L > t (but max. 8 mm)	DAC – 2 dB	0.5 t < L ≤ t (but max. 25 mm)
-	-	DAC – 6 dB	L > t (but max. 25 mm in both outer t/3)
-	-	DAC – 6 dB	L > t (but max. 50 mm in middle t/3)
Cracks are not permitted.			
For welds in duplex stainless steel, CRAs and clad/lined steel: Lack of fusion and lack of penetration are not permitted in the root of the weld.			
Transverse indications: Indications shall be considered as transverse if the echo amplitude transversely exceeds the echo amplitude from the same indication longitudinally with more than 2 dB. Transverse indications are unacceptable unless proven not to be planar, in which case the acceptance criteria for longitudinal indications apply.			
If an embedded defect is located close to a surface, such that the ligament height is less than half the defect height, the ligament height between the defect and the surface shall be included in the defect height.			
Total accumulation of discontinuities: The total length of acceptable indications with echo amplitude of reference level – 6 dB and above shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm nor more than 12% of total weld length. Any accumulation of defects in any cross-section of weld that may constitute a leak path or reduce the effective thickness of weld more than t/3 is not acceptable.			
If only one side of the weld is accessible for testing 6 dB shall be subtracted from the maximum echo permitted above.			
Notes: 1) Reference level is defined as the echo amplitude corresponding to the echo from the reflector in the reference blocks described in Figure D-1, Figure D-2 and Figure D-3 of this appendix, or equivalent reflector. 2) All indications exceeding 20% of the reference level shall be investigated to the extent that the operator determines the shape, length and location of the imperfection. 3) Indications that cannot be established with certainty shall whenever possible be tested with radiography. Indications that are type determined in this way shall meet the acceptance criteria in Table D-5. 4) Longitudinal imperfections where the echo height intermittently is below and above the acceptance level shall if possible be investigated with radiography. Indications that are determined in this way shall meet the acceptance criteria in Table D-5. If radiography cannot be performed, the length shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm. 5) Length and depth shall be determined by an appropriate method, see [D.2.3.35] and [D.2.3.36]. 6) Detectable imperfections are not permitted in any intersection of welds. 7) Systematic imperfections that are distributed at regular distances over the length of the weld are not permitted even if the size of any single imperfection meets the requirements above.			

D.2.11 Repair of welds

D.2.11.1 A repaired weld should be subject to the same testing requirements and acceptance criteria as the original weld.

D.2.11.2 In cases when the acceptance criteria are based on an ECA, specific acceptance criteria for repair welds shall be established by an ECA based on the fracture toughness properties obtained during qualification of the repair welding procedure.

D.2.11.3 Repair welding of cracks is not permitted unless the cause of cracking has been established not to be a systematic welding error. (If there is a crack in the weld, the weld is per definition considered rejected. This means a technical evaluation of the cause of cracking shall be performed. If it can be demonstrated that the crack is a one off situation, then repair welding may be performed subject to agreement).

D.3 Manual non-destructive testing and visual examination of plate, pipe and weld overlay

D.3.1 General

D.3.1.1 All non-destructive testing, visual inspection of plate, pipe and weld overlay shall be according to accepted procedures. Note that the requirements of [D.3.2] are not applicable to plate or pipe mills, see [D.3.2.1].

D.3.1.2 Manual non-destructive testing and visual examination procedures shall be prepared as required in [D.2.1.1] through [D.2.1.3] to reflect the requirements of the applied standard.

D.3.1.3 Acceptance criteria for manual non-destructive testing and visual examination of plate, pipe and weld overlay are given in [D.3.6].

D.3.2 Plate and pipe

General

D.3.2.1 These requirements are not applicable for plate and coil examined at the plate/coil mill as covered by [D.7], or for linepipe examined at the pipe mill as covered by [D.8].

General requirements for ultrasonic testing

D.3.2.2 Ultrasonic equipment shall meet the requirements given in [D.2.3.7] and [D.2.3.8].

D.3.2.3 Probes used for testing of pipe and plate shall be characterised as required by ISO 10375 and ISO 12715.

Angle shear-wave probes of 45° and 60° shall be used for C-Mn and low alloy steels. Angle probes for duplex stainless steel and austenitic steels shall be twin crystal (transmitter/receiver) compression-wave probes of 45° and 60°. Angle compression wave probes shall and can only be used for scanning without skipping.

Straight beam probes shall be single or twin crystal. Twin crystal probes shall be used when testing is performed on material with nominal thickness t < 60 mm. The focusing zone of the twin crystal probes shall be adapted to the material thickness to be examined.

Single or twin crystal probes can be used when testing is performed on material with nominal thickness t ≥ 60 mm. The single crystal probes shall have a dead zone as small as possible, e.g. 10% of the material thickness or 15 mm whichever is the smaller. Selected probes shall have a nominal frequency in the range of 2 MHz to 5 MHz and dimensions Ø 10 mm to Ø 25 mm.

D.3.2.4 The IIW or ISO calibration blocks (K1 – K2) according to ISO 2400 or ISO 7963 shall be used for calibration of range scale and for angle determination. These calibration blocks shall, as near as practicable, have the same acoustic properties as the material to be tested.

Manual ultrasonic thickness measurements

D.3.2.5 Manual ultrasonic thickness measurements shall be done in accordance with ASTM E797 or equivalent standard.

Ultrasonic testing for detection of laminar flaws

D.3.2.6 Manual ultrasonic testing for detection of laminar flaws in steel other than clad/lined steel shall be performed according to ISO 10893-8 App.A, ISO 10893-9 App.A or equivalent standard.

D.3.2.7 Manual ultrasonic testing for detection of laminar flaws in clad/lined steel shall be done in accordance with ASTM A578/578M or equivalent standard.

D.3.2.8 The surface condition of the material shall permit at least two successive back-wall echoes to be distinguished when the probe is placed on any area free from internal imperfections.

D.3.2.9 The range scale shall be selected such that there are always at least two back-wall echoes (reflections) on the screen.

D.3.2.10 The sensitivity shall be based on echoes reflected from Ø 6 mm flat bottom holes in reference blocks of the material used or of a material with similar with acoustic properties.

D.3.2.11 DGS diagram or DGS- scales can be used provided they are developed for the probe used and can be correlated to a Ø 6 mm flat bottom hole.

D.3.2.12 The pitch of the scanning grid shall be small enough to ensure detection of the smallest defect allowed according to the applicable acceptance criteria.

D.3.2.13 Sizing of indications shall be performed according to ISO 10893-9, App.A.

Manual ultrasonic testing for detection of transverse and longitudinal flaws

D.3.2.14 Manual ultrasonic testing for detection of transverse and longitudinal flaws in plate and pipe shall be done in general accordance with ASTM A577 or equivalent standard.

D.3.2.15 Probes shall meet the requirements of [D.3.2.3]. Additional angle probes will be required for testing of pipe.

D.3.2.16 Sensitivity for C-Mn and low alloy steel shall be a DAC curve based on reference blocks with a rectangular notch with depth 3% of the material thickness on both sides.

D.3.2.17 Reference blocks for duplex stainless steel and austenitic steels shall have one Ø 3 mm flat bottom hole perpendicular to the angle of incidence of the probe and at the largest possible depth from the scanning surface of the block. Reference blocks shall be of the actual material tested or of a material with similar with acoustic properties.

D.3.2.18 Low frequency shear wave angle probes may be used for duplex stainless steel and austenitic steels instead of twin crystal (transmitter/receiver) compression-wave probes. For acceptance, it shall be verified on the reference blocks that it is possible to obtain a DAC with a shear wave angle probe that is comparable to the DAC obtained with an angle compression wave probe.

D.3.2.19 The pitch of the scanning grid shall be small enough to ensure detection of the smallest defect allowed according to the applicable acceptance criteria.

D.3.2.20 All reference blocks shall be marked with an identification that relates to the specific application of each block.

Magnetic particle testing

D.3.2.21 Manual magnetic particle testing of:

— plate
— pipe
— edges
— bevels.

shall be done in accordance with ISO 9934 or equivalent standard.

Liquid penetrant testing

D.3.2.22 Manual liquid penetrant testing of:

— plate
— pipe
— edges
— bevels.

shall be done in accordance with ISO 3452 or equivalent standard. The penetration and developing times shall be long enough to allow effective detection of the smallest indications allowed.

Eddy current testing

D.3.2.23 Manual eddy current testing of C-Mn steel Pipe shall be done in accordance with ASTM E309 or equivalent standard.

Manual eddy current testing of duplex stainless steels and austenitic stainless steels shall be done in accordance with ASTM E426 or equivalent standard.

D.3.3 Weld overlay

D.3.3.1 Manual magnetic particle testing of ferromagnetic weld overlay deposits shall be performed in accordance with ISO 9934 or equivalent standard.

D.3.3.2 Manual liquid penetrant testing of non-magnetic weld overlay deposits shall be performed in accordance with ISO 3452 or equivalent standard.

D.3.3.3 Manual eddy current testing of weld overlay deposits shall be performed in accordance with ASTM E309 or equivalent standard.

D.3.3.4 Manual ultrasonic testing of weld overlay shall be performed according to ISO 10893-9, App.A or equivalent standard and:

— Straight beam probes shall be twin crystal. The focusing zone of the twin crystal probes shall be adapted to the material thickness to be examined.
— The surface condition of the material shall permit at least two successive back-wall echoes to be distinguished when the probe is placed on any area free from internal imperfections.
— The calibration of range scale shall be carried out using an IIW calibration block, a V2 calibration block or on a defect free area of known thickness in the material to be examined. The range scale is to be selected such that there are always at least 2 back-wall echoes (reflections) on the screen.
— The sensitivity shall be based on echoes reflected from a Ø 3 mm flat bottom hole in reference blocks made from a base material with similar acoustic properties of the actual base material with overlay deposited according to the same WPS as the actual overlay. The Ø 3 mm flat bottom hole shall be placed

approximately at the fusion line between overlay and base material. If the testing shall be performed of machined overlay, the scanning surface shall be machined to the same surface requirements as the overlay.
— All reference blocks shall be marked with an identification that relates to the specific application of each block.

Reporting

D.3.3.5 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5].

D.3.4 Visual examination

D.3.4.1 Visual examination shall be carried out in a sufficiently illuminated area; minimum 1000 lx. If required to obtain good contrast and relief effect between imperfections and background additional light sources shall be used.

D.3.4.2 For direct examination the access shall generally permit placing the eye within 600 mm of the surface to be examined and at an angle of not less than approximately 30°. If this is not possible then the use of mirrors, boroscopes, fibre optics or cameras shall be considered.

D.3.4.3 A sufficient amount of tools, gauges, measuring equipment and other devices shall be available at the place of examination.

D.3.4.4 The objects to be examined shall be cleaned to remove all scale and processing compounds prior to examination. The cleaning process shall not injure the surface finish or mask possible imperfections.

D.3.4.5 Reporting of visual examination shall include:

— Name of manufacturer
— Name of examining company
— Identification of examined object(s)
— Material
— Imperfections exceeding the acceptance criteria and their location
— Extent of examination
— Supplementary sketches/drawings.

D.3.5 Residual magnetism

D.3.5.1 Residual magnetism shall be measured with a calibrated Hall effect gauss meter or equivalent equipment. Four readings shall be taken 90° apart around the circumference of each end of the pipe, and at equal spacing for plate ends. The residual magnetism shall not exceed an average value (out of 4 measurements) of 2.0 mT (20 Gauss), with a maximum single value of 2.5 mT (25 Gauss). Some welding methods may require a more stringent acceptance criterion.

D.3.5.2 Any product that does not meet the requirements of [D.3.5.1] shall be considered defective.

D.3.5.3 All defective products shall be de-magnetized full length, and then their magnetism shall be re-measured until at least three consecutive pipes meet the requirements of [D.3.5.1].

D.3.5.4 The requirements for residual magnetism shall apply only to testing at the specific location since the residual magnetism in products may be affected by procedures and conditions imposed during and after handling and shipment.

D.3.6 Acceptance criteria for manual non-destructive testing of plate, pipe and weld overlay

D.3.6.1 For manual ultrasonic thickness measurements acceptance criteria shall be according to applicable specification or product standard.

D.3.6.2 Acceptance criteria for manual ultrasonic testing for laminar flaws in C-Mn, low alloy, duplex, other stainless steels and nickel based corrosion resistant alloys (CRA) are given in Table D-12.

D.3.6.3 Acceptance criterion for manual ultrasonic testing for detection of laminar flaws in clad steel is given in ASTM A263, A264 or A265 and shall correspond to the class 1 quality level. In addition, no areas with laminations or lack of bonding are allowed over a width extending at least 50 mm inside the location of future weld preparations.

D.3.6.4 For manual ultrasonic testing for detection of transverse and longitudinal flaws in C-Mn and low alloy steel, the acceptance criterion shall be that no indications exceed the DAC curve established against the rectangular notch with depth 3% of the thickness.

For manual ultrasonic testing for detection of transverse and longitudinal flaws in duplex stainless steel, the acceptance criterion shall be that no indications exceed the DAC curve established against the Ø 3 mm flat bottom hole.

D.3.6.5 Acceptance criterion for manual magnetic particle testing of plate/pipe bevels and edges shall be:

— No indications longer than 6 mm are permitted.

D.3.6.6 Acceptance criterion for manual liquid penetrant testing of plate/pipe bevels and edges shall be:

— no indications longer than 6 mm are permitted.

Guidance note:

For clad pipes made from explosion welded clad plates; indications from process related melt pockets within the bond zone of explosion welded material are acceptable. It is acknowledged that these indications do not indicate lamination or a degrade bond between backing and clad material. Lamination and disbonding imperfections shall be assessed according to the acceptance criteria above.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.3.6.7 Acceptance criterion for manual eddy current testing of pipe/pipe bevels and edges shall be:

— no indications longer than 6 mm are permitted.

D.3.6.8 Defects at pipe bevels and edges shall be examined ultrasonically as required in this subsection and the pipes cut back until no defects are present in the tested area.

D.3.6.9 Acceptance criteria for as-welded surfaces of magnetic and non magnetic weld overlay for visual examination, magnetic particle testing, liquid penetrant and eddy current testing are:

— no round indications with diameter above 2 mm and no elongated indications
— indications separated by a distance less than the diameter or length of the smallest indication, shall be considered as one indication
— accumulated diameters of round indications in any 100 × 100 mm shall not exceed 10 mm.

D.3.6.10 Acceptance criteria for ultrasonic testing of as-welded surfaces of magnetic and non-magnetic weld overlay shall be no loss of back wall echo and no echo from an indication shall exceed 66% of the echo reflected from Ø 3 mm flat bottom holes in reference blocks.

D.3.6.11 For machined surfaces, acceptance criteria shall be especially agreed upon.

D.3.6.12 Defects shall be ground out, re-welded and re-tested to meet the acceptance criteria above.

D.3.6.13 When any subsequent process requires homogenous material, i.e. ultrasonic examination, other acceptance criteria shall apply.

D.4 Non-destructive testing and visual examination of forgings

D.4.1 General

D.4.1.1 All non-destructive testing of forgings shall be performed according to accepted procedures.

D.4.1.2 Manual non-destructive testing and visual examination procedures shall be prepared as required in [D.2.1.1] through [D.2.1.3] to reflect the requirements of the applied standard.

D.4.1.3 Acceptance criteria for manual non-destructive testing and visual examination forgings are given in [D.4.5].

D.4.2 Ultrasonic and magnetic particle testing of C-Mn and low alloy steel forgings

Ultrasonic testing

D.4.2.1 Ultrasonic testing of forgings shall be performed in accordance with ASTM A388 and the requirements below.

Ultrasonic testing procedures

D.4.2.2 Ultrasonic testing procedures shall contain the information in [D.2.1.1] and:

- type of instrument
- type and dimensions of probes
- range of probe frequencies
- description of reference blocks
- calibration details, range and sensitivity
- surface requirements, including maximum temperature
- type of coupling medium
- scanning techniques supplemented with sketches, showing the probes used and area covered by each probe
- description of methods for recheck of areas with reduction or loss of back reflection
- recording details.

Ultrasonic apparatus

D.4.2.3 Verification of screen height linearity and amplitude linearity shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less). Records shall be made available upon request.

Probes

D.4.2.4 Straight beam probes with frequency 2 to 5 MHz and dimension Ø 10 to 30 mm shall be used. The probes shall be single or twin crystal. Twin crystal probes shall be used when testing is performed on material with nominal thickness t < 60 mm. The focusing zone of the twin crystal probes shall be adapted to the material thickness to be examined.

Single or twin crystal probes can be used when testing is performed on material with nominal thickness t ≥ 60 mm. The single crystal probes shall have a dead zone as small as possible, e.g. 10% of the material thickness or 15 mm whichever is the smaller.

D.4.2.5 Angle beam probes shall be used for testing on rings, hollow and cylindrical sections. Angle beam probes shall be available in angles, or be provided with wedges or shoes, ranging from 30° to 75°, measured to the perpendicular of the entire surface of the forging being tested.

Reference blocks for straight beam testing

D.4.2.6 Supplementary requirement S1 of ASTM A388 shall apply, but with the following additional requirements:

— For material thickness t ≤ 38 mm the flat bottom holes shall be Ø 1.6 mm
— For material thickness 38 mm < t < 60 mm the flat bottom holes shall be Ø 3 mm
— For material thickness t ≥ 60 mm the flat bottom holes shall be Ø 6 mm.

Reference blocks for angle beam testing

D.4.2.7 The reference notches shall be rectangular D and ID notches with a depth of:

— For material thickness t ≤ 38 mm, 3% of the thickness
— For material thickness 38 mm < t < 100 mm, 5% of the thickness
— For material thickness t ≥ 100 mm, 10% of the thickness.

D.4.2.8 A separate reference block shall have the same configuration, nominal composition, forging ratio, heat treatment and thickness as the forgings it represents.

D.4.2.9 Where a group of identical forgings is made, one of the forgings may be used as the separate reference block.

D.4.2.10 All reference blocks shall be marked with an identification that relates to the specific application of each block.

Preparation of forgings for ultrasonic testing

D.4.2.11 For forgings of uncomplicated geometry, the requirements of ASTM A388, chapter 6 shall apply.

Forgings of complex geometry

D.4.2.12 Forgings are required to be forged and/or to be rough machined to near final dimensions prior to heat treatment in order to obtain the required properties. This machining of forgings shall consider that cylindrical shapes and faces that are flat and parallel to one another shall be obtained in order to provide adequate conditions for ultrasonic testing. In the case of forgings with complex geometry, machining shall provide intersecting

cylindrical and/or flat faces. The machining shall be such that areas where adequate ultrasonic testing is not possible will be removed during the final machining. A sketch shall be provided for acceptance showing the areas of the forging where adequate ultrasonic testing will not be achieved.

Acceptance criteria shall be according to component final dimensions.

Calibration of amplification and testing procedure

D.4.2.13 The IIW or ISO calibration blocks (K1 – K2) according to ISO 2400 or ISO 7963 shall be used for calibration of range scale and for angle determination. These calibration blocks shall, as near as practicable, have the same acoustic properties as the material to be tested. Calibration of range scale can alternatively be done on a defect free area of known thickness in the material to be examined. The range scale is to be selected such that there are always at least 2 back-wall echoes (reflections) on the screen.

D.4.2.14 The calibration of the required amplification shall be performed according to ASTM A388, chapter 9. The probe size and frequency that provides optimum response shall be used for the testing.

D.4.2.15 Notes 2 and 3 of, chapter 9 in ASTM A388 shall be adhered to.

D.4.2.16 When scanning, the gain shall increased by minimum 6 dB above the corrected primary gain. For evaluation of indications the gain shall be reduced by the increased dB level used during scanning.

D.4.2.17 The method for re-check of areas with reduction or loss of back reflection, ASTM A 388, paragraph 9.2.4, shall be described.

D.4.2.18 Different frequencies, types, angles and diameter of probes shall be employed to obtain additional information about detected indication.

Sizing of indications

D.4.2.19 In general, the area containing imperfections shall be sized (area and length) using the 6 dB drop technique. The area refers to the surface area on the forgings over which a continuous indication exceeds the acceptance criteria. This area will be approximately equal to the area of the real defect provided the defect size is larger than the 6 dB beam profile of the probe.

D.4.2.20 If the real imperfection size is smaller than the 6 dB beam profile, the 6 dB drop technique is not suited for sizing. The area measured on the surface will be measured too large and not represent the real indication size. A guide to classify if the revealed indications are greater or smaller than the 6 dB drop profile is given in EN 10228-3, part 13.

D.4.2.21 If the size of the indication is evaluated to be smaller than the 6 dB drop profile at the depth of discontinuity a graphic plot, that incorporates a consideration of beam spread should be used for realistic size estimation.

Periodical checks of equipment

D.4.2.22 At approximately four-hourly intervals and at the end of testing, the range scale, probe angle and primary gain shall be checked and if necessary, corrected. Checks shall also be carried out whenever a system parameter is changed or changes in the equivalent settings are suspected. If deviation is found to be larger than 2% of range scale, or 3 dB of primary gain setting or 2° of nominal angle probe, the testing carried out with the equipment over the previous period shall be repeated.

Reporting

D.4.2.23 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5] and ASTM A388, chapter 9.

Manual magnetic particle testing of C-Mn steel forgings

D.4.2.24 Manual magnetic particle testing of C-Mn steel forgings shall be performed in accordance with ISO 9934 or equivalent standard.

D.4.3 Ultrasonic and liquid penetrant testing of duplex stainless steel forgings

Ultrasonic testing

D.4.3.1 Ultrasonic testing of duplex stainless steel forgings shall be performed in accordance with [D.4.2], but with the following additions to the requirements to:

— probes
— reference blocks for angle beam testing

— preparation of forgings for ultrasonic testing
— testing procedure.

Angle probes

D.4.3.2 Angle probes for duplex stainless steel shall be twin crystal (transmitter/receiver) compression-wave probes. Angle compression wave probes shall and can only be used without skipping.

D.4.3.3 Low frequency shear wave angle probes may be used for duplex stainless steel instead of twin crystal (transmitter/receiver) compression-wave probes, provided it is verified on the reference blocks that it is possible to obtain a DAC with a shear wave angle probe that is comparable to the DAC obtained with an angle compression wave probe.

D.4.3.4 Creep wave probes shall be used for detection of sub surface defects close to the scanning surface, unless testing can be performed from both sides.

Reference blocks for angle beam testing

D.4.3.5 Reference blocks for angle beam testing of duplex stainless steel with angle compression wave probes shall have side drilled holes and a 1 mm deep and 20 mm wide spark eroded notch according to Figure D-4 and Table D-7.

Preparation of forgings for ultrasonic testing

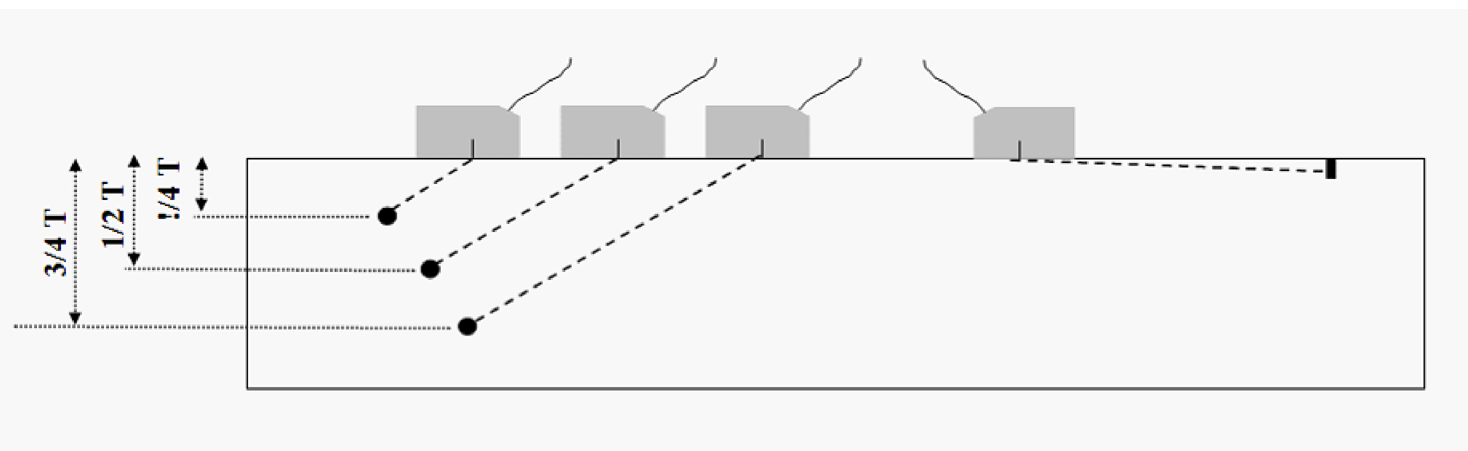

Figure D-4 Reference block for construction of DAC, duplex stainless steel

Table D-7 Reference block dimensions

Material thickness (t)	*Thickness of reference block (T)*	*Diameter of side drilled hole mm*	*Position of side drilled holes*
T < 20 mm	15 mm or t	2.4 ± 0.2	T/4, T/2 and T3/4
20 mm ≤ t < 35 mm	20 mm or t	3.0 ± 0.2	
35 mm ≤ t < 75 mm	50 mm or t		
75 mm ≤ t < 100 mm	90 mm or t	6.0 ± 0.2	The distance between the two outer holes and the nearest surface shall not exceed 12 mm
100 mm ≤ t < 150 mm	125 mm or t		

D.4.3.6 The machining of duplex stainless steel forgings for ultrasonic testing shall take into account that angle compression wave probes shall and can only be used without skipping.

Testing procedure

D.4.3.7 The testing procedure for duplex stainless steel forgings shall take into account that angle compression wave probes shall and can only be used without skipping. The testing shall hence be performed from as many faces that access permits.

Manual liquid penetrant testing of duplex stainless steel forgings

D.4.3.8 Manual liquid penetrant testing of duplex stainless steel forgings shall be performed in accordance with ISO 3452 or equivalent standard. The penetration and developing times shall be long enough to allow effective detection of the smallest indications allowed.

D.4.3.9 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5] and ASTM A388, chapter 9.

D.4.4 Visual examination of forgings

D.4.4.1 Visual examination of forgings shall be performed in accordance with [D.3.4], with acceptance criteria according to [D.4.5].

D.4.5 Acceptance criteria for forgings

D.4.5.1 Acceptance criteria for manual ultrasonic testing of forgings shall be:

Straight beam testing

— No single indication shall be larger than the indication received from the flat bottom holes in the reference block required in [D.4.2].

Angle beam testing of C-Mn and low alloy steel forgings

— No single indication shall exceed a DAC curve established using the notches in the reference block required in [D.4.2].

Angle beam testing of duplex stainless steel forgings

— No single indication shall exceed a DAC curve established using the side drilled holes in the reference *Multiple indications*
— No indications within 13 mm of each other in any direction shall exceed 50% of the reference curve.

Acceptance criteria for manual magnetic particle testing of C-Mn and low alloy steel forgings

D.4.5.2 Acceptance criteria for manual magnetic particle testing of C-Mn and low alloy steel forgings shall be according to Table D-8.

Acceptance criteria for manual liquid penetrant testing of duplex stainless steel forgings

D.4.5.3 Acceptance criteria for manual liquid penetrant testing of duplex stainless steel forgings done in accordance with ISO 3452 or equivalent standard shall be according to Table D-8.

Acceptance criteria for visual examination

Table D-8 Acceptance criteria for manual magnetic particle and liquid penetrant testing of forgings

A	Crack-like indications: not permitted
B	Linear indications with length more than 2 mm or three times the width: not permitted. Linear indications with length < 1.5 mm may be deemed irrelevant
C	Rounded indications: Diameter < 3 mm, accumulated diameters in any 100 × 150 mm area < 8 mm.

D.4.5.4 Acceptance criteria for visual examination of forgings shall be in accordance with ASTM A 961, Chapter 15. If the surface imperfections acceptable under 15.5 are not scattered, i.e. more than 3 off in any 100 × 150 mm area, such imperfections shall be considered injurious.

D.5 Non-destructive testing and visual examination of castings

D.5.1 General

D.5.1.1 All non-destructive testing of castings shall be done according to accepted procedures.

D.5.1.2 Manual non-destructive testing and visual examination procedures shall be prepared as required in [D.2.1.1] through [D.2.1.3] to reflect the requirements of the applied standard.

D.5.1.3 Acceptance criteria for manual non-destructive testing and visual examination of castings are given in [D.5.6].

D.5.2 Ultrasonic and magnetic particle testing of C-Mn and low alloy steel castings

D.5.2.1 Manual ultrasonic testing of castings shall be done according to ASTM A609, procedure A, and Supplementary requirement S1. In addition the requirements below apply.

Ultrasonic testing procedures

D.5.2.2 Ultrasonic testing procedures shall contain the information in [D.2.1.1] and:

— type of instrument
— type and dimensions of probes
— range of probe frequencies
— description of reference blocks
— calibration details, range and sensitivity
— surface requirements, including maximum temperature
— type of coupling medium
— scanning techniques supplemented with sketches, showing the probes used and area covered by each probe
— description of methods for re-check of areas with reduction or loss of back reflection
— recording details.

Ultrasonic apparatus

D.5.2.3 Verification of screen height linearity and amplitude linearity shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less). Records shall be made available upon request.

Probes

D.5.2.4 Straight beam (normal) probes with frequency 1-5 MHz and dimension Ø 10-30 mm shall be used. Straight beam, normal probes shall be single or twin crystal. Twin crystal probes shall be used when testing is performed on material with nominal thickness $t < 25$ mm. The focusing zone of the twin crystal probes shall be adapted to the material thickness to be examined.

D.5.2.5 Single or twin crystal probes can be used when testing is performed on material with nominal thickness $t \geq 60$ mm. The single crystal probes shall have a dead zone as small as possible, e.g. 10% of the material thickness or 15 mm whichever is the smaller.

Reference blocks

D.5.2.6 All reference blocks shall be marked with an identification that relates to the specific application of each block.

Casting conditions for ultrasonic testing

D.5.2.7 Castings shall as far as possible be machined according to [D.4.2.11] and [D.4.2.12].

Calibration of amplification and testing procedure

D.5.2.8 The IIW or ISO calibration blocks (K1 – K2) according to ISO 2400 or ISO 7963 shall be used for calibration of range scale and for angle determination. These calibration blocks shall, as near as practicable, have the same acoustic properties as the material to be tested. Calibration of range scale can alternatively be done on a defect free area of known thickness in the material to be examined. The range scale is to be selected such that there are always at least 2 back-wall echoes (reflections) on the screen.

D.5.2.9 The calibration of the required amplification shall be performed according to ASTM A609, chapter 8 and S1. The probe size and frequency that provides optimum response shall be used for the testing.

D.5.2.10 Note 3 of ASTM A609, chapter 8: When scanning, the gain shall be increased by minimum 6 dB above the corrected primary gain. For evaluation of indications the gain shall be reduced by the increased dB level used during scanning.

D.5.2.11 Rechecks shall be performed if the loss of back reflection is 50% or greater. The method for further investigation of areas with reduction or loss of back reflection, ASTM A 609 paragraph 8.5, shall be described.

D.5.2.12 Different frequencies, types, angles and diameter of probes shall be employed to obtain additional information about detected indication

Sizing of indications

D.5.2.13 In general, the area containing imperfections, shall be sized (area and length) using the 6 dB drop technique. The area refers to the surface area on the castings over which a continuous indication exceeds the acceptance criteria. This area will be approximately equal to the area of the real defect provided the defect size is larger than the 6 dB beam profile of the probe.

D.5.2.14 If the real imperfection size is smaller than the 6 dB beam profile, the 6 dB drop technique is not suited for sizing. The area measured on the surface will be measured too large and not represent the real indication size. A guide to classify if the revealed indications are greater or smaller than the 6 dB drop profile is given in EN 10228-3, part 13.

D.5.2.15 If the size of the indication is evaluated to be smaller than the 6 dB drop profile at the depth of discontinuity, a graphic plot that incorporates a consideration of beam spread should be used for realistic size estimation.

Periodical checks of equipment

D.5.2.16 At approximately four-hourly intervals and at the end of testing, the range scale, probe angle and primary gain shall be checked and corrected. Checks shall also be carried out whenever a system parameter is changed or changes in the equivalent settings are suspected. If deviation is found to be larger than 2% of range scale, or 3 dB of primary gain setting or 2° of nominal angle probe, the testing carried out with the equipment over the previous period shall be repeated.

Reporting

D.5.2.17 Reports shall be in accordance with [D.2.1.4], [D.2.1.5], and ASTM A609, chapters 9 and 19. All indications exceeding 50% of the DAC shall be reported.

Manual magnetic particle testing of C-Mn and low alloy steel castings

D.5.2.18 Manual magnetic particle testing of C-Mn steel castings shall be performed in accordance with ISO 9934 or equivalent standard.

D.5.2.19 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5].

D.5.3 Ultrasonic and liquid penetrant testing of duplex stainless steel castings

Ultrasonic testing

D.5.3.1 Ultrasonic testing of duplex stainless steel castings shall be performed in accordance with [D.5.2], but with the following additions to the requirements to:

— probes
— reference blocks for angle beam testing
— casting conditions for ultrasonic testing
— testing procedure.

Angle probes

D.5.3.2 Angle probes for duplex stainless steel shall be twin crystal (transmitter/receiver) compression-wave probes. Angle compression wave probes shall and can only be used without skipping.

D.5.3.3 Low frequency shear wave angle probes may be used for duplex stainless steel instead of twin crystal (transmitter/receiver) compression-wave probes, provided it is verified on the reference blocks that it is possible to obtain a DAC with a shear wave angle probe that is comparable to the DAC obtained with an angle compression wave probe.

D.5.3.4 Creep wave probes shall be used for detection of sub surface defects close to the scanning surface, unless testing can be performed from both sides.

Reference blocks for angle beam testing

D.5.3.5 Reference blocks for angle beam testing of duplex stainless steel with angle compression wave probes shall have side drilled holes and a 1 mm deep and 20 mm wide spark eroded notch according to Figure D-4 and Table D-7.

Casting conditions for ultrasonic testing

D.5.3.6 Duplex steel stainless castings shall be machined according to [D.4.2.11] and [D.4.2.12].

D.5.3.7 The machining of duplex stainless steel castings for ultrasonic testing shall take into account that angle compression wave probes shall and can only be used without skipping.

Testing procedure

D.5.3.8 The testing procedure for duplex stainless steel castings shall take into account that angle compression wave probes shall and can only be used without skipping. The testing shall hence be performed from as many faces that access permits.

Manual liquid penetrant testing of duplex stainless steel castings

D.5.3.9 Manual liquid penetrant testing of duplex stainless steel castings shall be performed in accordance with ISO 3452 or equivalent standard. Post-emulsified penetrants should be used on precision castings only. The penetration and developing times shall be long enough to allow effective detection of the smallest indications allowed.

D.5.3.10 Reports shall be in accordance with [D.2.1.4] and [D.2.1.5].

D.5.4 Radiographic testing of castings

General

D.5.4.1 Radiographic testing of castings shall be done according to ASME Boiler and Pressure Vessel Code, Sec.5, article 2, mandatory appendix VII or equivalent standard. In addition, the applicable requirements of [D.2.2] and the requirements below shall apply.

Procedures

D.5.4.2 Radiographic procedures shall in addition to the requirements of [D.2.2.3], give the following information:

— shooting sketches
— coverage
— source location
— location of IQI
— acceptance criteria.

D.5.5 Visual examination of castings

D.5.5.1 Visual examination of castings shall be performed in accordance with [D.3.4] and MSS SP-55.

D.5.5.2 Reports shall be in accordance with [D.3.4.5].

D.5.6 Acceptance criteria for castings

General

D.5.6.1 Acceptance criteria shall apply for the entire casting or portions of the casting. If different acceptance criteria shall apply for different portions of the casting, the critical areas of the casting shall be defined.

Guidance note:
Critical areas shall include abrupt changes of sections and at the junctions of risers, feeders and gates to the casting. Highly stressed areas such as weld necks shall be considered as critical areas.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.5.6.2 Acceptance criteria for manual ultrasonic straight beam testing of castings shall be:

— No crack-like indications are acceptable, and

— According to Table D-9.

Table D-9 Ultrasonic testing acceptance criteria for castings

Straight beam testing ASTM A609, 10.2.1, 10.2.2 and 10.2.3	
Critical areas	Other areas
Table 2, quality level 1	Table 2, quality level 3
Angle beam testing ASTM A609 S1.4.1 and Table 2	
Critical areas	Other areas
Table 2, quality level 1	Table 2, quality level 3

D.5.6.3 Acceptance criteria for manual radiographic testing of critical areas of castings shall be according to Table D-10.

Table D-10 Radiographic acceptance criteria for castings

Type of defect	*Acceptance criteria*	
	Standard	Maximum severity level
Gas porosity	ASTM E280	2
Inclusions		2
Shrinkage		2
Cracks		0
Hot tears		0
Inserts		0

D.5.6.4 Acceptance criteria for manual magnetic particle testing and manual liquid penetrant testing of castings shall be according to Table D-11.

Table D-11 Acceptance criteria for manual magnetic particle and liquid penetrant testing of castings

A	Crack-like defects: not permitted
B	Linear indications with length more than three times the width: not permitted. Linear indications with length < 1.5 mm may be deemed irrelevant.
C	Rounded indications: Diameter < 3 mm, accumulated diameters in any 100 × 150 mm area < 8 mm.

D.5.6.5 Acceptance criteria for visual inspection of castings shall be in accordance with MSS SP-055:

— Type 1: Not acceptable.
— Types 2 to 12: A and B.

Repairs by welding

D.5.6.6 Complete removal of the defect shall be confirmed by magnetic particle testing, or liquid penetrant testing for non-ferromagnetic materials, before re-welding.

D.5.6.7 Repair welds of castings shall meet the acceptance criteria designated for the particular portion of the casting.

D.6 Automated non-destructive testing

D.6.1 General

D.6.1.1 These requirements are applicable to all automated NDT processes except automated ultrasonic testing of girth welds where specific requirements are given in App.E. The requirements given in this subsection are additional to the requirements of any standard or recommended practice where automated NDT methods are prescribed or optional.

D.6.1.2 Automated non-destructive testing can replace manual non-destructive testing or one automated non-destructive testing method/system can replace another automated non-destructive testing method/system provided the equivalence of systems is documented with regard to function, operation, ability in detection and sizing and performance.

D.6.1.3 Documentation of capability/performance and qualification of automated NDT systems in pipe mills should not be required for systems meeting the documentation requirements given in [D.8.4.4].

D.6.2 Documentation of function and operation

The automated NDT equipment shall be documented with regard to function and operation. Items subject to documentation include:

— brief functional description of the equipment
— detailed equipment description
— operation manual including type and frequency of functional checks
— calibration
— limitations of the equipment with regard to material or weld features including size, geometry, type of flaws, surface finish, material composition etc.

— repeatability.

D.6.3 Documentation of performance

D.6.3.1 The capability and performance of automated NDT equipment shall be documented by statistical records covering, as relevant:

- accuracy in indication sizing (random and systematic deviation)
- accuracy in positioning/location
- defect characterisation abilities compared to the results of other NDT performed
- repeatability, and
- probability of detection values or data for different threshold settings to determine the threshold to be used for required detection during testing.

Guidance note:

Automated non-destructive testing equipment can generally be divided into two groups. One group consists of equipment intended for detection, sizing and positioning of indications (typically real time radiography) and one group consisting of equipment intended for detection only and where sizing and positioning of indications is performed by other means (typically ultrasonic testing of the weld seam according to ISO 10893-11). For the latter types of equipment, documentation of performance may be limited to demonstration of adequate detection of defects typical for the manufacturing process, threshold setting parameters and repeatability.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.6.4 Qualification

D.6.4.1 A full qualification programme for automated NDT equipment will in general comprise the following stages:

- initial evaluation and conclusions based on available information
- identification and evaluation of significant parameters and their variability
- planning and execution of a performance test programme
- reference investigations.

D.6.5 Evaluation of performance documentation

D.6.5.1 As a minimum a qualification will involve an assessment of the automated NDT equipment technical documentation, including the quality assurance system, and available information on equipment capability and performance. Limited practical tests shall be performed in many cases.

D.7 Non-destructive testing of pipe body of welded pipes

D.7.1 General

D.7.1.1 The pipe body material of welded pipes shall be tested with an ultrasonic inspection method. The non-destructive testing of this material should be performed during manufacture of plate and coil, but can be performed on the final pipe.

In addition, plate and coil shall be visually inspected. The testing shall be performed according to documented procedures.

Guidance note:

The pipe body is inspected for defects oriented parallel to the surface of plate and coil (e.g. laminations). Pipe manufacture (e.g. forming, expansion, heat treatment) does not have a significant influence on such defects; consequently it is not required to perform this inspection in the final delivery condition of the pipe.

Pipe body inspection does typically not look for defects oriented in the through-thickness direction (either transversely or parallel to the pipe axis). The probability of such defects occurring and not detected by visual inspection is considered negligible for wall thicknesses used for pipelines.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.7.1.2 The inspection shall be carried out in a manner that ensures detection of the minimum imperfection size to be considered.

The scanning velocity shall be set low enough so that the distance the probe travels while inactive is significantly less than the maximum length of allowable imperfections. There should be at least one inspection point per millimeter of movement.

The inspection should ensure 100% coverage of the material perpendicularly to the movement of equipment, with some overlap between inspection channels/tracks.

D.7.1.3 Lack of acoustic coupling shall be treated as an imperfection. An alarm for lack of acoustic coupling shall be incorporated in the inspection equipment for every probe/channel. This alarm shall give a visual signal, and should give an additional audio signal. The principle of detecting lack of acoustic coupling shall be described in the procedure. The trigger level for the lack of acoustic coupling alarm shall be stated in the procedure. The lack of acoustic coupling alarm shall be tested at least once per month (for instance by closing the water supply for a probe).

D.7.1.4 The inspected material shall have a surface condition and geometry that ensures the validity of the test. A reduction of 6-8 dB in back wall echo shall be detected and reported. When such variations in signal occur, the manufacturer shall, based on review of plate condition and inspection result, conclude whether the test is valid. An invalid test shall be repeated, or the plate shall be rejected.

D.7.1.5 Material that contains unacceptable imperfections or surface defects shall be rejected or cut until no unacceptable imperfections or defects are present in the material.

D.7.2 Requirements to automated ultrasonic inspection for pipe body

D.7.2.1 When automated inspection systems are used, documentation and qualification records meeting the requirements of [D.6] or [D.8.4.4] shall be available. Such documentation and records are not required to be project-specific, but the qualified parameters and relevant intervals shall be stated and justified. In addition, a full system calibration shall be done with intervals not exceeding 12 months.

D.7.2.2 The reference standard shall be a plate or pipe with the reflectors required for checking sensitivity, coverage, sizing (if used) and evaluation (if used). In addition, the reference standard shall have:

— Similar wall thickness to the inspected product, unless the inspection equipment can take into account variations in wall thickness (for instance by use of Distance-Gain-Signal curves).
— Similar acoustic properties.
— Width/diameter and length determined by the manufacturer.
— Identification and marking determined by the manufacturer.

D.7.2.3 The coverage of the inspection equipment shall be demonstrated by reflectors in the reference standard. The reflectors shall be of same type and size as reflectors used for sensitivity setting. The location shall be determined by the manufacturer. The following scenarios shall as a minimum be considered;

— For pipe; non-inspected area along longitudinal weld, measured in circumferential direction.
— For pipe and cut plate; non-inspected area at start and end of inspection.

— For cut plate; non-inspected area at edges parallel to movement of inspection equipment (inspection of cut plate is at least relevant when re-inspection is required due to failed dynamic calibration check).

D.7.2.4 The equipment shall be set up, optimized and calibrated in static mode. Subsequently the reference standard shall be run at least once through the inspection system in normal production conditions – this is the dynamic calibration check. If all relevant reflectors or artificial imperfections are detected above the registration level, the equipment is ready for production. The scanning velocity during dynamic calibration check is the maximum allowed velocity during production.

D.7.2.5 A dynamic calibration check shall be performed;

— every four hours or once every 10 items inspected (whichever is longer),
— at the start and end of each shift,
— at any change of equipment operator,
— whenever a malfunction of the equipment is suspected.

If a dynamic calibration check is unacceptable, all items inspected since last acceptable dynamic calibration check shall be re-inspected. Re-inspection and continued production is allowed only after the inspection equipment has been set up again and passed a new dynamic calibration check.

If a dynamic calibration check is unacceptable, it is allowed to do a double re-test with the reference standard. If both re-tests are acceptable, the calibration check can be considered passed. It is also allowed to visually inspect the reference standard and clean the surface. No change to any system settings shall be made.

D.7.2.6 When a function for determination of dimensions and size of imperfections is used, this shall be stated in the procedure. The function can determine the width, length or area, depending on requirements. The reference standard shall contain reflectors with the following dimensions and location;

— Area equal to maximum allowed for body. Located in body, mid-wall.
— Area equal to maximum allowed for body. Located in body, 3-6 mm from back wall.
— Area equal to maximum allowed for body. Located in body, 3-6 mm from front wall.
— Area equal to maximum allowed for edge. Located in edge, mid-wall.
— Area equal to maximum allowed for edge. Located in edge, 3-6 mm from back wall.
— Area equal to maximum allowed for edge. Located in edge, 3-6 mm from front wall.
— Width ≤ 8 mm. Located in body, mid-wall.
— Width ≤ 8 mm. Located in body, 3-6 mm from back wall.
— Width ≤ 8 mm. Located in body, 3-6 mm from front wall.
— Length ≤ 10 mm. Located in edge or body, mid-wall.
— Length ≤ 10 mm. Located in edge or body, 3-6 mm from back wall.
— Length ≤ 10 mm. Located in edge or body, 3-6 mm from front wall.

The type and shape of reflectors shall be determined by the manufacturer. These reflectors shall be detected and registered during each dynamic calibration check.At least once per week the result from the function for these reflectors shall be compared with their actual dimensions. The procedure shall contain a table that lists all reflectors, their actual dimensions and location in the test plate.Any under-sizing is unacceptable. In case of under-sizing all items inspected since last acceptable check are suspect and shall be evaluated again, after correction of the sizing algorithm.Variation in sizing and over-sizing is acceptable.

Guidance note:

The dimension and location of the required reflectors are intended to demonstrate that small and large reflectors are adequately sized. Imperfections with intermediary areas are expected to also be adequately sized. Consequently the area of the reflectors is selected with a view to the relevant acceptance criteria.

Width and length are also criteria. It is considered that the smallest width and length are most difficult for the function to determine. This is because the critical dimensions will typically be smaller than the size of the probe or channel. Consequently any larger width and length should be adequately determined.

It is required to have reflector or artificial imperfections at different depths, in order to confirm that the algorithm correctly takes into account the location in the wall thickness.

It is assumed that the inspection data for both edge and body are fed into one computer and handled by one sizing algorithm.

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Guidance note:

If the sizing algorithm is found to give under-size results, the suspect plates/pipes shall be evaluated again. This can be done by (i) re-inspecting the items with a full inspection routine or (ii) recalculating the sizes using the existing data.

As long as the sensitivity of the equipment is acceptable, the data produced by the system should be considered representative of the inspected items.

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D.7.2.7 When a function for evaluation of imperfections is used, this shall be stated in the procedure. The evaluation function requires as input dimensional data of imperfections, consequently the requirements to a sizing function shall be implemented. In addition, the reference standard shall contain reflectors with the following size, number and location;

— A group in plate body with a population density of one more that maximum allowed density within a given reference area. This group shall be evaluated as unacceptable. Location in plate body and depth to be decided by the manufacturer.
— A group in plate edge with a population density of one more that maximum allowed density within a given reference area. This group shall be evaluated as unacceptable. Location in plate edge and depth to be decided by the manufacturer.
— Two adjacent imperfections of such size and proximity that they shall be considered as one imperfection. Location and depth to be decided by the manufacturer.

These reflectors shall be detected and registered during each dynamic calibration check.At least once per week the result of the evaluation function for all reflectors in the reference standard shall be reviewed. The procedure shall contain a table that lists all reflectors, their location in the test plate and the expected evaluation result for each reflector.In case the evaluation result is incorrect and unacceptable, all items inspected since last acceptable check are suspect and shall be evaluated again, after correction of the evaluation function.

D.7.2.8 When functions for sizing of imperfections and/or evaluation of imperfections are used, a baseline for the system shall be established before start of production. The reference standard shall be tested ten times in conditions equal to production conditions. A report shall be issued, with the following information;

— Reference to inspection procedure and date of baseline inspections.
— Normal production reports for each dynamic calibration check.
— Dimensions for each reflector; average, minimum and maximum result.
— Evaluation result for each reflector or artificial imperfection.
— Conclusion on the readiness and stability of the system.

D.7.2.9 Each channel and each probe shall be checked at least once per month. This check shall have identical conditions for all channels and probes, so that the results may be compared and analyzed. The procedure shall state how this check is performed, and the manufacturer shall established quantitative criteria for the test. As a minimum, the back wall echo and the noise level shall be evaluated.

Guidance note:

There are several approaches to a full system check of individual probes and channels. The below list of examples is not exhaustive.

— Static calibration check, one probe/channel at a time. This should be possible to automate by the equipment supplier.
— Use of full wall in an area without any imperfections, either in the reference plate or a normal production plate.
— Include a transverse notch in the reference standard, typically with a width of somewhere between 4-8 mm.

The check should include a test of the sensitivity.

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D.7.3 Ultrasonic testing of C-Mn steel and corrosion resistance alloy

D.7.3.1 When performed, ultrasonic testing for laminar imperfections shall be in accordance with ISO 10893-9, and with additional requirements as stated in this section. If the testing is done on the final pipe, it shall be done in accordance with ISO 10893-8.

D.7.3.2 The inspection shall detect laminar imperfections in the material, and the material shall meet the acceptance criteria in Table D-12. The edge criteria shall be applied as follows:

— Transverse edge; 150 mm inside the location of future bevel for girth weld.
— Longitudinal edge for HFW pipe; 15 mm inside location of future bevel for longitudinal weld.
— Longitudinal edge for other pipe; 50 mm inside location of future bevel for longitudinal weld

Guidance note:

The edge criteria on transverse edge are intended to avoid having signals from base metal to interfere with AUT of girth weld. 150 mm should be sufficient for normal welding and inspection practice. However, the pipe purchaser should consider extending the edge criteria to take into account other factors, such as weld cut out and rebevelling.

If the pipe body material is inspected on the final pipe, it can be possible to waive the edge criteria for the longitudinal weld. However, the risk of pipe body imperfections that mask weld defects cannot be neglected, and should be considered when planning and performing pipe body inspection on the final pipe.

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D.7.3.3 A maximum inspection temperature shall be stated in the procedure. If water is used as couplant, the maximum inspection temperature shall be 80°C. A higher inspection temperature can be agreed, if it is demonstrated with practical tests in production conditions that the equipment provides reliable inspection and acceptable sensitivity. Relevant parameters shall be determined (e.g. water pressure).

If another liquid is used as couplant, the maximum inspection temperature shall be sufficiently below the boiling temperature of the substance.

Non-contact inspection equipment (e.g. electromagnetic acoustic transducer, EMAT) is allowed, provided the sensitivity and stability of the equipment has been documented.

D.7.3.4 The inspection coverage in the wall thickness direction shall be stated in the procedure. A non-inspected near-surface zone shall be maximum 3.0 mm. Reflectors of size and type required by ISO 10893-9 for sensitivity check shall be incorporated in the calibration standard at the relevant depths.

Guidance note:

Many UT systems have a near-surface zone where the inspection is less reliable. This goes for both front wall and back wall. The reason is that signals from imperfections may not be distinguished from the large signals from front wall and back wall. In other words, it is a question of system resolution, and how well the different signals can be identified and differentiated.

Inspection in the near-surface zone is less reliable, and in principle should be considered as not controlled. The near surface zone may have imperfections and defects. Still, a non-inspected surface zone may be acceptable;

— Imperfections at the surface or immediately close to the surface should be identified by visual inspection. Such imperfections would be associated with surface breaking defects in the slab or other types of defects introduced during rolling.
— Imperfections in the plate volume can occur, but it is unlikely that they are limited to a zone of only 2-3 mm close to the surface without being surface-breaking. Defects in the plate volume originate in the slab volume, and most slab defects are close to the centreline – which will become plate mid-wall and fully inspected by plate AUT. Slab defects not associated with the centreline should be distributed widely in the slab (e.g. pores, slag, inclusions) and consequently should be distributed also throughout the plate thickness.

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Table D-12 Ultrasonic testing, acceptance criteria for laminar imperfections

Service	*Maximum allowed imperfection*	*Minimum imperfection size to be considered*	*Size of reference area*	*Maximum population density*
Non-sour	Area: 1000 mm^2	Area: 300 mm^2 Length: 35 mm Width: 8 mm	1000 mm x 1000 mm	10 within reference area
Sour	Area: 500 mm^2	Area: 150 mm^2 Length: 15 mm Width: 8 mm	500 mm x 500 mm	5 within reference area
Acceptance criteria for edges				
Service	*Maximum allowed imperfection*	*Minimum imperfection size to be considered*	*Size of reference area*	*Maximum population density*
All	Area: 100 mm2 Length: 20 mm	Length: 10 mm	1000 mm length	3 within reference area
Notes: 1) Two or more adjacent imperfections shall be considered as one imperfection if they are separated by less than the smaller dimension of either indication. 2) The population density shall be the number of imperfections smaller than the maximum allowed and larger than the minimum imperfection size to be considered 3) The reference area when the plate/coil width is less than one side of the square reference area shall be 1.00 m2 for non-sour and 0.25 m2 for sour service. 4) The width of an imperfection is the dimension transverse to the rolling direction.				

D.7.4 Ultrasonic testing of bonding in corrosion resistance alloy clad plate

D.7.4.1 When performed, ultrasonic testing for lack of bonding shall be in accordance with ISO 10893-9, and with additional requirements as stated in this section.

D.7.4.2 The reference standard reflector shall be located within ±0.5 mm of the bonding interface.

The inspection report from lamination control of both CRA and C-Mn steel shall be available. If there are acceptable laminations in the plates, they can mask unacceptable lack of bonding. The manufacturer shall have alternative inspection methods to inspect such areas.

D.7.4.3 During calibration check in production conditions the signal from the reference reflector shall be at least 6 dB stronger than the signal from the interface between CRA and C-Mn steel material.

D.7.4.4 The acceptance criteria for plate body are:

— No single unbonded area shall exceed 25 mm in its longest dimension.
— Total unbonded area shall not exceed 1% of the total cladded surface area.

D.7.4.5 The acceptance criteria for plate edge are:

— No area with lack of bonding is allowed (i.e. no signal larger than the reference reflector).

The edge is the material extending 50 mm from the location of future weld preparations (both longitudinal and transverse welds).

Guidance note:

For plate edge, no lack of bonding is allowed. According to ISO 10893-9, the system sensitivity is defined by 6 mm flat-bottom hole. In practice, this means that lack of bonding smaller than 6 mm may be accepted.

When welding clad material, it is important to ensure the integrity of the CRA layer – both for longitudinal weld and girth weld. The weld inspection may have very strict requirements. Consequently imperfections that are acceptable based on 6 mm FBH sensitivity level may be large compared to allowable weld defects – and could mask weld inspection. In such cases it should be considered to introduce stricter requirements to plate inspection.

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D.7.5 Alternative test methods

D.7.5.1 If agreed alternative methods of testing may be acceptable, if the alternative test method is documented as required in [D.8.4.2] and the alternative test method is demonstrated to give at least the same sensitivity and capability in detection of imperfections.

D.7.5.2 The demonstration of the alternative test method shall be based on the principles given in [D.6] and using samples of plate similar to those ordered. The plates shall contain a representative and agreed size range of natural and/or artificial defects of types that are typical for the manufacturing process in question.

D.7.6 Visual examination of plate and coil

D.7.6.1 Visual examination shall be carried out in a sufficiently illuminated area, minimum 350 lux on the area of interest is recommended. If required to obtain good contrast and relief effect between imperfections and background additional light sources shall be used.

D.7.6.2 For direct examination the access should permit placing the eye within 600 mm of the surface to be examined and at an angle of not less than approximately 30°.

Guidance note:

The production process of coil can make it difficult or impossible to perform visual inspection. The coil can be too hot, moving too fast and not be sufficiently clean to be able to visually inspect. In such cases the visual inspection, if required, shall be performed at a later stage of the pipe production process.

The final visual inspection for pipe is after completion of all pipe production activities. The visual inspection at the plate/coil stage is preliminary, however still important to ensure the integrity of the final pipes.

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D.7.6.3 Relevant tools, gauges, measuring equipment and other devices shall be available at the place of examination.

D.7.6.4 The material to be examined shall be cleaned to remove all scale and processing compounds prior to examination. The cleaning process shall not injure the surface finish or mask possible imperfections.

D.7.7 Acceptance criteria and disposition of surface imperfections

D.7.7.1 Plate/coil shall meet the acceptance criteria specified by the pipe mill. The acceptance criteria shall under no circumstance be less stringent than the applicable requirements for pipe, as specified in [D.8.5].

D.7.7.2 Imperfections shall be dressed out by grinding. Ground areas shall blend smoothly into the surrounding material. Complete removal of defects shall be verified by local visual inspection and shall be supplemented with a suitable surface inspection method. The remaining wall thickness in the ground area shall be checked by ultrasonic wall thickness measurements to verify that the thickness of the remaining material is more than the specified minimum. Imperfections that encroach on the minimum permissible wall thickness after grinding shall be classified as defects.

D.8 Non-destructive testing of linepipe at pipe mills

D.8.1 General

D.8.1.1 The extent of non-destructive testing during manufacture of linepipe shall be as required in [7.6].

D.8.1.2 The types of testing required are defined as:

— ultrasonic testing
— surface imperfection testing
— radiographic testing.

Whenever the choice of non-destructive testing methods is optional, this is indicated in this subsection.

D.8.1.3 All NDT shall be performed according to documented procedures that, as a minimum, give information on the following aspects:

— applicable standard(s) or recommended practice(s)
— welding method (when relevant)
— joint geometry and dimensions (when relevant)
— material
— NDT method
— technique
— equipment, main and auxiliary
— consumables when relevant (including brand name)
— coverage calculation supplemented with sketches
— sensitivity
— calibration references and technique
— trigger or alarm settings
— for ultrasonic testing equipment the procedure shall describe the method for setting and checking the lack of coupling alarm
— assessment of imperfections
— method for demonstrating compliance of equipment with the assumptions in the procedure
— reporting and documentation of results

— assessment of imperfections, including decision tree corresponding with internal organization.

D.8.1.4 Personnel performing NDT shall be qualified according to [D.1.5].

D.8.1.5 All NDT for final acceptance of pipe shall be performed after completion of any cold expansion and heat treatment operations.

For seamless pipe, the NDT for final acceptance may be performed prior to cropping, bevelling and end sizing. Cold straightening and cold sizing of seamless pipe ends imposing a maximum strain of 1.5% may be performed after surface testing of the pipe body but prior to testing of pipe ends.

All NDT for in-house purposes may be performed at any time at the manufacturer's discretion.

D.8.1.6 If NDT of plate in accordance with [D.7] is performed at the plate mill, ultrasonic testing for laminar imperfections may be omitted at the pipe mill.

D.8.1.7 Reporting of NDT shall be according to the requirements of the applicable ISO standard unless otherwise agreed.

D.8.2 Suspect pipe

D.8.2.1 In all cases when pipe inspection results in the automated NDT system is giving signals equal to or greater than the threshold level or when surface imperfections are disclosed by visual examination, the pipe shall be deemed suspect.

Suspect pipe can be dealt with according to one of the following options:

— the suspect pipe can be re-inspected using the automated NDT equipment in the static mode. Pipes passing these tests are deemed acceptable
— the suspect area of the pipe can be re-tested by manual NDT using the same NDT method and sensitivity as the automated NDT, and using appropriate techniques. Pipes passing these tests are deemed acceptable
— the suspect area of welds, except HFW welds, can be radiographed to determine if the indication is caused by slag or porosity type indications. Pipes meeting the requirements of ISO 10893-6 or respectively ISO 10893-7 are deemed acceptable
— defective welds, except HFW welds, can be repaired by welding according to [D.8.3.1] through [D.8.3.7]
— defects can be removed by grinding according to [D.8.3.8]
— the suspect area can be cut off if the minimum specified length is met after cutting
— the pipe can be scrapped.

If the suspect area is cut off, then all NDT requirements pertaining to pipe ends shall be performed on the new pipe end.

D.8.3 Repair of suspect pipe

Repair welding

D.8.3.1 Repair welding of pipe body or repair welding of welds in HFW pipe is not permitted.

D.8.3.2 Repair welding of cracks is not permitted unless the cause of cracking has been established not to be a systematic welding error. (If there is a crack in the weld the pipe is per definition considered rejected.) This means a technical evaluation of the cause of cracking shall be performed. If it can be demonstrated that the crack is a one off situation, repair welding may be performed subject to agreement)

D.8.3.3 Repair welding shall be performed according to qualified repair welding procedures. Each repair shall be performed with a minimum of two passes over a length not less than 50 mm.

D.8.3.4 The total length of weld repair in any single pipe shall not exceed 5% of the weld length.

D.8.3.5 Weld defects separated by less than 100 mm shall be repaired as a single continuous repair.

D.8.3.6 Re-inspection of repair welds shall be 100% visual examination and 100% ultrasonic and/or 100% radiographic testing as required for the original weld.

D.8.3.7 Acceptance criteria for weld repairs shall be as for the original weld.

Repair of welds by grinding

D.8.3.8 Surface defects may be dressed out by cosmetic grinding. Ground areas shall blend smoothly into the surrounding material. Complete removal of defects shall be verified by local visual inspection and shall be supplemented with a suitable surface inspection method. The remaining wall thickness in the ground area shall be checked by ultrasonic wall thickness measurements to verify that the thickness of the remaining material is more than the specified minimum. Imperfections that encroach on the minimum permissible wall thickness and/or weld thickness shall be classified as defects.

Repair of pipe body by grinding

D.8.3.9 Repair of pipe body by grinding shall be performed according to [D.8.5.25] through [D.8.5.27].

Disposition of pipe containing defects

D.8.3.10 Disposition of pipe containing defects after repair shall be according to [D.8.5.28].

D.8.4 General requirements for automated non-destructive testing systems

Alternative methods of testing

D.8.4.1 Subject to agreement, alternative methods of testing may be accepted if the alternative test method is documented as required in [D.8.4.2] and the alternative test method is demonstrated to give at least the same sensitivity and capability in detection of imperfections.

D.8.4.2 The demonstration of the alternative test method shall be based upon the principles given in [D.6] and using sample lengths of pipe similar to those ordered. The pipes shall contain a representative and agreed size range of natural and/or artificial defects of types that are typical for the manufacturing process in question.

System calibration

D.8.4.3 All automated NDT systems shall have a full system calibration with intervals not exceeding 12 months. Documentation shall be available.

Documentation of system capabilities

D.8.4.4 Documentation of automated NDT systems shall be available to demonstrate that the systems are capable of detecting the reference indicators used to establish the specified test sensitivity. The documentation shall, as a minimum cover:

- NDT system operating procedures
- capability for the intended wall thickness
- capability for the intended material
- repeatability
- detection of defects typical for the manufacturing process with the equipment in question
- threshold level setting parameters
- dynamic test data demonstrating the systems capability under production test conditions.

Reference standards for ultrasonic and electromagnetic inspection

D.8.4.5 Reference standards shall meet the requirements of the applicable ISO standard and the requirements given in this appendix.

D.8.4.6 The reference standard shall be a length of pipe with the same outside diameter and wall thickness tolerances and with similar acoustic properties as the pipe tested during production. For welded pipe the reference standard shall contain a weld typical for the production weld to be tested.

D.8.4.7 Reference standards may be of any convenient length as decided by the manufacturer.

D.8.4.8 Reference standards shall contain reference indicators as required by this appendix for the pipe to be tested.

D.8.4.9 Verification of the dimensions and shape of all reference indicators shall be performed according to a documented procedure. Documentation shall be available. All reference standards shall be marked with an identification that relates to the specific application of each reference standard.

Validation of length of pipe tested

D.8.4.10 When automated non-destructive testing equipment is used, a short area at both pipe ends will normally not be tested. A sample pipe shall be fitted with one ⌀ 3.0 mm through drilled hole at the weld centerline at each end. The distance from the pipe end to the hole shall be equal to the length not covered by the automated testing equipment during production testing. Prior to start of production the pipe shall be passed through the ultrasonic testing equipment at the operational scanning velocity. For acceptance of the equipment, both holes shall be detected by all probes/focal law. These holes can be introduced in the reference block. If ⌀ 3.0 mm through drilled hole at the weld centerline at each end is unsuitable to register at scanning sensitivity for the technique introduced to the inspection Set Up, alternative reference reflectors shall be proposed and agreed on. For inspection of seamless pipes, a similar test shall be performed with adequate reflectors included at pipe ends.

Scanning velocity

D.8.4.11 The scanning velocity shall be selectable. The scanning velocity shall be set low enough so that the length between the activation of each probe (spatial resolution) is sufficiently short, i.e. the distance the probe travels while inactive, shall be significantly less than the maximum length of allowable imperfections.

D.8.4.12 The scanning velocity V_C for inspection of longitudinal welds shall be determined according to:

$$V_C \leq W_C \bullet PRF / 3$$

Where W_C is the narrowest - 6 dB effective beam width at the appropriate distance of all probes within the array and PRF is the effective pulse repetition frequency per probe.

D.8.4.13 The circumferential scanning velocity for inspection of seamless pipe and helical welds shall be decided depending on effective pulse spacing (pulse density) and on circumferential scanning speed and helical pitch. The effective pulse spacing (EPS) is specified as follows:

— EPS = circumferential scanning speed/PRF
— EPS shall not exceed 1 mm/pulse.
— The helical pitch (mm/revolution) shall not exceed the narrowest - 6 dB effective beam width of all probes within the array.

Lack of coupling

D.8.4.14 Automated ultrasonic testing systems shall incorporate a system for detection of lack of coupling. The settings for lack of coupling alarm and check of the settings shall be described in the manufacturer's written procedure.

Initial sensitivity and threshold settings (calibration)

D.8.4.15 The sensitivity and threshold settings shall be established according to a documented procedure. The system shall be optimised in the static mode. When the settings are optimised, the relevant parameters shall be recorded and the reference standard shall be passed 3 times through the equipment at the operational velocity. Any change in settings required to maintain the static mode settings shall be recorded as an average of the 3 runs. For acceptance of the settings, all reference reflectors need to be detected at or above the threshold.

D.8.4.16 During production testing the relative speed of movement between the pipe and the test assembly shall not exceed that used for the sensitivity and/or alarm settings during dynamic calibration.

Verification of sensitivity and threshold settings (calibration)

D.8.4.17 The sensitivity and/or alarm settings shall be verified every fourth hour or once every 10 pipes tested, whichever is the longer period, and:

— at the start and end of each shift
— at any change of equipment operator (for continuous shifts the end and start verification can be combined)
— whenever a malfunction of the equipment is suspected.

The verification frequency when manufacturing HFW pipe from coil shall be agreed upon. As a minimum the frequency shall be at the beginning and end of an inspection and at any stops in production.

Resetting of sensitivity and threshold settings (recalibration)

D.8.4.18 Resetting of sensitivity and threshold settings shall be performed whenever:

— the standard reflectors do not trigger the alarm during verification of sensitivity and threshold settings
— a change of component affecting the sensitivity and/or alarm setting is made in the system
— the verification of sensitivity and/or alarm settings fails to meet the requirements for the particular equipment.

For re-setting of sensitivity and threshold settings during production the settings shall be optimised in the static mode. When the settings have been optimised, the reference standard shall be passed once through the equipment at the operational velocity. Any change in settings required to maintain the static mode settings shall be recorded. For acceptance of the settings, all reference reflectors need to be detected at or above the threshold.

Retesting of pipes

D.8.4.19 If the verification of sensitivity and threshold settings fails to meet the requirements for the particular equipment, all pipes inspected since the previous successful verification shall be retested.

Specific requirements for ultrasonic testing equipment for welds

D.8.4.20 The equipment shall be capable of inspecting the entire thickness of the weld seam.

D.8.4.21 Before starting production testing, the range scale and angle of all probes shall be demonstrated to comply with the documented procedure.

D.8.4.22 Equipment for testing of welds shall have a weld tracking system. The system should be capable of tracking the weld centreline with an accuracy of ± 2 mm or better. For systems not meeting this requirement it shall be documented that:

— the sensitivity during production testing will not be affected by the lower accuracy of the tracking system
— that the lower accuracy is compensated by system sensitivity and gate settings.

D.8.4.23 The gates shall be set wide enough to cover 3 mm of the base material outside the fusion line and to compensate for:

— the tolerances of weld tracking system
— variations in the width of external and internal caps
— offsets between the external and internal weld bead.

Ultrasonic testing of CRA pipes and welds with CRA weld deposits

D.8.4.24 Ultrasonic testing of welds with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will in order to achieve an adequate detection of imperfections, normally require that special reference blocks and probes are used for testing of these materials.

D.8.4.25 Angle probes for duplex stainless steel and austenitic steels shall be twin crystal (transmitter/receiver) compression-wave probes. Angle compression wave probes shall and can only be used for scanning without skipping and creep wave probes shall therefore be used for detection of sub-surface defects close to the scanning surface.

D.8.4.26 Reference blocks for duplex stainless steel and austenitic steels materials and the weld deposits shall have a specific location and type of reference reflectors in general compliance with [D.2.4]. Surface notches will not be suitable due to the mode conversions at base material and a surface notch. This will result in multiple echoes with different arrival time appearing from the same notch. The actual reflection from the reflector will be weak and distinguishing this echo from other signals will often not be possible.

D.8.4.27 Specific ultrasonic testing procedures shall be developed for this testing. The procedures shall be developed considering the requirements [D.2.4] and addressing the specific features and characteristics of the equipment to be used.

D.8.4.28 It is recognised that not all equipment will be adaptable to meet the requirements above.

D.8.4.29 Low frequency shear wave angle probes may be used for duplex stainless steel and austenitic steels instead of the angle compression wave probes, provided it is verified on reference blocks made in accordance with [D.2.4] that it is possible to obtain a DAC with shear wave angle probe(s) that is comparable to a DAC obtained from angle compression-wave probes. The shear wave angle probes used for this verification shall be identical to the probes used in the production testing equipment.

D.8.4.30 If it is not possible to demonstrate adequate performance of low frequency shear wave angle probes for ultrasonic testing of duplex stainless steel and austenitic steels, other methods or combination of methods shall be used and the adequacy of the method(s) demonstrated.

D.8.4.31 Notches and through drilled holes are not considered a suitable reflector for compression wave angle probes due to the mode conversion and unpredictable arrival times of mode converted signals. When compression wave angle probes are used, other types of reflectors shall be used and the acceptance criteria specified accordingly.

Specific requirements for radiographic testing

D.8.4.32 Radiographic testing shall be performed in accordance with ISO 10893-6, image class B using wire type image quality indicators (IQI) in accordance with ISO 19232-1 or step/hole type on ISO 19232-2.

D.8.4.33 Digital radiographic testing techniques in accordance with ISO 10893-7 can be used provided the equipment has been demonstrated, in accordance with [D.6], to give sensitivity and detection equivalent to conventional x-ray according to ISO 10893-6.

D.8.4.34 If radioscopic testing techniques are used, the quality of the ray image has to be verified as required in [D.8.4.17].

D.8.5 Visual examination and residual magnetism

General

D.8.5.1 Visual examination shall be carried out in a sufficiently illuminated area; minimum 1000 lx, If required additional light sources shall be used to obtain good contrast and relief effect between imperfections and background.

D.8.5.2 In accordance with Table 7-16, each linepipe shall be subject to 100% visual inspection. This implies 100% visual inspection of the outside of the pipe body. The interior of the pipe shall be inspected from both ends as far as access permits. The interior of duplex stainless steel and clad/lined material should be 100% visually inspected.

D.8.5.3 A sufficient amount of tools, gauges, measuring equipment and other devices shall be available at the place of examination.

D.8.5.4 The pipes to be examined shall be cleaned to remove loose scale and processing compounds that may interfere with the examination. The cleaning process shall not affect the surface finish or mask possible imperfections.

D.8.5.5 Subject to agreement, alternative methods of testing may be accepted. It shall be demonstrated that the alternative test method give at least the same sensitivity and capability in detection of imperfections. The demonstration of the alternative test method shall be based upon the principles given in [D.6] on similar pipes to those ordered. The pipes shall contain a representative and agreed size range of natural and/or artificial defects of types that are typical for the manufacturing process in question.

Visual examination of all linepipe

D.8.5.6 End preparation such as bevelling shall meet the specified requirements.

D.8.5.7 The internal weld bead shall be removed by grinding for a distance of at least 100 mm from each pipe end. The transition between base material and weld metal shall be smooth and the height of the remaining weld bead shall not extend above the adjacent pipe surface by more than 0.5 mm.

D.8.5.8 If specified, the external weld bead shall be removed by grinding for a distance of at least 250 mm from each pipe end. The transition between base material and weld metal shall be smooth and the height of the remaining weld beads shall not extend above the adjacent pipe surface by more than 0.5 mm.

Visual examination of welds in linepipe

D.8.5.9 Each linepipe weld shall be subject to 100% visual examination in accordance with ISO 17637. For C-Mn steel linepipe with internal diameter (ID) ≥ 610, the internal weld shall be 100% visually inspected. The internal weld of C-Mn linepipe with ID < 610 mm shall be inspected from both ends as far as access permits.

D.8.5.10 The internal weld and adjacent surfaces in duplex stainless steel, CRA and clad linepipe shall be inspected full length. If necessary, the inspection of the internal weld shall be assisted by a boroscope, video endoscope or similar equipment.

D.8.5.11 Welds shall meet the requirements of Table D-4.

D.8.5.12 Line pipe containing welds not meeting the requirements above shall be classified as suspect pipe according to [D.8.2], and treated according to [D.8.3].

Surface conditions, imperfections and defects

D.8.5.13 The surface finish produced by the manufacturing process shall be such that surface defects can be detected by visual inspection.

D.8.5.14 All pipes shall be free from defects in the finished condition. The manufacturer shall take adequate precautions to prevent pipe damage and minimise the presence of imperfections.

D.8.5.15 Cracks, sweats or leaks are not acceptable and shall be classified as defects.

D.8.5.16 Surface imperfections evident by visual inspection shall be investigated, classified and treated as according to [D.8.5.17] to [D.8.5.22]. [D.8.5.19] applies to surface imperfections at the internal surface of clad or lined pipes.

D.8.5.17 Imperfections with depth ≤ 5% of the specified wall thickness, or 0.5 mm, whichever is greater, but maximum 0.7 mm for t ≤ 25 mm, and maximum 1.0 mm for t > 25 mm, and which do not encroach upon the specified minimum wall thickness, shall be classified as acceptable imperfections. The imperfections may remain in the pipe or be dressed out by cosmetic grinding.

D.8.5.18 Imperfections with depth larger than stated in [D.8.5.17], and which do not encroach upon the specified minimum wall thickness, shall be classified as dressable defects and shall either be removed by grinding in accordance with [D.8.5.25] or treated in accordance with [D.8.5.28], as appropriate.

D.8.5.19 For the internal surface of clad or lined pipes the following applies: Imperfections with depth ≤ 0.5 mm, and which do not encroach upon the specified minimum wall thickness, shall be classified as acceptable imperfections. The imperfections may remain in the pipe or be dressed out by cosmetic grinding. Imperfections with larger depth, and which do not encroach upon the specified minimum wall thickness, shall be classified as dressable defects and shall either be removed by grinding in accordance with [D.8.5.25] or treated in accordance with [D.8.5.28], as appropriate.

D.8.5.20 Imperfections which encroach upon the specified minimum wall thickness shall be classified as defects.

D.8.5.21 Two or more adjacent imperfections shall be considered as one imperfection if they are separated by less than the smaller dimension of either indication.

D.8.5.22 Imperfections with depth according to [D.8.5.17] or [D.8.5.19] of which the depth can not be assessed by suitable gauges or alternative means, shall either be removed by grinding in accordance with [D.8.5.25] or treated in accordance with [D.8.5.28], as appropriate.

Dents

D.8.5.23 For dents without any cold formed notches and sharp bottom gouges, the length in any direction shall be ≤ 0.5 D and the depth, measured as the gap between the extreme point of the dent and the prolongation of the normal contour of the pipe, shall not exceed 6.4 mm.

— For dents with cold-formed notches and sharp bottom gouges with depth according to [D.8.5.17] the depth of dents shall not exceed 3.2 mm.
— Dents > 1 mm are not acceptable at the pipe ends, i.e. within a length of 100 mm at each of the pipe extremities.
— Dents exceeding these dimensions shall be classified as defects.

Hard spots

D.8.5.24 Hard spots, as identified e.g. due to irregularities in the pipe curvature of cold-formed welded linepipe, shall be investigated to determine the hardness and dimensions of the area.

For linepipe intended for non sour service the hardness shall not exceed:

— 300 HV10 for C-Mn steels
— the values given in Table 7-11, for the material in question.

For linepipe intended for sour service (Supplementary requirement S) the hardness shall not exceed:

— 250 HV10 C-Mn steel unless a higher hardness has been qualified according to [6.2.2.2] and [B.3.4].
— for other steels, maximum allowable hardness according to ISO 15156-3.

Hard spots outside the hardness requirements for the applicable material larger than 50 mm in any direction and within 100 mm of the pipe ends regardless of size shall be classified as defects.

Grinding

D.8.5.25 Imperfections or defects according to [D.8.5.18] or [D.8.5.19] may be dressed-out by grinding. Ground areas shall blend smoothly into the surrounding material. Complete removal of defects shall be verified by local visual inspection and shall be supplemented with a suitable surface inspection method. The remaining wall thickness in the ground area shall be checked by ultrasonic wall thickness measurements to verify that the thickness of the remaining material is more than the specified minimum. If the defect was identified by automated equipment, re-inspection of repaired pipe shall be performed by the same automated equipment.

D.8.5.26 The sum of the ground area shall not exceed 10% of the sum of the external and internal surface area of each pipe. Ground areas which have been smoothly blended into the surrounding material and classified as cosmetic grinding shall not be counted in the calculation.

D.8.5.27 Full length machining of pipes is acceptable if machining is performed according to a qualified procedure that ensures freedom from circumferential grooves or other defects with depth > 0.5 mm. [D.8.5.26] does not apply to pipe that are machined full length.

Disposition of pipe containing defects

D.8.5.28 Linepipe containing defects shall be rejected or the area containing defects can be cut off. If pipes are cut, the minimum specified length shall be met after cutting and all NDT pertaining to pipe ends shall be performed on the new pipe end.

Residual magnetism

D.8.5.29 The longitudinal magnetic field shall be measured on pipe with D ≥ 168.3 mm and all smaller pipes that are inspected full length by magnetic methods or are handled by magnetic equipment prior to loading.

— The measurements shall be taken on the root face or square cut face of finished pipe. Measurements made on pipe in stacks are not considered valid.
— Measurements shall be made on each end of a pipe, for 5% of the pipes produced but at least once per 4 hr per operating shift using a Hall-effect gauss-meter or other type of calibrated instrument. In case of dispute, measurements made with a Hall-effect gauss-meter shall govern. Measurements shall be made in accordance with a written procedure demonstrated to produce accurate results.
— Pipe magnetism shall be measured subsequent to any inspection that uses a magnetic field, prior to loading for shipment from the pipe mill.
— Four readings shall be taken 90° apart around the circumference of each end of the pipe.

D.8.5.30 The average of the four readings shall be less or equal to 2.0 mT (20 Gauss), and no single reading shall exceed 2.5 mT (25 Gauss). Any pipe that does not meet this requirement shall be considered defective.

D.8.5.31 All pipes produced between the defective pipe and the last acceptable pipe shall be individually measured unless the provisions of [D.8.5.30] can be applied.

D.8.5.32 If the pipe production sequence is documented, pipe may be measured in reverse sequence, beginning with the pipe produced immediately prior to the defective pipe, until at least three consecutively produced pipes meet the requirements.

- Pipe produced prior to these three acceptable pipes need not be measured
- Pipe produced after the defective pipe shall be measured individually until at least three consecutive pipes meet the requirements.

D.8.5.33 All defective pipe shall be de-magnetized full length, and then their magnetism shall be re-measured until at least three consecutive pipes meet the requirements of [D.8.5.30].

D.8.5.34 For pipe handled with electromagnetic equipment after measurement of magnetism, such handling shall be performed in a manner demonstrated not to cause residual magnetism exceeding the acceptance criteria in [D.8.5.30].

D.8.5.35 The requirements for residual magnetism shall apply only to testing within the pipe mill since the residual magnetism in pipe may be affected by procedures and conditions imposed on the pipe during and after shipment.

D.8.6 Non-destructive testing of pipe ends not tested by automated NDT equipment

Untested pipe ends

D.8.6.1 When automated non-destructive testing equipment is used, a short area at both pipe ends will normally not be tested (see [D.8.4.10]). Either the untested area of the pipe shall be cut off or the ends subjected to manual or automated NDT to the same extent as required for the full length of pipe

D.8.6.2 The methods, sensitivity and acceptance criteria for testing of untested ends shall be the same as used for retesting of pipes having signals equal to or greater than the threshold level from the automated non-destructive testing equipment.

D.8.6.3 The manufacturer shall prior to start of production present for acceptance the proposed extent, methods, sensitivity and acceptance criteria for testing of untested ends with reference to applicable procedures. Otherwise the manufacturer shall demonstrate by using suitable reference indicators, that the examination system is suitable for an automated testing up to the pipe end

D.8.7 Non-destructive testing of pipe ends

D.8.7.1 These requirements apply to both seamless and welded pipe. Pipes not meeting the acceptance criteria below shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.7.2 Both ends of each pipe shall be tested for laminar imperfections in accordance with ISO 10893-8 and the additional requirements in [D.8.4] over a band at least 50 mm inside the location of future welding preparations for girth welds.

D.8.7.3 If additional non-destructive testing is specified by the purchaser, the width of the band should be:

- at least 150 mm inside the location of future welding preparations for girth welds if automated ultrasonic testing of girth welds during installation will be performed
- at least 100 mm inside the location of future welding preparations for girth welds if allowance for re-bevelling of pipe shall be included.

D.8.7.4 Acceptance criteria are:

- according to Table D-12
- [D.7.4.4] and [D.7.4.5] for clad pipe.

D.8.7.5 Magnetic particle testing or eddy current testing, manual or automated, of both end faces or bevels of each pipe in ferromagnetic steel for the detection of laminar imperfections shall be performed in accordance with the requirements in [D.8.4] and:

— ISO 10893-5 for magnetic particle testing
— ISO 10893-2 for eddy current testing.

D.8.7.6 Liquid penetrant or eddy current testing, manual or automated, of the end face or bevel of each pipe in non-ferromagnetic steel for the detection of laminar imperfections shall be performed in accordance with the requirements in [D.8.4] and:

— ISO 10893-4 for liquid penetrant testing
— ISO 10893-2 for eddy current testing.

D.8.7.7 The acceptance criterion is:

— Imperfections longer than 6 mm in the circumferential direction are not permitted.

Guidance note:

For clad pipes made from explosion welded clad plates; indications from process related melt pockets within the bond zone of explosion welded material are acceptable. It is acknowledged that these indications do not indicate lamination or a degrade bond between backing and clad material. Lamination and disbonding imperfections shall be assessed according to the acceptance criteria above.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.8.8 Non-destructive testing of seamless pipe

Pipe ends

D.8.8.1 Pipe ends shall be tested as required by [D.8.6] and [D.8.7].

Ultrasonic inspection for laminar imperfections in the pipe body

D.8.8.2 Ultrasonic inspection of the pipe body shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-8 amended as follows:

— the distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.8.3 The acceptance criteria are:

— according to Table D-12

Ultrasonic inspection for longitudinal imperfections in the pipe body

D.8.8.4 Ultrasonic inspection of the pipe body shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-10. The probe angles shall be chosen to obtain the best test result for the wall thickness/diameter ratio of the pipe to be tested.For pipes in CRA materials it shall be verified that the presence of any possible coarse, anisotropic zones will not impede the testing, see [D.8.4.24] through [D.8.4.31].

D.8.8.5 The acceptance criterion is:

— Acceptance level U2/C according to ISO 10893-10.

Ultrasonic inspection for transverse imperfections in the pipe body

D.8.8.6 Ultrasonic inspection of the pipe body shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-10. The probe angles shall be chosen to obtain the best test result for the wall thickness/diameter ratio of the pipe to be tested.

For pipes in CRA materials it shall be verified that the presence of any possible coarse, anisotropic zones will not impede the testing, see [D.8.4.24] through [D.8.4.31].

D.8.8.7 The acceptance criterion is:

— Acceptance level U2/C according to ISO 10893-10.

Ultrasonic thickness testing of the pipe body

D.8.8.8 Ultrasonic thickness testing of the pipe body shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-12.

D.8.8.9 The acceptance criterion is:

— The specified maximum and minimum wall thickness shall be met.

Surface testing for longitudinal and transverse imperfections in the pipe body of ferromagnetic pipe

D.8.8.10 Testing of ferromagnetic seamless pipe for the detection of longitudinal and transverse surface imperfections shall be performed in accordance with the requirements in [D.8.4] and one of the following standards:

— ISO 10893-2 (eddy current testing)
— ISO 10893-3 (flux leakage testing)
— ISO 10893-5 (magnetic particle testing).

D.8.8.11 For detection of internal indications ISO 10893-2 or ISO 10893-3 shall be preferred provided adequate signal amplitudes from the internal surface reflector are documented and used for sensitivity setting.

D.8.8.12 The acceptance criteria are:

— ISO 10893-2: Alarm level/acceptance level E2
— ISO 10893-3: Alarm level/acceptance level F2
— ISO 10893-5: Alarm level/acceptance level Table 2, M2.

Surface testing for longitudinal and transverse indications in pipe body of non-magnetic pipe

D.8.8.13 Testing of non-magnetic seamless pipe for the detection of longitudinal and transverse surface imperfections shall be performed in accordance with the requirements in [D.8.4] and one of the following standards:

— ISO 10893-2 (eddy current testing)
— ISO 10893-4 (liquid penetrant testing).

D.8.8.14 For detection of internal indications ISO 10893-2 shall be preferred provided adequate signal amplitudes from the internal surface reflector are documented and used for sensitivity setting.

D.8.8.15 The acceptance criteria are:

— ISO 10893-2: Alarm level/acceptance level E2
— ISO 10893-4: Alarm level/acceptance level P2.

Suspect pipe

D.8.8.16 Pipes not meeting the acceptance criteria above shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.9 Non-destructive testing of high frequency welding pipe

Pipe ends

D.8.9.1 Pipe ends shall be tested as required by [D.8.6] and [D.8.7]

Ultrasonic testing of the pipe body for detection of laminar imperfections

D.8.9.2 Ultrasonic testing of the pipe body for detection of laminar imperfections need not be performed at the pipe mill if testing of the coil edges was performed at the coil mill according to [D.7].

D.8.9.3 If performed at the pipe mill, ultrasonic testing of the pipe body for detection of laminar imperfections shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-8 amended as follows:

— the distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.9.4 Acceptance criteria are:

— according to Table D-12.

Ultrasonic testing of the area adjacent to the weld seam for detection of laminar imperfections

D.8.9.5 Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections shall be performed at the pipe mill if the strip is made by splitting of coil. If the strip is not made by splitting of coil and is tested for laminar imperfections at the coil mill according to [D.7], no testing for detection of laminar imperfections need to be performed at the pipe mill

D.8.9.6 If performed at the pipe mill, the testing shall be performed according to the requirements in [D.8.4] and ISO 10893-8.

D.8.9.7 Acceptance criteria are:

— according to Table D-12.

Ultrasonic testing for longitudinal imperfections in the weld seam

D.8.9.8 Ultrasonic testing of the full length of the weld seam of HFW pipe for the detection of longitudinal imperfections shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-11 with modifications as described in [D.8.9.9] through [D.8.9.18].

D.8.9.9 Accurate weld tracking with a tolerance ± 2 mm with respect to the centreline of the weld is essential due to the width of the weld.

D.8.9.10 The reference standard shall contain a typical weld, with the external flash removed and including tracks resulting from removal of the internal flash.

The reference reflectors shall be:

— external and internal reference notches located parallel to and in the centre of the weld. The notches shall be "N" type with a depth of 5% of the wall thickness notches with a depth of minimum 0.3 mm and maximum 1.2 mm.

D.8.9.11 One or more of the following probe configurations shall be used:

— Single pulse echo probes shall be selected such as the angle of incidence is as perpendicular to the radial centreline of the weld as possible.
— Tandem probes on each side of the weld with the angle of incidence as perpendicular to the radial centreline of the weld as possible.
— Probes alternating as transmitter-receiver with the angle of incidence as perpendicular to the radial centreline of the weld as possible.

The probe configuration shall provide a sufficient number of probes to cover the entire wall thickness from both sides of the weld.

D.8.9.12 The equipment shall include devices for weld tracking/centering and provide checking of adequate coupling for all probes.

D.8.9.13 Each probe shall be calibrated against the reference reflector located in the area of the weld to be covered by that probe.

D.8.9.14 For single pulse echo probes and tandem probes the threshold settings shall be as follows:

— If the testing is performed with one probe pair covering the entire wall thickness, the response from the intersections between the reference notches and the external and internal pipe surface shall optimised and the threshold level set at 80% of full screen height of the lowest of the obtained responses.
— If the testing is performed with probe pairs each covering a part of the wall thickness, the threshold level shall be set at 80% of full screen height.

D.8.9.15 For probes alternating as transmitter-receiver the threshold level shall be set corresponding to a loss of 75% of the transmitted signal.

D.8.9.16 For each probe, the following shall be recorded:

— type, frequency, angle and dimension
— the distance from the index point to the weld centreline
— the angle between the ultrasound direction and the major pipe axis.
— amplitudes and gain settings.

D.8.9.17 Gates shall be set such that reflections from the tracks resulting from removal of the internal flash are avoided but sufficiently wide to ensure that the tolerances in the weld tracking system will result in responses from indications inside the weld and the HAZ.

D.8.9.18 The settings for lack of coupling alarm shall be set and checked.

D.8.9.19 The acceptance criterion is:

— Pipes producing signals below the threshold shall be deemed to have passed the test.

Plate/strip end welds

D.8.9.20 Testing of plate/strip end welds (when such welds are allowed) shall, unless otherwise agreed be performed by ultrasonic testing according to this standard. The testing shall comply with the requirements of this standard and methods and a set-up suitable for the applied welding method shall be used.

Suspect pipe

D.8.9.21 Pipes not meeting the acceptance criteria above shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.10 Non-destructive testing of corrosion resistance alloy liner pipe

D.8.10.1 Testing of CRA pipe for the detection of longitudinal and transverse surface imperfections and the longitudinal weld shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-2 (eddy current testing).

— The acceptance criterion for eddy current testing is:
— The response shall not exceed half the response of alarm level/acceptance level E2 according to ISO 10893-2.

D.8.10.2 Testing of the weld seam can alternatively be performed in accordance with the requirements in [D.8.4] and ISO 10893-6 (radiographic testing). Digital radiography testing, if applicable, shall be performed in accordance with ISO 10893-7, class B.

D.8.10.3 The acceptance criteria for radiographic testing are:

— No cracks, lack of fusion, lack of penetration or pore clusters. Individual circular imperfections shall not exceed 1.5 mm or ¼ t, whichever is smaller. Accumulated diameters of permitted imperfections shall not exceed 3 mm or ½ t, whichever is smaller. No other discernable indications are allowed.

Untested pipe ends

D.8.10.4 Untested pipe ends shall be tested as required by [D.8.6].

Suspect pipe

D.8.10.5 Pipes not meeting the acceptance criteria above shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.11 Non-destructive testing of lined pipe

Non-destructive testing of the backing pipe

D.8.11.1 Non-destructive testing of the outer C-Mn steel backing pipe shall be performed prior to insertion of the CRA liner pipe. The backing pipe shall be subjected to the same testing with the same acceptance criteria that are required in this appendix for the type of backing pipe used.

Pipe ends

D.8.11.2 After insertion of the liner pipe and performing seal and/or clad welding the ends of lined pipe shall be tested for laminar imperfections in accordance with the requirements in [D.8.4] and ISO 10893-8 or ASTM A578 S7 in a band at each pipe end. For clad welded pipe ends this includes testing for bonding defects. The band shall be sufficiently wide to cover the width of the seal/clad weld between the C-Mn steel backing pipe and the CRA liner pipe. Manual or automated methods may be used.

D.8.11.3 The acceptance criterion is:

— No indications are allowed within the tested areas.

Seal and clad welds

D.8.11.4 The seal and/or clad welds at pipe ends shall be subject to manual liquid penetrant testing according to [D.2.6] or eddy current testing according to [D.2.7].

D.8.11.5 The acceptance criteria are:

— No round indications with diameter above 1 mm and no elongated indications.

— Indications separated by a distance less than the diameter or length of the smallest indication, shall be considered as one indication.
— Accumulated diameters of round indications in any 100 mm length of weld shall not exceed 6 mm.

D.8.12 Non-destructive testing of clad pipe

Pipe ends

D.8.12.1 Pipe ends shall be tested as required by [D.8.6] and [D.8.7].

Ultrasonic testing of the pipe body for detection of laminar imperfections

D.8.12.2 Ultrasonic testing of the pipe body for detection of laminar imperfections in the backing pipe need not be performed at the pipe mill if testing of the plate was performed at the plate mill according to [D.7].

D.8.12.3 If performed at the pipe mill, ultrasonic testing of the pipe body for detection of laminar imperfections shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-8 amended as follows:

— The distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.12.4 Acceptance criteria are:

— according to Table D-12.

D.8.12.5 Ultrasonic testing of the pipe body for detection of lack of bond between the cladding and backing pipe shall be performed in accordance with the requirements in [D.8.4] and ASTM 578 S7 amended as follows:

— The distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.12.6 The acceptance criterion is:

— ASTM A578 - S7. In addition, no areas with laminations or lack of bond are allowed in the plate edge areas.

Ultrasonic testing for longitudinal and transverse imperfections in the weld seam

D.8.12.7 For ultrasonic testing of the CRA part of the weld seam it shall be demonstrated that low frequency shear wave angle probes are adequate for detection as required in [D.8.4.24] through [D.8.4.31]. If it is not possible to demonstrate adequate performance of low frequency shear wave angle probes other methods or combination of methods shall used and the adequacy of the methodology demonstrated.

Ultrasonic testing of the weld seam of clad pipe for the detection of longitudinal and transverse imperfections, when demonstrated to give acceptable results, shall be in accordance with the requirements in [D.8.4] and ISO 10893-11 with modifications as described in [D.8.12.8] through [D.8.12.19].

D.8.12.8 The reference standard shall contain a typical production weld. The weld surface shall be ground flush with the original pipe contour in an area around each reference reflector sufficient to obtain signals without interference from un-ground weld reinforcements.

D.8.12.9 The reference reflectors shall be:

— One 1.6 mm diameter through-drilled hole at the weld centreline for detection of transverse indications.
— Longitudinal external and internal notches on both sides, parallel and adjacent to the weld seam for detection of longitudinal imperfections outside the root area. The notch shall be the “N” type with 5% of the wall thickness, but not more than 1.5 mm or less than 0.3 mm.

— One notch on each side of the internal weld cap located immediately adjacent to and parallel with the weld for detection of longitudinal imperfections in the root area. The notch shall be the “N” type with 3% of the wall thickness, but not more than 1.2 mm or less than 0.3 mm.
— If agreed, the reference reflectors for detection of transverse imperfections can be internal and external notches, “N” type with 3% of the wall thickness, positioned at right angles to, and centred over, the weld seam.
— Additional reflectors may be used to define the weld extremities and aiding in the gate settings. The use, type and numbers of such reflectors shall be at the manufacturer’s option.

The length of the notches shall be 1.5 times the probe (crystal) element size or 20 mm, whichever is shorter. The length does not include any rounded corners. The width of the notches shall not exceed 1 mm.

D.8.12.10 The probe angles shall be chosen to obtain the best possible test result for wall thickness and diameter of the pipe to be tested. The probe angle shall be chosen such that the angle of incidence is as perpendicular as possible to the weld bevel in the area covered by the probe.

D.8.12.11 The frequency of the probes used in the root area shall be as low as possible and not above 2 MHz.

D.8.12.12 The probe configuration for detection of the longitudinal indications shall provide a sufficient number of opposing probe pairs to cover the entire wall thickness. E.g. one pair of probes for the external and internal N5 notches and one pair for the internal N3 notches in the root area.

D.8.12.13 The probe configuration for detection of transverse indications shall be two wide beam, opposing probes travelling on bead. An X type configuration of the probes for detection of transverse indications may be used, subject to agreement.

D.8.12.14 The gates shall be set wide enough to compensate for:

— The tolerances of weld tracking system
— Variations in the width of external and internal caps
— Offsets between the external and internal weld bead.

D.8.12.15 Each probe shall be calibrated against the reference reflector located in the area of the weld to be covered by that probe. The response from the reference reflectors shall be optimised for each probe and probe pair:

— For detection of longitudinal imperfections in the root area the optimised response for each probe shall be obtained from the internal notch. The threshold level for each of the internal notches shall be set no higher than 50% of full screen height from the maximised response.
— For detection of longitudinal imperfections outside the root area the response from the external and internal notches shall optimised and the threshold level set to 80% of full screen height for each of the maximised responses.
— For detection of transverse imperfections the threshold level for the 1.6 mm through drilled hole or transverse notches shall be set no higher than 80% of full screen height.
— If the use of transverse notches is agreed for detection of transverse indications, the response from the external and internal notches shall optimised and the threshold level set to 80% of full screen height for each of the maximised responses.
— The additional reflectors allowed in [D.8.12.9] shall not be used for threshold settings.

D.8.12.16 For each probe, the following shall be recorded:

— type, frequency, angle and dimension
— the distance from the index point to the weld centreline
— the angle between the ultrasound direction and the major pipe axis
— amplitudes and gain settings.

D.8.12.17 Gates shall be set such that reflections from the weld caps are avoided but sufficiently wide to ensure full weld coverage and that, with the given tolerances of the weld tracking system, responses are obtained from indications located inside the weld and the HAZ.

D.8.12.18 The settings for lack of coupling alarm shall be set and checked.

D.8.12.19 The acceptance criterion when using shear wave probes is:

— Pipes producing signals below the threshold shall be deemed to have passed the test.

When compression wave angle probes are used, other reflectors may be used and in this case the acceptance criteria shall be specified and agreed accordingly.

Ultrasonic testing of the area adjacent to the weld seam for detection of laminar imperfections

D.8.12.20 Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections need not be performed at the pipe mill if testing of the plate edges was performed at the plate mill according to [D.7].

D.8.12.21 If performed at the pipe mill, the testing shall be performed according to the requirements in [D.8.4] and ISO 10893-8.

D.8.12.22 Acceptance criteria are:

— according to Table D-12.

Testing for the detection of surface imperfections in the weld area

D.8.12.23 Testing for the detection of longitudinal and transverse surface imperfections in the weld area shall be performed in accordance with the requirements in [D.8.4] and one of the following standards:

— ISO 10893-2 (eddy current testing)
— ISO 10893-3 (flux leakage testing)
— ISO 10893-5 (magnetic particle testing).

D.8.12.24 The acceptance criteria are:

— ISO 10893-2: Alarm level/acceptance level E2
— ISO 10893-3: Alarm level/acceptance level F2
— ISO 10893-5: Alarm level/acceptance level Table 3, M2.

Radiographic testing of welds

D.8.12.25 Full length radiographic testing of the weld shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-6.

D.8.12.26 For pipe subject to full length ultrasonic testing of the weld, radiographic testing of the weld at each pipe end shall include the area not covered by the automated ultrasonic testing and shall at least cover a weld length of 300 mm. The testing shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-6. For digital radiographic systems, reference is made to clause [D.8.4.33].

D.8.12.27 The acceptance criteria are:

— according to ISO 10893-6 or ISO 10893-7.

Suspect pipe

D.8.12.28 Pipes not meeting the acceptance criteria above shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.13 Non-destructive testing of submerged arc-welding longitudinal and submerged arc-welding helical pipe

Pipe ends

D.8.13.1 Pipe ends shall be tested as required by [D.8.6] and [D.8.7].

Ultrasonic testing of the pipe body for detection of laminar imperfections

D.8.13.2 Ultrasonic testing of the pipe body for detection of laminar imperfections need not be performed at the pipe mill if testing of the plate/coil edges was performed at the plate/coil mill according to [D.7].

D.8.13.3 If performed at the pipe mill, ultrasonic testing of the pipe body for detection of laminar imperfections shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-8 amended as follows:

— the distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.13.4 Acceptance criteria are:

— according to Table D-12.

Ultrasonic testing of the area adjacent to the weld seam for detection of laminar imperfections

D.8.13.5 Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections need not be performed at the pipe mill if testing of the plate/coil edges was performed at the plate/coil mill according to [D.7].

D.8.13.6 If performed at the pipe mill, the testing shall be performed according to the requirements in [D.8.4] and ISO 10893-8.

D.8.13.7 Acceptance criteria are:

— according to Table D-12.

Ultrasonic testing for longitudinal and transverse imperfections in the weld seam

D.8.13.8 Ultrasonic testing of the weld seam of SAW pipe for the detection of longitudinal and transverse imperfections shall be in accordance with the requirements in [D.8.4] and ISO 10893-11 with modifications as given in [D.8.13.9] through [D.8.13.20].

The equipment shall allow for the complete examination of the weld and its adjacent area for both longitudinal and transverse defects. The equipment shall be fitted with an automatic paint spray system (or alternative system, e.g. recording) for marking the areas giving ultrasonic indications and areas where a loss of ultrasonic coupling with the pipe has occurred.

To verify that no defects originating from hydrogen is present, a minimum of 2% of the pipes shall be examined by an optimized manual UT procedure for cracks. This investigation shall be done minimum 48 hours after welding. If an inspected pipe contains such defects, then production shall be stopped and all pipes put in quarantine. The root cause shall be determined. Based on the root cause, all pipes shall be considered for possible risk of hydrogen cracks based on production records. It may be necessary to inspect some or all of the pipes in quarantine.

D.8.13.9 The reference standard shall contain a typical production weld, including representative weld reinforcements.

D.8.13.10 The reference reflectors shall be in accordance with Table D-13.

Additional reflectors may be used to define the weld extremities and aiding in the gate settings. The use, type and numbers of such reflectors shall be at the manufacturer's option and shall be described in the documented procedure. The response from the reference reflectors shall define the reporting threshold.

Table D-13 Required reflectors in SAWL/SAWH pipe weld AUT reference standard

A	1.6 mm TDH, weld centreline
B [1]	3.0 mm TDH at weld toe edge at both sides of the weld
C [2]	N5 notch parallel and adjacent to weld seam at OD surface at both sides of the weld
D [2]	N5 notch parallel and adjacent to weld seam at ID surface at both sides of the weld
E	Maximum 3.0 mm side-drilled hole located at the weld centreline at ½ WT depth (mid thickness), and parallel to the weld.
F	3.0 mm TDH, weld centreline
G	N5 notch transverse to and over the weld seam at OD surface
H	N5 notch transverse to and over the weld seam at ID surface
I [3]	To confirm area of coverage at the pipe ends: Maximum 3.0 mm through drilled hole (TDH) located at the weld centreline. The position of the TDHs will define the untested area at the ends, and should not exceed 250 mm from each pipe end.

1) The weld toe of the widest weld cap should be used. (i.e. the reflector should be the farthest away from weld centerline). As an alternative, separate reflectors may be made for OD and ID weld cap.
2) The notch shall be the "N" type with 5% of the wall thickness, but not more than 1.5 mm or less than 0.3 mm. The length of the notches shall be 1.5 times the probe (crystal) element size or 20 mm, whichever is shorter. The length does not include any rounded corners. The width of the notches shall not exceed 1 mm.
3) To confirm coverage at the pipe ends. Location to be determined by the manufacture, but should be maximum 250 mm from pipe ned. The reflector to be decided by the manufacturer, but shall not be larger than a 3 mm diameter hole. Both pipe ends to have this reflector. The reflector should be a 3 mm through-drilled hole at weld centerline.

D.8.13.11 The inspection angles shall be chosen to obtain the best possible test result for wall thickness and diameter of the pipe to be tested.

D.8.13.12 The probe configuration for detection of the longitudinal indications shall provide a sufficient number of opposing probe pairs on both sides of the weld or focal laws to cover the entire wall thickness. Both ID and OD surface area shall be inspected by minimum 2 angles each, of these 2 angles one of them shall be not lower than 65°.

Dedicated channels set up on the mid wall SDH to cover the embedded parts of the weld is required if this is not possible to achieve. The sensitivity shall then be set at 80% FSH for the mid wall SDH. Additional buried SDHs might be included at different depths of the weld to demonstrate full coverage

Guidance note:

The reflectors required for detecting longitudinal defects may not detect lack-of-fusion in mid-wall. The risk is considered negligible for normal two-pass SAW process because the high heat input and large quantity of weld deposit. It is expected that consistent lack-of-fusion is unlikely, and will be detected in macro specimens. This would indicate an incorrect welding process, and a new qualification should be required. Single-event lack-of-fusion may occur, but would be associated with other gross process disturbances or weld defects that the pipe in question would be suspicious in any case. For multiple-pass SAW, or in cases where lack-of-fusion is considered a risk, additional requirements to reflectors or system setup may be needed.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

D.8.13.13 The probe configuration for detection of transverse indications shall be two wide beam, opposing probes travelling on bead. An X type configuration of the probes for detection of transverse indications may be used instead of wide beam probes on bead, subject to agreement. N5 transverse notches (reflectors G and H) shall be used to confirm correct beam orientation and for gate setting of transverse channels.

D.8.13.14 Each probe or focal law shall be calibrated against the reference reflector located in the area of the weld to be covered by that probe. The response from the reference reflector(s) shall be optimised for each probe and probe pair as described in Table D-14. All relevant reference reflectors shall be above the recording threshold during dynamic inspection.

Table D-14 contains a set of correspondances between channels and reflectors to ensure reasonable coverage of the weld. Table D-14 should be used, but alternative channels and reflectors may be used, provided they ensure similar coverage and inspection level. For each probe or focal law, the following shall be recorded:

— type, frequency, angle and dimension
— the distance from the index point to the weld centreline
— the angle between the ultrasound direction and the major pipe axis
— amplitudes and gain settings.

The following parameters shall be reported and a print out shall be made available at the AUT station:

— A comprehensive detailed list of probes/channels, longitudinal/transverse, ID/OD/Mid, flaw detection/coupling.
— A matrix showing all channels including coupling channels, with response from the different reflectors including calibration reflectors shall be made with dB levels, gain, signal height, trigger threshold. The table channels/reflectors (C/R), shall be included in the AUT procedure/working instructions and submitted to COMPANY for approval.
— Date, time, operator name and signature, inspector name and signature.

Table D-14 Requirements for channels and reference reflectors, AUT

Channel type	*Reference reflector*[1]	*Refelctors to confirm coverage static calibration*	*Comment*
Longitudinal OD	C	E, F, I	Minimum 2 angles
Longitudinal ID	D	E, F, I	Minimum 2 angles
Longitudinal Buried SDH	E		
Transverse	A	B, G	
Transverse, X-scheme	A	B, G	
1) Reflector types are described in Table D-13			

D.8.13.15 The gates shall be set wide enough to compensate for, and include as a minimum:

— the tolerances of weld tracking system
— variations in the width of external and internal caps
— offsets between the external and internal weld bead.

For longitudinal channels, the gate shall not include the notch C or D at the opposite side of the weld.

D.8.13.16 The settings for lack of coupling alarm shall be set and checked. The alarm level for lack of coupling should be set at maximum 14 dB loss of signal or reference echo.

D.8.13.17 Sensitivity/gain shall be set for each channel such that the reflectors in Table D-14 are consistently reported upon repeated dynamic scans. When the settings are optimised, the relevant parameters shall be recorded and the reference standard shall be passed 3 times through the equipment at the operational velocity. In case the equipment settings need to be corrected to maintain required sensitivity, the change in settings should be based on an average from three runs. For acceptance of the settings for a given probe/channel, the deviation in response from each reference reflector shall not be more than 3 dB over the three dynamic calibration checks. Gate settings shall not deviate more than 2.5 mm from the reference position.

One dynamic calibration verification scan of the reference standard shall be carried out at the start of each shift, whenever there is an equipment change over, whenever there is an operator change or every 4 hours, whichever is the first event met.

D.8.13.18 The acceptance criterion is:

Pipes producing signals below the reporting threshold shall be deemed to have passed the test.

Additional requirements for SAWH pipe strip/plate end welds

D.8.13.19 For SAWH pipe the full length of strip/plate end welds (when such welds are allowed) shall be ultrasonically tested as required above for the helical seam. Alternatively manual ultrasonic testing in accordance with [D.8.14] may be used for testing of test strip/plate end welds.

In addition, the joints where the extremities of the helical and strip/plate end welds meet shall be subject to radiographic testing in accordance with the requirements in [D.8.4] and ISO ISO 10893-6. For use of digital radiographic equipment, see [D.8.4.33].

D.8.13.20 Acceptance criteria for these tests are:

— For automated ultrasonic testing: according to [D.8.13.19] above
— For manual ultrasonic testing: according to [D.8.14]
— For radiographic testing: According to ISO 10893-6.

Additional requirements for testing of SAW CRA pipes and welds with CRA weld deposits

D.8.13.21 Ultrasonic testing of welds in CRA materials with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will, in order to achieve an adequate detection of imperfections, normally require that special reference blocks and probes are used.

D.8.13.22 The requirements given in [D.8.4.24] through [D.8.4.31] shall be fulfilled and special reference is made to [D.8.4.30] and [D.8.4.31].

D.8.13.23 When compression wave angle probes are used, other reflectors may be used and in this case the acceptance criteria shall be specified and agreed accordingly.

Testing of ferromagnetic pipe for the detection of surface imperfections in the weld area

D.8.13.24 Testing of ferromagnetic pipe for the detection of longitudinal and transverse surface imperfections shall be performed in accordance with the requirements in [D.8.4] and one of the following standards:

— ISO 10893-2 (eddy current testing)
— ISO 10893-3 (flux leakage testing)
— ISO 10893-5 (magnetic particle testing).

The acceptance criteria are:

— ISO 10893-2: Alarm level/acceptance level E2
— ISO 10893-3: Alarm level/acceptance level F2
— ISO 10893-5: Alarm level/acceptance level Table 3, M2.

Testing of non magnetic pipe for the detection of surface imperfections in the weld area

D.8.13.25 Testing of non-magnetic SAW pipe for the detection of longitudinal and transverse surface imperfections shall be performed in accordance with the requirements in [D.8.4] and one of the following standards:

- ISO 10893-2 (eddy current testing)
- ISO 10893-4 (liquid penetrant testing).

The acceptance criteria are:

- ISO 10893-2: Acceptance level E2
- ISO 10893-4: Acceptance level P2.

Radiographic testing

D.8.13.26 Radiographic testing of the weld at each pipe end shall include the area not covered by the automated ultrasonic testing and shall at least cover a weld length of 300 mm. The testing shall be performed in accordance with the requirements in [D.8.4], ISO 10893-6 and ISO 10893-7.

The acceptance criteria are:

- according to ISO 10893-6 for conventional RT and ISO 10893-7 for digital RT.

Suspect pipe

D.8.13.27 Pipes not meeting the acceptance criteria above shall be deemed as suspect pipe according to [D.8.2] and shall be treated according to [D.8.3].

D.8.14 Manual non-destructive testing at pipe mills

General

D.8.14.1 In all cases when the automated NDT system give signals equal to or greater than the threshold level, or surface imperfections are disclosed by visual examination, manual NDT may be performed in order to confirm the presence or absence of a defect. Automated or semi-automated NDT may be used as substitution of the manual NDT required in this sub-section provided the method is demonstrated to provide the same or better sensitivity in detection of imperfections.

D.8.14.2 In addition, manual NDT may be performed on pipe ends that are not tested by the automated equipment. See [D.8.6].

Radiographic testing

D.8.14.3 Radiographic testing shall be performed in accordance with the requirements in [D.8.4] and ISO 10893-6 or ISO 10893-7 to cover the full weld length or to supplement other NDT methods when the type of or severity of an indication in weld can not be determined with certainty.

The acceptance criteria are:

- according to ISO 10893-6 for conventional RT and ISO 10893-7 for digital RT.

All pipe; manual ultrasonic testing for laminar imperfections and thickness testing

D.8.14.4 Manual ultrasonic thickness testing and testing for laminar imperfections shall be performed on untested pipe ends and to confirm the presence or absence of a defect when automated NDT systems gives signals equal to or greater than the threshold level.

Manual ultrasonic testing of pipe ends, laminar imperfections

D.8.14.5 Any additional non-destructive testing shall be as specified by the purchaser.

D.8.14.6 If automated ultrasonic testing of girth welds during installation will be performed the width of the band should extend at least 150 mm inside the location of future welding preparations for girth welds.

D.8.14.7 If allowance for re-bevelling of pipe shall be included, the width of the band should extend at least 100 mm inside the location of future welding preparations for girth welds.

D.8.14.8 Acceptance criteria are:

— according to Table D-12.

Manual ultrasonic testing of pipe ends, radial cracks

D.8.14.9 If required, for detection of cracks angle probes shall be used to supplement the straight beam probes. Testing shall be in general accordance with ASTM A577 or equivalent standard and:

— Probes shall meet the requirements of [D.3.2.3].
— Sensitivity for C-Mn steel shall be a DAC curve based on reference blocks with a rectangular notch with depth 3% of the material thickness on both sides.
— Reference blocks for duplex stainless steel and austenitic steels shall have one Ø 3 mm flat bottom hole perpendicular to the angle of incidence of the probe and at the largest possible depth from the scanning surface of the block. Reference blocks shall be of the actual material tested or of a material with similar with acoustic properties.
— Low frequency shear wave angle probes may be used for CRA material instead of twin crystal (transmitter/receiver) compression-wave probes. For acceptance, it shall be verified on the reference blocks that it is possible to obtain a DAC with a shear wave angle probe that is comparable to the DAC obtained with an angle compression wave probe.

D.8.14.10 The acceptance criterion is:

— no indications shall exceed the DAC.

Manual ultrasonic testing of the pipe body for detection of laminar imperfections

D.8.14.11 Manual ultrasonic testing of the pipe body for detection of laminar imperfections need not be performed at the pipe mill if testing of the plate/coil edges was performed at the plate/coil mill according to [D.7].

D.8.14.12 If performed at the pipe mill, manual ultrasonic testing of the pipe body for detection of laminar imperfections shall be performed in accordance ISO 10893-8, App.A amended as follows:

— the distance between adjacent scanning tracks shall be sufficiently small to ensure detection of the minimum allowed imperfection size.

D.8.14.13 Acceptance criteria are:

— according to Table D-12.

Manual ultrasonic testing of the area adjacent to the weld seam for detection of laminar imperfections

D.8.14.14 Manual ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections need not be performed at the pipe mill if testing of the plate/coil edges was performed at the plate/coil mill according to [D.7].

D.8.14.15 If performed at the pipe mill, the manual NDT shall be performed according to ISO 10893-8, App.A.

D.8.14.16 Acceptance criteria are:

— according to Table D-12.

Manual ultrasonic thickness testing of the pipe body

D.8.14.17 Manual ultrasonic thickness testing of the pipe body shall be performed in accordance with the requirements ISO 10893-12.

D.8.14.18 The acceptance criterion is:

— the specified maximum and minimum wall thickness shall be met.

Seamless pipe; manual ultrasonic testing for longitudinal and transverse imperfections

D.8.14.19 Manual ultrasonic testing and testing of seamless pipe for longitudinal and transverse imperfections shall performed on untested pipe ends and to confirm the presence or absence of a defect when automated NDT systems gives signals equal to or greater than the threshold level.

D.8.14.20 For pipes in CRA materials it shall be verified that the presence of any possible coarse, anisotropic zones will not impede the testing, see [D.8.4.24] through [D.8.4.31].

D.8.14.21 Manual ultrasonic testing of the pipe body for longitudinal imperfections shall be performed in accordance with ISO 10893-10. The probe angles shall be chosen to obtain the best test result for the wall thickness/diameter ratio of the pipe to be tested.
The acceptance criterion is:

— acceptance level U2/C according to ISO 10893-10.

D.8.14.22 Manual ultrasonic inspection of the pipe body for transverse imperfections shall be performed in accordance with the requirements in ISO 10893-10. The probe angles shall be chosen to obtain the best test result for the wall thickness/diameter ratio of the pipe to be tested.
The acceptance criterion is:

— acceptance level U2/C according to ISO 10893-10.

Welded pipe; manual ultrasonic testing of welds

D.8.14.23 Manual ultrasonic testing and testing of welds in welded pipe for longitudinal and transverse imperfections shall be performed on untested pipe ends and to confirm the presence or absence of a defect when automated NDT systems gives signals equal to or greater than the threshold level.

D.8.14.24 Manual ultrasonic testing of welds in C-Mn steel material with C-Mn steel weld deposits shall be performed in accordance with [D.2.3] except that [D.2.3.16], [D.2.3.17], [D.2.3.23], [D.2.3.24] and [D.2.3.41] shall not apply.

Manual ultrasonic testing of welds in HFW pipe

D.8.14.25 The reference block shall be according to [D.8.9.10].

D.8.14.26 One or more of the following probe configurations shall be used:

— Single pulse echo probes with the angle of incidence as perpendicular to the radial centreline of the weld as possible.
— Tandem probes with the angle of incidence as perpendicular to the radial centreline of the weld as possible.

D.8.14.27 The probe angle for the initial scanning shall be chosen to obtain the best possible test result for wall thickness and diameter of the pipe to be tested and such that the angle of incidence is as perpendicular as possible to the weld bevel.

D.8.14.28 The DAC shall be constructed using the notches in the reference block. A 2-point DAC shall only be used if scanning is limited to one full skip or less. If scanning is performed using more than one full skip, a 3-point DAC shall be established as a minimum.

D.8.14.29 The acceptance criterion is:

— no maximised echo from any probe shall exceed the DAC.

Manual ultrasonic testing of welds in CRA materials and in clad pipe

D.8.14.30 Ultrasonic testing of welds in CRA materials with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will in order to achieve an adequate detection of imperfections normally require that special reference blocks and probes are used for testing of these materials. Unless it can be demonstrated as required in [D.2.4.18] and [D.8.4.29] that use of low frequency shear wave angle probes gives acceptable detection, manual ultrasonic testing of the CRA weld deposit in the root shall be performed as required in [D.2.4]

D.8.14.31 Angle beam probes shall be available in angles, or be provided with wedges or shoes, ranging from 30° to 75°, measured to the perpendicular of the surface of the pipe being tested. Probe angles shall be selected as required in [D.2.3]. The probe angles shall be chosen to obtain the best possible test result for wall thickness and diameter of the pipe to be tested and such that the angle of incidence is as perpendicular as possible to the weld bevel in the area covered by the probe. If shear wave angle probes are used for testing of the root the frequency shall be 2 MHz or lower.

D.8.14.32 The reference standard for testing with shear angle probes shall be according to [D.8.12.8] and [D.8.12.9].

Testing sensitivities shall be established as follows:

— For testing of longitudinal imperfections in the weld volume outside the root area, the DAC shall be constructed using the longitudinal external and internal notches. A 2-point DAC shall only be used if scanning is limited to one full skip or less. If scanning is performed using more than one full skip, a 3-point DAC shall be established as a minimum.
— For testing of the root area longitudinal imperfections sensitivity setting shall be against the notch in the root area on the opposite side of the weld and the response set to 50% of full screen height.
— For testing of transverse imperfections, the DAC shall be constructed using the 1.6 mm diameter through drilled holes at the weld centreline with 2 points (e.g. ½ and full skip).

D.8.14.33 Scanning for transverse indications shall be performed on bead. Probes with beam angles of 45° and 60° shall be available.

D.8.14.34 The acceptance criteria are:

— No maximised indications exceeding DAC for longitudinal and transverse indications.
— No maximised indications in the root area exceeding 50% of full screen height.

When compression wave angle probes are used, other types of reflectors are used and the acceptance criteria shall be specified and agreed accordingly.

Manual ultrasonic testing of welds in SAWL and SAWH pipe

D.8.14.35 The reference standard shall be according to [D.8.13.9] and [D.8.13.10].

D.8.14.36 Angle beam probes shall be available in angles, or be provided with wedges or shoes, ranging from 30° to 75°, measured to the perpendicular of the surface of the pipe being tested. Probe angles shall be selected as required in [D.2.3].

D.8.14.37 Testing sensitivities shall be established as follows:

— For testing of longitudinal imperfections in the weld volume, the DAC shall be constructed using the longitudinal external and internal notches. A 2-point DAC shall only be used if scanning is limited to one full skip or less. If scanning is performed using more than one full skip, a 3-point DAC shall be established as a minimum
— For testing of transverse imperfections, the DAC shall be constructed using the 1.6 mm diameter through drilled holes at the weld centreline with 2 points (e.g. ½ and full skip).

D.8.14.38 Scanning for transverse indications shall be performed on bead. Probes with beam angles of 45° and 60° shall be available. Use of 4 MHz probes shall be preferred.

D.8.14.39 Acceptance criterion is:

— no maximised indications exceeding DAC

Manual ultrasonic testing of welds in CRA materials and CRA weld deposits/materials.

D.8.14.40 Refer to [D.8.4.24] through [D.8.4.31]. Ultrasonic testing of CRA materials and welds with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will in order to achieve an adequate detection of imperfections require that special calibration blocks and probes are used for testing of welds in these materials. Angle probes generating compression waves should be used in addition to straight beam probes, angle shear wave probes and creep wave probes.

D.8.14.41 Unless it can be demonstrated as required in [D.2.4.18] and [D.8.4.29] that use of low frequency shear wave angle probes only gives acceptable detection, manual ultrasonic testing of CRA materials and welds with CRA weld deposits shall be performed as required in B400.

D.8.14.42 Acceptance criteria manual ultrasonic testing of CRA materials and welds with CRA weld deposits performed with angle compression wave probes are:

— according to Table D-6.

Manual magnetic particle testing

D.8.14.43 Manual magnetic particle surface testing shall be performed in accordance with [D.2.5] and ISO 10893-5.

D.8.14.44 Manual magnetic particle testing of pipe ends shall be performed in accordance with [D.2.5] and ISO 10893-5.

D.8.14.45 Manual magnetic particle testing of welds shall be performed as required by [D.2.5].

D.8.14.46 Acceptance criteria shall be according to the relevant requirements of this subsection.

Manual liquid penetrant testing

D.8.14.47 Manual liquid penetrant surface testing and testing of pipe ends shall be performed in accordance with ISO 10893-4.

D.8.14.48 Manual liquid penetrant testing of welds shall be performed in accordance with [D.2.6], paragraphs [D.2.6.2] through [D.2.6.5].

D.8.14.49 Acceptance criteria shall be according to the relevant requirements of this subsection.

Manual eddy current testing

D.8.14.50 Manual eddy current surface testing and testing of pipe ends shall be performed in accordance with ISO 10893-2.

D.8.14.51 Manual eddy current testing of welds shall be performed in accordance with [D.2.7], paragraphs [D.2.7.2] through [D.2.7.8] and ISO 10893-2 (eddy current testing)

D.8.14.52 Acceptance criteria shall be according to the relevant requirements of this subsection.

D.8.15 Non-destructive testing of weld repair in pipe

D.8.15.1 Weld repair of the body of any pipe and of the weld in HFW pipe is not permitted.

D.8.15.2 A repaired weld shall be completely re-tested using applicable NDT methods in accordance with [D.8.8] through [D.8.13].

Alternatively, manual NDT may be performed in accordance with [D.8.14] and with acceptance criteria in accordance with the requirements in [D.8.14]. In this case, manual ultrasonic testing shall be governing for embedded defects.

APPENDIX E AUTOMATED ULTRASONIC GIRTH WELD TESTING

E.1 General

E.1.1 Objective

E.1.1.1 This appendix details the examination requirements for the automated ultrasonic testing of pipeline girth welds.

E.1.2 Applicability

E.1.2.1 The appendix applies when automated ultrasonic testing (AUT) is performed on pipeline girth welds.

E.1.2.2
Automated ultrasonic testing (AUT) is a general term that includes several approaches and techniques, which are all acceptable for use as long as the general requirements of [E.2] can be fulfilled. This includes zonal discrimination technique, phased array scan group based setups (e.g. sectorial and/or linear scan groups) and ultrasonic imaging (e.g. total focusing method (TFM) or full matrix capture (FMC)). In addition, application of inspection can put limitations and change approaches within the techniques used, for instance due to differences between carbon steel and CRA materials.

E.2 Basic requirements

E.2.1 General

E.2.1.1 The primary requirement to any AUT system is that its performance is documented in terms of adequate detection and sizing, or rejection abilities, in relation to specified/determined acceptable imperfections. The performance of the AUT system has through the qualification to be demonstrated to meet or exceed the requirements in terms of detection or rejection set by the applicable acceptance criteria for any project.

E.2.1.2 The ultrasonic system to be used shall be accepted through qualification, see [E.8].

E.2.1.3 The ultrasonic system shall demonstrate 100% coverage of the weld and heat affect zone (HAZ) with adequate beam coverage overlap and signal strength for relevant imperfection sizes.

It shall have a fully automatic recording system to indicate the location of imperfections and the integrity of acoustic coupling. Different concepts of automated ultrasonic testing are acceptable, provided that [E.2.1.1] is fulfilled. This includes zonal discrimination, phased array techniques (for instance sectorial and/or linear scan groups) and ultraonic imaging techniques (for instance total focusing method (TFM), full matrix capture (FMC))

E.2.1.4 The information provided by all AUT channel types shall be actively used in order to ensure adequate imperfection detection and sizing.

E.2.1.5 The ultrasonic system may include scanner heads and system set-up specifically configured for testing of repairs where the primary function is to confirm the complete removal of rejected defect. As a minimum the AUT system with its normal set-up, but with gates wide enough to encompass the repair area and confirm that the AUT defects have been removed. During this special attention shall also be made to TOFD channel indications, and indications outside the normal gate settings.

Due to the wide variation in repair weld groove shapes that may limit the detection capabilities of the system, manual UT, or a dedicated semi-automatic UT system, shall support the AUT on weld repairs unless the groove shape is controlled to be within given tolerances and the scanner head is configured accordingly or if an AUT methodology that is qualified and documented to be capable to accurately detect and size imperfections is applied (e.g. ultrasonic imaging techniques or phased array based setup groups.). For supplementary UT, the provisions of App.D apply, meaning that ultrasonic testing shall be performed according to best workmanship with the intention to confirm that no new imperfections are introduced by repair welding.

E.2.1.6 The ultrasonic system shall incorporate facilities for detection of transverse imperfections, when it is clearly identified that the weld process, parent material, application and environmental condition may increase the risk for transversal type imperfections.

E.2.1.7 For each AUT setup, allowable wall thickness variations from nominal thickness is ±1.5 mm (total range 3.0 mm) applicable for pipes exposed for a total nominal strain of less than 0.4%, and ±1.0 mm (total range 2.0 mm) applicable for fatigue sensitive welds or when total nominal strains equal to and above 0.4%. For variations from nominal wall thickness outside these tolerances, additional AUT setups have to be employed to ensure that any part of the weld is scanned with a setup within the tolerance defined above.

Any deviation from above has to be validated through a full validation scope according to [E.9], which captures the applicable wall thickness variations. AUT setups that have the ability to accommodate larger wall thicknesses than the limits provided above, shall demonstrate this during the general AUT system qualification. When qualified, wall thickness variations within the qualified range shall be accepted for each AUT setup instead of the requirement above.

E.2.1.8 Counter bores may be used to compensate for large thickness variations if the counter bore is machined to provide parallel external and internal surfaces before the start of the taper. The length of the parallel surfaces shall at least be sufficient to allow scanning from the external surface and sufficient for the required reflection off the parallel internal surface.

E.2.1.9 An operating quality assurance system shall be used covering the development of ultrasonic examination systems, testing, verification and documentation of the system and its components and software against given requirements, qualification of personnel and operation of ultrasonic examination systems. The quality assurance system employed shall be documented in sufficient detail to ensure that AUT systems used for field inspection will be designed, assembled and operated within the essential variables established during the qualification and in all significant aspects will be equal to the qualified AUT system. In addition to the general requirements to quality assurance of Section 2, NDT contractors and organisations shall as a minimum supplement this with the requirements given in ASTM E1212.

The following shall be documented:

— document control
— system development including establishing performance
— requirements to the system, its components and calibration blocks
— selection/qualification/follow-up/auditing of suppliers/subcontractors
— procurement of system components and calibration blocks
— verification of delivered system components and calibration blocks against given requirements
— marking/identification of system components and calibration blocks complying with given requirements
— control and verification of software development/changes
— design of AUT system(s) set-up for specific field operation conditions/requirements
— assembly of AUT systems for field operation from verified components in stock, including identification of the system and identification/documentation of its components, calibration block(s) and spare parts
— verification/testing of AUT systems for field operation
— operational checks and field maintenance of AUT systems
— documentation/verification of in field modifications of AUT systems
— return of field systems, dismantling, check/repair/upgrading of system components

— verification of repaired/upgraded system components against given requirements
— AUT operator training and qualification.

Project specific set-up files, to be included in project specific procedures:

— Phased array focal laws (if applicable)
— Probe stand off
— Sound angles
— Target depth
— Required over trace
— Applied thresholds.

E.2.1.10 If an embedded imperfection is located close to a surface, such that the ligament height is less than half the imperfection height, the ligament height between the imperfection and the surface shall be included in the imperfection height.

E.2.1.11 Velocity changes and attenuation variations in the longitudinal weld seam shall be determined and compared to base pipe material. Those differences shall be documented through a comparison table. If there are attenuation differences greater than ±2 dB (total range 4.0 dB) or angle changes greater than 1.5 degrees (total range 3.0 degrees) compared to base pipe material, then procedural consideration shall be given to imperfection detection and evaluation in this area to ensure requirements of [E.2.1.1] are met.

Regardless of the difference, adequate inspection sensitivity in the longitudinal weld shall be confirmed during AUT qualification/validation testing.

E.2.1.12 All requirements for applications experiencing strains over 0.4% shall also apply to fatigue sensitive applications.

Requirements specific for CRA and coarse grain material examination

E.2.1.13 Weld deposits in duplex, austenitic stainless steels and nickel alloys may have a coarse grain structure with variations in grain size and structure resulting in unpredictable fluctuations in attenuation. Duplex and austenitic stainless steel base materials may have the same characteristics. Ultrasonic testing of welds with CRA (duplex, other stainless steels and nickel alloy steel) weld deposits will in order to achieve an adequate detection of imperfections require different AUT setup than for inspection of carbon steel materials. The AUT setup selected for the inspection shall be capable to comply with the requirement to signal-to-noise in [E.4.5.6].

E.2.1.14 Applicable to CRA weld deposits, AUT shall be verified on its capabilities on CRA boundary penetration, which shall be demonstrated. Verification on the penetration shall be done by determine the noise generated from the boundary, which shall not exceed a value 6 dB below the rejection threshold applied for the documented defect height detected with 90% POD or 85% POR at a 95% confidence level during qualification. In case these conditions cannot be met, internal visual inspection shall be used to aid on the sentencing of the root integrity, in conjunction with AUT. The methods shall be validated in a combined program. Defective welds shall be inspected with both AUT and using internal VT. Results shall be compared with RT, macros sectioning.

The signal to noise ratio between reference reflector and the structural noise of the CRA material in the weld area shall be minimum 6 dB. In any case the acoustical equivalent noise shall not exceed the smallest allowable defect height (ECA).

E.2.1.15 For the determination of certain root indications in coarse grain materials (concavity, root penetration) information may be used derived from laser profiling or camera having laser measurement tool (if laser profiling or camera can access root area). The capabilities of these tools should be proven during the validation program.

Requirements specific for carbon steel applications

E.2.1.16 For AUT of girth welds in seamless pipes: Wall thickness monitoring channels shall be incorporated into all AUT configurations. The thickness channel wedge placement shall allow continuous monitoring of pipe wall thickness at the furthest possible ID sound interacting point. The output from these channels shall be used to confirm that inspection is performed within the requirements of paragraph [E.2.1.7]. The wall thickness monitoring channels can be waived if it is documented that the wall thickness variations are within the ranges specified in paragraph [E.2.1.7] (e.g. with counter bored pipes).

E.2.1.17 Applicable to all fatigue sensitive carbon steel applications: ToFD shall be an integral part of inspection, not to be considered an augment or safety net option. ToFD channel shall use conventional transducers.

TOFD can be waived if AUT based on ultrasonic imaging technique is applied, provided that the full weld is scanned with the imaging technique, and adequate sensitivity for tip diffracted signals are documented upon the AUT qualification and/or validation.

E.2.2 Documentation

E.2.2.1 The configuration of the ultrasonic system shall for evaluation purposes be described and documented with regard to:

— brief functional description of the system
— reference to the standard or recommended practice used for design and operation of the system
— description of the quality assurance system
— equipment description
— limitations of the system with regard to material or weld features including sound velocity variations, geometry, wall thickness, size, surface finish, material composition, etc.
— number and type of transducers, or phased array set up with description of characteristics and set-up
— number of and height of examination zones, where relevant
— gate settings
— function of scanning device
— ultrasonic instrument, number of channels and data acquisition system
— recording and processing of data
— calibration blocks
— coupling monitoring method
— temperature range for testing and limitations
— coverage achieved
— maximum scanning speed, PRF and direction
— reporting of indications and documentation of calibration and sensitivity settings.

E.2.3 Ultrasonic system equipment and components

General requirements

E.2.3.1 The system shall be capable of examining a complete weld including the heat affected zone in one circumferential scan. This requirement may, as agreed, be deviated from for very thick/small diameter pipe, if it is not possible to cover the whole depth range in one scan.

E.2.3.2 There shall be recordable signal outputs for at least each 1 mm of weld length for each inspection channel.

E.2.3.3 The ultrasonic instrument shall provide a linear A-scan presentation. The instrument linearity shall be determined according to the procedures detailed in ASTM-317-01 or EN12668. Instrument linearity shall not deviate by more than 5% from ideal. Alternatively, tests performed according to the manufacturer requirements and specifications can be carried-out.

The assessment of ultrasonic instrument linearity shall have been performed within 12 months of the intended end use date. For production AUT with an expected duration exceeding 6 months, but less than one year, the assessment of instrument linearity may be performed immediately before the start of work.

A calibration certificate shall be made available upon request.

E.2.4 Specific requirements for ultrasonic instruments using multiple channels, pulse echo, tandem and/or through transmission techniques.

E.2.4.1 The instrument shall provide an adequate number of inspection channels to ensure the examination of the complete weld through thickness in one circumferential scan, if possible (see [E.2.4.1]). Each inspection channel shall provide:

— pulse echo or through transmission modes
— one or more gates, each adjustable for start position and length
— gain adjustment
— recording threshold between 5 and 100% of full screen height
— recording of either the first or the largest signal in the gated region
— signal delay to enable correlation to distance marker positions (real time analogue recording only)
— recordable signal outputs representing signal amplitude and sound travel distance
— specific requirements to ultrasonic instruments using the ToFD technique

E.2.4.2 The instrument shall provide a ToFD B-scan image. ToFD function software shall incorporate adequate facilities for online indication assessment using range calibrated cursors. A-scan reference and numerical translation of time of flight positions shall be incorporated.

Depth range efficiency shall be identified for each ToFD set up. For wall thickness greater than 35mm, at least two ToFD channels shall be required and coverage overlap of ToFD channels shall be demonstrated.

TOFD channels can be waived for AUT using ultrasonic imaging technique to display the whole weld, provided that capability to capture tip diffraction signals in the images are documented in qualification and validation.

E.2.4.3 The instrument shall fulfil the requirements to ultrasonic instruments described in EN12668-1 and ISO 16828, Chapter 6 *Equipment requirements*

Specific requirements to ultrasonic instruments using phased arrays.

E.2.4.4 The phased array system shall incorporate means for periodical verification of the function of required active elements necessary to maintain a specific focal law in compliance with ISO 18563.

E.2.4.5 A system preventing any unqualified alterations to agreed focal laws shall be implemented for the phased array AUT system. This system shall be verified and documented. Phased array focal law controlling parameters (may be a combination of: angle, start element, center element, total number of elements, index, etc) shall be indicated in the AUT procedure. Unqualified change limits shall comply with [E.5.3.1].

Unqualified alterations on agreed single focal laws to setups can be accepted if the changes are made according to a qualified and validated concept that adapts the focal laws to one or several essential variables which are monitored in real time. In such case, the concept shall be validated through a full validation scope of minimum 29 observations according to [E.9]. This option is in particular applicable for adaptive focal laws to wall thickness variations.

E.2.4.6 If additional conventional transducers to the phased array ones are used, for example for transverse inspection and ToFD, the information for all transducers shall be available in the same set up and recording system.

The recording system

E.2.4.7 The recording or marking system shall clearly indicate the location of imperfections relative to the 12 o'clock position of the weld, with a ± 1% accuracy or 10 mm, whichever is greater. The system resolution shall be such that each segment of recorded data from an individual inspection channel does not represent more than 2 mm of circumferential weld distance.

Acoustic coupling

E.2.4.8 Acoustic coupling shall be achieved by contact or couplant column using a liquid medium suitable for the purpose. An environmentally safe agent may be required to promote wetting, however, no residue shall remain on the pipe surface after the liquid has evaporated.

The method used for acoustic coupling monitoring and the loss in signal strength defining a loss of return signal (loss of coupling) shall be described.

Transducers

E.2.4.9 Prior to the start of field weld examination, details of the types and numbers of transducers or focal laws shall be specified. Once agreed, there shall not be any transducer or focal law design changes made without prior agreement. Transducers other than phased arrays shall be characterised according to EN12668-2. Transducers shall be documented with respect to manufacturer, type, characteristics and unique identification (serial number).

Transducer characteristics shall include (not all parameters are applicable to phased array transducers):

— frequency
— beam angle
— wedge characteristics
— beam size (Not relevant for PA probes)
— pulse shape
— pulse length
— signal to noise (Not relevant for PA probes)
— focus point and length for focused transducers.

In addition, the following characteristics shall be included for phased array probes:

— Number of elements
— pitch
— Size of elements

E.2.4.10 Transducers used for zonal discrimination shall give signals from adjacent zones (over-trace), given that there is no shift in weld bevel angle between the zones. For adjacent zones of comparable size and with equal calibration sensitivity, the over-trace shall be within 15% FSH to 50% FSH when the peak signal from the calibration reflector representing the zone of interest is set to 80% FSH.

E.2.4.11 TOFD (frequency, standoff, crystal size, pulse length, etc) shall be optimized for detection sensitivity, spatial resolution, OD and ID dead zones (See [E.2.4.5]).

E.2.4.12 Transducer wedges shall be contoured to match the curvature of the pipe.

E.2.4.13 Transducer/wedge surface wear shall be monitored during the course of operations.

E.2.4.14 Software modules which allows for automated compensation and correction for any essential parameter can be used, provided that correct function is qualified and demonstrated prior to use.

E.2.5 Calibration blocks

E.2.5.1 Calibration blocks shall be used to set AUT system sensitivity, and to verify the inspection system for field inspection and to monitor the ongoing system performance. Calibration blocks shall be manufactured from a section of pipeline specific linepipe. The wall thickness of the pipe used for calibration blocks shall preferably correspond to the nominal wall thickness of the pipes used, unless a number of calibration blocks are needed to cover wall thickness variations outside the limitations given in [E.2.1.7].

E.2.5.2 Acoustic velocity and attenuation measurements shall be performed on material from all sources of pipe material supply to be used. These measurements shall be performed according to [E.11.1] unless an equivalent method is agreed. If differences in acoustic velocity for the same nominal wall thickness from any source of supply results in a beam angle variation of more than 1.5°, specific calibration blocks shall be made for material from each source of supply showing such variations.

E.2.5.3 Details of the specific weld bevel geometries including relevant dimensions and tolerances shall be provided in order to determine the particulars and numbers of calibration blocks required.

E.2.5.4 Type and size of reference reflectors shall be determined by the required sensitivity to achieve the necessary probability of detection (PoD) and sizing capability as determined by the smallest allowable imperfection deriving from the agreed acceptance criteria. The calibration block design shall provide adequate reflectors for the relevant defects at inspection, taking into account the applied ultrasonic technique. The principal reference reflectors shall be flat bottom holes (FBHs) and surface notches. Other reflector dimensions and types may be used, if it is demonstrated during the system qualification that the imperfection detection and sizing capabilities of the system is acceptable. Specific reflectors for ToFD shall be incorporated, to confirm TOFD system functionality.

E.2.5.5 The calibration blocks shall be designed with sufficient surface area so that the complete transducer array will traverse the target areas in a single pass.

E.2.5.6 Drawings showing the design details for each type of calibration block shall be prepared. The drawings shall show:

— the specific weld bevel geometry, dimensions and tolerances
— the height and position of examination zones, if applicable
— the reference reflectors required and their relative positions, dimensions and orientations.

E.2.5.7 The calibration block shall be identified with a hard stamped unique serial number providing traceability to the examination work and the material source of supply for which the standard was manufactured. Records of the correlation between serial number and wall thickness, bevel design, diameter, and ultrasound velocity shall be kept and be available.

The machining tolerances for calibration reflectors are:

-	Hole diameters	± 0.2 mm
-	Flatness of FBH	± 0.1 mm
-	All pertinent angles	± 1°
-	Notch depth	± 0.1 mm
-	Notch length	± 0.5 mm
-	Central position of reference reflectors	± 0.1 mm
-	Hole depth	± 0.2 mm.

E.2.5.8 The lateral position of all reference reflectors shall be such that there will be no interference from adjacent reflectors, or from the edges of the blocks.

E.2.5.9 Holes shall be protected from degradation by covering the hole with a suitable sealant. If it can be proven that filling of surface notches and other near surface reflectors may influence the reflecting ability of the reference reflector, avoidance of filling can be subject to agreement.

E.2.5.10 Dimensional verification of all reference reflectors and their position shall be performed and recorded according to a documented procedure. Replicas of all reflectors shall be produced and appropriately labelled and stored for reference to the calibration block and shall be available for review for all parties involved. Each reflector shall be verified by manual ultrasonic testing with a probe relevant for the AUT testing to ensure that the reference reflector pairs yield reflective signals within ±3dB. This requirement is not applicable for asymmetric reference block designs.

E.2.5.11 Whenever possible, an AUT system similar to that used during field inspection shall be successfully calibrated against the calibration block after dimensional verification of the block. The set-up data shall be recorded and the same data used to verify that any additional/spare calibration blocks will not give significantly different calibration results.

E.2.5.12 A calibration block register shall be established. The register shall include all calibration blocks, including spare blocks, to be used, identified with a unique serial number and include the drawings, dimensional verification records, ultrasound velocity, name of the plate/pipe manufacturer and the heat number.

E.2.5.13 Acoustic properties of calibration block material shall be determined as defined in [E.11]. For seamed pipe, the acoustic property comparison between pipe and seam welds shall be provided. When attenuation due to surface condition shows variation of one standard deviation greater than ±3dB (total range 6 dB), impact of surface condition on detection and sizing accuracy shall be analyzed. The data and analysis shall be reviewed with the involved parties. Calibration block design shall take this data into consideration. The inspection company should decide the best methodology for measurement of attenuation, which shall be accepted by all involved parties.

E.2.5.14 The calibration block shall include the following reflectors for TOFD, as a minimum:

— An ID V-notch of suitable size to document the size of the ID surface dead zone

— An OD V-notch of suitable size to document the size of the ID surface dead zone.

E.2.5.15 Applicable to clad and lined pipe welds applications: A transfer measurement procedure shall be estabilshed in order to ensure adequate inspection sensitivity of welds. The procedure shall include tests on a piece of an acutal project weld. The weld shall be made from representative production material using project specific approved welding procedure.

E.2.5.16 Applicable to carbon steel zonal discrimination setup: The reference block shall include: FBH of not larger than 3 mm positioned on the position of the theoretical weld fusion line in the reference block, OD and ID surface notches, volumetric reflectors 1.5 mm FBH.

E.2.5.17 Applicable to ultrasonic imaging techniques: The reference block shall include embedded reflectors not larger than 3 mm at different depths and orientations in the weld, in addition to surface notches at OD and ID surface.

The amount, position and orientations of the reflectors shall be sufficient to document adequate inspection sensitivity in the full weld area. It shall be demonstrated that the system procedure covers the HAZ, reference is made to [E.2.1.3].

E.2.5.18 For calibration blocks made of seamless pipes (SMLS), thickness survey shall be performed on calibration block blank in no greater than 20mm x 20mm grids. The wall thickness variation shall be within the specified wall thickness variation. The average thickness shall be used to define calibration block's applicable thickness range. Maximum and minimum wall thickness of each strip shall be included in the calibration block package.

E.2.5.19 Applicable for all calibration blocks used with AUT setups including thickness measurement channel: The accuracy of the wall thickness channels shall be verified. The thickness channel shall have the capability to measure pipe wall thickness to accuracy better than ±1.0% of the total wall thickness.

E.2.6 Recorder set-up

E.2.6.1 The maximum allowable circumferential scanning velocity shall be determined so that there are at least 3 pulse firings within each 6 dB beam width at the appropriate operating distance of all transducers within the an array, as described in [D.8.4.12].

E.2.6.2 Distance markers shall be provided on the recording at intervals not exceeding 100 mm of circumferential weld length.

E.2.7 Circumferential scanning velocity

E.2.7.1 The maximum scanning velocity shall be determined such that there is no evidence of strip losing data in the recorded scans.The same scanning velocity shall be used during calibration verification and weld inspection.

E.2.8 Power supply

E.2.8.1 Constant power supply shall be ensured for the ultrasonic system. There shall be provisions for alternative power supply in case of failure in the main power supply. There shall be no loss of inspection data as a result of a possible power failure.

E.2.9 Software

E.2.9.1 All recording, data handling and presenting software, including changes thereto, shall be covered by the quality assurance system and all software versions shall be identifiable by a unique version number.

E.2.9.2 The software version number, and for phased array equipment also each identified set-up (executable focal law programme) in use, shall be clearly observable on all display and printout presentations of calibration and examination results.

E.2.9.3 For phased array equipment, each identified set-up shall be available for review. Focal law versioning software shall allow tracking of all parameter changes through the entire course of operation. The cumulative change during production shall be in accordance with [E.5.3.1].

E.2.9.4 Software updates shall not be performed on systems during field examination use.

E.2.10 Reference line, band position and coating cut-back

Reference line

E.2.10.1 Prior to welding a reference line shall be placed on the pipe surface at a fixed distance from the centerline of the weld preparation on the inspection band side. This reference line shall be used to ensure that the band is adjusted to the same distance from the weld centerline as to that of the calibration block.

Guiding band positioning

E.2.10.2 The tolerance for band positioning is ± 1 mm relative to the weld centerline, unless it can be demonstrated and qualified wider tolerance for band offset for the AUT scanner setup applied (e.g. for ultrasonic imaging techniques).

The band can be positioned either wholly on the bare pipe or on the corrosion coating.

Positioning of the band on the corrosion coating will require that the coating thickness is not excessive and that the coating is sufficiently flat and will remain hard enough at the temperatures in the pipe resulting from preheat and welding to avoid that the band supports slips or penetrates the coating.

Positioning of the band partly on bare pipe and partly on the corrosion coating may result in instability problems for scanner and should be avoided, unless corrective actions to band saddles are made to accommodate its position.

Coating cut back

E.2.10.3 The cut-back of the corrosion coating to bare pipe shall be wide enough to accommodate the footprint of all transducers at the required stand-off distance + minimum 20 mm. The cut-back of any weight coating shall allow placing the band wholly on the bare pipe or on the corrosion coating or partly on both, as applicable, and sufficient to avoid interference between weight coating and scanner.

The coating cut back required allowing for scanner mounting and movement shall be clearly identified in the operating manuals.

E.2.11 Reference line tools

E.2.11.1 The tool used to align the scanning band to the reference line shall be adjusted to account for weld shrinkage, when shrinkage is considered to be greater than 1 mm. Shrinkage is determined by marking the reference line on both pipe ends during WPQ or for the first 25 welds, and then measuring the distance between them after welding.

The tools used for marking the reference line for band positioning, shall give accuracy in the position of the reference line of ± 0.5 mm relative to the bevel root face. The accuracy of each reference line tool shall be documented and each tool shall be uniquely identified.

E.2.12 Operators

E.2.12.1 Details of each AUT operator shall be provided prior to start of field weld examination.

E.2.12.2 Operators performing interpretation shall be certified to Level 2 by a Certification body or Authorised qualifying body in accordance with ISO 9712 or the ASNT Central Certification Program (ACCP). In addition they shall document adequate training and field experience with the equipment in question, by passing a specific and practical examination. If requested, they shall be able to demonstrate their capabilities with regard to calibrating the equipment, performing an operational test under field conditions and evaluating size, nature and location of imperfections.

E.2.12.3 Operators who are not accepted shall not be used, and operators shall not be substituted without prior approval. In case additional operators are required, details of these shall be accepted before they start to work.

E.2.12.4 One individual shall be designated to be responsible for the conduct of the ultrasonic personnel, the performance of equipment, spare part availability and inspection work, including reports and records.

E.2.12.5 The operators shall have access to technical support from one individual qualified to Level 3 at any time during execution of the examination work.

E.2.13 Spares

E.2.13.1 There shall be a sufficient number of spare parts available at the place of examination to ensure that the work can proceed without interruptions.

E.2.14 Slave monitors

E.2.14.1 The system shall include the possibility to provide slave monitors for use by supervising personnel, if agreed.

E.3 Procedure

E.3.1 General

E.3.1.1 A detailed AUT Procedure shall be prepared for each weld joint geometry to be examined prior to the start of any welding. The procedure is as a minimum, and as relevant for the equipment in question, to include:

— functional description of equipment
— reference standards and guidelines controlling equipment maintenance
— instructions for scanning device, ultrasonic instrument, ultrasonic electronics, hard- and software for recording, processing, display, presentation and storage of inspection data
— number of examination zones for each wall thickness to be examined, as relevant
— transducer configuration(s), characteristics, types, coverage; and/or focal law details
— description/drawings of calibration block(s), including type, size and location of all calibration reflectors
— pre-examination checks of equipment
— methodology for sensitivity setting and for fusion zone transducers; overtrace (signal amplitude from adjacent zones) requirements consistent with the overtrace used as basis for establishing height sizing corrections for amplitude sizing
— gate settings
— equipment settings
— threshold settings
— the added gain above PRL ([E.4.1.2]) to be used for mapping channels
— dynamic verification of set-up
— signal strength defining a loss of return signal (loss of coupling)
— visual examination of scanning area, including surface condition and preparation
— identification of inspection starting point, scanning direction, and indication of length inspected
— method for scanner alignment and maintenance of alignment
— verification of reference line and guide band positioning
— maximum allowed temperature range
— control of temperature differentials (pipe and calibration block)
— calibration intervals
— calibration records
— couplant, coupling and coupling control
— operational checks and field maintenance
— transducer and overall functional checks
— height, depth and length sizing methodology
— acceptance criteria, or reference thereto
— instructions for reporting including example of recorder chart and forms to be used
— spare part philosophy.
— TOFD crossover and corresponding depth
— Focal law versioning system to track parameter changes and prevent unauthorised changes beyond agreed limits
— Focal law controlling parameters and their equivalences in terms of required changing limits.

E.3.1.2 The AUT procedure shall be submitted for acceptance.

E.4 Calibration (sensitivity setting)

E.4.1 Initial static calibration

Transducer positioning and primary reference sensitivity

E.4.1.1 The system shall be optimised for field inspection in accordance with the details given in the AUT procedure and using the relevant calibration block(s). The calibration block shall have the same orientation (vertical/horizontal) as the pipe to be tested, unless it has been proven through the qualification tests that differences in response are negligible.

E.4.1.2 The gain level required to produce the peak signal response is the Primary Reference Level (PRL) for that reflector.

Zonal discrimination fusion zone channels

E.4.1.3 Pulse echo and tandem transducers shall be positioned at its operating (stand-off) position and adjusted to provide a peak signal from its calibration reflector. In the case of phased arrays, the focal laws shall be designed to provide a peak signal from each of the calibration reflectors as appropriate. This signal shall be adjusted to the specified percentage of full screen height (FSH).

Carbon steel applications

E.4.1.4 For single TOFD channels, the transducer spacing shall be selected to place the theoretical crossing of beam centres at the weld centreline at 66 to 95% of the wall thickness.

For double TOFD channels the theoretical crossing of beam centres at the weld centreline shall be at 66 to 95% of the wall thickness for one channel and approximately 33% of the wall thickness for the other channel.

The amplitude of the lateral wave shall be between 40 and 80% of full screen height (FSH). In cases when use of the lateral wave is not applicable, e.g. surface conditions and steep beam angles, the amplitude of the back wall signal shall be set at between 12 to 24 dB above FSH. When use of neither the lateral wave nor the back wall signal is applicable, the sensitivity should be set such that the noise level is between 5 and 10% of FSH.

Mapping channels

E.4.1.5 Each transducer shall be positioned at its operating (stand-off) position and adjusted to provide a peak signal from its calibration reflector. In the case of phased arrays, the focal laws shall be designed to provide a peak signal from each of the calibration reflectors as appropriate. This signal shall be adjusted to the specified percentage of FSH.

Additional gain shall not be added during sensitivity setting, dynamic calibration and calibration verification during field examination.

E.4.1.6 The required added gain for volumetric mapping channels shall be no smaller than 8 dB above PRL. Exception can be for inspection of clad and lined weld.

E.4.1.7 The mapping display threshold for the root, cap, and volumetric channels shall be set at as close as possible to background levels to provide additional information on potential defects. The software shall provide means to continuously adjust display threshold level for ease of defect characterization.

CRA and coarse grain applications

E.4.1.8 For CRA applications, added gain for mapping channels shall be determined through AUT qualification/validation and scanning results of development and procedure qualification welds.

E.4.2 Gate settings

E.4.2.1 With each transducer positioned for a peak signal response from the calibration reflector the detection gates shall be set as detailed in the agreed AUT procedure and as detailed below.

Fusion zone channels

E.4.2.2 Applicable for zonal discrimination setup: The detection gates are to be set with each transducer/focal law positioned for the peak signal response from the calibration reflector. The gate shall start before the theoretical weld preparation and a suitable allowance shall be included to allow for the width of the heat affected zone, so that complete coverage of the heat affected zone is achieved. The gate ends shall at least be after the theoretical weld centreline, including a suitable allowance for offset of the weld centreline after welding.

E.4.2.3 For specific applications, e.g. for CRA weldments with angle compression waves with the reference reflectors positioned at the far side of the weld, an extension of the gate onto the far bevel and HAZ is required.

Similar considerations may apply in the root area related to monitoring of guidance band offset.

ToFD technique

E.4.2.4 Ideally the time gate start should be at least 1 μs prior to the time of arrival of the lateral wave, and should at least extend up to the first back wall echo. Because mode converted echoes can be of use in identifying imperfections, it is required that the time gate also includes the time of arrival of the first mode converted back wall echo.

E.4.2.5 As a minimum requirement, the time gate shall at least cover the depth region of interest.

E.4.2.6 Where a smaller time gate is appropriate, it will be necessary to demonstrate that the imperfection detection capabilities are not impaired.

Mapping channels

E.4.2.7 The mapping channels shall encompass the HAZ and the total weld volume dedicated to the transducer or focal law.

E.4.3 Evaluation threshold

Threshold level

E.4.3.1 It shall be verified that the evaluation threshold level, based on data from the AUT system qualification, is set low enough to detect the minimum height critical defect identified in the acceptance criteria (see [E.8.3]).

E.4.3.2 The evaluation threshold levels shall in any case not be set higher than required in the following.

Fusion zone channels

E.4.3.3 The evaluation threshold for fusion zone channels shall be at least 6 dB more sensitive than the reference reflector, unless a different sensitivity is required for detection of indications depending upon the size of reflectors used and the applicable acceptance criteria.

E.4.4 TOFD technique

E.4.4.1

E.4.4.2 The recording threshold for ToFD is not recommended to be changed from the calibration threshold. However, a change of threshold may be prescribed in the procedure.

Mapping channels

E.4.4.3 The evaluation threshold for mapping channels shall be at least 12 dB more sensitive than the reference reflector signal PRL for volumetric indications and at least 8 dB more sensitive than PRL for linear indications.

For CRA material welds the evaluation threshold for mapping channels shall be at least 8 dB more sensitive than the reference reflector signal or as qualified during the validation of the system.

E.4.5 Dynamic calibration

General requirements, Detection channels

E.4.5.1 With the system optimised, the calibration block shall be scanned. The position accuracy of the recorded reflectors relative to each other shall be within ± 2 mm, and with respect to the zero start within ± 10 mm.

E.4.5.2 For all phased array focal laws or transducers the recording media shall indicate the required percentage of FSH and locate signals from each calibration reflector in its correctly assigned position.

E.4.5.3 For all reference reflectors used to set and verify sensitivity for the setup, amplitude response shall not deviate by more than ±2dB from the initial calibration.

E.4.5.4 If the dynamic calibration of out of above defined limits, recalibration shall be performed to verify that it is not caused by scanner mechanical instability. More than three attempts shall not be permitted in production to bring the calibration within tolerance. When this occurs, the operator shall perform thorough operational check and perform re-calibration. The changes in parameters shall be logged.

Coupling monitor channels

E.4.5.5 The coupling monitor channels shall indicate no loss of return signal as required by the procedure.

CRA and coarse grain applications

E.4.5.6 Applicable to all CRA applications: It shall be demonstrated an adequate signal-to-noise ratio with the AUT setup selected for inspection, the noise level shall be minimum 6 dB below PRL at the target area for each channel or focal law. This does not apply to creeping wave channels.

Carbon steel applications

E.4.5.7 Over trace shall meet the requirements of [E.2.4.13].

E.4.6 Recording of set-up data

E.4.6.1 Sufficient data shall be recorded on a set-up sheet to enable a duplication of the original set-up at any stage during field inspection.

As a minimum the PRL, the signal to noise (S/N) ratio, the stand-off distance for each transducer, and settings for gate start and gate length for each channel shall be recorded.

E.4.6.2 The calibration qualification chart shall be used as the inspection quality standard to which subsequently produced calibration charts may be judged for acceptability. This recording shall be kept with the system Log Book. For phased array equipment also the identified set-up (executable focal law programme) used shall be recorded.

E.4.6.3 In addition to the qualification chart required above, any changes in the data records made in accordance with [E.4.6.1] above shall be recorded.

The set-up sheet shall after dynamic calibration include as a minimum:

— PRL and the signal to noise (S/N) ratio for each transducer or focal law (if phased array)
— the stand-off distance for each transducer and alignment of tandem transducers
— the settings for gate start and gate length for each channel
— the gain to be added to any channel during field examination
— filtering settings, when applicable
— the order of transmitters and receivers
— calibration block identification.

E.5 Field inspection

E.5.1 Inspection requirements

General requirements

E.5.1.1 The ultrasonic system used for examination during production shall in all essential aspects be in compliance with the set-up and configuration of the system used for system qualification (see [E.8]). Any change of set-up data, components, calibration block from the qualified procedure shall be noted to all involved parties and be made available for review upon request.

Documentation

E.5.1.2 The following documentation shall be available at the place of field examination:

An AUT system dossier for each operating AUT system including performance/characteristics data and identification of at least:

— pulser/receiver
— transducers
— umbilical
— encoder
— software version and executable focal law programmes (when applicable)
— other essential equipment.

An AUT system spare parts dossier including:

— performance/characteristics data and identification of essential spare parts.

A calibration block register including:

— the documentation for each calibration block, including spares, as required by [E.2.5.13].

An AUT personnel qualification dossier including:

— certificates for all AUT personnel.

An AUT procedures dossier including:

— AUT procedures to be applied
— AUT system check and maintenance instructions
— work instructions for AUT personnel.

Additional information including:

— other NDT procedures
— AUT and NDT acceptance criteria.

E.5.1.3 The AUT system dossier shall be updated when changes of parts/components are made and shall at all times reflect the current configuration of the AUT system in use.

The AUT system spare parts dossier shall be updated whenever parts/components are replaced or new parts/components arrive and shall at all times reflect the number of spares available.

System log book

E.5.1.4 The system log book shall be kept at the place of inspection, and be made available for review upon request.

The system log book shall be continuously updated and at least include the following information:

— set-up data as required in [E.4.5]
— the calibration qualification chart(s)
— replacement of main components with spares from stock
— replacement of calibration block
— results from operational checks
— results of periodical verifications (linearity checks, calibration block wear, element verification for phased array transducers etc.).

E.5.1.5 Soft copy recordings for each calibration scan (and phased array set up file, if appropriate) shall be included sequentially with the weld inspection charts. If agreed, 1 calibration for each 10 consecutive ones, shall be provided in hard copy together with each weld inspection scans. The last weld number examined before calibration and the time at which the calibration was performed shall appear on each calibration chart.

Pre- examination tests

E.5.1.6 Before the ultrasonic system is used for field examination of production welds the system shall be tested. After calibration of the complete system using the applicable set-up sheet parameters, the calibration block shall be scanned. If any of the echo amplitudes from the reflectors of the calibration block deviate more than 2 dB from the initial calibration, corrections shall be made.

The system shall not be used until 5 consecutive satisfactory scans are obtained.

The total noise level from transducer, material including weld, electronics and any other sources shall not exceed the single output representing the smallest critical defect.

At least one scan shall be performed with the scanning surface wiped dry. The coupling monitor channels shall indicate loss of return signal as required by the procedure.

In addition, a power failure shall be simulated and operation of the system on the alternative power source with no loss or corruption of examination data shall be verified.

Verification of calibration

E.5.1.7 The calibration of the system shall be verified by scanning the calibration block before and after inspection of each weld. The gain added to any channel for field examination shall be removed during verification scans.

E.5.1.8 One calibration scan is required before and after each weld inspected for following welds: procedure welds, welder qualification welds, fatigue sensitive welds, first 20 production welds, first 20 consecutive welds after an unacceptable calibration, fatigue sensitive welds, repair welds, CRA welds. For other types of welds, the frequency of calibration scans may be reduced to a minimum of 1 scan for each 10 consecutive welds. If a calibration scan fails, the preceeding welds counting back to last acceptable calibration shall be re-scanned.

E.5.1.9 The verification scans shall not show amplitude changes in any channel outside ± 2 dB from the reference calibration chart (see [E.4.5.1]).

E.5.1.10 The peak signal responses from each verification scan shall be recorded. Any gain changes required to maintain the PRL in the set-up sheet (see [E.4.5.2]) shall be recorded.

Re-calibration

E.5.1.11 The system shall be re-calibrated and a new reference calibration chart shall be established according to [E.4] if a verification scans shows amplitude changes in any channel outside ± 2 dB from the reference calibration chart or if gain changes outside ± 2 dB are required to maintain the PRL in the set-up sheet.

E.5.1.12 The system shall also be re-calibrated and a new reference calibration chart and a new set-up sheet established:

— at any change of calibration block
— at any change of nominal wall thickness
— at any change of components, transducers, wedges or after resurfacing of transducers
— before and after examination of repairs, if system is outside initial tolerances
— after any adjustments to scanner head or transducers
— after any change in the order of transmitters and receivers and filtering settings.

Weld identification

E.5.1.13 Each weld shall be numbered in the sequence used in the pipe tracking system.

E.5.1.14 The starting point for each scan shall be clearly marked on the pipe and the scan direction shall be clearly marked using an arrow. If the scanning direction is changed from the regular direction, this shall be noted on the records of the scan.

E.5.2 Operational checks

E.5.2.1 Operational checks shall be performed according to a documented procedure. The execution of and the results of the operational checks shall be recorded in the system log book.

E.5.2.2 The following operational checks shall be performed for every weld inspected:

— reference line shall be within required tolerance and clearly marked around the pipe circumference
— the scanning surface shall be free of weld spatter and other that may interfere with the movement of transducers
— physical damage and loose connections in the band. band position shall be within a tolerance of maximum ± 1.0 mm
— the pipe surface temperature and the difference between calibration block temperature and pipe temperature shall be within the required tolerance.
— The entire circumference of the weld has been completely inspected with sufficient overlap

E.5.2.3 The following operational checks shall be performed daily or at least once per shift:

— the scanner head shall be checked for physical damage and loose connections
— the bevel prepared at the bevelling station shall be of the specific weld bevel geometry, dimensions and tolerances shown on the drawings of the calibration block in use
— the calibration block in use shall be checked for physical damage and scanning tracks
— transducers shall not be rocking in the scanner and shall be in firm contact with the scanning surface. the transducers shall be firmly screwed onto the wedges. the transducer wear faces (wedges) shall be checked for scores which may cause local loss of contact

— the transducer stand-off distance shall be as recorded in the set-up sheet within ± 0.5 mm
— the position accuracy of the chart distance markers shall be shall be ± 1 cm or better.
— Transducer element verification check

E.5.2.4 Other operational checks such as linearity checks and field maintenance shall be performed according to the AUT system check and maintenance instructions.

Guidance note:

Checking of transducer angles may require a custom made block since the standard V1 block may not be wide enough to include the carbide tips during checks and due to that the gap between the V1 block and transducers with radiused surfaces will be too large for adequate checks.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

E.5.2.5 A verification scan shall be performed prior to resuming inspection after the operational checks required in [E.5.2.3] and any field maintenance. The verification scan shall meet the requirements given in [E.5.1.9].

If necessary, a re-calibration shall be performed and a new reference calibration chart shall be established according to [E.4].

E.5.2.6 Phased Array transducer with 2 adjacent dead elements or minimum 10% dead elements of the full array shall be replaced, unless:

— The identical probe and wedge configuration (with dead elements) has been used and successfully passed qualification program or
— Justification that channels with dead element(s) can maintain US/DS symmetry requirements has been approved by all involved parties.

E.5.3 Adjustments of the automated ultrasonic testing system

E.5.3.1 Adjustments to the AUT system other than correcting deviations from the qualified set-up sheet following operational checks and maintenance shall not be performed.

During production, cumulative change of parameters shall be limited to: gain adjustment of ±6dB, effective inspection angles of ±1.5 degrees, effective index change ±2.0mm while over trace requirements in [E.2.4.13] are still maintained.

E.5.3.2 Practices such as changing transducer angles by lifting transducer front and back by adjusting of carbides, changing stand-off distances and changing the order of transmitter/receivers etc. are not permitted.

E.5.4 Workmanship acceptance criteria

E.5.4.1 Acceptance criteria applicable for automated ultrasonic testing (AUT) of pipeline girth welds exposed to total nominal strains <0.4% are given in Table E-1. Table E-1 is not applicable to C-Mn pipes and low alloy steel subjected to sour service conditions or to fatigue sensitive welds. Acceptance criteria for fatigue sensitive welds are provided in Table E-2. The AUT system shall be qualified according to this appendix. The acceptance criteria of Table E-1 and Table E-2 assumes a height sizing accuracy within ±1 mm, a depth estimate accuracy of ±2 mm and a length sizing accuracy within ±5 mm, as evaluated according to clause [E.8.4.2]. The acceptance criteria of Table E-1 and Table E-2 are therefore only valid as long as the height sizing accuracy is documented to be within ±1mm upon the qualification. The inspection threshold is recommended set at 40% FSH for pulse echo zones. In addition, clause [E.8.4.1] shall be satisfied for maximum acceptable imperfection heights specified in Table E-1.

E.5.4.2 For AUT system used for inspection of girth welds in pipelines of duplex stainless steel, CRA and clad/lined materials, a probability of rejection of 85% at a 95% confidence level or higher shall be documented through the qualification for defects in the root of heights smaller than 1.0 mm, considering the applied AUT rejection criteria for root defects.

E.5.4.3 In order for Table E-1 to be applicable, requirements of [E.2.1.1] and [E.8.4.1] shall be satisfied.

Table E-1 Acceptance criteria for automated ultrasonic testing of girth welds

<table>
<tr><td>Base material</td><td>Defect location</td><td>Acceptance criteria 1) 2) 3)</td></tr>
<tr><td></td><td>Individual defect indications</td><td>Maximum accumulated length of defect indications in any 300 mm weld length</td></tr>
<tr><td rowspan="3">C-Mn and low alloy steels5,7)</td><td>Root</td><td rowspan="2">Height: the lesser of 3.0 mm and 0.2 t
Length: t, but max. 25 mm 4)</td></tr>
<tr><td>Surface</td></tr>
<tr><td>Embedded 6)</td><td>Height: the lesser of 3.0 mm and 0.2 t
Length: 2t, but max. 50 mm</td></tr>
<tr><td rowspan="3">Duplex stainless steel, CRAs and clad/lined steel</td><td>Root 8)
Up to 3 mm from inside surface, and up to 1.5 mm above clad/liner thickness for clad/lined steel</td><td>Height: max. 1 mm, the lesser of a third of clad/liner thickness and 1 mm for clad/lined steel
Length: t, but max. 25 mm</td></tr>
<tr><td>Surface</td><td>Height: the lesser of 3.0 mm and 0.2 t
Length: t, but max. 25 mm</td></tr>
<tr><td>Embedded 6)
At least 3 mm from inside surface, and at least 1.5 mm above clad/liner thickness for clad/lined steel</td><td>Height: the lesser of 3.0 mm and 0.2 t
Length: 2t, but max. 50 mm</td></tr>
<tr><td colspan="3">Cracks are not permitted.</td></tr>
<tr><td colspan="3">Porosity9):
Accumulated length of porosity signals exceeding a threshold 12 dB below the PRL in the volumetric channels: For single layer welds: 1.5% of the full circumferential length. For multi layer welds 3 t, max 100 mm in any 300 mm of weld length. Isolated pores shall be evaluated as planar imperfections.</td></tr>
</table>

Notes:

1) Planar defects interaction shall be assessed according to the criteria of BS 7910. Interacting planar defects shall be attributed effective defect dimensions according to BS 7910, and the effective defects so obtained shall meet the above acceptance criteria.
2) Imperfections above evaluation threshold in any intersection of the weld, which are located at the weld bevel of the same side as the intersection, are not permitted.
3) Systematic imperfections that are distributed at regular distances over the length of the weld are not permitted even if the size of any single imperfection meets the requirements above.
4) Acceptance criteria of Table D-4 shall also be satisfied.
5) This table is not applicable for C-Mn and low alloy steels in sour service.
6) If an embedded defect is located close to a surface, such that the ligament height is less than half the defect height, the ligament height between the defect and the surface shall be included in the defect height, and the defect shall be considered as a root or surface defect, as applicable.
7) POD and sizing accuracy of the AUT system shall be according to [E.5.4.1].
8) The probability of rejection (PoR) for a 1 mm high imperfection shall be qualified to be higher or equal to 85% at 95% confidence level.
9) Any addition of gain from PRL during scanning shall be added to the threshold

E.5.4.4 Workmanship acceptance criteria, fatigue sensitive welds

Acceptance criteria and the AUT system performance for fatigue sensitive welds shall be in accordance with [E.5.4] and additional requirements of Table E-2.

Table E-2 Acceptance criteria for automated ultrasonic testing of girth welds, fatigue sensitive welds

Base material	*Defect location*	*Acceptance criteria* [1) 2) 3)]	
		Individual defect indications	*Maximum accumulated length of defect indications in any 300 mm weld length*
C-Mn and low alloy steels [5,7)]	Root	Height: the lesser of 1 mm and 0.2 t	Length: t, but max. 25 mm [4)]
	Surface		
	Embedded [6)]	Height: the lesser of 3 mm and 0.2 t	Length: 2t, but max. 50 mm
Duplex stainless steel, CRAs and clad/lined steel	Root [8)] Up to 3 mm from inside surface, and up to 1.5 mm above clad/liner thickness for clad/lined steel	Height: max. 1 mm, the lesser of a third of clad/liner thickness and 1 mm for clad/lined steel;	Length: t, but max. 25 mm
	Surface	Height: the lesser of 1 mm and 0.2 t	Length: t, but max. 25 mm
	Embedded [6)] At least 3 mm from inside surface, and at least 1.5 mm above clad/ liner thickness for clad/lined steel	Height: the lesser of 3 mm and 0.2 t	Length: 2t, but max. 50 mm

Cracks are not permitted.
Porosity 9) Accumulated length of porosity signals exceeding a threshold 12 dB below the PRL in the volumetric channels: For single layer welds: 1.5% of the full circumferential length. For multi layer welds 3 t, max 100 mm in any 300 mm of weld length. Isolated pores shall be evaluated as planar imperfections.
1) Planar defects interaction shall be assessed according to the criteria of BS 7910. Interacting planar defects shall be attributed equivalent defect dimensions according to BS 7910, and the effective defects so obtained shall meet the above acceptance criteria. 2) Imperfections above threshold in any intersection of the weld, which are located at the weld bevel of the same side as the intersection, are not permitted. 3) Systematic imperfections that are distributed at regular distances over the length of the weld are not permitted even if the size of any single imperfection meets the requirements above. 4) Acceptance criteria of Table D-4 shall also be satisfied. 5) This table is not applicable for C-Mn and low alloy steels in sour service. 6) If an embedded defect is located close to a surface, such that the ligament height is less than half the defect height, the ligament height between the defect and the surface shall be included in the defect height, and the defect shall be considered as a root or surface defect, as applicable. 7) POD and sizing accuracy of the AUT system shall be according to [E.5.4.1]. 8) The Probability of Rejection (PoR) for a 1 mm high imperfection shall be qualified to be higher or equal to 85% at 95% confidence level. 9) Any addition of gain from PRL during scanning shall be added to the threshold

E.6 Re-examination of welds

E.6.1 General

E.6.1.1 Welds shall be re-examined whenever any of the following occur:

Sensitivity

E.6.1.2 Welds examined at a sensitivity outside ± 2 dB from the PRL shall be re-examined.

Coupling loss

E.6.1.3 Welds exhibiting a loss of acoustic coupling over a circumferential distance which exceeds the minimum allowable defect length as derived from applicable acceptance criteria, shall be re-examined. If the coupling loss still persist and cannot be resolved after cleaning/brushing the surface, then the affected area of weld may be subjected to Manual UT assessment and any other channels generated by separate probes (i.e. TOFD) if these channels are considered not affected.

Out of calibration

E.6.1.4 If a verification scan shows that the system is in any way out of calibration, all welds examined since the last successful verification scan shall be re-examined.

E.7 Evaluation and reporting

E.7.1 Evaluation of indications

E.7.1.1 Indications from weld imperfections shall be evaluated against the defect acceptance criteria.

E.7.1.2 The AUT procedure shall describe the methodology to determine indications height, depth and length sizing. This includes rules to account for over trace and beam spread correction. All information available shall be used in the evaluation to avoid under-sizing, - and excessive over-sizing of imperfections.

E.7.1.3 Indications recorded from sources other than weld imperfections shall be evaluated. Their nature shall be clearly identified in the examination report.

E.7.1.4 All evaluations shall be completed immediately after examination of the weld.

E.7.2 Examination reports

E.7.2.1 The examination results shall be recorded on a standard ultrasonic report form. The reports shall be made available on a daily basis or on demand.

E.7.2.2 The following items are as a minimum to be reported for each indication found to be not acceptable:

— project reference
— pipeline identification
— weld identification/number
— date
— ultrasonic procedure number with associated revision
— circumferential position of indication
— height, depth and length of indication
— transverse location of imperfections/indications (US, DS, Central)
— maximum amplitude for each reported indication
— indication type.

E.7.3 Inspection records

E.7.3.1 The following inspection records shall be provided:

— a hard copy record of each weld examined
— an assessment of the weld quality according to the acceptance criteria
— hard copy records of all calibration scans
— examination data in electronic form.

E.7.3.2 In lieu of hard copy records an alternative recording media is acceptable. Where weld interpretation has been performed using digitally processed signals, the data files shall be stored and backed up immediately following

the examination of each weld. The stored data shall be in the same format as used by the operator to assess the acceptability of welds at the time of examination.

E.7.3.3 If agreed, a software package and one set of compatible hardware shall be provided in order to allow the weld data file to be retrieved in the same manner as the operator viewed the data at the time of inspection.

E.8 Qualification

E.8.1 Scope and qualification

E.8.1.1 Automated ultrasonic systems used for linepipe girth weld inspection shall be qualified and the performance of the system shall be documented.

For applications other than carbon steel girth weld examinations, specific requirements can apply and should be agreed upon.

Prior to project use, any qualified AUT system shall be subject to project specific AUT validation if the system is within the qualified range of validity, as specified in [E.9]. The scope of AUT validation shall be in accordance with [E.9]. A reduced scope of validation may be agreed for welds exposed to nominal strains < 0.4%, but shall comprise at least 12 imperfections, including minimum 3 observations for each group (ID Surface, fill, OD Surface) and/or critical imperfection type.

E.8.2 General

E.8.2.1 The AUT system shall be qualified according to DNVGL-RP-F118 for the applications it is intended used for. The qualification shall be based on the required performance as identified by the requirements for Probability of Detection (PoD) and sizing ability; or, alternatively a requirement to defect rejection.

E.8.2.2 The qualification is AUT system specific and shall only be valid when all essential variables remain nominally the same as covered by the documented qualification. This standard does not require a new qualification to be performed provided that the documented performance i.e. PoD and sizing ability meets or exceeds the requirements for the specific application being considered.

E.8.2.3 Qualification involves a technical evaluation of the AUT system and application in question combined with any required practical tests.

E.8.2.4 The qualification shall be based on a detailed and agreed qualification programme, that covers the following:

— Qualification objective, i.e. materials, weld process, groove geometries and performance requirement (PoD and Sizing accuracy).
— Details of trials to establish and document environmental and application related tolerances such as temperature consistency, beam and focal law consistency, mechanical stability and electronic interference sensitivity.
— Details of reliability trials and trial welds, including trial weld seeded imperfection map.

E.8.2.5 The agreed qualification programme and its implementation shall be supervised and endorsed by a recognised and competent independent 3rd party.

E.8.2.6 The requirements in this section are applicable for the following types of qualification programs:

— Full scale qualification program aimed to quantify probability and sizing accuracy of an AUT procedure to document fitness for purpose for a specific application;
— Pre qualification to document the capabilities of an AUT procedure prior to employment on specific applications.
— When required by fitness for purpose approach to define AUT acceptance criteria by ECA.

E.8.2.7 A qualification methodology document shall be established and agreed upon by all involved parties upfront qualification.

E.8.3 Scope

E.8.3.1 A qualification programme shall document the following:

— fulfilment of the requirements to AUT systems according to this appendix
— the repeatability of the AUT system under variable examination conditions
— the sensitivity of the AUT system to the temperature of tested objects
— the ability of the AUT system to detect defects of relevant types and sizes in relevant locations
— the accuracy in sizing and locating imperfections.
— correct functioning of automated features and interpretation driven by software.

E.8.4 Requirements

Detection

E.8.4.1 The detection ability of an AUT system shall be deemed sufficient if the probability of detecting a defect of the smallest allowable height determined by an Engineering Critical Assessment (ECA) or by other considerations is 90% shown at a 95% confidence level (i.e. a 90%|95% PoD).

Sizing accuracy

E.8.4.2 Sizing accuracy shall be established during the qualification programme. For this purpose it is required to demonstrate the accuracy over the range of expected imperfection sizes. Based on the determined sizing errors, the under sizing error tolerances giving less than or equal to 5% probability of under sizing shall be determined and used in relation to any ECA specified defect sizes.

No specific tolerance is required for over sizing of indications. Over sizing of indications should however be within reasonable limits since excessive oversizing will result in unnecessary repairs during pipeline construction. A systematic over sizing, i.e. over sizing on average, of 0.8 mm or above shall lead to investigations and corrective actions to reduce the over sizing in the affected parts of the AUT set-up.

Rejection

E.8.4.3 The detection criterion of [E.8.4.1] and the undersizing tolerance specified in [E.8.4.2] may be combined into one rejection criterion: There shall be more than 85% probability of rejecting a defect, which is not acceptable according to determined ECA criteria. This shall be shown at a 95% confidence level, i.e. a Probability of Rejection (PoR) of 85%|95% is required. This rejection criterion approach may be preferable when the two step process detection-sizing is not followed, e.g. when acceptance or rejection is based directly on echo amplitudes, or solely on AUT reported imperfection sizes.

E.8.4.4 The AUT system shall be deemed unqualified for its purpose with respect to ECA determined non-acceptable defects if it is not possible to document adequate detection and sizing abilities according to [E.8.4.1] and [E.8.4.2], or adequate rejection abilities according to [E.8.4.3].

E.8.5 Variables

E.8.5.1 Variables, which shall be taken into account during a qualification, include, but are not necessarily limited to:

— welding method and groove geometry
— welding consumables (Distinction is made on materials with substantially differences in ultrasonic response, for instance between C-Mn, 13% Cr, duplex or austenitic steels)
— base material (Distinction is made on materials with substantially differences in ultrasonic response, for instance between C-Mn, 13% Cr, duplex or austenitic steels).
— wall thickness limitations

— pipe diameter limitations
— temperature consistency
— root and cap channels transducer set-up
— transducer set-up for other channels (the number of these channels may be increased or decreased provided there are no set-up changes)
— focal law design procedure (Phased array probes only)
— reference reflectors
— system, data acquisition and data treatment
— software version (except changes affecting viewing or display only)
— AUT operator/interpreter training and qualification.
— inspection sensitivity in longitudinal seam area
— interpretation methodology
— for CRA applications: clad thickness, pre-existing imperfections in clad layer, type of clad layer and clad material.

E.8.6 Qualification programme

General

E.8.6.1 A full qualification programme for a specific application of an AUT system will in general comprise the following stages:

1) Review of the technical documentation of the AUT system
2) Review of the operating methodology for the AUT system
3) Review of the quality assurance system for development, verification, maintenance and operation of the AUT system.
4) Review of available performance data for the AUT system.
5) Evaluation and conclusions based on the information made available.
6) Identification and evaluation of significant parameters and their variability.
7) Planning and execution of a repeatability test programme, see [E.8.8.5] and [E.8.8.6].
8) Planning and execution of a temperature sensitivity test programme, see [E.8.8.7] and [E.8.8.8].
9) Planning and execution of a reliability test programme, see [E.8.8.9] and [E.8.8.10].
10) Documentation of results from the repeatability and reliability test programmes.
11) Reference investigations by supplementary NDT and destructive testing.
12) Evaluation of results from repeatability, temperature sensitivity and detection ability and sizing accuracy trials.

E.8.6.2 The extent of the qualification programme will reflect the range for which the AUT system is intended to be used, as described in the general AUT procedure.

E.8.6.3 Practical tests of the AUT system is a requirement. Information pertaining to these practical tests is given in [E.8.8].

For a full qualification historical qualification data, in compliance to the requirements of [E.8.7] and [E.8.8], can be utilised if these data can be clearly identified and supported with all relevant documentation. However the minimum amount of new data shall at least represent 50% of the total minimum required qualification observations according to [E.8.7.4]. It shall be noted that once undergone a full qualification, the results are valid as historical data for use according to this standard on similar configuration, see [E.10.1.1]. Validity for specific configurations can be documented through validation scopes including a limited number of defective welds and defects if deemed relevant.

E.8.6.4 Functioning of software modules that performs automated considerations with impact on the inspection performance shall be demonstrated. Either by manufacturing and testing of suitable test blocks or by designing the scope of defective welds such as the functionality will be demonstrated during reliability trials. Automated AUT scan interpretation algorithms will be sufficiently documented by the scope of reliability trials described in this sub-section, and does not require specific trials. Function demonstration of software module for automatic compensation of wall thickness variations requires a test piece where the full wall thickness range is represented.

E.8.7 Test welds

E.8.7.1 Qualification testing shall be performed using test welds containing intentionally induced imperfections typical of those expected to be present in welds produced with the welding methods to be used. The preferred method for seeding intentional imperfections is by varying welding process parameters to induce natural imperfections. However, machined imperfection techniques may substitute 70% of the total number of imperfections in each imperfection group. See Table E-3. Hence a minimum of 30% natural imperfections shall be part of the data population.

Machined planar imperfections shall be positioned and oriented at the weld fusion line. Machined imperfection techniques shall not be used to produce ID and OD surface breaking imperfections due to the similarity to the reference reflector for these channels. Small depth machined surface breaking imperfections, <0.5 mm, can be accepted upon agreement between all involved parties.

E.8.7.2 The material and the weld geometry shall be as for the actual use of the equipment. Minor variations to for instance the weld root groove, which are regarded irrelevant in relation to the AUT system, may be acceptable.

If repair welds are to be covered by the qualification, a representative selection of these should also be included.

E.8.7.3 The intentionally introduced imperfections shall vary in length, height and location. Too close spacing and stacking of the imperfections shall be avoided. Due to the POD analysis requirement, it is required also to include sizes which are smaller than, or around those expected using anticipated AUT threshold settings. If a POR analysis shall be performed, imperfections of vertical sizes below the rejection threshold is required. For the height sizing analysis, it is required to include some imperfections with sizes around the critical imperfection sizes in Table E-1 and E-2.

E.8.7.4 As a minimum 29 imperfections, or ultrasonically independent parts of imperfections, is required for each group of imperfections. Ultrasonically independent parts of imperfections are those several beam widths apart. In order to show sufficient detection ability (90% POD) at the required confidence level (95%) the number of imperfections and their variation in imperfection types and location is referenced in Table E-3.

E.8.7.5 The locations where imperfections were intentionally induced shall be recorded. The presence and sizes of the induced imperfections in the test welds shall be confirmed as soon as possible after completion. For this purpose the test welds shall be subject to supplementary NDT. For carbon steel applications, this includes as a minimum independent TOFD inspection for buried imperfections, supplemented by PA-UT or manual UT to cover the ID and OD surface areas. In addition, radiographic testing and any surface technique (MT, ET) might be performed. For CRA applications, radiographic testing of the test welds shall be performed. The reference point for all testing shall be the same and shall be indicated by hard stamping on the test welds. The techniques used for this testing shall be optimised for the weld geometries in question. If agreed by all parties, the AUT system to be qualified can be used for verification of quality of the seeded defective welds.

E.8.7.6 The report from the supplemental NDT shall identify the actual imperfections present in the test welds with respect to circumferential position, length, and height. The required number of observations for the agreed scope of qualification, i.e. according to number and distribution provided in Table E-3, shall be confirmed by supplemental NDT. Additional test welds shall be made if the number of confirmed imperfections does not fulfill the requirements. The report shall be kept confidential.

Table E-3 Numbers of deliberate imperfections for AUT qualification

			Zonal discrimination, Cs-steel		
Imperfection type group	*General requirements*[4]	*Clad and weld overlay CRA*	*J-Bevel*	*V-Bevel*	*X-Bevel*
ID Surface[1,2,6,9]	29	29	29	29	29
Hot Pass Zone[1,5]		29	29		
Buried[1,7]	29	29	29	29	29
OD Surface[1,3,8]	29	29	29	29	29
Volumetric[10, 11]	2	4	2	2	2
Other	Slag inclusion: 2 Inter-run LOF: 2		Inter-Run LOF: 2	Slag Inclusion: 2 Inter-run LOF: 2	Slag inclusion: 2
Total	93	120	120	93	91

1) Shall be planar imperfections relevant for the weld in the specific area
2) Shall also encompass subsurface imperfections with bottom part maximum 2 mm from ID surface. Does not apply to X-bevel
3) Shall also encompass subsurface imperfections with bottom part maximum 5 mm from OD surface. Does not apply to X-bevel
4) Applicable to all applications not specified elsewhere in this table
5) Hot pass area refers to particular weld bevel geometry for the hot pass with J-bevel. For CRA clad and weld overlay applications the hot pass area covers the embedded parts of the CRA layer at the ID surface and the transition zone between CRA layer and backing pipe.
6) Applicable for X-bevel: OD surface group is encompassing the cross-section from OD surface to one welding pass above the root region. This group shall include surface breaking imperfections and min 10 sub surface imperfections with bottom part maximum 5 mm from the root.
7) Applicable for X-bevel: Fill group is encompassing the root/cross penetration area. Imperfections shall be located at the cross penetration including areas where a shift in groove geometry is made.
8) Applicable for X-bevel: ID surface group is encompassing the cross-section from ID surface to the root region. shall include surface breaking imperfections and min 10 sub surface imperfections.
9) ID surface Imperfection group in CRA clad and weld overlay shall include imperfections with heights <1.0 mm.
10) Volumetric type shall include Cluster porosity or scattered porosity, and minimum 1 copper inclusion when relevant for the welding process.
11) Cluster porosity and copper inclusions shall not be included in the PoD analyses, but are included to demonstrate detection and recognition

E.8.8 Qualification testing

E.8.8.1 The testing described in the following is required for a full qualification. If validation testing is performed, the testing and documentation requirements given shall apply as applicable to the actual testing performed.

E.8.8.2 The test welds shall be subjected to testing by the AUT system.

For testing, a low echo amplitude recording threshold shall be used. This threshold should be selected somewhat above the noise level. PoD analysis will determine the actual detection capability and shall be expressed as the smallest detectable flaw height at 90/95% PoD at the agreed reporting threshold.

E.8.8.3 The reference point for circumferential positioning shall be a hard stamped on the test welds.

E.8.8.4 The AUT system shall be set-up, calibrated and subject to test runs before starting the formal qualification.

Repeatability testing

E.8.8.5 The testing shall include:

— one initial scan of the calibration block in the horizontal (5G) position
— minimum 10 scans of the calibration block(s) in the 5G position with the centre of the calibration block(s) in the 12 o'clock and 6 o'clock positions
— if relevant for the application of the AUT system, series of 3 consecutive scans shall be repeated with the calibration block(s) in the vertical (2G) position and/or in the 45º (6G) position.

E.8.8.6 All scans shall be given a unique number and the documentation of the test scans shall include:

— hard copy and electronic output of all scans
— a table for repeatability test scans showing for each scan the maximum amplitude response of each transducer to its dedicated calibration reflector and the deviation for each scan from the initial calibration scan.

Temperature sensitivity testing

E.8.8.7 The test welds shall after the initial scans be heated to the elevated temperature expected during field inspection. Typical test welds containing at least 6 clearly identifiable and distinct AUT indications each shall be used for scanning with the pipe axis in the horizontal position. Clearly identifiable indications shall include 2 root/ID indications, 2 embedded indications and 2 OD indications. The calibration block(s) shall be kept at environmental temperature or be heated to an agreed temperature and maintained at this temperature during scanning. The temperature of the heated weld shall be logged and reported for each scan, in addition the ambient temperature shall be logged.

The testing shall include:

— one initial scan of the calibration block
— one initial scan of the non-heated weld
— one scan of the heated test weld immediately followed by a scan of the calibration block(s)
— within 5 minutes repeat one scan of the heated test weld immediately followed by a scan of the calibration block(s). Repeat this sequence for at least 15 cycles.

If the AUT system shows unacceptable temperature sensitivity the test can be repeated with agreed different test conditions.

E.8.8.8 All scans shall be given a unique number and the documentation of the test scans shall include:

— hard copy and electronic output of all scans
— a table for the temperature sensitivity test scans of the defective weld showing the maximum amplitude response and AUT sized height for each identified indication for each scan.

Detection ability and sizing accuracy testing

E.8.8.9 The test welds shall be scanned with the pipe axis horizontal.

The scanning directions identified as clockwise or counter clockwise (CW or CCW) shall be hard stamped on the test weld. The calibration block shall be in the least favourable position as determined by the repeatability testing. See [E.8.8.5]. The welds shall be scanned and all indications above defined thresholds shall be evaluated.

The testing shall include:

— one initial scan of the calibration block
— one scan of the test weld in the CW direction

— one scan of the calibration block(s)
— one scan of the test weld in the CCW direction
— one scan of the calibration block(s)
— assessment and sizing of indications.

Scans in CCW direction requires the band to be moved to the opposite side of the weld compared to the CW direction scans. It is recommended that the full test programme described above should be performed twice, with two independent sets of operators.

E.8.8.10 All scans shall be given a unique number indicating weld number, the scan sequence and the scanning direction and the documentation of the test scans shall include:

a) hard copy and electronic output of all scans
b) imperfection/indication number with reference to sizing method and for each imperfection/indication the dimensions:

    — circumferential position
    — length
    — height
    — depth to bottom of indication
    — transverse location of imperfection/indications (US, DS, C(entral))
    — maximum amplitude for each scan and variations in maximum amplitude between scans
    — main AUT zone
    — imperfection type.

It may further be required to report height, location, depth and echo amplitude at certain additional local defect positions (see also [E.8.7.3]).

In addition the following information shall be provided:

— weld identification
— pipe material
— pipe thickness/diameter
— welding method
— groove geometry
— calibration block documentation.

Verification of coupling alarm settings

E.8.8.11 Scans shall be performed on different test welds. The couplant flow shall be reduced and the surface wiped dry between scans until the coupling alarm level/coupling monitor channels indicates loss of return signal. The level at which the coupling alar/coupling monitor channels indicates loss of return signal shall be recorded. The final level for coupling alarm/coupling monitor channels settings shall be at least 4 dB lower than the recorded value.

E.8.8.12 Band offset sensitivity trial The tolerance on band offset sensitivity shall be documented through repeated scans of a defective weld. The tolerance might vary for different AUT procedures. Zonal discrimination AUT procedures shall be qualified for a band offset variation of minimum ±1 mm. For other inspection concepts, for instance multishoot Phased array and ultrasonic imaging, larger band offset tolerances should be qualified to a tolerance to minimum ±3 mm. The testing shall include

— one initial scan of a defective weld with no band offset
— minimum 3 scans of a defective weld with the band offset 1 mm or 3 mm to the DS side
— minimum 3 scans of a defective weld with the band offset 1 mm or 3 mm to the US side
— The defective weld selected for the band offset scans shall include at least 6 imperfections, and contain at least 1 imperfection in each the cap, root and fill areas.

E.8.9 Reference destructive testing

E.8.9.1 The reports from the AUT qualification testing shall be validated for accuracy in the determination of imperfection circumferential position, length, height and depth by reference destructive testing.

E.8.9.2 The testing shall be by cross-sectioning, preferably by the salami method, by making more cross-sections around each location chosen. The imperfections as reported in the AUT reports shall be used when selecting the areas for cross-sectioning.

In addition, locations where the AUT shows indications near the agreed reporting threshold level, locations where indications are identified by the supplementary NDT (see [E.8.7.5]), locations where intentionally induced imperfections were planned but not reported and randomly chosen locations shall be included.

E.8.9.3 Mark-up of welds should be performed using the AUT scanner. Each position for a cross-section should preferably be hard stamped close to the weld cap, consistently at the same side (US or DS) for the whole weld. Cross-section indication number and clockwise scanning position should be hard stamped for each position. Alternatively, reports from Immersion UT can be accepted for weld macro location mark-up if agreed between all parties. Immersion UT shall be performed in accordance with the guidelines of DNVGL-RP-F118.

E.8.9.4 The cross-sections shall be referenced to and validated against the recording chart positions.

E.8.9.5 The weld sections containing imperfections shall be machined in increments of maximum 2.0 mm. Each machined cross-section of the weld shall be polished with 800 grit and etched and the imperfection location, height and depth measured with accuracy better than ± 0.1 mm.

E.8.9.6 Each cross-section shall be documented by a photograph with 5 - 10x magnification, and the photograph shall include:

— Weld number
— Specimen number
— Imperfection/indication number
— Circumferential position
— US and DS side of the weld
— A millimetre reference scale.

E.8.9.7 Destructive testing shall be in accordance with ISO 17639. The extent of macro sectioning shall include:

— Sufficient locations so the requirements to minimum number of imperfection observations in different weld areas and of different types as provided in Table E-3 are fulfilled. Each independent observation shall be from an independent weld imperfection.
— Imperfection of sizes around the critical imperfection heights provided in Table E-1 and/or Table E-2
— For determination of detection and sizing capabilities the position of a clearly defined local or total maximum height of the imperfection, as defined by AUT, shall be selected for salami cross-sectioning.
— Areas where the AUT shows indications near or below the agreed reporting threshold level shall be selected for sectioning.
— Areas with single imperfection indications at weld bevel should be preferred as cross-section positions. Stacked imperfections should be avoided.
— Areas of uniform imperfection height should be the preferred positions for cross-sectioning.
— Minimum 1 imperfections from each of the main imperfection groups according to Table E3 (i.e. ID surface, buried, OD surface, volumetric) shall be macro sectioned at ends for length sizing accuracy evaluation. Macro sectioning shall start at least 5 mm from each end of the imperfection as defined by AUT and the applicable recording threshold, and continue until no indication of the imperfection can be found at the macro.

— If the supplementary NDT indicates presence of imperfections not identified in the AUT reports, these areas shall also be selected for sectioning.
— Areas without any observations from supplementary NDE or AUT shall be randomly subject to sectioning. If IUT has been performed this requirement can be omitted.

E.8.9.8 The position of maximum imperfection height shall be the location for cross-sectioning at each selected AUT indication. The tool used to mark the reference line should facilitate an accuracy in marking of ± 0.5 mm or better.

E.8.10 Analysis

Repeatability

E.8.10.1 The data from the repeatability test programme shall be analysed with respect to system repeatability and stability. The maximum deviations in amplitude from each reference reflector between the initial scan and the scans performed with each calibration block position shall be determined.

The acceptable variation in amplitude on repeated calibration block scans is ± 2 dB. For band offset scans on defective welds, the same ± 2 dB criteria can be applied for maximum channel amplitude variations or variations in sized defect heights can be evaluated. For the latter approach, the variation in sized defect heights shall not exceed ± 1 mm when used with workmanship acceptance criteria, or alternatively exceed the sizing inaccuracy allowance subtracted from the ECA derived acceptance criteria.

Temperature sensitivity

E.8.10.2 The data from the temperature sensitivity test programme shall be analysed with respect to the influence of temperature build-up in the transducers over time. The maximum variations in amplitude from each selected indication between the initial scan and the scans performed with heated test weld shall be determined.

Based upon an acceptable variation in amplitude of ± 2 dB or in height sizing not exceeding the sizing accuracy derived at the analysis described in paragraph [E.8.10.3], the analysis shall determine the:

— acceptable maximum temperature of welds
— the sum of transducer inactive time on weld and scanning time
— the minimum time between scanning of hot welds
— the maximum temperature difference between weld and calibration block.

Detection ability and sizing accuracy

E.8.10.3 The data recorded during the tests and reference investigations shall be analysed with respect to:

— accuracy in height sizing (random and systematic deviation, and 5% fractile)
— accuracy in length sizing
— accuracy in imperfection depth estimate and ligament determination for sub-surface imperfections within 5 mm from ID and OD surfaces
— AUT imperfection characterisation abilities compared to the results of the destructive tests and the other NDT performed
— as relevant, determination of PoD/PoR values or curves for different assumed echo amplitude or other employed threshold settings to determine the threshold to be used during examination.

E.8.10.4 The analysis shall be performed by recognised and applicable statistical methods, e.g. according to Nordtest NT Techn. Report 394 (Guidelines for NDE Reliability Determination and Description, Approved 1998-04). The omission of any reported indication in the analysis shall be justified.

E.8.10.5 Reference imperfection height used in the analysis shall be the maximum height identified by macro sectioning for each observation.

E.8.11 Reporting

E.8.11.1 A qualification report shall as a minimum contain:

— a technical documentation of the AUT system
— outcome of the technical evaluation of the AUT system according to this appendix
— description of the specimens and tests performed, including sensitivities used
— definitions of the essential variables (see [E.9.2]) for the welds and equipment used during qualification testing
— data recorded for each imperfection and each imperfection cross-section (sizes, locations, types, measured and determined during reference investigation, echo amplitudes)
— outcome of the analysis of data ([E.8.10])
— justification of any omission of destructive data from analysis
— conclusion of the qualification
— Range of validity of the essential parameters listed in paragraph [E.10.2.1].

E.9 Project specific automated ultrasonic testing procedure validation

E.9.1 Scope

E.9.1.1 Project specific AUT procedure validation shall be performed in order to demonstrate that the project specific AUT procedure can accomplish the qualified performance capabilities, provided that all essential variables remain within reason equivalent to what has been pre-qualified. The scope of project specific validation shall be detailed in a document, which shall provide justification for that the essential variables of the procedure are within reasonable equivalency to referenced pre-qualification.

E.9.1.2 For a project with multiple pipe sizes and bevel geometries, etc., it shall be regarded as sufficient if the validation program is conducted on pipe sizes that may present more AUT challenges, provided that the pipe configurations are covered by the same pre-qualification status. The selected pipe sizes are to be agreed to by the involved parties.

E.9.1.3 If software upgrade not impacting data collection and signal processing is foreseen prior to production after validation program, software equivalence shall be verified.

E.9.1.4 In case one or several essential variables as listed in [E.8.5.1] are outside the pre-qualified range of validity, the validation scope shall comprise welds with at least 29 deliberately induced imperfections for the affected weld configurations. The variables that are identified to be outside the range of validity has to be addressed in the validation scope.

E.9.1.5 For fatigue sensitive welds when acceptance criteria Table E-2 is applicable, the validation scope shall comprise welds with at least 29 deliberately induced imperfections.

E.9.1.6 When the project specific pipe configurations are covered by the range of validity of the pre-qualification, the validation scope shall comprise minimum 12 imperfections, including 3 observations for each group (ID surface, fill, OD Surface and volumetric).

E.9.1.7 A project specific AUT procedure validation shall consist of the following minimum activities:

— Review of project specific AUT procedure including any pertaining ITP, cal block design reports (WPS), AUT set up files and project specific AUT acceptance criteria including supporting ECA or fatigue reports.

— A compliance assessment of the proposed project specific AUT procedure and AUT system qualification results and pre requisites.
— Verification of hardware and software including calibration block fabrication tolerances.
— Verification of AUT set up on relevant calibration block.
— Review deliberately induced defective weld plan and verify that welds are made with relevant process and geometries.
— Perform supplementary NDT as per clause [E.8.7.5].
— Perform AUT inspection on deliberately defective welds.
— Perform weld evaluation at relevant interpretation/reporting threshold, report imperfection height, depth and length.
— Destructive testing of agreed number of observations.

E.9.1.8 One defective weld, similar to and additional to the validation welds, shall be made available for AUT setup adjustments and fine-tuning upfront the AUT validation trials. This weld shall not be used as a part of any of the AUT validation trials.

E.9.2 Assessment

E.9.2.1 The performance requirement i.e AUT system capabilities in terms of PoD and sizing accuracy shall be verified adequate in relation to the smallest allowable weld imperfection permitted by either ECA/fatigue analysis derived acceptance criteria or other quality standard description. If the AUT system performance results as concluded in the AUT system qualification are not in compliance with the project specific demands then this situation shall lead to a new qualification as per this document.

E.9.2.2 Performance of the AUT scanning shall be conducted at ambient temperature unless otherwise agreed and at project specific reporting threshold in compliance with pre requisites given by the AUT system Qualification report. Scanning shall be performed with nominal band setting unless otherwise agreed. Reverse scanning shall be performed unless otherwise agreed. All relevant AUT indications exceeding noise level shall be reported on a suitable format containing all relevant signal information.

E.9.2.3 The number of locations for destructive testing shall be agreed upon between all involved parties, and shall as a minimum include 12 independent locations for all project pipe configurations covered by the same AUT pre-qualification. The minimum number of independent locations is 29 if the pipe configurations are not fully covered by the AUT pre-qualification. The selection criteria shall be as follows:

Imperfection indications exhibiting dimensions equivalent or larger than the AUT system PoD but smaller or equivalent to the project specific smallest allowable imperfection as identified in the project specific acceptance criteria adjusted for sizing accuracy.

The type and distribution of defect types, including sizes, shall be typical for the welding methods and weld groove geometries the AUT system is to be qualified for.

E.9.2.4 One volumetric indication shall be included for verification.

E.9.2.5 Reference block repeatability trials shall be evaluated according to paragraph [E.8.10.1].

E.9.2.6 Band offset trials shall be evaluated according to paragraph [E.8.10.1].

E.9.2.7 AUT setup symmetry shall be evaluated according to paragraph [E.8.10.5].

E.9.2.8 A summary report containing all collected data shall be prepared and a comparison between supplementary NDT, AUT and macro section data shall be made. Evaluation of sizing accuracy according to clause [E.8.4.2] shall be performed.

E.9.2.9 Based on validation results, acceptance of AUT system for project use and Imperfection undersize correction used for ECA correction shall be justified. The justification shall include all observations of performance outside the pre-qualified results. When the justification is accepted by all parties, the project specific AUT procedure shall be regarded as validated.

The purpose of the validation is not to perform a PoD analysis but to verify that the project specific AUT procedure capability is adequate for detection of the smallest project specific critical defect.

E.9.2.10 Detailed project specific AUT set-up shall be reported in a specific document. It shall contain all the necessary information to allow all involved parties to check that the set-up is strictly similar for the production phase.

E.10 Validity of qualification

E.10.1 Validity

E.10.1.1 A qualification is AUT procedure and system specific.

Upon successful completion of the qualification scope it is assumed that the AUT system will remain qualified within the range of qualification for an infinite time period provided that the AUT system remains virtually unchanged, i.e. with no changes that are judged to have an impact on the performance parameters.

E.10.1.2

AUT Qualification conducted on larger diameter and heavier wall thickness pipes shall not be regarded as valid for AUT examination of weld dimensions with OD below 4" OD and/or when wall thickness is below 8.0 mm.

Guidance note:

Girth welds of small diameter and/or thin wall thickness pipes can provide limitations for efficient inspection with AUT, and UT inspection in general. In particular low wall thickness configurations with corresponding acceptance criteria can be challenging for AUT with regards to accurate height sizing and depth positioning. AUT qualification or validation according to this appendix requirements is therefore required for dimensions when OD is below 4" OD and/or when wall thickness is below 8.0 mm, regardless of qualification status for larger diameter and heavier wall thickness pipes.

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E.10.2 Essential variables

E.10.2.1 The following essential variables apply:

— welding method and groove geometry (including repair welds, if relevant)
— root and cap transducer set-up
— wall thickness (wall thickness variation requiring any change in focal law set up, adding or removing legs.
— diameter (diameter variation requiring transducer curvature which may impact on length accuracy. Systems qualified on sample larger than 12” may not be readily qualified on smaller diameter. Beam profile and effect of transducer curvature shall be determined.
— base material and welding consumables (The distinction is made on materials with substantially differences in ultrasonic response, for instance between C-Mn, 13% Cr, duplex or austenitic steels.)
— transducer set-up for other channels (the number of these channels may be increased or decreased to accommodate changes in wall thickness provided there are no set-up changes)
— focal laws
— reference reflectors
— working temperature range
— system, data acquisition and data treatment
— software version (except changes affecting viewing, display or bug-fixing only).

E.10.2.2 Changes in the essential variables for an existing qualified system will require validation trials of the modified system, in order to demonstrate validity of the qualification results. Validation trials shall be according to [E.9].

E.11 Determination of wave velocities in pipe steels

E.11.1 General

E.11.1.1 The procedure defined covers methods that may be used to determine acoustic velocity of ultrasonic waves in linepipe steels. Equivalent methods may be used subject to agreement.

Linepipe used in oil and natural gas transmission exhibit varying degrees of anisotropy with varying acoustic velocities depending on the propagation direction with resultant changes in the refracted angle of the sound in the steel. This is especially critical where focused beams are used for zonal discrimination. It is thus required to determine the ultrasonic shear or longitudinal (as appropriate) wave velocity for propagation in different directions.

E.11.2 Equipment

E.11.2.1 To determine the wave velocity (shear or compression) directional dependency an ultrasonic wave transducer of the same frequency used in the inspection with a crystal diameter of 6 - 10 mm should be used in combination with an ultrasonic apparatus with bandwidth at least up to 10 MHz and a recommended capability of measuring ultrasonic pulse transit times with a resolution of 10 ns and an accuracy of ± 25 ns. Devices for measuring mechanical dimension of the specimens should have a recommended accuracy of ± 0.1 mm. As couplant an easily removable glue or special high viscosity shear or compression wave couplant (as appropriate) is recommended.

E.11.3 Specimens

E.11.3.1 A specimen is cut from a section of pipe to be tested and the corresponding results are specific for a particular pipe diameter, wall thickness and manufacturer. Specimen dimensions should be a minimum of 50 × 50 mm.

A similar arrangement can also be used for measuring velocities in a plane normal to pipe axis.A minimum of three parallel surfaces are machined for the plane to be evaluated; one pair of surfaces is made in the radial direction (perpendicular to the D surface) and the other pair made 20° from the perpendicular to the D surface, see Figure E-1. Additional pairs of parallel surfaces may be machined at other angles in the plane to be evaluated if more data points are desired.

The machined surfaces should be smooth to a 20 µm finish or better. Minimum width of the specimen surface to be measured should be 20 mm and the minimum thickness between the parallel surfaces to be measured should be 10 mm. Vertical extent of the test surface will be limited by the pipe wall thickness.

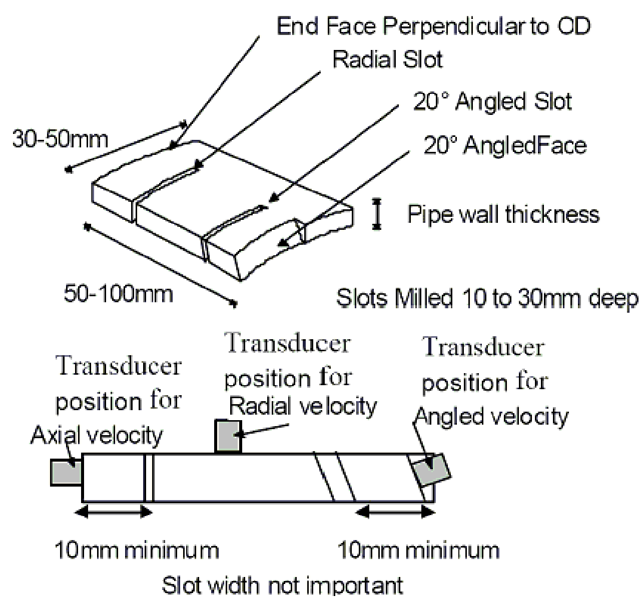

Figure E-1 Test specimen and transducer placement

E.11.4 Test method

E.11.4.1 Using the machined slots as reflectors for the wave pulses with the transducer in the appropriate positions and measuring the pulse transit times determines together with the mechanically measured pulse travelling distances the wave velocities in the axial and 20° direction (Figure E-1).

A similar measurement in the through thickness direction determines the radial velocity. Pulse transit times shall be measured between the faster reflection signals of 1^{st} and 2^{nd} back wall echo.

In case SAWH pipes are used, the velocity derived using the slower reflection signals of 1st and 2nd back wall echo shall also be determined. The mode with the highest signal-to-noise ratio shall be used as the sound velocity for the tested material.

A minimum of three readings shall be made for each plane in which testing shall be done.

E.11.5 Accuracy

Errors in velocity determination shall not be greater than ± 20 m/s.

E.11.6 Recording

Values for the velocities determined can be tabulated and graphed. By plotting velocities on a two dimensional polar graph for a single plane, velocities at angles other than those made directly can be estimated.

The effect of temperature on velocity can be significant under extreme test conditions; therefore the temperature at which these readings have been made should also be recorded.

APPENDIX F REQUIREMENTS FOR SHORE CROSSING AND ONSHORE SECTIONS

F.1 General

F.1.1 Objective

F.1.1.1 The objective of this appendix is to provide the complementary requirements to the shore crossing zone, including the onshore part of the submarine pipeline system compliant with the safety philosophy for the offshore part. This appendix specifies the requirements for design, construction and operation of parts of pipeline systems in the shore crossing zone.

This appendix is meant to assist the project execution of submarine pipeline developments where parts are going onshore.

Guidance note:

A submarine pipeline system always includes the shore crossing up to a point above the highest astronomical tidal water level plus storm surge and wave run-up. Thus, the engineering design, construction, operation and abandonment of the pipeline section at the shore crossing shall be undertaken in compliance with this offshore standard. The location of the code break between this offshore standard and the relevant onshore standard will usually differ for all pipeline systems depending on the site conditions and on the length of the onshore pipeline section. The presence of valves or isolation joints may also have an impact on where to select the code break. This implies that a, sometimes significant, part of the pipeline system can be located onshore. This part of the pipeline system may have different legislations, failure modes and failure consequences compared to the submarine part.

The exact limit of the submarine pipeline system at the onshore end may differ from this definition herein based on different statutory regulations which may govern.

Onshore standards or recommended practices may also take precedence of this part due to legislation aspects.

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F.1.1.2 The appendix also covers the requirements for the shore approach.

F.1.2 Scope and application

F.1.2.1 The limitations found in [E.8.8.8] are in general also applicable for this appendix.

F.1.2.2 The onshore section is limited by the definition of submarine pipeline system.

F.1.2.3 This appendix does not cover regular onshore pipelines, i.e. pipelines starting and ending onshore not having any submarine parts. River crossings or crossing of fresh water lakes are not considered as submarine sections.

Guidance note:

This appendix is not meant to replace current industry practice onshore standards or recommended practices or any national requirements.

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F.1.2.4 Specific requirements for the onshore parts given in this appendix overrule requirements given elsewhere in the standard.

F.1.2.5 At the shore crossing of a pipeline, the code break with the onshore standards or recommended practices should be defined on a case by case basis with consideration given to the following:

— The code break should occur immediately to one side of a pipe connection such as a weld, mechanical connector, or isolation joint, such that the connection itself falls under one code or the other.

— The application of multiple pipeline standards to the same section of pipeline (an overlap) should be avoided.
— There should not be a section of pipeline where no pipeline standard applies (a gap).

F.1.2.6 The code break for an open cut and cover shore crossing design should be defined on a case by case basis, once a sufficient level of engineering definition has been achieved, see . Consideration should be given to the:

— extreme low and extreme high water levels, and the length along the pipeline between them (extreme water level is that water level resulting from the design environmental event being a combination of tide, storm surge and wave run-up)
— system design aspects that may influence the code break;
— electrical isolation points
— beach valves
— pipeline construction method, such as;
— method of pipeline installation
— offshore to onshore tie-in weld or mechanical connector
— pre-commissioning requirements
— implications for design
— construction practicalities
— ongoing maintenance of the pipeline.

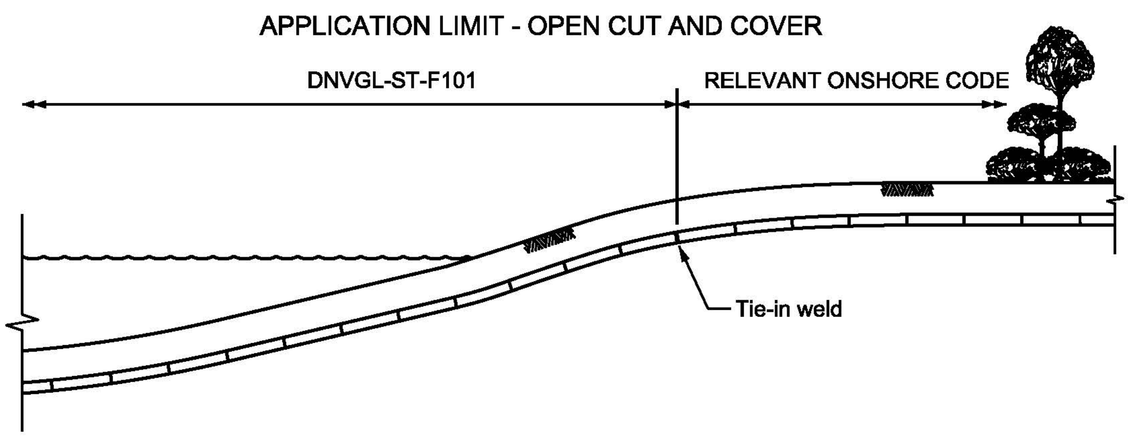

Figure F-1 Typical application of this standard and relevant onshore standards or recommended practices for conventional open cut and cover solution

F.1.2.7 The code break for a HDD shore crossing design should be at the onshore tie-in weld, assuming that a fabricated bend is introduced between the inclined pipeline section (installed by the HDD method) and the onshore pipeline section, see . However, deviation of this principle is possible, for instance, when the HDD section of the pipeline transitions to the onshore section of the pipeline in an elastic bend.

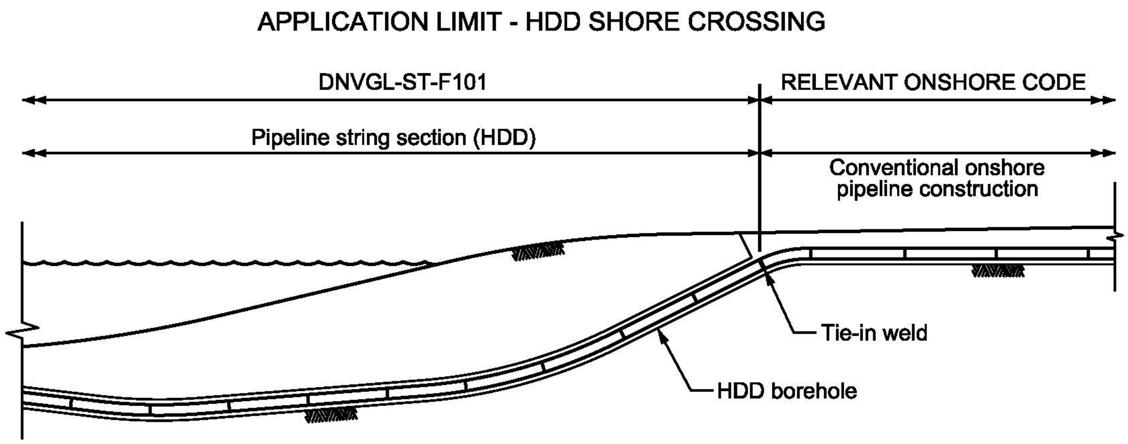

Figure F-2 Typical application of this standard and relevant onshore standard or recommended practice for HDD solution

F.1.2.8 The code break for a jetty-based shore crossing design should be at the first weld or mechanical connector between the riser and the pipeline section on the jetty. The relevant onshore pipeline standard should be applied to the pipeline section on the jetty.

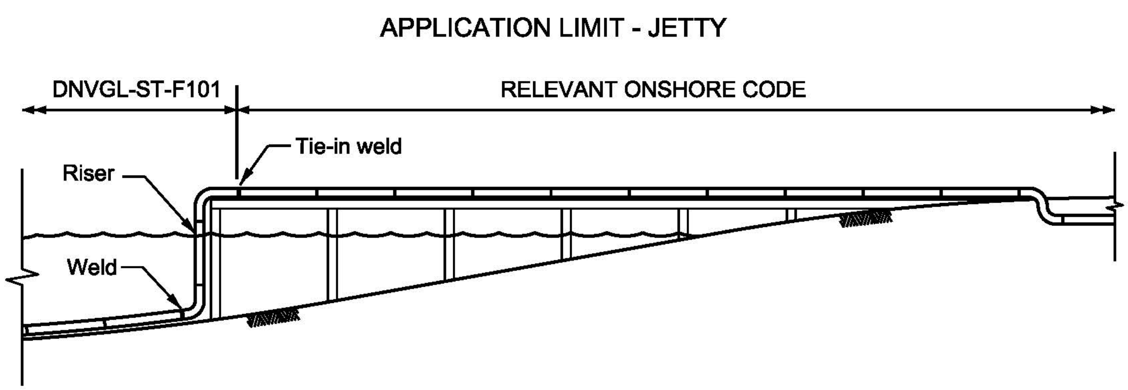

Figure F-3 Typical application of this standard and relevant onshore standard or recommended practice for jetty solution

F.1.2.9 A tunnelled shore crossing designs may or may not include a tie-in riser or metrology spool on the onshore side of the crossing, see . The location of the code break may differ, and could either be at the base (case 1) or at the top (case 2) of the riser/tie-in spool (Figure 1d). If there is no tie-in riser or metrology spool, then the code break should be at the onshore tie-in weld to the pipeline section installed through the tunnel.

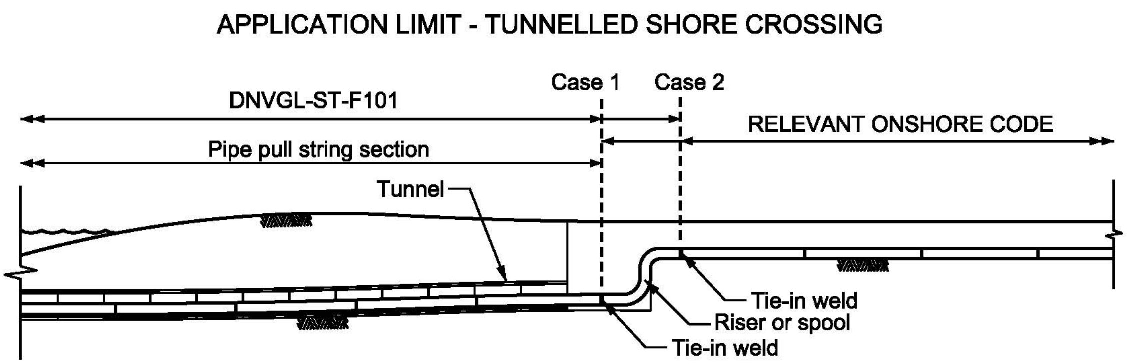

Figure F-4 Typical application of this standard and relevant onshore standards for tunnel solutions

F.1.2.10 Onshore pipelines are normally regulated by national regulations and cover a wide range of areas from public safety, traffic and roads, waterways, environmental impact, etc. Some of these regulations may be stricter than the requirements given in this standard and care shall be exercised when assuring compliance with different national regulations.

F.1.3 Other standards or recommended practices

F.1.3.1 This appendix is fully aligned with the requirements given in ISO 13623

Guidance note:

ISO 13623 requires a specific utilisation for shore crossing (landfalls). According to this standard the assessment of risk will constitute selection of safety class for each specific pipeline and pipeline sections. The safety class classification for a shore crossing will normally give the same utilisation as required by ISO 13623 however this does not always need to be the case. This implies that the utilisation at shore crossings may differ from the ISO 13623 requirements and care should be taken when stating compliance with ISO 13623 for a specific pipeline development.

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F.1.3.2 Onshore pipelines are normally regulated by national regulations and cover a wide range of areas from public safety, traffic and roads, water ways, environmental impact, etc. Some of these regulations may be stricter than the requirements given in this standard and care shall be exercised when assuring compliance with different national regulations.

F.1.4 Systematic review

F.1.4.1 The overall requirement to systematic review in Sec.2 shall be reflected in the concept development, design, construction, operation and decommissioning of the pipeline section at the shore crossing.

F.1.4.2 Typical potential threats at shore crossings, over and above those relevant to the other sections of the pipeline system, may include, but may not necessarily be limited to:

— congested areas (human population, tourism, industry, ports and harbors, existing pipelines, live hydrocarbon plants, and the like)
— environmentally sensitive areas (flora and fauna)

— heritage and cultural sites
— fishing and boating (recreational and professional)
— ship/plane wrecks and unexploded ordnances
— geohazards (e.g. eroding coastline, unstable cliffs, acid sulphate soils)
— surface and subsurface hydrology
— coastal geomorphology processes
— breaking waves and strong tidal currents
— long term still water level fluctuations
— seismic events and tsunamis
— Functionality of different cathodic protection systems, at the interface of the subsea and onshore pipeline sections
— cathodic protection current shielding from casings and tunnel pipes
— differences between onshore and offshore standards or recommended practices requirements
— bundled pipelines or pipelines in close proximity to each other (potential cathodic protection system interference, consequence of failure of one pipeline onto the others, inspectability, and the like)
— wetting and drying cycles from tidally driven water level fluctuations, and their impact on pipeline coating degradation, external corrosion and cathodic protection system functionality
— construction risk in relation to shallow water, hostile nearshore seastate, geotechnical conditions and novel construction methods
— design, construction and operational interface between onshore and offshore
— interface of potentially different regulatory regimes
— potential new infrastructure which may impact shoreline geomorphology processes
— external impact (vehicle impact, dropped objects, vessel grounding/beaching, and the like)
— axial expansion
— external coating wear and tear, during construction and during the operational life of the pipeline system
— security threats.

F.1.4.3 At a shoreline crossing where a code break occurs, the classification system may vary between the standards or recommended practices. In this case the standards or recommended practices should be assessed to determine the most appropriate way to manage the classification definition for the shore crossing.

F.1.4.4 The requirement for a beach valve should be subject to a risk assessment, which should consider the:

— requirements to isolate inventory of the onshore pipeline section from the offshore pipeline section
— risks associated with having a beach valve in the system.

F.1.4.5 The functional requirements for a beach valve should include, but not necessarily be limited to:

— onshore isolation integrity requirement
— type of valve and valve connection to the pipeline
— bleed valve vent requirements
— corrosion protection, protection from the elements, and earthing
— environmental impact and aesthetics
— accessibility and protection against security threats.

F.1.5 Definitions

F.1.5.1 Battery limit - the limit at which the scope of work ends. The battery limit can be different for designer, installation contractor, verifier and operators. Normally defined at as including or up to a certain weld.

F.1.5.2 Code break - the exact point at which the design standards or recommended practicees changes from submarine to onshore pipeline system. Normally defined at as including or up to a certain weld. This is often defined at the location of the first flange or valve onshore. Note that this may differ based on different statutory regulations.

F.1.5.3 First (or last) valve onshore - valve separating the offshore and onshore pipeline. Often the position of the battery limit and the code break. Often an emergency shut down valves (ESDV)

F.1.5.4 Isolation joint - a special component separating (isolating) the offshore cathodic protection from the onshore cathodic protection system and installed within the onshore part of the offshore pipeline. It is normally positioned very close to the high water mark as the offshore cathodic protecting system has limited protection capabilities when the pipeline is not submerged in water.

F.1.5.5 Shore crossing - the section of the pipeline which transitions between a permanently submerged (subsea) pipeline to a permanently dry (onshore) pipeline.

F.1.5.6 Near shore - the transition from the offshore pipeline to the shore approach area. Often not well defined, but can be the area in where the pipeline goes from laying on the sea-bed to being positioned in an open trench to where it is buried. Sometimes the extent of the areas is defined by the reach of the installation vessel or trenching equipment, and sometimes this area is given special attention by the fishing industry.

F.1.5.7 Onshore part of offshore pipeline - the first part of the pipeline on shore. It is distinct as the offshore design standard is still applicable, while the pipeline is not permanently submerged. The length is normally short, up to some kilometres.

F.1.5.8 Onshore pipeline - the pipeline on shore following onshore standard and normally subject to different authority regulations

F.1.5.9 Right-of-way – corridor of land within which the pipeline operator has the right to conduct activities in accordance with the agreement with the land owner.

F.1.5.10 Shore approach - the last part of the pipeline before it comes on shore. The need for burying the pipeline in the shore approach area should be evaluated and include:

— environmental loading (breaking waves, current and tide)
— requirements to a clean beach for recreation
— shipping activity or
— protection (reduced access by 3rd parties).

F.2 Safety philosophy

F.2.1 General

F.2.1.1 The design philosophy for the shore approach and the onshore pipeline shall comply with Sec.2. This implies that the consequences of failure (economical, environmental and human) shall be quantified by the concept of safety class. The safety class should be determined by fluid category, location class and phase (construction, operation) of the pipeline.

F.2.1.2 The presence of people and facilities necessitates a further refinement of the location classes used offshore. In highly populated areas the consequences may be more severe than for offshore, requiring a higher safety class, very high. These complementary issues are described in this sub-section.

Guidance note:

It should be noted that ISO 13623 contain even more stringent utilisation requirements than safety class very high. However, as this standard is meant to only cover onshore parts of an offshore pipeline system it is not foreseen that such a line will be located in areas with even higher population densities.

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F.2.2 Safety philosophy

F.2.2.1 The safety philosophy outlined in [2.2] is applicable for shore approach and onshore sections.

Guidance note:

In particular is it important to perform a systematic review of all hazards to identify consequences as third party presence is more significant onshore.

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F.2.2.2 The health, safety and environmental aspects outlined in [2.2] is applicable for shore approach and onshore sections also.

F.2.3 Quantification of consequence

F.2.3.1 Fluids shall be categorised in line with Sec.2 of this standard.

F.2.3.2 A location class shall be determined for each part of the pipeline as shown in Table F-1.

Table F-1 Location classes onshore

Location class	*Description*
1 (equivalent to location class 1 as defined in Sec.2)	Locations subject to infrequent human activity with no permanent human habitation. Location class 1 is intended to reflect inaccessible areas such as deserts and tundra regions
2	Locations with a population density of less than 50 persons per square kilometre. Location class 2 is intended to reflect such areas as wasteland, grazing land, farmland and other sparsely populated areas
3 (equivalent to location class 2 as defined in Sec.2)	Locations with a population density of 50 persons or more but less than 250 persons per square kilometre, with multiple dwelling units, with hotels or office buildings where no more than 50 persons may gather regularly and with occasional industrial buildings. Locations class 3 is intended to reflect areas where the population density is intermediate between location class 2 and location class 4, such as fringe areas around cities and towns, and ranches and country estates.
4	Locations with a population density of 250 persons or more per square kilometre, except where a location class 5 prevails. A locations class 4 is intended to reflect areas such as suburban housing developments, residential areas, industrial areas and other populated areas not meeting location class 5.
5	Location with areas where multi-storey buildings (four or more floors above ground level) are prevalent and where traffic is heavy or dense and where there may be numerous other utilities underground.

F.2.3.3 The population density in Table F-1, expressed as the number of persons per square kilometre, shall be determined by laying out zones along the pipeline route, with the pipeline in the centreline of this zone having a width of:

— 400 m for category D fluids, and
— to be determined for category E fluid pipelines, but not less than 400 m. The determination shall include the possibility of very low temperature during a leakage of high pressure pipelines, giving high density gas that may float significant distance prior to ignition.

F.2.3.4 Half the zone width shall not be less than the effective distance of fluid release.

F.2.3.5 The length of the zones shall be 1.5 km and located at any location along the pipeline. The length of the random sections may be reduced where physical barriers or other factors exist, which will limit the extension of the more densely populated area to a distance less than 1.5 km.

F.2.3.6 The possible increase in population density and level of human activity from planned future developments shall be determined and accounted for when determining population density.

F.2.3.7 Additional considerations shall be given to the possible consequences of a failure near a concentration of people such as found in a church, school, multiple-dwelling unit, hospital, or recreational area of an organised character in location classes 2 and 3.

F.2.3.8 Pipeline design according to this standard is based on potential failure consequence and is quantified by the concept of safety class. These may vary for different phases and locations and are defined in Table F-2.

Table F-2 Definition of safety classes

Safety class	*Description*
Low	Where failure implies low risk of human injury and minor environmental and economic consequences.
Medium	Where failure implies risk of human injury, significant environmental pollution or very high economic or political consequences.
High	Where failure during operating conditions implies high risk of human injury, significant environmental pollution or very high economic or political consequences.
Very high	Where failure during operating conditions implies very high risk of human injury.

F.2.3.9 The acceptable failure probability of safety class Very High is one order of magnitude lower than for safety class high as given in Sec.2 of this standard.

F.2.3.10 The safety class determined by the crossing shall apply from:

— for road crossings
— the road right-of-way boundary
— if this boundary has not been defined, to 10 m from the edge of the hard surface of major roads and 5 m for minor roads
— for railways
— 5 m beyond the railway boundary or
— if this boundary has not been defined, to 10 m from the rail.

F.2.3.11 The safety class can often be determined based on the location class and fluid category. Typical selection of safety class is given in Table F-3.

Table F-3 Classification of safety classes

Phase	*Fluid category*	*Location class*				
		1	2	3	4	5[2]
Temporary[1]	All	Low				-
Operating onshore	A,C	Low		Medium		-
	B	Medium	Medium	High	Very High	-
	D,E	Medium	Medium	High	Very High	-

1) Installation until commissioning (temporary) will normally be classified as safety class low. During temporary conditions after commissioning of the pipeline, special considerations shall be made to the consequences of failure, i.e. giving a higher safety class than low.

2) This standard is not applicable for areas in location class 5.

F.3 Design premise

F.3.1 General

F.3.1.1 The basis for design premises for the shore approach shall be as given in Sec.3. Special attention shall be given to aspects related to installation, on-bottom stability, fatigue due to direct wave loading and 3rd party activities. Statutory requirements apply.

F.3.1.2 The shore crossing should be constructed by either

— open cut and cover
— horizontal directional drilling (HDD)
— tunnelling
— jetty, or
— combinations of the above.

F.3.2 Routing

F.3.2.1 The requirements in [3.3] apply to the shore approach section. Additional requirements are given below.

F.3.2.2 The routing shall be selected and prepared so that risk of fire, explosions and un-intended occurrences is at an acceptable level. Spacing between pipelines, associated equipment, harbours, ship traffic and buildings shall be evaluated by risk assessments considering the service of the pipeline.

Guidance note:

The preferred means of routing for shore approach pipeline will be to bury them. Examples of additional protective means are Concrete coating or cover, additional steel wall thickness, deeper trenching, additional marking and means to minimize the possibility for impacts from ship traffic and vehicles.

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F.3.2.3 Special focus shall be on:

— safety of public
— protection of environment

- 3rd party activities
- access
- other property and facilities.

F.3.2.4 Pipeline conveying category B, C, D and E fluids should avoid built-up areas or areas with frequent human activity.

F.3.2.5 In absence of public safety statutory requirements, a safety evaluation shall be performed in accordance with the general requirements for:

- Pipeline conveying category D fluids in locations where multi-storey buildings are prevalent, where traffic is heavy or dense, and where there may be numerous other utilities underground.
- Pipelines conveying category E fluids.

F.3.2.6 An Environmental Impact Assessment (EIA) shall be performed. The EIA shall consider as a minimum:

- temporary works during construction and operation (e.g. repair, modifications etc.)
- the long-term presence of the pipeline
- leakage.

F.3.2.7 The route shall permit the required access and working width for the construction and operation (including any replacement), of the pipeline. The availability of utilities necessary for construction and operation should also be reviewed.

F.3.2.8 The route shall be tidy and free from flammable materials on and in the vicinity of the pipeline system. A safety area along the pipeline shall be defined which may restrict public access and activities. The extent of the area shall be established based on risk analyses and shown on the plan for the pipeline system.

F.3.2.9 Facilities along the pipeline route should be identified and their impact evaluated in consultation with the operator of these facilities. Facilities should not be allowed closer than 4 m from the pipeline.

F.3.2.10 A wider restriction zone compared to public access may apply to future development (buildings etc.).

F.3.3 Environmental data

F.3.3.1 Environmental data shall be collected as described in Sec.3. Long term shore profile shall be considered. Special attention shall be given to tidal variations.

F.3.4 Survey

F.3.4.1 Route and geophysical and geotechnical surveys shall be carried out to identify and locate with sufficient accuracy the relevant geographical, geological, geotechnical, corrosive, topographical and environmental features, and other facilities such as other pipelines, cables and obstructions, which may impact the pipeline route selection. The surveys shall be continuous, and the accuracy and tolerance should be selected with regard to the adjoining land and offshore surveys.

F.3.4.2 Nearshore and shore crossing survey coverage should be continuous and in agreement within specified tolerances and accuracies of both adjoining land and offshore route surveys.

F.3.5 Marking

F.3.5.1 The pipeline system shall be marked in such a way that its location in the terrain is clearly visible. Provisions shall be made to restrict public access to pipelines that are not buried.

F.3.5.2 Warning signs shall be placed within visible distance and at each side of crossings with rivers, roads and rail ways giving information on:

— content
— operator
— phone number to nearest manned station which may be alerted in the event of fault on the pipeline.

F.4 Design

F.4.1 General

F.4.1.1 The pigging requirements in [3.4.1.2] and [3.4.1.2] applies to the pipeline system.

F.4.2 System design

F.4.2.1 Any electrical equipment within the location class areas shall comply with the location class requirements.

F.4.2.2 The need for lightening rod and means to avoid build up of static electricity shall be considered.

F.4.2.3 Branch connections for pipelines on land shall be supported by consolidated backfill or provided with adequate flexibility.

F.4.2.4 Braces and damping devices required to prevent vibration of piping shall be attached to the pipe by full encirclement members.

F.4.2.5 For structural items, doubler plates and rings welded directly to pressure containing parts, the following apply:

— Design shall be performed for all relevant failure modes, e.g. fracture and instability.
— For duplex stainless steels and 13Cr martensitic stainless steels a stress analysis shall be performed in each case to determine that local stresses will not initiate HISC. Recommended practice for design of duplex stainless steels is given in DNVGL-RP-F112.
— Welding directly to the pressure containing parts shall be performed in accordance with qualified welding procedures according to App.C.
— NDT shall be performed to ensure structural integrity of the pressure containing parts.
— The toe-to-toe distance from other welds shall be minimum $2 \cdot t$ or 50 mm, whichever is larger.

F.4.2.6 For doubler plates or rings the following apply:

— Design shall be performed for all relevant failure modes.
— Doubler plates should be circular.
— Welds shall be performed in accordance with qualified welding procedures.
— Doubler rings shall be made as fully encircling sleeves with the longitudinal welds made with backing strips, and avoiding penetration into the main pipe material.
— Other welds shall be continuous, and made in a manner minimising the risk of root cracking and lamellar tearing.

F.4.3 Design loads

F.4.3.1 The loads shall be established as described in Sec.4. Special attention shall be given calculations of loads from 3rd party activities such as traffic (potential cyclic loading) and other construction work.

F.4.3.2 The loads shall be classified into functional, environmental, interference or accidental loads as per Sec.4 of this standard with the additional requirements below.

F.4.3.3 Traffic axle loads and frequency shall be established in consultation with the appropriate authorities or other relevant sources and with recognition of existing and forecast residential, commercial and industrial developments.

F.4.4 Design criteria

F.4.4.1 The design should comply with the requirements in Sec.5. Special attention shall be given to statutory requirements.

F.4.4.2 For safety class Very High the safety class factors in Table F-4 apply.

Table F-4 Partial safety class resistance factor for safety class very high

Limit state	γ_{SC}
Pressure containment	1.593
Other limit states	1.5

F.4.4.3 Buried pipelines on land should be installed with a cover depth not less than shown in Table F-5.

Table F-5 Minimum cover depth for buried pipelines on land (alternative, preferred formulation to the table above)

Safety class 3)	*Cover depth [m]* 1) 2) 4) 5) 6) 7)	
	Trench blasted in rock	*Other*
Low	0.5	0.8
Medium		0.8
High		1.2
Very high		1.2

1) Cover depth shall be measured from the lowest possible ground surface level to the top of the pipe, including coatings and attachments.
2) Special consideration for cover may be required in areas with frost heave.
3) River crossings, road crossings and railway crossing shall in this context be classified as safety class High.
4) Cover shall not be less than the depth of normal cultivation +0.3 m.
5) For river crossings; to be measured from the lowest anticipated bed.
6) For roads and railway crossings; to be measured from the bottom of the drain ditches
7) The top of pipe shall be at least 0.15 m below the surface of the rock.

F.4.4.4 The effect of cover depth shall be considered in the expansion evaluations.

F.4.4.5 If the pipeline is not laid at a frost free depth, the mass below the pipe's centre line must be frost proof.

F.4.4.6 Pipelines may be installed with less cover depth than indicated in Table F-5, provided a similar level of protection is provided by alternative methods. The design of alternative protection methods should take into account:

- any hindrance caused to other users of the area
- soil stability and settlement
- pipe stability cathodic protection
- pipeline expansion
- access for maintenance.

F.4.4.7 Pipelines running parallel to a road or railway should be routed outside the corresponding right-of-way.

F.4.4.8 The vertical separation between the top of the pipe and the top of the rail should be a minimum of 1.4 m for open-cut crossings and 1.8 m for bored or tunnelled crossings.

F.4.4.9 Protection requirements for pipeline crossings of canals, rivers and lakes should be designed in consultation with local water and waterways authorities.

F.4.4.10 Crossings of flood defences can require additional design measures for prevention of flooding and limiting the possible consequences.

F.4.4.11 Crossing pipelines and cables should be kept separated by a minimum vertical distance of 0.3 m.

F.4.4.12 Pipeline bridges may be considered when buried crossings are not practicable. Pipe bridges shall be designed in accordance with structural design standards, with sufficient clearance to avoid possible damage from the movement of traffic, and with access for maintenance. Interference between the cathodic protection of the pipelines and the supporting bridge structure shall be considered.

F.4.4.13 Provisions shall be made to restrict public access to pipe bridges.

F.4.4.14 If other criteria are used, the nominal failure probabilities shall be demonstrated to be as specified in Sec.2.

F.5 Construction

F.5.1 General

F.5.1.1 The same requirements as for the Offshore part of the pipeline system shall be applied to the onshore part, if applicable. Where this is not applicable, the requirements of ISO 13623 should be complied with.

F.5.2 Linepipe

F.5.2.1 The material selection should comply with the requirements of Sec.6 and manufacture of line pipe should comply with the requirements in Sec.7.

F.5.3 Components and assemblies

F.5.3.1 The requirements to components and structural items as well as assemblies should comply with Sec.8.

F.5.3.2 Field, i.e. cold, bends with a bend radius corresponding to a permanent strain up to 1.25% are permitted provided that a qualification programme is performed, documenting that the material requirements are met after bending. Field bends shall be made on bending machines that provide sufficient support to the pipe cross-section to prevent buckling or wrinkling of the pipe wall and to maintain coating integrity. Bends should not be made from pipe lengths containing girth welds that are within 1 m of the bend. Longitudinal weld seams should be placed near the neutral axis of field bends. Tangent length (i.e. distance from end of bend to first girth weld) should be at least 1.5 pipe diameters or 500 mm, whichever is larger.

F.5.4 Corrosion protection and coatings

F.5.4.1 The corrosion protection shall comply with Sec.9.

F.5.4.2 All metal pipelines should be provided with an external coating and, for buried or submerged sections, cathodic protection. Corrosion protection should be provided by impressed current.

F.5.4.3 The design of the impressed current protection system shall strive for a uniform current distribution along the pipelines and shall define the permanent location for the measurement of the protection potentials.

F.5.4.4 Protected pipelines should be electrically isolated from other structures, such as compressor stations and terminals, by suitable in-line isolation components.

F.5.4.5 Isolation joints should be provided with protective devices to prevent damage from lightning or high-voltage earth current where possible. Low-resistance grounding to other buried metallic structures shall be avoided. Electrical continuity shall be provided across components, other than couplings/flanges, which would otherwise increase the longitudinal resistance of the pipeline. Spark gaps shall be installed between protected pipelines and lightning protection systems.

F.5.4.6 Test points for the routine monitoring and testing of the cathodic protection should be installed at the following locations:

— crossings with DC tractions systems
— road, rail and river crossings and large embankments
— sections installed in sleeve pipes or casings
— isolated couplings
— where the pipeline runs parallel to high-voltage cables
— sheet piles
— crossings with other major metallic structures with, or without, cathodic protection.

F.5.4.7 The primary corrosion control for internal corrosion is identical with the submarine part, see Sec.9.

F.6 Operation

F.6.1 General

F.6.1.1 The requirements to safe and reliable operation of the pipeline systems and the pipeline integrity management (PIM) as described in Sec.11 apply.

F.6.1.2 The whole route shall regularly be checked for:

- any required re-classification of location class due to changes in premises like populations etc.
- new facilities
- new intruders or changed configurations that may cause increase risk of threats.

F.7 Documentation

F.7.1 General

F.7.1.1 In addition to the requirements in Sec.12, the following apply:

- crossing locations related to lakes, straits, rivers, streams, transport communication arteries and similar
- maps necessary to evaluate the proposed route classification
- relevant drawings on bridges etc.
- maps with any crossing services (cables, sewage etc.).

CHANGES – HISTORIC

There are currently no historical changes for this document.