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4" FLOWLINES

OPERATION, HANDLING AND MAINTENANCE MANUAL

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02	Issued for Construction	23-MAY-2023	AMGO	RFRA	DOBR	MWLR
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Revision History

Rev. no.	Description of changes
A	This is the first issue of this document.
B	This is the second issue of this document. • Typos adjusted. • Purchase order numbers moved from front sheet to table in page 2. • Carcass collapse pressure adjusted in Table 2-1. • Friction factor adjusted in Table 3-2.
C	This is the third issue of this document. • Note regarding H_2S content included in section 2.
00	This is the fourth issue of this document. The document has been updated to rev 00, issued for construction, following customer's approval.
01	This is the fifth issue of this document. References updated in order to include a new end-fitting design.
02	This is the sixth issue of this document. References updated.

List of Holds
There are no holds in this document.

Purchase Order / Sales Order	15762-DWG-COM-	Well	Service
4511134320 4511134323 (RESALE)	101-MRL-150-04	MRL-150	4" Gas Lift Service
4511134318 4511134319 (RESALE)	102-MRL-156-04	MRL-156	4" Gas Lift Service
4511149988 4511149992 (RESALE)	103-MRL-223-04	MRL-223	4" Gas Lift Service

4511131429 4511131431 (RESALE)	104-MRL-103-04	MRL-103	4" Gas Lift Service
4511152688 4511152690 (RESALE)	105-P9-04	P9	4" Gas Lift Service
4511137201 4511137206 (RESALE)	106-MRL-167-04	MRL-167	4" Gas Lift Service
4511150233 4511150234 (RESALE)	107-P7-04	P7	4" Gas Lift Service
4511153346 4511153347 (RESALE)	108-P8-04	P8	4" Gas Lift Service
4511137207 4511131012 (RESALE)	110-MRL-210-04	MRL-210	4" Gas Lift Service
4511152635 4511150229 (RESALE)	109-MRL-231-04	MRL-231	4" Gas Lift Service
4511516312	112-7-MRL-102H-04	MRL-102H	4" Gas Lift Service
4511448781	111-6-MRL-199-04	MRL-199	4" Gas Lift Service
4511719888	113-7-MRL-145-04	MRL-145	4" Gas Lift Service
4511719887	114-7-MRL-206-04	MRL-206	4" Gas Lift Service
4511744986	115-7-VD-017H-04	VD-017H	4" Gas Lift Service
4511717013	116-4-RJS-377-04	RJS-377	4" Gas Lift Service
4511854373	117-P10-04	P-10	4" Gas Lift Service

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1 INTRODUCTION

1.1 PROJECT BASIS

This document is part of the call-off project documentation for BC-2095 & BC-2092, between Petrobras and NOV Flexibles, described in [2].

The project includes the pipe sections presented in section 2. Reference is given to Design Report, Flexible Pipe [3] for further information regarding the pipe structures, including a layer-by-layer description, and the Material Selection Report [6]-[7] for material specifications of the pipes and end-fittings. For as-built documentation, reference is given to [12].

1.2 PURPOSE AND SCOPE OF DOCUMENT

The Operating, Handling and Maintenance Manual gives general information about the pipes. It also outlines the conditions, maintenance tasks and restrictions under which the pipes shall be operated and handled.

The pipe structures included in this project have been evaluated specifically for the applications mentioned in section 1.1. In case Petrobras at some point intend to transfer the structures to another location or service, it is recommended that NOV Flexibles is contacted in order to evaluate the consequence for the pipes

The NOV pipes are designed and manufactured in compliance with [15]. For further information on system, pipe and component description as well as recommendation for handling, transportation, installation, integrity and conditioning monitoring, reference is made to ISO 13628-11, [13].

All documents produced by NOV Flexibles for this project are registered in *Master Document Register*, [1].

Regarding installation requirements in general, reference is made to *Installation Feasibility* [8].

2 PIPE DATA SHEETS

2.1 PIPE DESIGN: 15762-PID-401 – ID 4.0 INCH GAS LIFT (FLOWLINE)

Table 2-1 Pipe cross-section

Pipe:	15762-PID-401_SF-04							
Layer no.	**Layer type**	**Layer name**	**Profile**	**No. of elements**	**Lay angle [deg]**	**Pitch [mm]**	**Thickness [mm]**	**Outer diameter [mm]**
1	Carcass	Duplex 2101	1.0x50-Std	1	87.2	16.4	6	113.6
2	Bedding Tape	Diolen	0.2x100	2	-73.3	107.5	0.4	114.4
3	Bedding Tape	Diolen	0.2x100	2	-73.4	107.5	0.4	115.2
4	Polymer Extrusion	HDPE Neutral	-	-	-	-	6.5	128.2
5	Pressure Armour C-Wire	Sour 800	C2	2	-	21.4	4.4	137.0
6	Bedding Tape	Diolen	0.2x100	2	-69.6	160.0	0.3	137.5
7	Tensile Armour	Sour 1000	3x7.5	48	25.6	923.0	3	143.5
8	Bedding Tape	Diolen	0.2x100	2	-71.9	147.3	0.3	144.1
9	Tensile Armour	Sour 1000	3x7.5	50	-25.2	981.0	3	150.1
10	Bedding Tape	Diolen	0.2x100	2	73.6	138.6	0.3	150.7
11	Bedding Tape	Diolen	0.2x100	2	-73.7	138.6	0.3	151.3
12	Bedding Tape	Diolen	0.2x100	2	-77.5	105.5	0.4	152.0
13	Polymer Extrusion	HDPE	-	-	-	-	6.8	165.6

GENERAL PIPE DATA			
Manufacturer identification	15762-PID-401_SF-04	Structure Identification Code	NOV-101-9101
Application	4" SF	Service	Sour Service
Service life [years]	25	Annulus volume per meter pipe [dm3/m]	0.527
Pipe inner diameter [mm]	101.60	Pipe outer diameter [mm]	165.64
Minimum bending radius, storage [m]	1.15	Minimum bending radius, service [m]	2.43
Mass in air, empty bore [kg/m]	45.97	Mass in air, seawater filled [kg/m]	55.30
Mass in air, fluid filled [kg/m]	48.39	Mass in seawater, empty bore [kg/m]	23.89
Mass in seawater, seawater filled [kg/m]	33.22	Mass in seawater, fluid filled [kg/m]	26.30
DESIGN INPUT DATA			
Design pressure diff. [MPa]	20.70	Design temperature max. [°C]	60.00
Design temperature min. [°C]	4.00	Design water depth (operation) [m]	1065
FAT pressure (nominal) [MPa]	26.91	Early leak test pressure, topside (nominal) [MPa]	22.77
Inplace leak test (nominal) [MPa]	22.77	Structural integrity test (nominal) [MPa]	25.88
FLUID DATA			
H2S [ppm]	10.00/200.00[1]	CO2 [mol%]	1
H20 [mol%]	100.00	Cl [g/l]	103.56
HCO3 [g/l]	296.00	Fluid density [kg/m^3]	265/865[2]
PIPE STRUCTURAL PROPERTIES			
Axial stiffness of pipe in tension [MN]	331.74	Torsional stiffness [kNm2/deg]	6.92
Bending stiffness at 20 °C [kNm2]	16.42	Burst pressure [MPa]	69.35
Damaging pull, straight pipe [kN]	1831.15	Carcass collapse pressure [MPa]	16.60
Max. depth, empty, straight pipe [m]	1377.93	Max. tension at ope. pres., straight pipe, rec. operation, end of life [kN]	1124.7
Max. tension, early leak test, end of life [kN]	1310.31	-	

[1] Applicable for hydrate dissociation scenario.
[2] Density value depends on the bore fluid (gas lift/diesel)

3 INSTALLATION, HANDLING AND INTERFACE REQUIREMENTS

3.1 HANDLING AND STORAGE LIMITATIONS

3.1.1 Handling guideline

Handling of the pipe should be performed without exceeding the limits in section 2. Furthermore, the following should be adhered to.

Steel surfaces and/or steel wires in direct contact with the flexible pipe should be avoided, as they can damage the outer sheath or other layers. NOV Flexibles recommends that axial pull is applied either through pull heads bolted to the end fitting flange or by use of Chinese fingers. Chinese fingers must have a suitable surface finish to prevent damage to the outer sheath of the pipe.

The handling of the end fitting should be carried out using soft slings or polypropylene ropes.

Special care should be taken to avoid local contact with sharp edges during handling.

In case the pipe is subjected to a tension causing a bending moment close to the end terminations by being bent e.g. over a chute or onto a reel, a minimum free length, FL, must be ensured. The free length is defined as the distance between the end-fitting and the first point of contact with the adjacent structure as shown Figure 3.1. The length is found as the length of one outer tensile armour pitch.

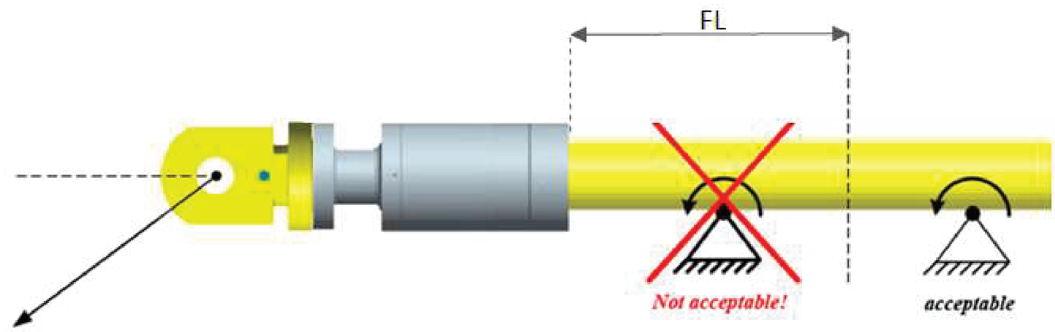


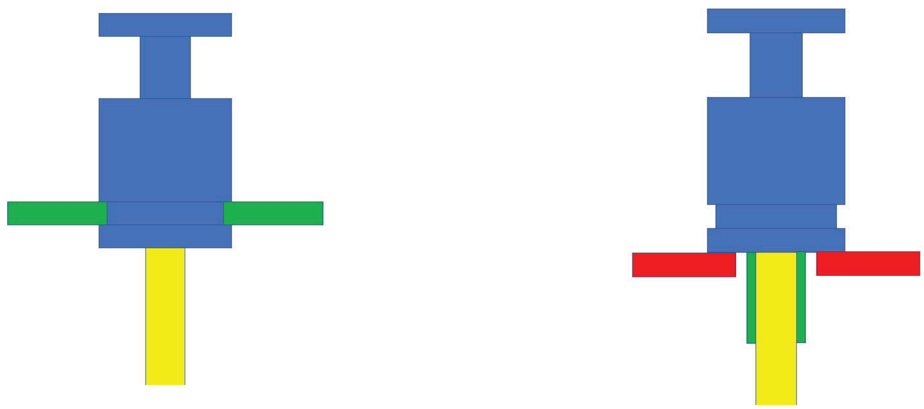
Figure 3.1 Pipe handling and free length (FL) restriction near end termination

The specific pitch values are presented in section 2 for each pipe section. Note that the higher value for a particular pipe – that for the outer tensile armour layer – is governing.

Further instructions on pipe handling are given in the document *Installations Feasibility* [8].

3.1.2 End-fitting support at hang-off during installation

During the installation, the end fitting can be supported at the hang-off groove, which is the preferred solution, or back of the end fitting. When the end fitting is supported at the back of the end fitting, the outer sheath must be protected by a protection layer. The protection layer shall be able to withstand handling and loading during installation, including any potential contact loads, and should cover the exposed outer sheath so that no damage occurs on it.



Recommended support during installlation: Support at the hang-off groove

Alternative support: Support at the back side of the end fitting with protection of the outer seath

Figure 3.2 End-fitting support at hang-off during installation

3.1.3 Gas venting system

The gas venting system consists of three venting connections in each end fitting. The following will be delivered with each end fitting in terms of gas venting, see Figure 3.1.

Table 3-1 - Gas Venting System

Pipe application	Designation	Not mounted at delivery
4" Gas Lift	Flowline end fittings	3 venting valves

3.1.4 MODA system

The MODA system is not applicable.

3.1.5 Friction coefficients for a pipe in caterpillar

During pipe handling with a caterpillar it must be ensured that the caterpillar tension can be transferred to the structural layers of the flexible without pipe delamination. An estimated friction coefficient for the critical layer interface is given in Table 3-2.

Table 3-2 Static friction coefficients

Friction coefficient between materials	Nominal value
Outer sheath/2nd tensile armour	0.12

The friction coefficient shall be selected as the minimum of the value for friction coefficient stated above and the friction coefficient between the outer sheath and the caterpillar.

Normally the friction coefficient given in Table 3-2 is the governing value. The value is a nominal value and must be combined with a reasonable factor of safety. NOV recommends a safety factor of 1.5.

3.1.6 Onshore storage

During periods of onshore storage the pipe must be adequately protected against the environment. The pipe must be stored on suitable reels or turn table designed to accommodate the pipe minimum-bending radius (MBR).

Blinds shall be fitted on the end fitting flanges to protect the pipe bore.

It is recommended that the pipe is covered by tarpaulins for environmental protection; e.g. abrasion caused by wind carried particles, sunlight etc.

It is recommended that the pipe is stored empty of all fluid content or filled with demineralized water. For wet storage in general, reference is made to section 5.

Note: It is particularly important that in case the pipe has been filled with seawater, e.g. during retrieval, it is subsequently flushed with potable water as pockets of sea water, salt deposits and marine organisms may cause serious damage to the carcass during a prolonged storage period.

3.2 WINDING/UNWINDING

During winding and unwinding, any change in spooling speed needs to happen slowly. Care should be taken that the bending limitations in section 2 are respected. For loads on the pipe, e.g. when bent over a chute, see section 4.

Further instructions on pipe winding/unwinding (re-spooling and reeling) are given in the document *Installations Feasibility* [8].

3.3 ACCESSORIES

Handling of any accessories, such as bend stiffeners, bend restrictors, buoyancy modules, clamps or pipe protection equipment, should be done accordance with relevant documentation on storage, handling and installation.

In case **bending restrictors** are mounted on a particular pipe, the following applies: The bend restrictor elements are of a split-collar design and thus allows for removal / replacement of any number of elements during operation after careful evaluation of the system.

For other accessories, such as **clamps** or **pipe protection**, please consult relevant documentation.

3.4 INTERFACE REQUIREMENTS

The end fitting forms the transition from the flexible pipe to the interface flange. It will be an integral part of the flexible pipe and consists of numerous internal components. The end fitting design ensures that all layers of the flexible pipe are fully secured and that the loads from the individual layers are safely transferred to the end fitting whilst maintaining fluid tight integrity.

All voids inside the end fitting are filled with cured epoxy and consequently the end fitting cannot be disassembled or disconnected from the pipe without destroying the integrity of the end fitting and/or the pipe structure.

Reference to general arrangement drawings of end fittings are given in section 8. The same applies for the specifications for the flanges.

3.5 INSTALLATION REQUIREMENTS

Installation feasibility including requirements and limitations is in general described in the document Installation Feasibility [8]. Here, some of this information is repeated for clarity and compensated with operationally relevant information.

3.5.1 Bending and compression

Limitations on pipe compression during bending are presented for each pipe section in Appendix C.

Two annulus conditions are considered:

- A dry annulus
- A flooded annulus

Only an empty pipe is considered. A pressurized or a water filled pipe will have a higher capacity. Therefore, the approach is conservative.

3.5.2 Bending, tension and caterpillar restrictions

During pipe handling with a caterpillar, it must be ensured that the caterpillar tension can be transferred to the structural layers of the flexible without pipe delamination. Furthermore, restrictions on bending for a pipe in tension over a chute must consider the crushing strength of the pipe.

In general, bending, tension and caterpillar restrictions are summarized for each installation vessel in mechanical compatibility graphs which are presented in the document *Installation Feasibility* [8].

3.5.3 Tension versus bore pressure

When a pipe is subject to tension, the amount of tension will limit how much the pipe can be pressurized. A relation between allowable tension versus bore pressure is presented in Appendix C.

3.6 MAXIMUM DESIGN WATER DEPTHS

All pipe sections are designed to a given maximum design water depth. These are summarized in Table 3-3.

Table 3-3 Maximum design water depths

Application	Section	Pipe design number	Design Water Depth [m]
Gas Lift	Flowline	401	1065

The project specific design water depths are presented in the *Design Premise* [2]. Project specific operation water depths for each structure are presented in section 2.

4 OPERATIONAL MANUAL AND GUIDELINES

4.1 SERVICE LIFE

4.1.1 Service life

The pipe structures included in this project have been evaluated specifically for the applications mentioned in section 1.1. The service life is 25 years.

4.1.2 Design life with damaged outer sheath

If the outer sheath is perforated, the annulus of the pipe will be filled with seawater. This may reduce the service life significantly. Damage in the outer sheath should be repaired as soon as possible to prevent the exchange of seawater in the annulus.

Corrosion of the armour wires depends on duration of exposure, temperature, and oxygen content of the surrounding water. NOV Flexibles recommends that an analysis is made based on the gathered data to evaluate the remaining service life in case of damage to the outer sheath.

In case the outer sheath is perforated and the annulus is filled with seawater, the fatigue life for dynamic pipes will be reduced. NOV Flexibles recommends that an analysis is made based on the gathered data to evaluate the remaining service life in case of damage to the outer sheath. Fatigue calculations are found in *Fatigue Report, Flexible Pipe* [5].

4.2 CORROSION PROTECTION

4.2.1 External surfaces

All end fittings are coated on the outside for corrosion protection. Specification of the coating system and repair procedure is given in *Material Selection Report* [7].

4.2.2 Cathodic protection

Sacrificial anodes connected to the end fitting generate the cathodic protection. The anodes are identical on each end fitting. New anodes shall be mounted on the end fitting if these are missing, damaged or not working.

The amount of protection is established on a project basis. Please consult the *Design Report, End Fitting* [4] for required anode weights for each end-fitting.

4.3 GAS-VENTING SYSTEM DESCRIPTION

4.3.1 Gas venting valves

The NOV Flexibles pipe is designed with an annulus pressure relief system, which consists of three independent vent ports in each end fitting.

It is very important not to restrict the free venting of gas from the end fittings of the flexible pipe as negligence of this or malfunctioning of the gas venting system might cause the outer sheath of the pipe to burst.

Notice that a ruptured outer sheath allows seawater to ingress the pipe annulus, which can seriously reduce the service life of the flexible pipe as per section 4.1.

In case top side end fittings are delivered with plugged vent ports these plugs must be removed before the pipe is taken into service. In case the pipe is taken out of service and disconnected from hang-off, the vent ports should be re-fitted in order to avoid unintentional seawater flooding of the pipe annulus.

All subsea end fittings are equipped with vent valves.

Piping may be connected to the valves/ports, but the total back pressure in the venting system including the opening differential pressure of valves must be less than 2 barg.
Each pipe must have its own venting system and must not be combined with venting systems from other pipes in order to ensure that the annuluses are not directly connected.

The end fittings are prepared with three (3) threaded holes for mounting of the venting valves/piping. See the relevant end-fitting general assembly drawings for details on vent port and valve positions [9].

Data for the venting system is listed in Table 4-1.

Table 4-1 Description of the gas vent valves

Vent ports size (all end fittings):	M24
Vent valve size (all end fittings):	M24
Vent valve description:	Spring loaded relief valve including filter
Valve relief pressure (differential):	1.8 ± 0.2 bar at 20°C
Valve type:	Type A-5

4.3.2 Permeation rate

Permeation rates for different operational scenarios for gas and oil pipes are described in separate documents and are based on the reference engineer design premise [2]. See Table 4-2 for relevant references.

Table 4-2 Permeation rates documents

NOV doc. no.	Document name	Applicable for project scope of work
15762-ENG-17827-00	Calculation of permeated gases 4” Service Flowline	X

4.3.3 Maximum retrieval rate

During call-off projects, NOV Flexibles will estimate the maximum retrieval rate for each pipe section to allow accumulated gasses to safety escape from the pipe annulus. The actual retrieval rates will depend on the pipe cross-section, pipe length, end-fitting design, water depth and gasses present in the bore and annulus. The methodology is currently being established.

4.4 ALLOWABLE PRESSURISATION/DEPRESSURISATION RATES

Allowable pressurisation/depressurisation (or decompression) rates for different internal fluids are summarized in Table 4-3.

Table 4-3 Maximum allowable rates of pressure changes

Internal Fluid	Unit	Pressurisation rate	Depressurisation rate
Liquid[3]	bar/min	230	230
Gas	bar/min	80	80

During the process of depressurization of gas pipes, it is most advisable always to monitor the temperature variations in the pipe to prevent cooling below the minimum allowable temperatures.

4.5 RESTRICTIONS ON FLUID COMPONENTS AND INJECTED CHEMICALS

4.5.1 Fluid design parameters and chemicals

The pipes are designed for a specific combination of bore pressures, bore temperatures and bore fluid components as stated in the Design Report [3]. These compositions are not to be exceeded during operation.

The pipes are designed for sweet/sour service annulus conditions according to the ISO 15156 definition, [14].

NOV Flexibles takes no responsibility for application of untested chemicals and/or if temperature and concentration limits are exceeded as well as effects originating from untested combinations of applied chemicals. This applies for both the production fluid (oil, gas or water) and injected fluids/chemicals.

4.5.2 Chemical compatibility, inner liner

The HDPE has been found compatible with a number of injection chemicals listed below in the specified concentrations.

For further details of chemicals, concentrations and temperatures please contact NOV Flexibles.

4.5.2.1 Chemical compatibility, HDPE

The following injection chemical have been tested and found compatible with HDPE.

[3] Liquid is defined as all the fluids that during a pressurization/depressurization event are in liquid phase (even multiphase fluids with gas phase under different pressures and temperatures).

Table 4-4 HDPE compatible injection chemicals

Function	Product name	Temperature [ºC]	Concentration
Corrosion inhibitor	EC 1118 A	53	100 %
Corrosion inhibitor	EC 1154 A*	53	100 %
Corrosion Inhibitor	EC 1170 A*	53	100 %
Corrosion inhibitor	Norust 720	53	100 %
Corrosion inhibitor	Norust CR 486	53	100 %
Defoamer	Defoamer AF-400	55	2 ppm
Biocide	Baktron B1150	55	500 ppm
Biocide	Baktron K-67	55	500 ppm
Corrosion inhibitor	Cortron 956-G	55	30 ppm
Scale inhibitor	Gyptron SA960	55	30 ppm
Oxygen scavenger	OS2	55	10 ppm

*Swelling >10%, because of aromatic ingredients in the inhibitor

HDPE is resistant to most chemicals in concentrations below 1-5 %. Thus, from a general trend no severe degradation is expected using most inhibitors.

HDPE is resistant to water and methanol (MeOH) at all relevant temperatures.

Note that even if a polymer is not degraded by a given chemical, some swelling and diffusion may be expected.

If suggested alternative inhibitors are not represented by the data above, the specific inhibitors must be tested.

4.5.3 Chemical compatibility outer sheath

The outer sheath of the pipes is made of HDPE, and the sheath must only be marked with compatible types of paints:
Turpentine, Acetone, Hexane, Benzene, Spirit, Methanol, Water

NOT ALLOWED is paint based on solvents as:
Toluene, Xylene, Trichlorethylene and other chlorides.

4.6 PIGGING

NOV Flexibles recommends using a bi-directional pig with a soft neoprene disc type for testing, commissioning, liquid evacuation and cleaning.
Bi-directional brush pigs may be used provided the brush is made from a material compatible with carcass material, and the brush does not damage the carcass.

Pigs with steel scrapers and/or steel brushes are not allowed as these might damage the internal carcass.

For wax removal, pigs equipped with a jetting head may be applied. Intelligent pigging may be applied.

4.7 ALLOWABLE MAXIMUM LOADS

For a pipe in operation (including shut-downs and leak tests), allowable maximum loads are described in the *Design Report, Flexible Pipe* [3].

5 FLOODING WITH SEAWATER

In case the flexible pipes are flooded with seawater during installation, care must be taken to minimize corrosion of the carcass. The permissible durations depend on the chemical composition of the water and the carcass steel grade.

Generally, the following durations apply as shown in Table 5-1.

Table 5-1 Duration limitations for carcass exposure to raw seawater

Combination	Limitation for exposure
Pipe filled with seawater, demineralized water, low-chloride fresh water or glycol-water mixture, but no end covers, i.e. free exchange of seawater	14 days
Pipe filled with seawater and end covers closed	1 year
Pipe necessary chemical inhibitors and oxygen scavengers added to the seawater, end covers closed	1 year
Pipes filled with demineralized water or glycol water-mixture from delivery, end covers closed	No restrictions

Note that in the Table 5-1, "Inhibitor" refers to adding a proper inhibitor against oxygen scavenger, bacteria and corrosion.

The different durations are independent of each other, but if e.g. un-inhibited seawater is followed by inhibited water, the pipe bore must be flushed with 3 times the bore volume with inhibited water.

Procedures for displacing the seawater must be considered as part of the installation procedures. For liquid service or mixed liquid/gas service pipes, displacement with the operating fluid is considered enough. For pipes specified and used for dry gas service, NOV Flexibles recommends to displace the seawater with potable water in accordance with section 9.5.5 of API 17B [13].
The described durations apply to all seawater temperatures and anyplace in the world. With more information about installation procedures, possible measures taken to avoid corrosion, and the environmental conditions at the intended location of installation, less restrictive limitations may be allowable. NOV Flexibles is always prepared to participate in such considerations.

6 INSPECTION, MONITORING AND MAINTENANCE PLAN

6.1 IN-SERVICE INSPECTION PLAN

NOV Flexibles recommends inspection of:

- Flexible pipe integrity
- End fitting integrity
- Bending stiffener
- Bending restrictor
- Hold back anchoring

For submerged installations it is recommended that the inspections are done by ROV’s.

When inspections are performed it should always be assessed if the present marine growth has an impact on the system integrity.

The operator should contact NOV Flexibles immediately if any damage – or potential damage occurs to the flexible pipe system, in order to allow NOV Flexibles to evaluate the situation and determine the consequences and the actions to be taken.

NOV Flexibles should have access to relevant installation procedures, inspection reports, video surveys or other relevant data on the subject.

6.1.1 Flexible Pipe

NOV Flexibles recommends annual inspection on the pipe of:

- Outer sheath integrity
- Outer geometry

Inspection of outer sheath integrity is of great importance as a damaged outer sheath not only leads to seawater exposure of the armour wires but also give rise to severe failure modes. These counts lateral buckling, armour wire fatigue, bird-caging and collapse of the internal carcass.

In accordance with the above mentioned special attention should be addressed to the touch down point (TDP) where the outer sheath is more exposed to sharp objects and wear. Furthermore the failure modes lateral buckling, bird-caging, collapse and over bending are more prone to occur in this region, especially for free-hanging configurations.

Lateral buckling, bird-caging and collapse are failure modes that are associated with low internal pressure and damaged outer sheath. Hence inspection of these failure modes should be considered when installing the risers or if the production has been shut down.

Lateral buckling may result in excessive pipe twist and may be identified from the longitudinal pipe markings.

Bird-caging results in increased outer diameter that may be identified by visual inspection and/or by use of gauge rings.

Collapse results in an ovalisation of the pipe cross section and may be identified by visual inspection and/or by use of calibre rings.

6.1.2 End fittings

NOV Flexibles recommends annual inspection on the end fittings. The end fittings shall be inspected with respect to the integrity of the cathodic protection and for obstruction of the venting valves. Obstruction of the venting valves may cause burst of the outer sheath. In this context special attention should be made to end fittings on the seabed. To avoid obstruction of venting valves it is recommended that these are cleaned with a water jet when inspection is performed. See the relevant end fittings general assembly drawings for details on geometry and further details [9].

If anodes are attached to the end fittings, the cathodic protection is considered acceptable when the integrity of the cathodic protection system is intact and the anodes are visible. Visual inspection by ROV cameras should be used to disclose deficiencies of the CP system such as damaged or missing anodes, damaged cables and excessive anode consumption.

6.1.3 Bend Stiffeners

Not applicable.

6.1.4 Buoyancy modules

Not applicable.

6.1.5 Bend Restrictor

NOV Flexibles recommends annual inspection on the bend restrictors. The bend restrictors shall be inspected for outer damage/over bending and possible initiation of cracks. A damaged bend restrictor may cause the pipe to over bend in the sensitive area near the end fitting. See the relevant bend restrictor general assembly drawings for details on geometry and further details [10].

6.1.6 Hold Back Anchors

The anchor bases shall be inspected every 24 months. The survey shall document that the hold back position is maintained. Inspection of the anchors should focus on any evidence of impact and evidence of damage. If any part of an anchor is found damaged by the survey NOV Flexibles should be informed.

The following items are required for a detailed inspection:

- Flexible pipe near hold back structure
- Holdback clamp is secured in the clamp housing
- Clamp housing closed and locking pin in place
- Clamp housing locking pins to be inspected for wear and corrosion. The pins shall be replaced if deemed necessary.
- Anodes

6.2 SURVIVAL SCENARIOS

Should any survival scenario occur the riser shall as a minimum be inspected (visual, ultra-sonic etc.) to evaluate possible damage to any ancillary equipment or pipe layer, being fire protection, outer sheath(s), tension wires, pressure armour, and carcass.

NOV Flexibles can perform an assessment of the integrity of the riser system. In case this is requested, NOV Flexibles will specify which data is needed so that an integrity assessment can be performed on the riser system.

It is recommended that the riser system is not put into service again until results from such an assessment have verified the riser system integrity.

Any damage or visual abnormality to the risers must be reported to NOV Flexibles for an evaluation of whether the risers can be put into service again or if any replacement is necessary.

6.3 REPAIR PROCEDURES OF OUTER SHEATH

If damage is inflicted on the outer sheath a qualified assessment of the damage must be made in accordance with the general guidelines in Appendix A as per [11].

It is very important that a major damage is repaired as soon as possible in order to prevent the free exchange of seawater in the pipe annulus.

NOV Flexibles requires access to relevant data if the pipe is damaged.

Note: The design life of the pipe will be seriously reduced if the armour wires in the pipe are exposed to seawater.

Note: Outer sheath repairs must be performed in strict compliance with the NOV Flexibles repair procedure by qualified and NOV Flexibles approved personnel only.

6.4 VACUUM TESTS FOLLOWING INSTALLATION AND DURING OPERATION

The main aspects of a vacuum test procedure for pipes following installation and during operation are presented in Appendix B[4]. These can be used to build a test procedure for a given pipe considering specific field conditions and operating conditions. Inputs from the data sheets in section 2 should be considered, such as the annulus volume per meter pipe and pipe cross-section.

[4] Based on internal template “Procedure for offshore annulus test”, NOV doc. no. TM-ENG-070

7 PRODUCT LIABILITY

National Oilwell Varco Denmark I/S will accept no warranty claim in case of damage to the product where any design condition and/or parameter as outlined in the NOV design premises and the NOV design reports as well as any criteria and/or requirement described in this document and associated documentation is incorrect, exceeded, violated or not fulfilled.

A detailed study and assessment of the suitability of the pipe for any other application must be conducted and approved by NOV Flexibles prior to such a decision.
NOV Flexibles does not take any responsibility in case of the following actions:

- Changing any application of the system as described in the NOV Flexibles design premise and design reports without the prior written consent of NOV Flexibles, thereby exposing the pipe to any operating conditions for which it is not suitable.
- Exceeding any design parameters e.g.
  - Internal pressure
  - De-pressurisation rate
  - Internal temperature
  - Minimum bending radius (MBR)
  - Allowable tension
- Modifying any part of the end fittings
- Welding on the end fittings
- Exposing any part of the pipe and/or end fittings to open flames or other heat sources (i.e. welding, weld splatter or similar)
- Restricting the free flow from the venting system in the end fittings
- Introducing new/other chemicals not tested for compatibility with the pipe inner liner without the prior written consent of NOV Flexibles
- Using any non-compatible type of paint on the outer sheath of the pipe
- Applying steel wires, sharp tools or any other hard or sharp material directly in contact with the outer sheath of the pipe
- Performing un-authorised outer sheath repair work
- Damage caused by pigs used against guidelines in section 4.6

Contact address:

National Oilwell Varco Denmark I/S
Priorparken 480
DK-2605 Brøndby
Denmark
Telephone: +45 43 48 30 00
Fax: +45 43 48 30 10
Email: RS-DNK-SASInfo@nov.com
Contact person: NOV Flexibles System Assessment Services
NOV Project reference: 15762 4" Service Flowline

8 REFERENCES

8.1 NOV DOCUMENTS

[1] Master Document Register, NOV doc. no. 15762-DOC-MGMT-001
[2] Design Premise, NOV doc. no. 15762-DOC-ENG-100
[3] Design Report, Flexible Pipe, NOV doc. no. 15762-DOC-ENG-500
[4] Design Report, End Fitting, NOV doc. no. 15762-DOC-ENG-511 and 15762-DOC-ENG-512
[5] Fatigue Report, Flexible Pipe, NOV doc. no. 15762-DOC-ENG-050
[6] Material Selection Report, Flexible Pipes, NOV doc. no. 15762-DOC-ENG-010
[7] Material Selection Report, End Fittings, NOV doc. no. 15762-DOC-ENG-020 and 15762-DOC-ENG-021
[8] Installation Feasibility, NOV doc. no. 15762-DOC-MNL-100
[9] GA Drawings End Fitting, NOV doc. no. 15762-DWG-EF-101 and 15762-DWG-EF-102
[10] GA Drawings Slimguard Bend Restrictors, NOV doc. no. 15762-DWG-SBR-110
[11] Repair of Outer Sheath MDPE and PA, NOV doc. no. AI-SOF-502-UK
[12] Manufacturing Data Book, NOV doc. no. 15762-DOC-MDB-PIPE-100-00

8.2 STANDARDS AND SPECIFICATIONS

[13] API Recommended Practice 17B, Fifth edition, May 2014/Petroleum and natural gas industries — Design and operation of subsea production systems — Part 11: Flexible pipe systems for subsea and marine applications, First edition, September 2007
[14] Petroleum and natural gas industries – Materials for use in H2S-containing environments in oil and gas production, ISO 15156

8.3 CUSTOMER SPECIFICATIONS

[15] I-ET-3000.00-1519-291-PAZ-001 - R0 - Flexible Pipe Technical Specification

APPENDIX A REPAIR PROCEDURES OF OUTER SHEATH (PA, PE)

CLASSIFICATION OF TYPE OF REPAIR
The damage characteristic (appearance/behaviour) can differ widely from case to case.
NOV repair philosophy is mainly based on experiences in the past and the functionality of the outer sheath.

As a general rule:
No repair shall be performed if the minimum acceptance criteria according to the quality plan can be fulfilled after scraping and/or heating with an air gun.

The damage shall be repaired in accordance with the Repair Procedure [11].

CLASSIFICATION 1: MINOR DAMAGES
Minor damages can be superficial scratch/indentations/ removal of PE/PA e.g. by gouging or tearing out - bubbles, wrinkles, hard lumps etc. in the surface and with a typical depth of 1-3 mm.
No repair shall be performed on these damages only scraping or heating with an air gun is needed

CLASSIFICATION 2: LARGER DAMAGES
This kind of damages can be deeper scratches/indentations/removal of PE/PA e.g. by gouging or tearing out where grinding is not acceptable or more or less perforated outer sheath.

CLASSIFICATION 3: PARTIAL OR TOTAL REPLACEMENT OF OUTER SHEATH
For this kind of repair NOV has supplied repair material. If damages larger than 1m in length on the outer sheath occurs, repair must be evaluated from case to case.

For all three classifications:
Repair report must be filled in.

APPENDIX B VACUUM TEST PROCEDURE – MAIN ASPECTS

This section describes the main aspects required in a procedure for performing a vacuum test for pipes during installation and in operation.

1. HEALTH, SAFETY AND ENVIRONMENT

All safety related topics on the operation must adhere to applicable instructions and work procedures on site.

The test equipment shall be handled with care, especially the high pressure nitrogen bottles.

2. PIPE PARTICULARS

The annulus volume per meter pipe is listed in the pipe's data sheets. The nominal annulus volume given there is influenced by the manufacturing tolerances, especially with regards to insulated pipes where the annulus volume is relatively high. Furthermore the cavity within the end-fittings may be taken into account in the estimate of the total volume.

3. SOURCES OF INACCURACY

The following factors may influence the accuracy of the measurements.

- If the pipe is in service there will be gasses diffusing into the annulus thus increasing the measured volume. The inaccuracy here should be evaluated based on the calculated or measured diffusion rate.
- The temperature of the annulus for pipes in service. Fluctuations in temperature may cause fluctuations in pressure depending on the magnitude.
- For pipes in a lazy-wave configuration water may have gathered in the sag-bend section of the configuration due to water condensation in the annulus, thus trapping gasses on either side of the pipe. In such a situation only the annulus volume of the upper catenary can be measured.
- As it is impossible to evacuate the entire annulus volume, there may still be non-inert gasses in the annulus. This has an impact on the calculation when using the ideal gas law to approximate the free annulus volume.

4. RECOMMENDED TEST MEDIUM

Nitrogen should be used as test medium.

5. INSTRUMENTATION

The following instrumentation is recommended for the testing:

- 1 digital low pressure manometer (-1 to 3 barg) measuring the annulus pressure
- 1 digital high pressure manometer (0 to 300 barg) measuring the bottle pressure
- 1 vacuum pump[5]
- 1 thermometer
- 1 analogue flowmeter

[5] Multiple vacuum pumps may be used to speed up the test.

The pressure manometers should be ATEX IS certified (II 2 G EEx ia IIC T4) in order to be intrinsically safe. The manometers should be driven by batteries so that no external power supply is required. A principle sketch of a proposed test setup is provided on Figure 8.1.

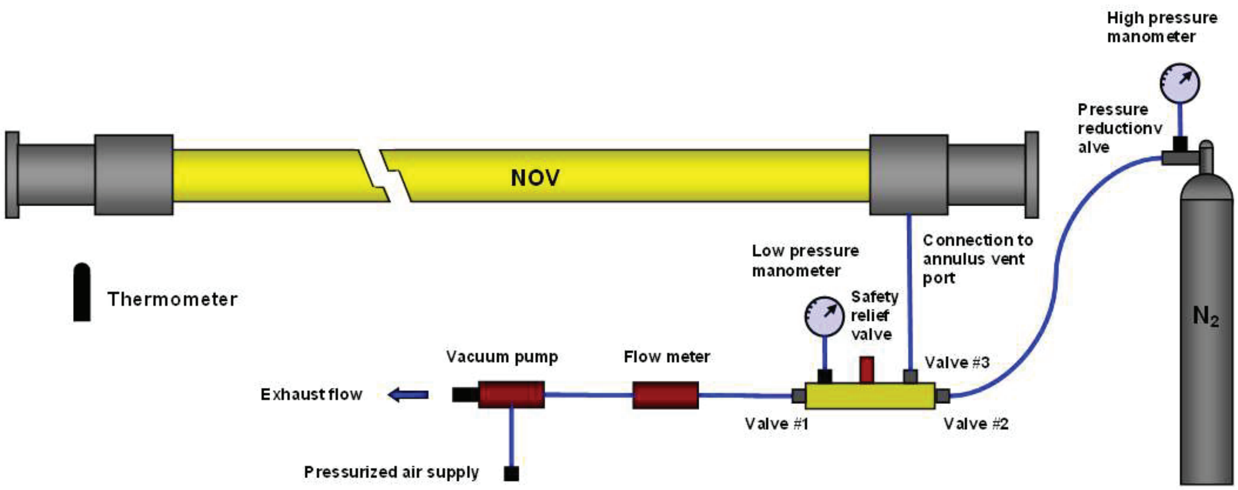


Figure 8.1 Principle sketch of test setup

All the instruments should be connected via plastic hoses to one main block where the pressure is equally distributed. The low pressure manometer should be connected directly to the block thus measuring the pressure within the block. Furthermore, the block should contain three regular valves and one safety relief valve with the following function:

- Valve #1: Seals off the vacuum pump from the remaining system
- Valve #2: Seals off the high-pressure Nitrogen bottle from the remaining system
- Valve #3: Seals off the annulus from the remaining system
- Safety valve: Ensures that the pressure in the block and annulus does not exceed the maximum continuous outer sheath hoop stress (σ), according to the following relation:

  $$\sigma = \pi \cdot OD/(2 \cdot t)$$

  where *OD* is the outer sheath outer diameter and *t* is its thickness.
  A typical value is 3 barg.

The high pressure manometer should be attached to the pressure reduction valve which connects the nitrogen bottle to the block via valve #2. The pressure reduction valve ensures that nitrogen is fed with a constant pressure to the block.

With this system it is possible to perform the vacuum test and annulus volume test by connection to one venting port on the end-fitting and controlling the three regular valves on the block.

If necessary the test equipment can be connected to several venting ports by use of tees.

The following ancillary equipment should also be used during testing:

- Pressure regulator and reduction valve suitable for nitrogen (0-200 bar) to be connected to the nitrogen bottle.
- Sufficient length of pressure hoses to connect the measuring equipment to the end-fitting vent port, nitrogen bottle and vacuum pump.
- Sufficient length of pressure hose to connect the vacuum pump to the pressurised air supply.
- Normal Thread Pipe (NTP) fitting, typically ¼" or ½", to connect the pressure hose to the end-fitting vent port.
- NTP plugs, typically ¼" or ½", for the vent ports.
- Laptop for analysing the test results.
- Bottled soap water for detecting leaks.
- Adaptor for connecting the pressure regulator to the nitrogen bottle.
- Necessary tools for connection of the test equipment.

Prior to commencing the tests, all calibration certification shall be controlled and validation confirmed.

6. MEASUREMENTS

The pressure should be sampled by the pressure manometers during the test. The sampling rate should be at least one sample per 5 seconds.

The following measurements should be sampled during nitrogen inlet and stabilisation/hold periods.

- Annulus pressure accuracy ±0.1%
- Bottle pressure accuracy ±0.1%
- Temperature accuracy ±1 °C (recommended, but depends on equipment)

7. TEST PROCEDURE

The annulus vacuum test is typically performed prior to the annulus volume test.

Testing pressure

The nominal test pressure is recommended to be at a minimum of -600 mbarg or as close as possible.

Hold period

The hold period is usually six (6) hours but two (2) hours is often considered sufficient. The hold period can start after achieving the target annulus pressure.

Testing details

Set-up and Checks

1. Necessary work permits shall be collected prior to commencing the test.
2. Those required to witness the test shall be contacted.
3. The safety of the work area shall be evaluated by relevant representatives at site. If the work area is deemed unsafe during or prior to the test, the test should be aborted. Work may

continue when potential sources of hazards have been eliminated.

4. The annulus is vented to atmospheric pressure.
5. Ensure that the main valve on the nitrogen bottle is shut.
6. Connect the test equipment only to the nitrogen bottle in order to test the safety relief valve on the block.
7. Ensure that the pressure reduction valve is turned off
8. Turn off valves #1 and #3 while keeping valve #2 open.
9. Turn on the main valve on the nitrogen bottle and gradually open the pressure reduction valve. The safety relief valve shall open at a pressure of no more than the pressure that does not exceed the outer sheath hoop stress.
10. Turn off the main valve on the nitrogen bottle.
11. Turn off the pressure reduction valve and allow the pressure in the block to be vented to atmospheric pressure by opening valves #1 and #3.
12. Connect the test equipment to the end-fitting vent port and connect the pressurised air supply to the vacuum pump. The pressure reduction valve remains connected to the nitrogen bottle.
13. Remaining vent ports on the end-fitting are fitted with plugs or venting valves are left in place.

Start Annulus Vacuum Test

14. Turn off valve #2 and open valves #1 and #3.
15. Start recording pressure on the low pressure manometer and note down the start time of the test and the temperature.
16. Initiate evacuation of the gas contained in the annulus by turning on the pressurised air.
17. Stop evacuation when the annulus pressure has reached a pressure below the nominal test pressure. Turn off valve #1 such that the annulus remains at a state of vacuum.

Completion of Test

18. Allow the pressure to stabilise for no less than 30 min.
19. Note down the pressure, temperature and the start time of the hold period.
20. Check that pressure is being monitored correctly.
21. Check acceptance criteria (no leaks or sudden increase in pressure). No ingress of air into the pipe during the test period shall be observed/monitored.
22. In case pressure increases occur the cause of ingress of air shall be investigated. The problem shall be identified and reported. In case the pressure increase is caused by leaks in the test equipment, the problem shall be fixed and go to outline point 15.
23. Note down the pressure, temperature and the end time of the hold period.

Testing details for the annulus volume test are outlined in the following. The annulus volume test is performed in connection with the vacuum test. If the annulus volume test is not required then the annulus is vented to atmospheric pressure after the vacuum test.

Start Annulus Volume Test

24. Turn on the main valve on the nitrogen bottle.
25. Turn on valve #2 such that nitrogen can be fed into the annulus. Valve #1 remains shut and valve #3 remains open.
26. Note down the start time of the annulus volume test and note down the temperature and pressure on the low- and high pressure manometers.
27. Gradually open the pressure reduction valve such that nitrogen is feed into the annulus with a constant pressure of approximately 2 barg.
28. Monitor the annulus pressure and ensure that the safety relief valve does not open. This is done

by reducing the feed pressure if it comes close to the opening pressure of the safety relief valve.

29. Allow the annulus pressure to stabilise at a constant pressure of approximately 2 barg. The system is stable when no pressure reduction is monitored on the nitrogen bottle and no pressure increase is monitored on the block/annulus.

Completion of Test

30. Allow the pressure to remain at a stable state for no less than 30 min.
31. Note down the end time of the annulus volume test and note down the temperature and end pressure on the low- and high pressure manometers.
32. Turn off the main valve on the nitrogen bottle.
33. Turn off the pressure reduction valve.
34. Disconnect the measuring system from the end-fitting vent port and allow the annulus to be vented to atmospheric pressure.
35. If required obtain acceptance from relevant representatives.

The free annulus volume is estimated by using the formulas given in the following section.

In case circumstances at the test site does not allow for the above described procedure to be followed, the test set-up and procedure must be altered to suit the circumstances.

Acceptance criteria

The recommended acceptance criterion for the vacuum test is that the pressure change must not exceed 4% of the nominal test pressure during the hold period.

8. CALCULATION OF THE FREE ANNULUS VOLUME

Nitrogen is an inert gas and its behavior is well described by the ideal gas law. The annulus can therefore be determined by the following equation.

$$V_a = V_b \frac{(P_{b2} \cdot T_{b1} - P_{b1} \cdot T_{b2}) T_{a1} T_{a2}}{(P_{a1} \cdot T_{a2} - P_{a2} \cdot T_{a1}) T_{b1} T_{b2}}$$

Where

V_a is the volume of the annulus
V_b is the volume of the nitrogen bottle
P_{b1} is the bottle pressure at the beginning of the test
P_{b2} is the bottle pressure at the end of the test
T_{b1} is the bottle temperature at the beginning of the test
T_{b2} is the bottle temperature at the end of the test
P_{a1} is the annulus pressure at the beginning of the test
P_{a2} is the annulus pressure at the end of the test
T_{a1} is the annulus temperature at the beginning of the test
T_{a2} is the annulus temperature at the end of the test

The temperature must be in Kelvin.
The temperature in the nitrogen bottle is assumed to be at ambient temperature.

If the temperature in the bottle and in the annulus is equal and constant during the test, the annulus volume can be determined by the following equation.

$$V_a = \frac{\Delta P_b \cdot V_b}{\Delta P_a}$$

Where,

ΔP_b is the pressure reduction in the bottle during filling of nitrogen
ΔP_a is the pressure increase in the annulus

When performing the annulus volume test on a pipe in service, the temperature of the annulus may be determined by thermal analysis. This requires that the bore temperature top-side and subsea as well as the ambient/sea temperature during the test is well established. Otherwise, the annulus temperature can be based on an estimated bore temperature.

APPENDIX C PIPE CAPACITIES

In the following, capacities of the pipes and top-side end-fittings are presented.

In the following, the bending and compression capacities of each pipe section are described.

Two annulus conditions are considered:

- A dry annulus
- A flooded annulus

Only an empty pipe is considered. A pressurized or a water-filled pipe will have a higher capacity.

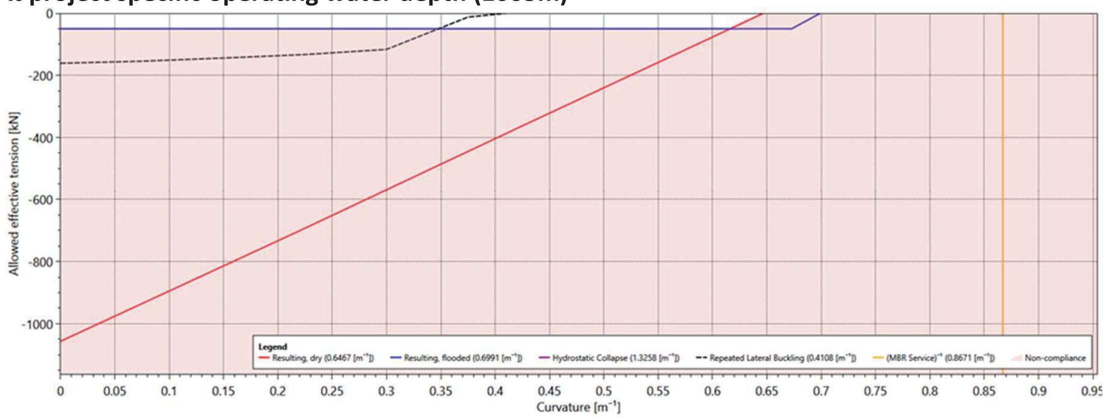
Bending and compression
For all pipes, the bending and compression capacities are presented below.

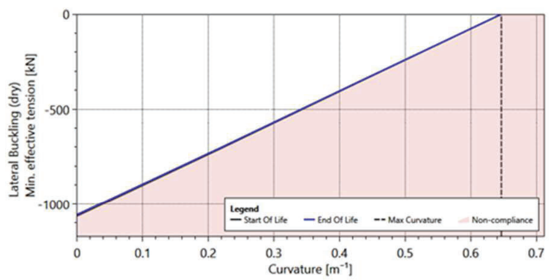
Please note that for top riser sections, two charts are stated: 1) considering the project operating water depth and 2) considering the maximum project water depth.

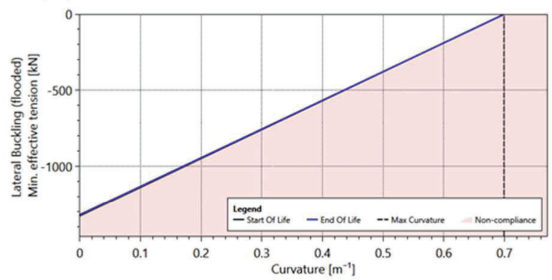
Pressure x tensile load
For all pipes, the relationship between allowable pressure and topside tension is described. The base case pressure is the nominal early leak test pressure, presented in section 2. Only start of life is considered (no corrosion of wires accounted for).

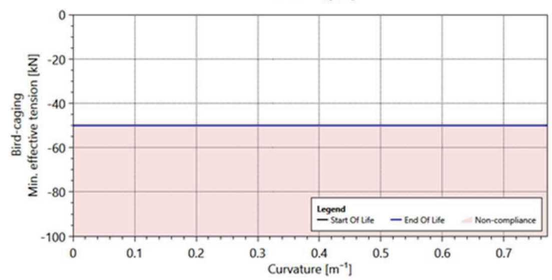
PIPE DESIGN: NOV-101-9101 (15762-PID-401) - ID 4 INCH GAS LIFT (FLOWLINE)

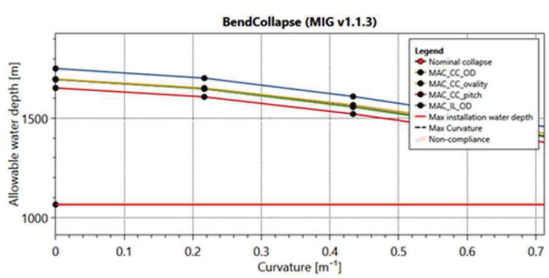
At project specific operating water depth (1065m)

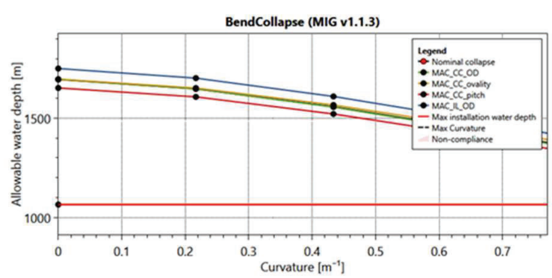


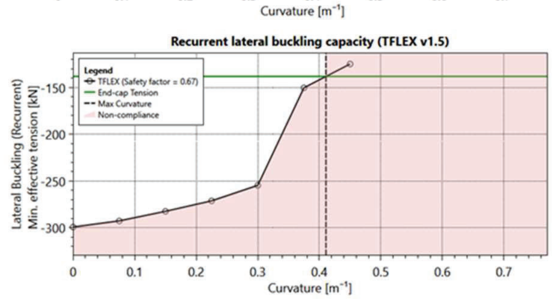


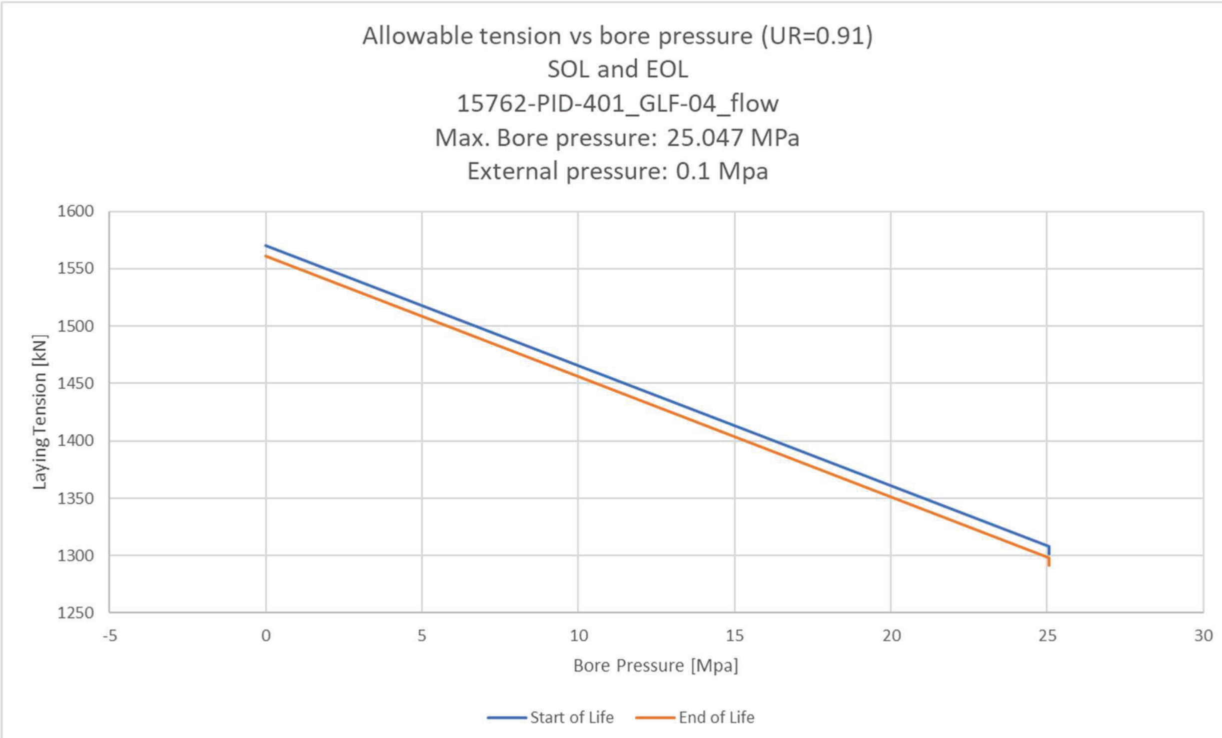











Allowable tension vs bore pressure (UR=0.91)
SOL and EOL
15762-PID-401_GLF-04_flow
Max. Bore pressure: 25.047 MPa
External pressure: 0.1 Mpa
1600
1550
1500
1450
1400
1350
1300
1250
Laying Tension [kN]
-5
0
5
10
15
20
25
30
Bore Pressure [Mpa]
Start of Life
End of Life