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Maritime works

Part 1-4: General — Code of practice for materials

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Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 July 2021. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

This part of BS 6349 supersedes BS 6349-1-4:2013, which is withdrawn.

Relationship with other publications

BS 6349 is published in the following parts:

- Part 1-1: *General – Code of practice for planning and design for operations*;
- Part 1-2: *General – Code of practice for assessment of actions*;
- Part 1-3: *General – Code of practice for geotechnical design*;
- Part 1-4: *General – Code of practice for materials*;
- Part 2: *Code of practice for the design of quay walls, jetties and dolphins*;
- Part 3: *Code of practice for the design of shipyards and sea locks;*
- Part 4: *Code of practice for design of fendering and mooring systems*;
- Part 5: *Code of practice for dredging and land reclamation*;
- Part 6: *Design of inshore moorings and floating structures*;
- Part 7: *Guide to the design and construction of breakwaters*;
- Part 8: *Code of practice for the design of Ro-Ro ramps, linkspans and walkways*.

Information about this document

This is a full revision of the standard, and introduces the following principal changes.

a) The standard has been updated to reflect current industry practice. In particular, the concrete section has been updated to be generally in line with the recommendations of BS 8500.

b) The metals section has been reorganized and updated. In particular, the clauses on corrosion, protective coatings, wraps and cathodic protection have been updated and incorporated into the appropriate section.

c) A new section on polymers has been added.

d) The sections on stone for armouring and protective works and bituminous materials have been updated.

e) The previous clauses on piles, rails, pipes and pavements have been removed from this standard as they are structural elements rather than materials.

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As a code of practice, this part of BS 6349 takes the form of recommendations and guidance. It is not to be quoted as if it were a specification. Users are expected to ensure that claims of compliance are not misleading.

Users may substitute any of the recommendations in this part of BS 6349 with practices of equivalent or better outcome. Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

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Section 1: General

Introduction

The materials covered by this part of BS 6349 include the basic materials used in civil engineering construction, and composite or manufactured materials where these are normally considered to be materials in their own right.

The materials covered in this part of BS 6349 are as follows:

a) concrete: complementary guidance to BS EN 206, BS 8500-1:2015+A2 and BS 8500-2;

b) metals;

c) timber;

d) polymers;

e) stone for armouring or protection works; and

f) bituminous materials.

Protective measures and treatments against corrosion of metals cover a wide range of methods that can be applied in the construction, operation and maintenance of maritime structures. These are also addressed in this part of BS 6349.

1 Scope

This part of BS 6349 gives recommendations for the materials used in the design and construction of maritime environment structures, and includes specific provisions for use in a seawater environment.

NOTE Materials used in these conditions are often subject to more onerous environmental conditions than onshore structures, and thus particular attention is paid to the use of durable materials to provide the required performance and design life.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document[1]. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

ANSI/AWWA C217, *Microcrystalline wax and petrolatum tape coating systems for steel water pipe and fittings*

ASTM D1765, *Standard classification system for carbon blacks used in rubber products*

BS 4449, *Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification*

BS 4482, *Steel wire for the reinforcement of concrete products – Specification*

BS 4483, *Steel fabric for the reinforcement of concrete – Specification*

[1] Documents that are referred to solely in an informative manner are listed in the Bibliography.

BS 4486, *Specification for hot rolled and hot rolled and processed high tensile alloy steel bars for the prestressing of concrete*

BS 5896, *High tensile steel wire and strand for the prestressing of concrete – Specification*

BS 6349-1-1, *Maritime works – Part 1-1: General – Code of practice for planning and design for operations*

BS 6349-4, *Maritime works – Part 4: Code of practice for design of fendering and mooring systems*

BS 6744, *Stainless steel bars – Reinforcement of concrete – Requirements and test methods*

BS 7371-6, *Coatings on metal fasteners – Part 6: Specification for hot dipped galvanized coatings*

BS 7542, *Method of test for curing compounds for concrete*

BS 8500-1:2015+A2:2019, *Concrete – Complementary British Standard to BS EN 206 – Part 1: Method of specifying and guidance for the specifier*

BS 8500-2, *Concrete – Complementary British Standard to BS EN 206 – Part 2: Specification for constituent materials and concrete*

BS 8666, *Scheduling, dimensioning, cutting and bending of steel reinforcement for concrete – Specification*

BS EN 206, *Concrete – Specification, performance, production and conformity*[2)]

BS EN 446, *Grout for prestressing tendons – Grouting procedures*

BS EN 447, *Grout for prestressing tendons – Basic requirements*

BS EN 523, *Steel strip sheaths for prestressing tendons – Terminology, requirements, quality control*

BS EN 912, *Timber fasteners – Specifications for connectors for timbers*

BS EN 1090-1, *Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components*

BS EN 1090-2, *Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures*

BS EN 1090-3, *Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures*

BS EN 1097-1, *Tests for mechanical and physical properties of aggregates – Part 1: Determination of the resistance to wear (micro-Deval)*

BS EN 1337-3:2005, *Structural bearings – Elastomeric bearings*

BS EN 1369, *Founding – Magnetic particle testing*

BS EN 1559-1, *Founding – Technical conditions of delivery – Part 1: General*[3)]

BS EN 1559-2, *Founding – Technical conditions of delivery – Part 2: Additional requirements for steel castings*[3)]

BS EN 1561, *Founding – Grey cast irons*

BS EN 1563, *Founding – Spheroidal graphite cast irons*

BS EN 1990, *Eurocode – Basis of structural design*

BS EN 1992 (all parts), *Eurocode 2 – Design of concrete structures*

BS EN 1993 (all parts), *Eurocode 3 – Design of steel structures*[4)]

2) This standard also gives informative references to BS EN 206:2013+A1:2016.
3) This standard also gives an informative reference to all parts of the BS EN 1559 series.
4) This standard also gives informative references to BS EN 1993-1-1 and BS EN 1993-5:2007.

BS EN 1995 (all parts), *Eurocode 5 – Design of timber structures*

BS EN 1999 (all parts), *Eurocode 9 – Design of aluminium structures*[5)]

BS EN 10025 (all parts), *Hot rolled products of structural steels*

BS EN 10080, *Steel for the reinforcement of concrete – Weldable reinforcing steel – General*

BS EN 10164, *Steel products with improved deformation properties perpendicular to the surface of the product – Technical delivery conditions*

BS EN 10210 (all parts), *Hot finished steel structural hollow sections*

BS EN 10219 (all parts), *Cold formed welded steel structural hollow sections*

BS EN 10248 (all parts), *Hot rolled sheet piling of non alloy steels*

BS EN 10249 (all parts), *Cold formed sheet piling of non alloy steels*

BS EN 10348-2, *Steel for the reinforcement of concrete – Galvanized reinforcing steel – Part 2: Galvanized reinforcing steel products*

BS EN 12680-3, *Founding – Ultrasonic testing – Part 3: Spheroidal graphite cast iron castings*

BS EN 12954, *General principles of cathodic protection of buried or immersed onshore metallic structures*

BS EN 13383 (all parts), *Armourstone*[6)]

BS EN 13670, *Execution of concrete structures*

BS EN 14545, *Timber structures – Connectors – Requirements*

BS EN ISO 179-1, *Plastics – Determination of Charpy impact properties – Part 1: Non-instrumented impact test*

BS EN ISO 527-2, *Plastics – Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics*

BS EN ISO 868, *Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness)*

BS EN ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread*

BS EN ISO 898-2, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes – Coarse thread and fine pitch thread*

BS EN ISO 1133 (all parts), *Plastics – Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics*

BS EN ISO 1183-1, *Plastics – Methods for determining the density of non-cellular plastics – Part 1: Immersion method, liquid pycnometer method and titration method*

BS EN ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test method*

BS EN ISO 1628-3, *Plastics – Determination of the viscosity of polymers in dilute solution using capillary viscometers – Part 3: Polyethylenes and polypropylenes*

BS EN ISO 2063-1, *Thermal spraying – Zinc, aluminium and their alloys – Part 1: Design considerations and quality requirements for corrosion protection systems*

BS EN ISO 10684, *Fasteners – Hot dip galvanized coatings*

5) This standard also gives a normative reference to BS EN 1999-1-1:2007+A2:2013.
6) This standard also gives an informative reference to BS EN 13383-1:2002.

BS EN ISO 12944 (all parts), *Paints and varnishes – Corrosion protection of steel structures by protective paint systems*

BS EN ISO 13174, *Cathodic protection of harbour installations*

BS EN ISO 14713 (all parts), *Zinc coatings – Guidelines and recommendations for the protection against corrosion of iron and steel in structures*

BS EN ISO 15527, *Plastics – Compression-moulded sheets of polyethylene (PE-UHMW, PE-HD) – Requirements and test methods*

BS ISO 34-1, *Rubber, vulcanized or thermoplastic – Determination of tear strength – Part 1: Trouser, angle and crescent test pieces*

BS ISO 37, *Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties*

BS ISO 48-4, *Rubber, vulcanized or thermoplastic – Determination of hardness – Part 4: Indentation hardness by durometer method (Shore hardness)*

BS ISO 132, *Rubber, vulcanized or thermoplastic – Determination of flex cracking and crack growth (De Mattia)*

BS ISO 812, *Rubber, vulcanized or thermoplastic – Determination of low-temperature brittleness*

BS ISO 813, *Rubber, vulcanized or thermoplastic – Determination of adhesion to a rigid substrate – 90° peel method*

BS ISO 815-1, *Rubber, vulcanized or thermoplastic – Determination of compression set – Part 1: At ambient or elevated temperatures*

BS ISO 1407, *Rubber – Determination of solvent extract*

BS ISO 1431-1, *Rubber, vulcanized or thermoplastic – Resistance to ozone cracking – Part 1: Static and dynamic strain testing*

BS ISO 1817, *Rubber, vulcanized or thermoplastic – Determination of the effect of liquids*

BS ISO 2000, *Rubber, raw natural – Guidelines for the specification of technically specified rubber (TSR)*

BS ISO 2781, *Rubber, vulcanized or thermoplastic – Determination of density*

BS ISO 4649, *Rubber, vulcanized or thermoplastic – Determination of abrasion resistance using a rotating cylindrical drum device*

BS ISO 4650, *Rubber – Identification – Infrared spectrometric methods*

BS ISO 9924-1, *Rubber and rubber products – Determination of the composition of vulcanizates and uncured compounds by thermogravimetry – Part 1: Butadiene, ethylene-propylene copolymer and terpolymer, isobutene-isoprene, isoprene and styrene-butadiene rubbers*

BS ISO 14654, *Epoxy-coated steel for the reinforcement of concrete*

ISO 6601, *Plastics — Friction and wear by sliding — Identification of test parameters*

ISO 12473, *General principles of cathodic protection in seawater*[7)]

ISO 16204, *Durability — Service life design of concrete structures*

ISO 17357 (all parts), *Ships and marine technology – Floating pneumatic rubber fenders*

NACE SP0375, *Field-applied underground wax coating systems for underground metallic pipes: application, performance, and quality control*

PD 6484, *Commentary on corrosion at bimetallic contacts and its alleviation*

7) This standard also gives an informative reference to ISO 12473:2017.

Other publications

[N1] LLOYD'S REGISTER. *Code for lifting appliances in a marine environment.* London: Lloyd's Register, 2020.

[N2] LLOYD'S REGISTER. *Rules for the manufacture, testing and certification of materials.* London: Lloyd's Register, 2020.

[N3] ENERGY INSTITUTE. *Guidelines for the use of anti-corrosion tape systems for process pipework.* London: Energy Institute, 2017.

[N4] CIRIA, CUR, CETMEF. *The Rock Manual – The use of rock in hydraulic engineering.* C683. Second edition. London: CIRIA, 2007.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this part of BS 6349, the terms and definitions given in BS 6349-1-1 and the following apply.

3.1.1 elastomer

macromolecular material which returns rapidly to approximately its initial dimensions and shape after substantial deformation by a weak stress and release of the stress

[SOURCE: BS ISO 1382:2020, **3.167**]

3.1.2 polyurethane

polymer prepared by the reaction of an organic di- or polyisocyanate with compounds containing two or more hydroxyl groups

NOTE Polyurethanes might be thermosetting, thermoplastic, rigid or soft and flexible, cellular or non-cellular.

[SOURCE: BS EN ISO 14896:2009, **3.1**]

3.1.3 rubber

(raw material) natural or synthetic elastic polymer (elastomer) which forms the basis of the compound used in many rubber products

NOTE Rubber has three different definitions, dependent on context. It can be the finished material of a product, but can also be a raw material or an intermediate material used during the manufacture of a product.

[SOURCE: BS ISO 1382:2020, **3.421**]

3.2 Abbreviated terms

For the purposes of this part of BS 6349-1-4, the following abbreviated terms apply.

ACEC	aggressive chemical environment for concrete
ALWC	accelerated low water corrosion
ASR	alkali-silica reaction
DEF	delayed ettringite formation
FRP	fibre-reinforced plastic
ggbs	ground granulated blastfurnace slag
GRP	glass-reinforced plastic

HAT	highest astronomical tide
LAT	lowest astronomical tide
MIC	microbiologically induced corrosion
MHWS	mean high water springs
MLWS	mean low water springs
MT	magnetic testing
MWL	mean water level
PT	penetration testing
RT	radiographic testing
SMYS	specified minimum yield strength
TGA	thermogravimetric analysis
UT	ultrasonic testing

Section 2: Concrete

*COMMENTARY ON SECTION **2***

The maritime environment is particularly severe for reinforced concrete structures where chloride ingress from seawater accelerates corrosion of any embedded reinforcement. Consequently, the specification for concrete, in terms of both materials and workmanship, needs to focus on the concrete being constructible and durable, as well as having structural strength. The same factors apply to design and detailing.

This section applies primarily to concrete structures constructed and located in the UK, and caution is needed if the guidance on durability is used outside similar temperate climate regions. In this event, it is necessary to be aware of the different environmental conditions of exposure (such as conditions of aridity and higher or lower temperatures), make an assessment of the impact and take appropriate measures. It might be necessary to seek specialist advice for specific requirements for other climate regions. Further guidance on design and construction of concrete structures in a marine environment can also be found in Annex A and CIRIA C674 [2].

4 General recommendations for concrete

The structural design of the concrete elements of maritime structures should be carried out in accordance with the principles of relevant design standards, such as BS EN 1992, as appropriate to the contract and to the application of the structure.

The environmental conditions should be identified for all stages of construction and operation to determine the appropriate exposure conditions for the design of the structure or specific elements. The design of the structure should take into account all appropriate environmental factors to ensure that the durability design is suitable for the intended working life.

Unless where specifically stated in this part of BS 6349, the specification and production of maritime concrete in the UK should conform to BS 8500 as a minimum. The recommendations provided in this part of BS 6349 should be used to supplement the requirements of BS 8500 where appropriate.

5 Design and construction of concrete structures

The following factors should be taken into account as a minimum in the design and construction of concrete structures.

a) The work might be substantially or permanently underwater, where access is difficult and visibility is negligible.

b) The work might be within reach of waves at every tide and therefore subject to wave action, scour and contamination by seawater.

c) The periods between tides in which the work is accessible might be very short, and it might be necessary to work during low tides at night as well as during the daytime.

d) Erosion of concrete due to abrasion can be a cause of serious damage to maritime structures. It can occur at water level with floating objects or at bed level where beach materials can continually be washed against the structure.

e) In cold climates, freezing and thawing and impact of ice can affect concrete adversely.

f) Concrete can suffer chemical attack from foundation soils, seawater and contaminants.

g) Steel reinforced, post-tensioned and prestressed concrete, particularly in the tidal zone, can suffer chloride ingress and serious corrosion damage to steel.

Temporary works should be simple and capable of rapid erection during tidal access, and should be strong enough to protect immature concrete and resist high temporary loadings in adverse weather.

The shape of concrete structures and members should be such that they can be formed by simple formwork, which can be easily fixed and is grout-tight, rigid and strong. Complicated shapes should not be used unless unavoidable. Thin cross-sections, in which the cover to reinforcement is sensitive to the accuracy of steel fixing, should not be used unless unavoidable.

Steel reinforcement should be carefully detailed such that it can be rapidly and accurately fixed while having adequate rigidity to resist displacement during placing and compaction of the concrete. Detailing of the reinforcement should be in accordance with BS EN 1992-1-1 and BS 8666. Due allowance should be made to include practical tolerances for the positioning of reinforcement, especially in difficult site environments.

Structural members and joint spacing should be designed to limit early thermal cracking, and/or steel reinforcement provided in order to control the size and spacing of cracks.

NOTE 1 Thick sections and massive concrete structures are at risk of early-age thermal cracking. Further guidance is given in CIRIA C766 [3].

NOTE 2 Further guidance on construction considerations is given in CIRIA C674 [2]. Additional information on execution of construction is given in BS EN 13670.

6 Durability of concrete structures

The following general factors should be taken into account for the assessment of durability.

a) Design for durability of concrete in maritime works (which can include elements of buildings, bridges or tunnels in coastal locations) is dependent upon the recognition of the specific exposure conditions that affect the various elements of a structure, both macro and microclimate and the adoption of appropriate design, detailing, materials and workmanship to suit these conditions. The specification of the concrete materials and details, such as location of construction joints and cover to reinforcement or prestressing steel (if any), is an integral part of the design process. Structural design and detailing should be undertaken in parallel to the design and selection of materials and details, such as cover, relating to durability.

b) The maritime environment can be very aggressive to concrete in terms of physical weathering, abrasion and chemical attack. Chloride-induced corrosion can also damage embedded metal or reinforcement. The assessment of durability in conjunction with maintenance strategy should be a fundamental part of the design process.

c) The durability of correctly placed and compacted reinforced concrete is mainly due to the cover to the reinforcement and the quality of the concrete; the quality is primarily governed by the water/cement ratio, type of cementitious materials and, to a lesser extent, the cement content. Whilst the concrete grade has traditionally been used as an indicator of quality, the strength of the concrete, and especially that measured at 28 days, is not a reliable indicator of durability performance.

d) Durability is not in itself a limit state, but is the means by which the serviceability and structural limit states are maintained for the lifetime of the structure. Being inherently time-related, design for durability is directly related to the intended operational life and maintenance strategy for the structure.

One of the following macroclimates should be chosen to assess the durability category, together with the correct application of microclimate (as described in Clause 7):

1) cold with freezing;
2) temperate (including UK);
3) hot wet; and
4) hot dry.

NOTE 1 These are the four main divisions of macroclimate that affect many of the deterioration processes.

Whilst much of the general guidance remains universally applicable to all macroclimatic conditions, the limiting values set out in Clause 7 and in BS 8500 should be used for concrete cast and/or exposed to a temperate UK macroclimate. For other macroclimatic conditions, specialist assistance should be sought, or reference made to specialist/local guidance documents.

NOTE 2 Annex A gives further information on the effect of macroclimate for concrete in a marine environment. See also CIRIA C674 [2].

7 Deterioration processes in concrete structures

7.1 General

Concrete structures should be designed to account for the following actions where applicable:

a) chloride-induced corrosion;
b) corrosion induced by carbonation;
c) freeze–thaw;
d) sulfate attack;
e) delayed ettringite formation;
f) physical processes of weathering;
g) abrasion; and
h) alkali-silica reaction.

All concrete that is directly exposed to seawater in a UK temperate environment should, as a minimum, be in accordance with Table 1 for abrasive conditions and BS 8500-1:2015+A2, Table A.13 for non-abrasive conditions. When CEM I cement alone is used, the C_3A content should not exceed 10%.

Table 1 — *Limiting values for composition and properties for both reinforced and unreinforced concrete with normal-weight aggregates exposed to both UK seawater conditions and abrasion for a required design working life up to 100 years*[A)] [B)]

Max. w/c ratio[C)]	Min. cement content or combination content (kg/m^3) for max. aggregate size				Cement and combination types[D)]	Indicative compressive strength class[E)]
	40 mm	20 mm	14 mm	10 mm		
0.45	340	360	380	380	CEM I	C40/50
					IIA	C35/45
					IIB, IIIA	C32/40
					IVB-V	C30/37
					IIIB	C28/35

A) Abrasive conditions are defined as exposure to aggressive wave action, cavitations or beach sediments; further information is given in CIRIA C674 [2]. Abrasion due to chains, ropes or other operational reasons should be assessed separately.

B) Additional resistance can be achieved by incorporating steel fibres, abrasion resistance aggregate (Los Angeles Abrasion LA30) or IIA-D cement in the concrete, or, for formed surfaces, if controlled permeability formwork is used.

C) Maximum free water/cement ratio, in accordance with BS EN 206.

D) For thick concrete sections (typically, but not limited to, >600 mm thickness), an appropriate cement type should be chosen that enables the deleterious effects of heat of hydration to be controlled. Normally, increased proportions of ggbs or fly ash may be used to mitigate the risks for early age and DEF-induced cracking. Further guidance is given in CIRIA C766 [3].

E) Water/cement ratio limit is the ruling parameter in terms of overall durability, with the cement content being secondary. The indicative compressive strength class is the anticipated 28-day strength based on the cement or combination type, and not a minimum strength class for structural requirements.

7.2 Chloride-induced corrosion

The correct classification should be assessed in accordance with Table 2 to determine the factors for the concrete specification and cover requirements.

NOTE 1 XSM exposure categories are used in this edition of BS 6349-1-4 rather than the XS categories used previously:

- *to provide a more refined approach to exposure classification in a marine environment than the exposure categories given in BS EN 1992-1-1, BS EN 206 and BS 8500; and*
- *to differentiate more clearly between the guidance on the limiting concrete mix proportions given in BS 6439-1-4 and BS 8500 so as to prevent errors in specification and supply.*

Further guidance on the classification of exposure conditions and the effect of climate is given in Annex A.

Table 2 — *Maritime exposure classes for chloride induced corrosion of steel in concrete by seawater*

Class designation	Description of environment	Informative examples	BS 8500/BS EN 206 classification[A)]			
			Class designation	**Description of the environment**	**BS EN 206 informative examples**	**BS 8500 informative examples**
XSM1	Exposed to airborne salt but not in direct contact with seawater	Exterior concrete surfaces in coastal areas not otherwise classified as being exposed to any other XSM classification	XS1	Exposed to airborne salt but not in direct contact with seawater	Structures near to or on the coast	External reinforced and prestressed concrete surfaces in coastal areas
XSM2	Permanently submerged	Concrete surfaces which are: • below MLWS; or • buried in saline ground[B)] and below the water table	XS2	Permanently submerged	Parts of marine structures	Reinforced and prestressed concrete surfaces completely submerged or remaining saturated, e.g. concrete below mid-tide level
XSM3	Mainly wetted, occasionally dry	Concrete surfaces which are: • between MHWN and MLWS; or • buried in saline ground[B)] and above the water table	XS3	Tidal, splash and spray zones	Parts of marine structures	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash and spray zones, including exposed soffits above sea water

Table 2 — *Maritime exposure classes for chloride induced corrosion of steel in concrete by seawater (continued)*

Class designation	Description of environment	Informative examples	BS 8500/BS EN 206 classification[A)]			
			Class designation	Description of the environment	BS EN 206 informative examples	BS 8500 informative examples
XSM4	Regular wetting/ drying or subject to hydraulic pressure gradient	Concrete surfaces which are: • between MHWN and the extreme water level plus maximum wave height; or • exposed to direct splashing/ spraying with seawater, e.g. by waves impacting against the structure; or • both “wet” and “dry” faces of air-filled voided structures where one face would otherwise be classified as being exposed to XSM2 or XSM3 conditions	XS3	Tidal, splash and spray zones	Parts of marine structures	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash and spray zones, including exposed soffits above sea water

A) The relationship between the XSM and XS classes is provided for reference.

B) Where chloride level in groundwater or via 2:1 water soil extract is greater than 1 200 mg/l, measured in accordance with BS 1377-3.

For marine structures located in the UK, the recommendations given in Table 3 to Table 5 should be adopted for XSM conditions where:

a) the reinforcement conforms to BS 4449, BS 4482 and BS 4483 (or BS EN 10080);

b) the concrete is fully compacted and properly cured;

c) no methods of enhanced protection of the reinforcement are to be adopted (see Annex B); and

d) a service life design has not been undertaken.

NOTE 2 The tables may be used to determine the amount of cover required for a type of concrete (e.g. for low heat concretes for thicker sections), or the types of concrete appropriate for a known cover.

NOTE 3 Concrete which is not fully compacted and properly cured prior to first exposure to saline environment, or with other construction defects, does not provide the same level of resistance to chloride ingress when subsequently exposed to that environment.

NOTE 4 In the case of reinforcement corrosion, the serviceability limit state used in the development of Table 3 to Table 5 for XSM exposure was to the initiation of reinforcement corrosion. Other definitions of durability failure which could be used as part of a detailed probabilistic or partial factor service life design include:

- *cracking resulting from reinforcement corrosion; and*
- *spalling and/or loss of steel and/or concrete section.*

For pre-tensioned concrete generally and post-tensioned concrete anchorages, the minimum cover given in Table 3 to Table 5 should be increased by 10 mm as an additive safety element ($\Delta c_{dur,\gamma}$). The cover should also be provided to the ends of tensioning members on pre-tensioned elements and to the anchorage for post-tensioned elements.

NOTE 5 The term "additive safety element" is defined in BS EN 1993-1-1.

For all other situations (e.g. different macroclimates, design working lives, durability failure criteria, different cement types, inclusion of methods of enhanced protection of reinforcement, or where the concrete is not fully compacted or contains other construction defects), a systematic probabilistic or partial factor service life design should be undertaken, as set out in ISO 16204 or a similar approach.

NOTE 6 This approach can also be adopted if a greater level of granularity to that given in the above referenced tables is required, e.g. for intermediate water cement ratios and cement/combination compositions.

NOTE 7 The term "design working life" is defined in BS EN 1990.

NOTE 8 Systematic (or explicit) design methods are developing, but are at the transition stage. As a result, the specification has almost certainly to be expressed in prescriptive terms, i.e. with mix limitations for concrete properties and cover to reinforcement, all selected from tabulated values. Further guidance is given in CIRIA C674 [2] and Concrete Society Technical Report 61 [4]. Specialist advice may also be sought if this approach is considered applicable to the design of the structure, particularly outside UK temperate climatic conditions.

NOTE 9 Guidance on enhanced protection of reinforcement is given in Annex B.

7.3 Carbonation-induced corrosion

For marine structures located in the UK, constructed with reinforcement conforming to BS 4449, BS 4482 and BS 4483 (or BS EN 10080), where the concrete is fully compacted and properly cured, and in the absence of any methods of enhanced protection of the reinforcement, the requirements given in BS 8500 should be adopted for XC exposure conditions.

NOTE 1 Concrete which is not fully compacted and properly cured does not provide the same level of carbonation resistance when subsequently exposed to that environment.

NOTE 2 In a marine environment, design for XSM exposure conditions (as described in Table 2) is usually more onerous.

NOTE 3 XC exposure conditions are defined in BS 8500.

Table 3 — *Maximum water/cement ratio*[A)]*, minimum cement/combination content*[B)] *and indicative compressive strength class*[C)] *for normal-weight concrete*[D)] *of 20 mm maximum aggregate size for reinforced and prestressed*[E)] *concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 30 years (1 of 2)*

Nominal cover[E)] (mm)	30+Δc	35+Δc	40+Δc	45+Δc	50+Δc	55+Δc	60+Δc	65+Δc	70+Δc	75+Δc	80+Δc	Cement/ combination types[F)]
XSM1 Exposed to airborne salt but not in direct contact with seawater	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.45 360 C35/45	0.50 340 C32/40	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	CEM I, IIA, IIB-M, IIB-S
	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	0.52 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	0.52 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM2 Permanently submerged	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.42 360 C35/45	0.45 360 C35/45	0.50 340 C32/40	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	CEM I, IIA, IIB-M, IIB-S
	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM3 Mainly wetted, occasionally dry	-	-	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.42 360 C35/45	0.45 360 C35/45	0.47 340 C32/40	0.50 340 C32/40	CEM I, IIA, IIB-M, IIB-S
	-	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	0.35[G)] 380 C35/45	0.45 360 C32/40	0.5 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	0.35[G)] 380 C35/45	0.45 360 C28/35	0.5 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM4 Regular - wetting/drying or subject to hydraulic pressure gradient	-	-	-	-	-	-	0.35[G)] 380 C45/55	0.37 380 C40/50	0.40 380 C40/50	0.45 360 C35/45	0.47 340 C32/40	CEM I, IIA, IIB-M, IIB-S
	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	0.35[G)] 380 C35/45	0.40 360 C32/40	0.45 340 C28/35	0.50 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	0.35[G)] 380 C35/45	0.40 380 C32/40	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB

Table 3 — *Maximum water/cement ratio[A], minimum cement/combination content[B] and indicative compressive strength class[C] for normal-weight concrete[D] of 20 mm maximum aggregate size for reinforced and prestressed[E] concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 30 years (2 of 2)*

A dash (-) indicates that a greater cover should be used.

A) Maximum free water/cement ratio in accordance with BS EN 206.

B) Minimum cement/combination content depends on maximum aggregate size and should be adjusted for concretes with a maximum aggregate size other than 20 mm in accordance with BS 8500-1:2015+A2. Depending on aggregate type and the specified consistency class, higher cement contents might be required and this should be taken into account, such as when assessing early age cracking.

C) Resistance to chloride ingress is primarily dictated by cement type/combination and the w/c ratio, with cement content and aggregate type being secondary factors. Compressive strength class measured at early ages, e.g. 28 days, is a poor indicator of chloride resistance and has only historically been used as a convenient proxy measurement due to the difficulty in measuring the water/cement ratio directly. The compressive strength class is provided in this table is an indicative value and is not a requirement; failure to achieve the given values should not be used as a reason for rejection. The values of compressive strength class given are provided to indicate what 28-day strength class is likely to be achieved for a particular concrete as an aid to the structural designer. Concretes with significant levels of additions tend to have reduced 28-day compressive strengths when compared to CEM I or similar concretes with the same water/cement ratio, but continue to increase in strength over longer periods of time. Air-entrained concrete has a lower compressive strength class than that indicated in this table, typically in the region of 10 MPa lower, but provides an equivalent resistance to chloride ingress.

D) Also applies to heavyweight concrete. For lightweight concrete, the maximum w/c ratio and minimum cement or combination content applies, but the indicative compressive strength class should be changed to a lightweight compressive strength class.

E) Expressed as minimum cover to reinforcement (C_{min}) plus an allowance in design for deviation (Δc), e.g. to allow for workmanship. An additional 10 mm should be added to C_{min} for prestressed steel not in ducts and to post-tensioning anchorages. The minimum cover should also be increased where surface erosion of the concrete is anticipated, such as a result of abrasion, freeze–thaw damage or the action of aggressive chemicals.

F) This column covers the following cement combination types.

a) CEM I-SR0 and CEM I-SR3 should not be used. CEM I-SR5 can be used and should be taken as being equivalent to CEM I.

b) IIA-D can be used and should be evaluated as CEM I, with the effective water/cement ratio being calculated using the *k* concept in accordance with BS EN 206.

c) IIA-L, IIA-LL, IIB-L and IIB-LL cements should be evaluated as CEM I on the basis of an effective water/cement ratio. The effective water/cement ratio should be calculated using the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

d) IIA-M and IIB-M should be evaluated on the basis of the most appropriate CEM II cement type, after disregarding the amount of limestone present over and above that permitted in a CEM I cement and an effective water/cement ratio. The effective water/cement ratio should be calculated from the effective cement content which is the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

e) For cement types not specifically listed, no advice is given and specialist advice should be sought.

G) In some parts of the UK, it is not possible to produce a practical concrete with a maximum water/cement ratio as low as 0.35 with the locally available aggregate.

Table 4 — *Maximum water/cement ratio[A)], minimum cement/combination content[B)] and indicative compressive strength class[C)] for normal-weight concrete[D)] of 20 mm maximum aggregate size for reinforced and prestressed[E)] concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 50 years (1 of 2)*

Nominal cover[E)] (mm)	30+Δc	35+Δc	40+Δc	45+Δc	50+Δc	55+Δc	60+Δc	65+Δc	70+Δc	75+Δc	80+Δc	Cement/ Combination types[F)]
XSM1 Exposed to airborne salt but not in direct contact with seawater	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.45 360 C35/45	0.50 340 C32/40	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	0.55 320 C28/35	CEM I, IIA, IIB-M, IIB-S
	0.35[G)] 380 C40/50	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	0.40 380 C35/45	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	0.40 380 C32/40	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM2 Permanently submerged	-	-	-	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.42 360 C35/45	0.45 360 C35/45	0.50 340 C30/40	CEM I, IIA, IIB-M, IIB-S
	- -	-	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	0.35[G)] 380 C40/50	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	0.35[G)] 380 C35/45	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM3 Mainly wetted, occasionally dry	-	-	-	-	-	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.42 360 C35/45	CEM I, IIA, IIB-M, IIB-S
	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	0.35[G)] 380 C40/50	0.4 380 C35/45	0.45 360 C32/40	0.5 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	0.35[G)] 380 C35/45	0.4 380 C32/40	0.45 360 C28/35	0.5 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM4 Regular - wetting/drying or subject to hydraulic pressure gradient	-	-	-	-	-	-	-	-	-	-	0.35[G)] 380 C45/55	CEM I, IIA, IIB-M, IIB-S
	-	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	-	0.35[G)] 380 C40/50	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	-	0.35[G)] 380 C35/45	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB

Table 4 — *Maximum water/cement ratio[A], minimum cement/combination content[B] and indicative compressive strength class[C] for normal-weight concrete[D] of 20 mm maximum aggregate size for reinforced and prestressed[E] concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 50 years (2 of 2)*

A dash (-) indicates that a greater cover should be used.

A) Maximum free water/cement ratio in accordance with BS EN 206.

B) Minimum cement/combination content depends on maximum aggregate size and should be adjusted for concretes with a maximum aggregate size other than 20 mm in accordance with BS 8500-1:2015+A2. Depending on aggregate type and the specified consistency class, higher cement contents might be required and this should be taken into account, such as when assessing early age cracking.

C) Resistance to chloride ingress is primarily dictated by cement type/combination and the w/c ratio, with cement content and aggregate type being secondary factors. Compressive strength class measured at early ages, e.g. 28 days, is a poor indicator of chloride resistance and has only historically been used as a convenient proxy measurement due to the difficulty in measuring the water/cement ratio directly. The compressive strength class is provided in this table is an indicative value and is not a requirement; failure to achieve the given values should not be used as a reason for rejection. The values of compressive strength class given are provided to indicate what 28-day strength class is likely to be achieved for a particular concrete as an aid to the structural designer. Concretes with significant levels of additions tend to have reduced 28-day compressive strengths when compared to CEM I or similar concretes with the same water/cement ratio, but continue to increase in strength over longer periods of time. Air-entrained concrete has a lower compressive strength class than that indicated in this table, typically in the region of 10 MPa lower, but provides an equivalent resistance to chloride ingress.

D) Also applies to heavyweight concrete. For lightweight concrete, the maximum w/c ratio and minimum cement or combination content applies, but the indicative compressive strength class should be changed to a lightweight compressive strength class.

E) Expressed as minimum cover to reinforcement (C_{min}) plus an allowance in design for deviation (Δc), e.g. to allow for workmanship. An additional 10 mm should be added to C_{min} for prestressed steel not in ducts and to post-tensioning anchorages. The minimum cover should also be increased where surface erosion of the concrete is anticipated, such as a result of abrasion, freeze–thaw damage or the action of aggressive chemicals.

F) This column covers the following cement combination types.

a) CEM I-SR0 and CEM I-SR3 should not be used. CEM I-SR5 can be used and should be taken as being equivalent to CEM I.

b) IIA-D can be used and should be evaluated as CEM I, with the effective water/cement ratio being calculated using the *k* concept in accordance with BS EN 206.

c) IIA-L, IIA-LL, IIB-L and IIB-LL cements should be evaluated as CEM I on the basis of an effective water/cement ratio. The effective water/cement ratio should be calculated using the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

d) IIA-M and IIB-M should be evaluated on the basis of the most appropriate CEM II cement type, after disregarding the amount of limestone present over and above that permitted in a CEM I cement and an effective water/cement ratio. The effective water/cement ratio should be calculated from the effective cement content which is the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

e) For cement types not specifically listed, no advice is given and specialist advice should be sought.

G) In some parts of the UK, it is not possible to produce a practical concrete with a maximum water/cement ratio as low as 0.35 with the locally available aggregate.

Table 5 — *Maximum water/cement ratio[A)], minimum cement/combination content[B)] and indicative compressive strength class[C)] for normal-weight concrete[D)] of 20 mm maximum aggregate size for reinforced and prestressed[E)] concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 100 years (1 of 2)*

Nominal cover[E)] (mm)	30+Δc	35+Δc	40+Δc	45+Δc	50+Δc	55+Δc	60+Δc	65+Δc	70+Δc	75+Δc	80+Δc	Cement/Combination types[F)]
XSM1 Exposed to airborne salt but not in direct contact with seawater	-	-	-	-	-	-	-	0.35[G)] 380 C45/55	0.40 380 C40/50	0.45 360 C35/45	0.50 340 C32/40	CEM I, IIA, IIB-M, IIB-S
	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	0.40 380 C32/40	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM2 Permanently submerged	-	-	-	-	-	-	-	-	-	-	-	CEM I, IIA, IIB-M, IIB-S
	- -	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.52 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	-	0.35[G)] 380 C35/45	0.40 380 C32/40	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM3 Mainly wetted, occasionally dry	-	-	-	-	-	-	-	-	-	-	-	CEM I, IIA, IIB-M, IIB-S
	-	-	-	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.52 320 C25/30	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	-	-	-	-	0.4 380 C35/45	0.45 360 C32/40	0.5 340 C28/35	0.55 320 C25/30	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	-	-	-	-	0.4 380 C32/40	0.45 360 C28/35	0.5 340 C25/30	0.55 320 C20/25	0.55 320 C20/25	IVB-V, IIIB
XSM4 Regular - wetting/drying or subject to hydraulic pressure gradient	-	-	-	-	-	-	-	-	-	-	-	CEM I, IIA, IIB-M, IIB-S
	-	-	-	-	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	IIB-P, IIB-Q, IIB-V,IIIA
	-	-	-	-	-	-	0.35[G)] 380 C40/50	0.40 380 C35/45	0.45 360 C32/40	0.50 340 C28/35	0.55 320 C25/30	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	-	-	-	-	-	-	0.35[G)] 380 C35/45	0.40 380 C32/40	0.45 360 C28/35	0.50 340 C25/30	0.55 320 C20/25	IVB-V, IIIB

Table 5 — *Maximum water/cement ratio[A)], minimum cement/combination content[B)] and indicative compressive strength class[C)] for normal-weight concrete[D)] of 20 mm maximum aggregate size for reinforced and prestressed[E)] concrete exposed to XSM exposure conditions in a temperate climate for an intended working life of up to 100 years (2 of 2)*

A dash (-) indicates that a greater cover should be used.

A) Maximum free water/cement ratio in accordance with BS EN 206.

B) Minimum cement/combination content depends on maximum aggregate size and should be adjusted for concretes with a maximum aggregate size other than 20 mm in accordance with BS 8500-1:2015+A2. Depending on aggregate type and the specified consistency class, higher cement contents might be required and this should be taken into account, such as when assessing early age cracking.

C) Resistance to chloride ingress is primarily dictated by cement type/combination and the w/c ratio, with cement content and aggregate type being secondary factors. Compressive strength class measured at early ages, e.g. 28 days, is a poor indicator of chloride resistance and has only historically been used as a convenient proxy measurement due to the difficulty in measuring the water/cement ratio directly. The compressive strength class is provided in this table is an indicative value and is not a requirement; failure to achieve the given values should not be used as a reason for rejection. The values of compressive strength class given are provided to indicate what 28-day strength class is likely to be achieved for a particular concrete as an aid to the structural designer. Concretes with significant levels of additions tend to have reduced 28-day compressive strengths when compared to CEM I or similar concretes with the same water/cement ratio, but continue to increase in strength over longer periods of time. Air-entrained concrete has a lower compressive strength class than that indicated in this table, typically in the region of 10 MPa lower, but provides an equivalent resistance to chloride ingress.

D) Also applies to heavyweight concrete. For lightweight concrete, the maximum w/c ratio and minimum cement or combination content applies, but the indicative compressive strength class should be changed to a lightweight compressive strength class.

E) Expressed as minimum cover to reinforcement (C_{min}) plus an allowance in design for deviation (Δc), e.g. to allow for workmanship. An additional 10 mm should be added to C_{min} for prestressed steel not in ducts and to post-tensioning anchorages. The minimum cover should also be increased where surface erosion of the concrete is anticipated, such as a result of abrasion, freeze–thaw damage or the action of aggressive chemicals.

F) This column covers the following cement combination types.

a) CEM I-SR0 and CEM I-SR3 should not be used. CEM I-SR5 can be used and should be taken as being equivalent to CEM I.

b) IIA-D can be used and should be evaluated as CEM I, with the effective water/cement ratio being calculated using the *k* concept in accordance with BS EN 206.

c) IIA-L, IIA-LL, IIB-L and IIB-LL cements should be evaluated as CEM I on the basis of an effective water/cement ratio. The effective water/cement ratio should be calculated using the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

d) IIA-M and IIB-M should be evaluated on the basis of the most appropriate CEM II cement type, after disregarding the amount of limestone present over and above that permitted in a CEM I cement and an effective water/cement ratio. The effective water/cement ratio should be calculated from the effective cement content which is the actual cement content minus the difference between the total amount of limestone and the maximum amount permitted from CEM I. Where the amount of limestone is not declared, it should be assumed to be the maximum permitted for the declared cement type.

e) For cement types not specifically listed, no advice is given and specialist advice should be sought.

G) In some parts of the UK, it is not possible to produce a practical concrete with a maximum water/cement ratio as low as 0.35 with the locally available aggregate.

7.4 Sulfate attack

*COMMENTARY ON **7.4***

Exposure classes for sulfates in the ground and groundwater are normally related to the type of sulfate and concentration of sulfate ions. However, the disruptive effect of sulfates is mitigated in seawater by the presence of chlorides. Blends of cements or combinations containing blastfurnace slag or fly ash and Portland cement provide good sulfate resistance as well as having enhanced resistance to chloride ion penetration.

Where sulfates are present, the appropriate design requirements should be assessed in relation to the concrete's ACEC class in accordance with BS 8500 for concrete in a UK environment.

7.5 Delayed ettringite formation (DEF)

Where the heat of hydration or accelerated curing is likely to take the peak concrete temperature above 70 °C, the potential for DEF should be assessed and mitigated where necessary.

NOTE 1 With information on the pour dimensions, concrete mix, environmental conditions and formwork type/stripping times and construction sequence, the maximum internal concrete temperature and core-to-surface temperature differentials (and hence risk of early thermal cracking) can be estimated to assess the risk. The results of this modelling can be verified by monitoring the surface and core temperatures of trial pours.

NOTE 2 Risk of DEF can be reduced by:

- *the use of cement or cement combination, containing at least 50% ggbs or 25% fly ash or equivalent;*
- *reducing the cement/combination content by increasing the aggregate content, such as by increasing the maximum aggregate size; or*
- *instigating hot-concreting procedures to minimize the temperature of the fresh concrete, minimize thermal gain from the environment and maximize heat dissipation into the surrounding environment whilst controlling temperature differentials (see ACI 305R-20 [5] and Concrete Society CS163 [6]).*

NOTE 3 The use of cements or combinations containing ggbs or fly ash in suitable proportions has the combined effect of reducing the temperature rise and increasing the temperature at which DEF occurs by limiting the total SO_3 and alkali in the cement.

7.6 Freeze–thaw

Concrete located within the UK should be designed for resistance to freeze–thaw conditions in accordance with BS 8500.

NOTE 1 It is not normally necessary to categorize marine concrete within the UK as an XF4 exposure classification purely due to direct exposure to seawater. XF4 classification is typically limited to horizontal surfaces to which de-icing salts are directly applied.

NOTE 2 Air-entraining admixtures are beneficial for concrete exposed to freeze–thawing, particularly pavement surfaces, especially those that are subject to the application of de-icing salts, but the concrete strength is lower than would otherwise be achieved, and controlling the required amount of air is often difficult where the cement content is in excess of 400 kg/m^3. Where this is an issue, resistance to freeze–thaw in UK conditions can be obtained with more confidence by the use of higher strength non-air-entrained mixes.

7.7 Alkali-silica reaction

Concrete should be designed and specified to minimize the risk of ASR in accordance with BS 8500-2.

8 Materials and workmanship in concrete structures

8.1 General

All materials used in the production of plain, reinforced and prestressed concrete should be in accordance with the relevant British Standard for concrete located in the UK.

In this clause, all recommendations are based on reinforcement and prestressing being in accordance with BS 4449, BS 4482, BS 4483, BS 4486 or BS 5896. For reinforcement or prestressing in accordance with other standards, such as BS 6744, BS EN 10348-2 or BS ISO 14654, specialist advice should be obtained.

The execution of concrete structures should be in accordance with BS EN 13670, in conjunction with a project specification tailored for the works being undertaken and the particular requirements for the marine environment as set out in this clause.

NOTE Examples of project specifications in the UK which may be used as guidance are the National Structural Concrete Specification (NSCS) [7] and ICE Specification for piling and embedded retaining walls [8], but neither is specifically tailored for works in a marine environment. Further information on diaphragm wall and displacement piles is given in BS EN 1538 for diaphragm walls and BS EN 12699 for displacement piles.

For concrete works located outside of the UK, the relevant local equivalent standards should be applied.

8.2 Chloride content of concrete

The chloride ion content class of the concrete as delivered (percentage by mass of cement or combination), as calculated by the procedure given in BS 8500-2 from all constituents, should be as shown in Table 6.

Table 6 — *Chloride content class of concrete for maritime structures*

Concrete type	Chloride content class	Maximum chloride ion content by mass of cement
Heat-cured or containing prestressing steel in direct contact with concrete	Cl 0,10	0.10%
Containing steel reinforcement or other embedded metal	Cl 0,30	0.30%
Plain (unreinforced)	Cl 1,0	1.0%

If testing of either production cube/cylinders or cores removed from the structure is undertaken, the results should be assessed taking into account the limitations of current routine sampling and testing technologies.

NOTE Further information is given in Concrete Society publication TR32 [9].

8.3 Reinforcement

Where possible, reinforcement should be maintained free from salt contamination whilst in transit, in storage, during fixing and until final encapsulated in concrete. Where the surface of the reinforcement does become contaminated, the contamination and any loose millscale or flaky rust should be removed prior to concrete placement.

NOTE Power washing with potable water is generally adequate to remove most contamination, with further measures only being necessary in the case of corrosion-induced pitting. Light surface rust, if not contaminated with salt, can be left in place.

8.4 Pre-tensioning and post-tensioning systems

Prestressing wire, strand or bar should be in accordance with BS 5896 or BS 4486.

Ducts for post-tensioning should be in accordance with BS EN 523. Grouts for filling ducts should conform to BS EN 446 and BS EN 447.

NOTE At the time of publication of this part of BS 6349, there is no standard for post-tensioning systems kits. European Technical Assessments (ETAs) are available for these systems.

8.5 Cover

The nominal cover, C_{nom}, i.e. the figure used for detailing and shown on the drawings for construction, should be the minimum cover value, C_{min}, together with an allowance for deviation, Δc_{dev}.

The minimum cover to reinforcement should be taken as the minimum distance from the surface of the concrete to any steel reinforcement, links, tendons or sheaths. The thickness of the tying wire is not included, but ends of tying wire should be turned away from the cover zone and into the body of the concrete.

The minimum tolerance for construction against formwork, Δc_{dev}, for in-situ concreting undertaken in a marine environment should be 15 mm. Increased cover tolerances, Δc_{dev}, should be provided where access, visibility or opportunity for inspection and maintenance is limited and should be at least 50 mm in the case of piles and diaphragm walls or for ground-bearing members to accommodate the greater difficulty in fixing reinforcement in these elements. Lower tolerances should be used only when conformity can be demonstrated.

NOTE 1 For structures designed in accordance with BS EN 1992, the minimum cover C_{min} is the greater of the cover needed for:

- *safe transmission of bond forces (see BS EN 1992-1-1);*
- *durability (protection of reinforcement against corrosion) – $C_{min,dur}$ plus the addition of allowances for an additive safety element ($\Delta c_{dur,\gamma}$) (e.g. due to the use of prestressing steel or reduction due to the provision of enhanced protection measures ($\Delta c_{dur,st}$ or $\Delta c_{dur,add}$); and*
- *adequate fire resistance (see BS EN 1992-1-2).*

NOTE 2 The provision of increased cover commonly conflicts with a requirement to control the surface width and spacing of flexural and early age thermal cracks using the approach given in BS EN 1992-1-1. In maritime conditions, however, the requirement for durability usually determines the necessary cover. Further information on this conflict is given in CIRIA C766 [3].

8.6 Curing

The methods and implementation of curing should be chosen and planned in advance of construction.

NOTE 1 Curing is a very important aspect of the construction phase and plays a significant role in ensuring the intended working life is achieved when concrete is exposed to an aggressive marine environment.

NOTE 2 Water loss in the days following casting can result in poor surface properties which jeopardize the achievement of the required level of durability, especially when exposed to a marine environment at an early age.

Concrete should be cured for a period not less than those shown in Table 7. Curing should be applied/implemented no later than the onset of the final set and be maintained throughout the required minimum curing period.

NOTE 3 In drying environments (e.g. hot and/or windy), the commencement of curing before the initial set can be beneficial in preventing early age cracking and defects, although the measures applied will likely be different to those applied post final set. Further information is given in ACI 308R-16 [10].

Table 7 — *Minimum curing periods for different cement types*

Cement or combination type	Minimum period, $t_{cure,min}$ (days), for mean ambient temperatures above 15 °C
CEM I, CEM II/A-L(LL), II/A, II/B-S	5
IIIA, II/B-V, IIB-V+SR	7
IIIB, IVB-V	10

Where the mean ambient temperature is below 15 °C, the curing period should be calculated using the following equation:

$$t_{cure} = t_{cure,min} \times \left(\frac{36}{T_{a,mean} + 16} \right)^2$$

where:

t_{cure} is the curing period, in days;
$t_{cure,min}$ is the minimum curing period in days;
$T_{a,mean}$ is the mean ambient temperature, in °C.

NOTE 4 Properly implemented and maintained wet curing is the most effective method available, particularly when the water/cement ratio of the concrete mix is less than 0.42. Where wet curing is not possible, high-efficiency spray-applied curing membranes can be used, provided that they can be protected from removal by the marine environment.

For formed surfaces, the time up until the formwork is removed may be included as part of the curing period provided water is applied to the joint between concrete and formwork so that it runs down the surface of the concrete and keeps it uniformly wet. This application of water should not be undertaken before the surface of the immature concrete has hardened sufficiently to resist damage.

Curing of massive elements, e.g. caissons and massive piers or units, presents logistical difficulties for fixing of the curing materials, and securing plastic or other sheeting against wind and weather. Such practicalities should be taken into account at the design stage, as opposed to placing reliance on measures that might not be practicable to carry out.

Saline/brackish water should not be used for wet curing reinforced concrete. To minimize the risk of thermal shock to immature concrete, the temperature of water used for wet curing should be not more than 10 °C less than the temperature of the surface of the concrete to which it is being applied.

Spray applied curing membranes should be in accordance with BS 7542 with an efficiency of at least 90%.

NOTE 5 Curing membranes may beneficially contain either a fugitive dye or be aluminized so that coverage can be verified.

8.7 Underwater concreting

*COMMENTARY ON **8.7***

Underwater concreting can be carried out in situ by placing conventionally mixed fresh concrete by the methods listed in this subclause.

Guidance on developments in underwater concreting is given in Concrete Society Technical Report 35 [11].

The principal methods of placing fresh concrete under water are:

- *tremie-type methods. Contact between the concrete face and water is carefully controlled by injecting fresh concrete only into the mass of previously placed but fluid concrete, by tremie,* *pumping, underwater skip or hydro valve. These methods are suitable for plain concrete and simple, massive reinforced concrete sections;*

- *by preventing contact between fresh concrete and water, as in pre-filled bags or pumping into collapsed flexible forms. This method is not suitable for reinforced concrete;*
- *by introducing admixtures and/or additives that give enhanced cohesive, self-levelling and self-compacting properties. These methods are suitable for reinforced sections; and*
- *grouting with or without admixtures or additions, for grouted aggregate concrete or the grouting of connections between structural members, fissures, voids or joints.*

Reinforced concrete members with concrete placed underwater should be designed for structural strengths and tolerances that can feasibly be achieved in situ and appropriate to the logistics of construction and quality control.

For normal working methods, the mix design should be carried out in the same way as for work in the dry. The concrete should be free flowing, cohesive and self-compacting with a specified minimum slump or flow value (typically S4 or F5 as specified in BS 8500-1:2015+A2).

NOTE Both superplasticizers and anti-washout admixtures are typically required for concrete placed underwater.

The following additional factors should be taken into account when selecting and placing underwater concrete.

a) A concrete that is highly workable and can be pumped has the characteristics required for most underwater applications. High strength concrete is not normally necessary. The properties of concrete properly placed underwater are broadly similar to those of the same concrete placed in the dry. The quality of the finished product is controlled by the quality of the materials and workmanship, together with the care taken to obviate defects such as areas of washout, silt inclusions, etc.

b) Adjustment of the cement content and the use of either water reducing or specialist admixtures can achieve the high consistence required. It is usually unnecessary for cement contents to exceed 420 kg/m^3, and a range of 320 kg/m^3 to 420 kg/m^3 is typical. The consistence may be measured using a slump flow method as described in BS EN 206.

Section 3: Metals

*COMMENTARY ON SECTION **3***

Metals are typically more susceptible to corrosion in a maritime environment. This is mainly due to:

- *the presence of salts in the seawater;*
- *the erosion of protective corrosion products, by wave action and cyclic deflections (especially if the structure is designed to absorb energy by deflection), in the splash zone and by suspended solids in high water velocities and by abrasive action of fenders and similar;*
- *localized corrosion mechanisms; and*
- *the inadequacy of preventative measures and/or maintenance.*

*In addition to structural characteristics, the need to control corrosion is a significant factor in the selection of metal components. Where required, corrosion protection or corrosion allowances need to be included to account for general and localized section loss during service life. Section loss is typically non-uniform and might be in the form of pitting; this can itself be localized into areas of high corrosion rate with proximate areas of lower corrosion rates. There are many reasons for this non-uniform distribution of corrosion (see **9.5.3**).*

9 Structural steels and castings

9.1 Steel plates and sections

*COMMENTARY ON **9.1***

*The most common metals used in maritime structures are hot rolled, weldable, structural steels. Other metals that are sometimes used in maritime structures, usually for special reasons and in specific components, include cold formed alloy steels, stainless steels, cast steels, cast irons, wrought irons, aluminium alloys and copper alloys (see Clause **10**).*

9.1.1 General

Weldable structural steels should conform to:

a) BS EN 10025 for structural sections and flat products;

b) BS EN 10210 and BS EN 10219 respectively for hot and cold formed hollow sections;

c) BS EN 10248 for hot rolled sheet piling; and

d) BS EN 10249 for cold formed sheet piles.

*NOTE 1 Structural steels are designated based on minimum yield strength (i.e. S275, S355), typically denoted by a “subgrade” based on impact energy (see **9.1.2**).*

Steel grades should be selected to be compatible with steel structures that are:

1) designed in accordance with BS EN 1993; and

2) executed in accordance with BS EN 1090-1 and BS EN 1090-2.

NOTE 2 BS EN 1090 requires the designer to specify various options and hence the standard needs to be supported by an application specification. An example in the UK is BCSA National Structural Steelwork Specification (NSSS) [12].

If elements of the structure meet other standards (e.g. tubular sections in accordance with ANSI/API 5 L), compatibility of design should be maintained throughout.

Underwater welding should not be carried out unless it is absolutely necessary. Procedures for underwater welding, where required, should be developed and approved with specialist advice.

9.1.2 Steel toughness and through thickness properties

Steel subgrade should be selected in accordance with BS EN 1993-1-10 (including the UK National Annex) and BS EN 1993-5:2007 for steel piling. The steel subgrade should possess adequate fracture toughness to reduce the risk of brittle fracture.

To reduce the risk of lamellar tearing during welding, through-thickness properties should be selected in accordance with BS EN 1993-1-10.

9.1.3 Internal soundness of long and flat steel products

In addition to the requirements of BS EN 10025, steels requiring enhanced through-thickness properties (“z-grade”) for welding should meet the ultrasonic requirements in BS EN 10164.

NOTE Testing for internal imperfections is an optional additional requirement of the BS EN 10025 series of steel product standards. Standards covering inspection and acceptance levels include BS EN 10160, BS EN 10306 and BS EN 10308.

9.2 Steel castings

An application-specific casting specification should be developed with specialist metallurgical advice.

The casting specification should include the factors identified in BS EN 1090-2.

NOTE 1 BS EN 1090-2 contains recommendations for steel castings based on BS EN 10340 and BS EN 1559.

NOTE 2 Provided that the relevant properties defined by BS EN 1090-2 are declared, casting grades in BS EN 10293 may also be used.

9.3 Chains

Chains and chain fittings (i.e. chains, shackles, swivels, tensioners, rings and similar items) fixed to maritime structures for use other than mooring (e.g. fender chains) should meet the requirements for loose gear given in the *Code for lifting appliances in a marine environment* published by Lloyd’s Register (Lloyd’s *Code for lifting appliances*) [N1].

Chains and chain fittings should be of steel grade U2 or U3 in accordance with the *Rules for the manufacture, testing and certification of materials* published by Lloyd’s Register (Lloyd’s *Rules for materials*) [N2].

Each item of chain (inclusive of its fittings) should be proof-load tested and subject to a breaking test in accordance with the requirements for loose gear given in Chapter 10 of Lloyd’s *Code for lifting appliances* [N1].

Each item of chain (inclusive of its fittings) should be clearly and permanently marked in accordance with the requirements for loose gear given in Chapter 10 of Lloyd’s *Code for lifting appliances* [N1].

Each item of chain (inclusive of its fittings) should be supplied with a manufacturer’s certificate for materials in accordance with Lloyd’s *Rules for materials* [N2] and should be supplied with manufacturer’s certificates for tests in accordance with the requirements for loose gear given in Chapters 1 and 13 of Lloyd’s *Code for lifting appliances* [N1].

Testing and certification of materials. *Users of this part of BS 6349 are advised to consider the desirability of selecting chains that are certified by Lloyd’s Register (or similar) following the principles of Lloyd’s Code for lifting appliances [N1].*

9.4 Cast irons

*COMMENTARY ON **9.4***

Cast irons are broadly divided into two categories for maritime applications: grey and ductile. More complex cast irons are available, but their application in maritime works is limited. A common example of a cast iron maritime component is a mooring bollard.

Grey cast iron characteristically lacks ductility, and its use in maritime applications is increasingly superseded by ductile cast iron.

Ductile cast iron should be chosen in accordance with BS EN 1563 and grey cast iron in accordance with BS EN 1561, supplemented by BS EN 1559-1 and BS EN 1559-2.

Following specialist metallurgical advice, the designer should obtain evidence to verify that the chosen material is suitable for the application.

NOTE 1 The following tests are likely to be required to verify the material:

a) the following destructive tests on items taken at random during production. The application specification specifies whether the items to be tested are destructive product samples, extension pieces or separate items cast simultaneously:

1) tensile and elongation tests (one unit per melt);

2) impact tests (if required, three units per melt);

3) reduction of area test (one unit per melt if relevant);

4) chemical analysis (one unit per melt); and

5) microscopic examination of cross-sections (one unit per melt);

b) the following non-destructive tests on items taken at random from each manufacturing lot:

1) 100% visual inspection;

2) MT or PT of surface-breaking discontinuities on 10% of each manufacturing lot; and

3) UT or RT to detect sub-surface discontinuities on 10% of each manufacturing lot.

Unless otherwise specified, the acceptance criteria for cast iron components should be:

a) SM2 and LM3/AM3 to BS EN 1369 for MT;

b) severity level 2 to BS EN 12680-3 for UT; and

c) severity level 3 for RT.

NOTE 2 Ductile cast irons typically differ in casting from grey irons in the addition of magnesium. As magnesium rapidly oxidizes at elevated temperatures, its useful working window is short during casting. As such, it is recommended that test pieces, if cast separately, are cast after the products to account for magnesium fade.

9.5 Corrosion and corrosion mitigation

*COMMENTARY ON **9.5***

This subclause covers methods of corrosion mitigation and protection typically utilized for new construction. Additional approaches and systems might also be appropriate for use on the maintenance of existing marine structures.

9.5.1 General

A corrosion protection/mitigation strategy should be developed to address the management and maintenance requirements associated with each component over the design life of the structure.

The strategy should also take into account:

a) the health and safety of those undertaking the works and during maintenance;

b) the consequence of failure;

c) any environmental hazards resulting from the works;

d) the reliability of the mitigation and protection system; and

e) technical effectiveness.

NOTE 1 Most corrosion mitigation measures are provided at the time of construction, but the strategy could equally make provision for retrofitting; for example, initial design might allow only for sacrificial steel thickness, but with the provision to retrofit cathodic protection if required.

Protection against and mitigation of the effects of the corrosion of steelwork in a marine environment should be provided by one or more of the following:

1) an allowance for loss of steel thickness, via the use of a thicker steel section, the use of higher strength grade of steel than that chosen for the structural performance in the design, or the addition of steel plates;

2) optimization of the design such that high stresses do not occur where corrosion rates are highest;

3) use of protective paints, coatings, wraps or concrete encapsulation; and

4) use of cathodic protection.

NOTE 2 Sole reliance on the provision of an allowance for corrosion places a requirement on the asset owner/operator to survey the structure periodically to ensure the actual losses in thickness due to corrosion are no more than assumed. This is particularly an issue in the event of accelerated low water corrosion (ALWC) or other forms of accelerated or localized corrosion, including stray current corrosion from the cathodic protection systems on berthing vessels.

NOTE 3 Repainting of marine piling above MWL might be possible but, due to access and environmental constraints, might not be practicable. Repainting might be viable in an extended life asset maintenance programme along with cathodic protection for the below MWL elevations. In the case of tubular/hollow section piles, the protective coating could be replaced with a microcrystalline wax or petrolatum wrap, possibly within a more robust polymer compressive wrap once the coating has reached the end of its useful working life.

NOTE 4 Cathodic protection can only provide corrosion protection to the immersed parts (up to approximately MWL) and buried parts of the structure/component to which it is electrically connected/attached. If cathodic protection is used as a corrosion prevention strategy, the other measures need to be included to address those areas atmospherically exposed above MWL.

NOTE 5 Cathodic protection of high tensile ties and anchors with a specified minimum yield strength (SMYS) >550 N/mm^2 requires particular caution, as these materials might be hydrogen sensitive and might fail prematurely due to hydrogen-induced stress cracking (HISC). Specialist testing of the high yield material to determine a safe potential limit might be required (see ISO 12473:2017, Table 2).

NOTE 6 The combination of painting and cathodic protection can be beneficial in that the cathodic protection removes the need to repair construction/operational damage to the paint system below MWL, and painting allows a smaller capacity or an extended working life for the cathodic protection system. The selected paint system needs to be resistant to cathodic disbondment.

Cast irons should be protected using the same principal approach as steelwork.

9.5.2 Corrosion allowance

Marine environments include a range of exposure zones, and where the effects of corrosion are to be mitigated through the provision of a corrosion allowance, either in full or in part, the corrosion allowance should be determined for each exposure zone. This determination should take into account:

a) any other corrosion protection measures (e.g. cathodic protection or paints/coatings), their anticipated effectiveness and their anticipated life, including any planned maintenance;

b) the structural and functional susceptibility of the element to the effects of corrosion;

c) the likelihood of localized corrosion occurring (see **9.5.3**); and

d) the consequence of failure.

Corrosion allowance should not be used to account for localized corrosion mechanisms.

If an allowance of greater than 7.5 mm of section thickness is calculated from the corrosion rate over the design life, corrosion protection should be provided.

NOTE If the calculated section loss is >7.5 mm, it is unlikely that mitigation by corrosion allowance will be effective or, due to variable corrosion rates and distribution of localized corrosion, reliable.

9.5.3 Localized corrosion

Designers should allow for localized corrosion caused by the following mechanisms:

a) repeated removal of the protective corrosion product layer, particularly in the low water or immersion zones by the action of fendering systems, waterborne sands and gravels or other wear related mechanisms;

b) bimetallic or galvanic corrosion;

NOTE 1 PD 6484 provides guidance on bimetallic corrosion risks.

c) accelerated corrosion due to microbiologically induced corrosion (MIC), which can occur at any level in immersed and tidal exposed steel. For bare steel structures, MIC is often prevalent in the low water zone and in this location has been termed “accelerated low water corrosion” (ALWC). ALWC can result in localized corrosion, within a 1 m range, centred between mean low water level and LAT. It is often randomly located on plan around a structure;

NOTE 2 Where ALWC occurs on sheet piles, corrosion is generally located at outpan corners and the adjacent web on “Z” sheet pile sections, on outpans on a “U” section, and centrally on straight section piles. It also occurs on tubular piles and it can occur at any elevation; it has been seen above MLW level on shelving beaches. On coated piles it can be found at any elevation at coating defects.

NOTE 3 MIC, and in particular ALWC, can occur almost anywhere on coastal steel infrastructure and might occur at any time during the design life of the works.

NOTE 4 In the presence of MIC, and in particular ALWC, it is anticipated that cathodic protection, with or without a coating, will be required from the time of construction to prevent the occurrence of perforations.

NOTE 5 Further information is available in CIRIA publication C634 [13] and the PIANC report Accelerated low water corrosion [14].

d) localized corrosion occurring just above and just below seabed level. In both locations it can be a result of MIC and also of differential aeration between the water and the bed. Depending on the conditions, the highest corrosion rates can be just below the bed, where inspection and hence detection is unlikely;

e) localized corrosion occurring at the interface of partly concrete-embedded steel members depending on the local situation and conditions; and

NOTE 6 Steel embedded in concrete that is not saturated by water is cathodic relative to the same steel in seawater. Rapid corrosion can therefore occur at the interface of a partly embedded member. This effect lessens if the concrete is fully saturated as the steel/concrete potential approaches that of steel in seawater. Wraps and coatings can be applied to overcome these effects as can cathodic protection when the interface is below MWL.

f) interaction with a vessels cathodic protection system.

NOTE 7 Structures where vessels are regularly berthed with their own cathodic protection systems, in particular impressed current systems, might be subject to stray current corrosion cause by DC current flowing from the vessel anodes onto the structure and then returning back into the seawater, from the structure, causing localized accelerated corrosion.

In locations and works where the designer considers localized corrosion to be a particular risk, affected areas should be protected one of the following measures:

1) cathodic protection, either on its own or in conjunction with a protective paint, coating or wrap; or

2) encapsulation in concrete.

Structures without protection against localized corrosion should be inspected at regular intervals, in particular at low water, in order that any unexpected corrosion activity can be detected at an early stage.

NOTE 8 Inspection could encourage corrosion by the repeated removal of localized partially protective corrosion products.

NOTE 9 Localized corrosion is unlikely to result in global failure of a sheet piled structure owing to the continuous nature of the structure. If corrosion of a sheet piled wall leads to local perforation, loss of retained material might lead to collapse of adjacent surfacing or structures supported on the backfill. The risk of failure from localized corrosion is potentially greater on other pile types and structural members.

Sensitive components and structures should be protected against the effects of pitting corrosion and where this can occur, provision should be made for maintenance and inspection access.

NOTE 10 Pitting corrosion to elements in tension, i.e. ties and anchors, can have serious and rapid consequences. In such cases, even small corrosion pits can cause stress concentrations that could promote premature failure below the nominal design and/or yield stress of the material. This can take the form of stress corrosion cracking (SCC) in sensitive materials.

9.5.4 Corrosion rates

*COMMENTARY ON **9.5.4***

The rate at which material thickness is lost as a result of corrosion activities in a particular zone is referred to as the corrosion rate for that zone. Corrosion rates are highly variable as they are not only related to the zone in which the component or structure is operating but are also time dependent. With the exception of localized corrosion sites, corrosion rates tend to reduce with time as the presence of corrosion products protects the steel substrate but much of the data used historically were mean values derived from measurements of thickness loss over a known life span. Some steel products are also manufactured in corrosion resistant steel grades where the material demonstrates improved corrosion performance in a particular exposure zone when compared to conventional structural steel grades.

Corrosion rates should be representative of the anticipated corrosion conditions for each zone to which the structure will be exposed over its working life, taking into account the mean values given in BS EN 1993-5 and information obtained from an assessment of the corrosion performance of similar structures in the vicinity of that proposed wherever possible.

NOTE 1 BS EN 1993-5:2007 provides suggested design figures for loss of thickness due to corrosion in soils and in waters for varying design lives based on the mean values of corrosion from the survey of a number of sheet pile wall *installations; values for design lives no greater than 25 years are based on measurements whilst values for design lives in excess of 25 years are extrapolated.*

NOTE 2 A subsequent European Commission Science Research Development study published in 2007 [15] stated that the values given in BS EN 1993-5 were not developed from a reliability based evaluation of the structural implications, but nonetheless were concluded to be safe from a structural standpoint when applied to the single design example of sheet piling examined within the report, with the caveat that this might not be the case of other situations.

A risk assessment should be carried out to assess what impact higher than expected corrosion rates might have on:

- structural capacity;
- effects of perforation;
- reduction in design life; and
- increased maintenance.

NOTE 3 Historical corrosion rates for steel sheet piles measured at a number of UK locations are given in Annex C.

NOTE 4 Loss of retained fill behind a sheet pile or combined wall due to pile perforation might result in the loss of support to the paving or structures located behind the wall. Loss of fill within a filled hollow section might make it more susceptible to buckling. Perforation of a plugged hollow section results in increased corrosion of the internal surface. Perforation of sheet pile walling likely results in increased corrosion of the buried face local to the perforation. The ability of discrete piles and tie bars or waling bolts to distribute loads elsewhere might be lower than would be the case on a section of sheet pile wall.

The assessment of corrosion rates and the risk assessment should be used to develop a corrosion protection/mitigation strategy for the structure throughout its working life.

If the level of risk caused by unexpectedly high corrosion rates is unacceptable, then either additional protection should be provided from the outset, or a strategy should be developed for corrosion management involving regular inspections and the introduction of additional protection when required.

The designer should determine whether any claimed reduction in corrosion rates for proprietary steels and steels containing additional alloying elements are applicable to the environment expected at the structure location, before reducing the corrosion allowance in the design.

NOTE 5 Weather-resistant steels are not generally recommended for maritime structures, because their enhanced resistance to atmospheric corrosion is affected by chloride-contaminated maritime environments.

NOTE 6 Steel containing between 0.25% and 0.35% copper is more resistant to atmospheric corrosion than ordinary steel but does not afford any useful improvement in corrosion resistance in the other marine exposure zones.

NOTE 7 Steel containing both copper and phosphorus, in accordance with ASTM C690, is reported to provide improved corrosion resistance performance than ordinary steel in both the atmospheric and splash zones.

NOTE 8 Steel containing chromium and aluminium is reported to provide improved corrosion performance in the intertidal, low water tidal and continuous seawater immersion zone.

NOTE 9 Reliance on corrosion allowance might place a requirement on the asset owner/operator to survey the structure periodically to ensure the actual corrosion rates are not exceeding the design allowance.

9.6 Protective paints, coatings and wraps

9.6.1 General

Protective paints, coatings and wraps should be capable of being applied to manufacturers' recommended standards. They should be able to provide protection to the structure in the given exposure conditions for the required lifespan of the structure.

The design should allow for the effect that defects in paints, coatings and wraps might have on the structure as a whole and on individual components, as the defect site might be subject to accelerated corrosion.

9.6.2 Paints

NOTE 1 For the purposes of this part of BS 6349, paints are defined as protective coatings which dry and cure at ambient conditions. Coatings not included within this category include powder coating materials, stoving enamels or heat cured materials.

Paints for marine applications should be specified and applied in accordance with BS EN ISO 12944 for the appropriate exposure environment and the required durability.

NOTE 2 BS EN ISO 12944 defines the life of a paint system in terms of its durability range. The durability range is not a "guarantee time" but a technical consideration/planning parameter that can help the asset owner/operator set up a maintenance programme. The guarantee time is usually shorter than the durability range. There are no rules that link the two periods of time.

NOTE 3 NORSOK M CR 501 provides supplementary guidance and details coatings systems that have been prequalified for particular exposure conditions.

For structures with site assembly and site coating after assembly, a primer should be specified that:

a) protects the steel for extended construction periods; and

b) can withstand abrasion associated with handling and fabrication with a minimum of damage, prior to the longer term protective paints being applied.

For deck areas of maritime structures exposed to weathering, abrasion associated with cargo handling operations and spills of diesel fuels, lubricants and corrosive compounds, paints should be specified that have high impact resistance and resistance to spills of solvents and corrosive chemicals, i.e. the thermosetting materials.

For immersed or driven piles, the paint system should be suitable for long-term immersion and/or burial. It should also be compatible with cathodic protection, if this is to be provided or might form a part of a future maintenance strategy.

NOTE 4 Incompatible paint systems can disbond if cathodic protection is subsequently applied.

NOTE 5 The combination of painting and cathodic protection can be beneficial in that the cathodic protection removes the need to repair construction/operational damage to the paint system below MWL.

9.6.3 Wraps

*COMMENTARY ON **9.6.3***

Wraps of different types have been developed, in particular, for tubular piles. These can be petrolatum tape based, glass-reinforced resin based, adhesive tapes normally used for buried pipelines, polymer or fibre reinforced polymer sheets which can be tensioned with proprietary flanged arrangements or polymer sheets.

Wraps can offer advantages over the recoating of in-situ tubular piles with paint systems because they avoid the environmental challenges of surface preparation for paint application. They can be relatively quick to install and the work can be undertaken from floating pontoons.

The system that is selected should be capable of being applied, robust and suitable for the exposure conditions, because it is not normally possible to easily inspect the steel below the wraps.

When selecting a wrap for a particular application, specialist advice should be obtained, and a performance trial carried out if necessary.

9.6.4 Cold applied microcrystalline wax and petrolatum tape wrapping systems

*COMMENTARY ON **9.6.4***

Cold applied microcrystalline wax and petrolatum tape wrapping systems can be applied to the external surfaces of pipe work, hollow section piles/structural elements and tie bars, and are also suitable for corrosion protection to buried steel. Their performance in marine tidal conditions can be expected to be inferior to high performance marine coatings conforming to BS EN ISO 12944.

Cold applied microcrystalline wax or petrolatum tape wrapping systems should be in accordance with ANSI/AWWA C217 and the relevant parts of NACE SP0375 and Energy Institute Guidelines [N3] for the use of anti-corrosion tape systems for process pipework.

NOTE Some manufacturers include additives to the microcrystalline wax/petroleum tape when it is intended for use specifically in a marine environment. These include water displacing, corrosion inhibiting and bactericide chemicals additives.

Tapes should be protected from damage both during installation and whilst in service. For tapes in service, this protection should include the provision of an outer protective wrap where appropriate. For tapes in buried or immersed/tidal applications, outer protective wraps should be compatible with cathodic protection, if such a system forms part of the corrosion mitigation strategy for the wrapped item. When applied to non-buried/non-permanently immersed components, the outer protective wrap and any associated fixings should be UV-stabilized as appropriate for the design life and macroclimate.

9.6.5 Pipeline coating systems

*COMMENTARY ON **9.6.5***

Pipe tubes, such as those in accordance with ANSI/API 5 L, are commonly utilized as tubular piles in marine works. Occasionally intentionally, but more commonly due to the piles being fabricated from excess pipeline material, the piles are coated with a coating system that was originally developed and intended for use on the external surfaces of submerged or buried pipe work. These systems include three-layer polyolefin coatings, single-layer fusion bonded epoxy and two-layer polyethylene tape coatings. Sheet piling has also been coated with single layer fusion bonded epoxy.

Buried and submerged pipeline coatings are developed particularly for their intended service and are unlikely to be suitable for corrosion protection of driven piles.

Some failures of the two- and three-layer coatings in marine applications have occurred and these have led to shielding of the underlying steel surface from cathodic protection. This does not occur with wet-applied coatings or fusion bonded epoxies. Occasionally, neoprene sheet coatings have been applied to sheet steel piles, but performance has been mixed and MIC has been found behind disbonded neoprene coating.

Generic pipeline coating systems, which are inappropriate for maritime corrosion protection requirements, should not be used.

9.6.6 Metallic coatings

Metallurgical zinc coatings should be selected in accordance with the guidance in BS EN ISO 14713-1.

Hot dip galvanizing should be in accordance with BS EN ISO 14713 and BS EN ISO 1461. For fixings, the galvanizing should be in accordance with BS 7371-6 or BS EN ISO 10684.

NOTE 1 It is unlikely that sherardized or electrodeposited coatings will provide a sufficient level of corrosion protection in most marine environments without further protection (e.g. a paint or coating). Hot dip galvanized coatings without further protection also only have a limited life, with the upper tidal/splash zones usually exhibiting the highest rates of zinc loss and hence lowest life. The application of paint coatings to zinc requires specific treatment, such as an etch or etch primers to sweep blast cleaning of the zinc to promote adhesion of paints. The effectiveness of subsequent paint systems is dependent on workmanship.

The thickness of galvanizing should be achievable for the element being treated.

NOTE 2 The thickness of a hot dip galvanized coating is limited by the thickness of the element being treated, the surface roughness and the composition of the steel, and for small items whether centrifugally spun post dipping.

Zinc or aluminium thermal sprayed coatings should be selected in accordance with the guidance in BS EN ISO 2063-1.

Metal coated and non-metal coated steel elements should not be combined for elements which are either buried or are within or below the splash zone, unless they can be galvanically isolated. The galvanic isolation should have a design life appropriate for the design of the interconnected elements.

NOTE 3 Galvanic isolation can fail as a result of poor installation and inadequate testing of isolation or in service. The failure of just one set of isolating components might expose quite large elements to bimetallic corrosion.

NOTE 4 The connection of metallic coated and uncoated steel elements which are either buried or immersed without galvanic isolation results in premature consumption of the applied metallic coating. Additional guidance is provided in PD 6484.

9.6.7 Concrete encasement

*COMMENTARY ON **9.6.7***

Concrete encasement of steel piling is often restricted to the splash zone by extending the concrete cope to below the mean high water springs level (MHWS). However, in some instances, both splash and tidal zones are protected by extending the cope to below the MLWS level which can also give protection against ALWC.

The following factors should be taken into account when specifying concrete encasement.

a) Steel reinforced concrete exposed in the MLWS to MHWS level and up to HAT can be particularly vulnerable to intermittent wetting and drying by seawater, enhanced migration of chlorides to the reinforcement and resultant corrosion and spalling.

b) The immersed steel below the concrete might be vulnerable to increased corrosion rates if the concrete is not fully saturated with external water.

Where concrete encasement is adopted, the recommendations in Section **2** should be met, with the cover being the distance from any exposed concrete surface to the embedded reinforcement or the surface of embedded steelwork generally, whichever is the lesser.

Where the steel piling exits the area of concrete encasement, the required cover cannot be provided locally, and the risk of premature corrosion and concrete spalling should therefore be addressed and mitigated. To achieve this, either:

1) the steel should be painted within and outside the cover zone with a high performance coating; or

2) an appropriate sacrificial steel thickness (corrosion allowance) should be provided.

If sacrificial steel is provided, spalling of the concrete can occur, and this should be allowed for in the design.

9.7 Cathodic protection

*COMMENTARY ON **9.7***

*Properly designed, installed and maintained cathodic protection systems with immersed anodes can provide full protection against corrosion to steelwork located between MWL and the seabed, including any mud/sediment layer, and into the ground for sufficient distance to address the risks of under-seabed localized corrosion (see **9.5**).*

Cathodic protection systems can protect against accelerated and localized corrosion such as ALWC, other forms of MIC, galvanic corrosion and interaction from the cathodic protection systems of vessels moored alongside.

Unless specifically included in the design through the use of buried anodes, cathodic protection might not provide protection down to the toe of any steel piling and is unlikely to provide any protection to the rear, buried face of sheet piling. Cathodic protection cannot provide corrosion protection to steelwork which is exposed to the atmosphere for the majority of the time.

Cathodic protection systems should be designed, installed and operated in accordance with ISO 12473, BS EN 12954 and BS EN ISO 13174 as appropriate for the specific structure. The design of cathodic protection systems, even apparently relatively simple galvanic anode systems, is a specialist task and should be undertaken by suitably qualified and experienced cathodic protection specialists.

NOTE 1 BS EN ISO 15257 provides a suitable assessment and certification of competence for cathodic protection personnel.

For new works, where the structural and cathodic protection design teams are different, the two teams should liaise and coordinate such that their works are mutually compatible.

NOTE 2 The design of a cathodic protection system and the structural design of a marine structure is rarely carried out by the same organization, with typically the cathodic protection system being designed after the structural design has been finalized, and in some cases actually under construction.

NOTE 3 Commonly there is a need for electrical continuity to be provided between different parts of the same structure to facilitate the effective operation and monitoring of the performance of the cathodic protection system. If impressed current cathodic protection is used, there will, in many instances, be a need for both AC and DC cable ducts and the provisions of robust cable protection and anode mountings to be designed to withstand the same environmental exposure as the structure.

The design of the cathodic protection system and any construction provisions should be carried out when the structure is being designed, rather than being designed and retrofitted following construction.

If a corrosion protection system, comprising coatings above mean water level and/or cathodic protection, is designed to be implemented in the future, then it should be detailed and appropriately noted on the construction drawings, specifications, and operational and maintenance manuals.

NOTE 4 The use of cathodic protection places a management liability on the part of the operator of the marine structure. For galvanic cathodic protection systems, the operation and maintenance requirements of a correctly designed and installed system are limited to periodic performance measurements, and replacement of the anodes once exhausted. The operation and maintenance requirements for an impressed current cathodic protection system are generally greater due to the need to maintain the electrical supply and equipment and need to adjust the system settings over time. Marine impressed current systems are considerably more complex than galvanic anode systems; the complexity can reduce reliability and increase maintenance demands.

In situations where a metallic-hulled vessel is likely to be berthed in a particular location for any substantial period of time, or different vessels repeatedly berth at the same location, the risk of stray currents between the vessel and the cathodically protected structure should be mitigated in the cathodic protection system design and its effectiveness established by testing.

NOTE 5 Impressed current cathodic protection (on the vessel or the structure) is more likely to cause significant stray current on the other than galvanic anode systems, due to the generally lower individual anode current outputs of anodes used in the latter.

NOTE 6 Cathodic protection can cause embrittlement of high strength steels and other corrosion-resistant alloys.

Steels with SMYS >550 N/mm^2 should in general not be used in conjunction with cathodic protection. If there are no practicable alternatives, then such steels should be specifically tested to determine a safe potential limit (see ISO 12473).

NOTE 7 This applies particularly to sheet steel pile anchor rods and their bearing plates and nuts. These materials might also be vulnerable to stress corrosion cracking if not adequately protected from corrosion.

10 Aluminium and its alloys

*COMMENTARY ON CLAUSE **10***

Aluminium in its pure state possesses relatively low tensile strength, but because of its ductility and, for some alloys, excellent resistance to corrosion, it is frequently used in both rolled and extruded forms where strength is unimportant. Pure aluminium can be strengthened by cold working, but alloys of aluminium are usually used where increased strength is required.

Aluminium is alloyed with a range of elements to achieve specific properties. The current standards classify alloys of aluminium according to their chemical composition, denoted by a number that represents the principal alloying element(s), a designation defining whether the alloy has been heat treated, and what method of production has been used. This classification, in addition to product form and tolerances, is described in BS EN 485, BS EN 515, BS EN 573, BS EN 586, BS EN 603, BS EN 604-1, BS EN 754, BS EN 755, BS EN 1301, BS 1473 and BS EN 1999, which deal with the specification and use of aluminium alloys for general and structural engineering purposes.

10.1 General

Aluminium grades should be selected to be compatible with aluminium structures that are:

- designed in accordance with BS EN 1999; and
- executed in accordance with BS EN 1090-3.

NOTE 1 BS EN 1999-1-1:2007+A2, Annex C gives guidance on the selection of alloys based on strength, weldability and surface treatment.

NOTE 2 Many product shapes and forms are not commonly available in many of the alloy options.

10.2 Structural properties

*COMMENTARY ON **10.2***

Aluminium alloys undergo significant reduction in strength in weld heat affected zones (HAZ). In many weldable alloys, the reduction is greater than 50% of the specified minimum yield strength.

Aluminium has an elastic modulus that is one third of that for steel. The coefficient of linear thermal expansion of aluminium is between (23×10^{-6}) per °C and (24.5×10^{-6}) per °C, which is approximately twice that of steel.

Full details of the engineering properties of the principal alloys for structural use are given in BS EN 1999-1-1:2007+A2.

The design of aluminium structures should take into account:

a) the deflection of laterally loaded structural elements and the buckling of structural elements loaded in-plane;

b) forces arising from temperature effects; and

c) the factors in BS EN 1999-1-3 concerning fatigue.

10.3 Corrosion and corrosion protection

*COMMENTARY ON **10.3***

This subclause covers methods of corrosion protection that are typically utilized for new construction. Additional approaches and systems might be necessary for the maintenance of existing marine structures.

Corrosion of aluminium and its alloys should be mitigated by prevention and protection.

NOTE 1 BS EN 1999-1-1:2007+A2, Annex D provides recommendations for corrosion prevention and protection.

NOTE 2 Pockets and crevices likely to trap water, dirt or condensation are likely to lead to corrosion.

Bimetallic combinations should be reviewed for suitability in accordance with PD 6484, and where practicable should not be used.

NOTE 3 Bimetallic combinations are used by design between immersed aluminium alloy galvanic anodes for cathodic protection (intended to corrode) and steel (intended to be protected by the corroding aluminium).

NOTE 4 Partially immersed aluminium ladders connected to steel structures act as anodes and can rapidly lose structural competence.

NOTE 5 Although PD 6484 advises methods for mitigation of the localized corrosion that occurs, for example, to aluminium alloys in contact with steel, including coatings applied to the steel and electrical isolation of steel from aluminium alloys, these are difficult to implement during construction and might not be reliable in the long term.

Aluminium should not be cast in concrete where this can be avoided. If is necessary to embed aluminium into concrete, the recommendations in BS EN 1999-1-1:2007+A2, Annex D should be followed.

NOTE 6 Aluminium reacts rigorously with alkaline solutions, evolving aluminium corrosion products and hydrogen. Wet concrete is strongly alkaline (typically pH 13 to pH 14). Where wet concrete is in contact with aluminium, loss of section and copious gas production occurs, resulting in local damage to the aluminium and concrete (voids/pockets).

11 Other metals

Other metals used in maritime structures (see Commentary on Section **3**) should conform to the relevant standards.

Stainless steels should be designed and selected generally in accordance with BS EN 1993-1-4, taking into account the micro exposure environment for the stainless steel, its PREN number, the chloride levels and temperature and the presence of crevices. Specialist advice should be sought in the selection of stainless steels for marine exposure.

Specialist advice should be sought for the selection of copper alloys.

NOTE Copper alloys are rarely used in maritime structural works. Small marine appurtenances and components of maritime furniture are occasionally manufactured from copper alloys.

Section 4: Timber

12 General recommendations for timber

The use of timber in maritime structures should be in accordance with BS EN 1990 and BS EN 1995.

The choice of timber for any maritime structures should be made on the basis of the strength, properties and durability of the selected timber in the environment to which the structure is to be subjected. Different timbers should be used, where appropriate, for different elements of any structure.

Availability of the proposed specified timber should also be taken into account before the final choice of timber is made.

NOTE Data on the properties of various species of timber is given in the TRADA publication Timber for marine and freshwater construction [16].

13 Resistance to environmental hazards

13.1 Mechanical damage

Species of timber to be used in any maritime structure should be selected to resist the particular type of damage or wear that is expected throughout the design life of the structure.

13.2 Biological attack

*COMMENTARY ON **13.2***

Resistance to biological attack is best achieved by the correct choice of timber for its position in the structure and the marine environment concerned.

In freshwater situations, fungal decay is the major hazard, and the use of preservatives or timber having appropriate natural durability is essential.

Natural resistance to fungal decay varies from species to species. Variation is also observed within single species, and in some timbers the heartwood core can be less durable than the outer zones. Sapwood of nearly all species is susceptible to fungal decay. Despite these variations, naturally durable timbers can be identified and can be used successfully in conditions where more perishable species would rapidly decay. Natural resistance to marine borers does not parallel resistance to fungal decay. No timber is known to be completely resistant to marine borers, and only a few species possess the high resistance necessary to give satisfactory lives in areas where activity is intense. In the UK, timbers are normally classified for their natural resistance to marine borers as follows:

- *very durable: suitable for use under conditions of heavy attack by Teredo and Limnoria, and expected to provide at least 20 years of life;*
- *moderately durable: suitable under conditions of moderate attack, mainly by Limnoria; and*
- *non-durable: suitable for only short service life.*

NOTE Guidance on the performance of various species of timber is given in several sources such as TRADA [16] and timber importers.

The need to provide protection against fungal decay for the superstructure of any structure should be taken into account in all marine environments, and appropriate measures taken.

13.3 Fungal decay

In order to reduce the danger of fungal attack, the structural detailing should be designed to allow drainage of surface water, and to eliminate places in which fresh water can accumulate and enter joints.

End grain in joints should be treated with sealing compounds having an appropriately long effective life, and measures should be taken, wherever possible, both in the storage of timber and in the detailing of joints, to prevent splitting.

Timber should not be embedded in concrete, brick or any other situations where this might lead to retention of moisture.

13.4 Marine borers

*COMMENTARY ON **13.4***

The two most common types of marine borer that attack maritime structures are the crustacean Limnoria (the gribble) and the mollusc Teredo (the shipworm). Both are capable of causing extensive damage quickly. Shipworm is confined to marine sites and estuaries and is unable to exist in fresh water. Shipworm in British waters has been found mainly in the sea around southern England, although climate change is leading to an increase in occurrences further north within the British Isles.

*See also Note to **13.2**.*

The possibility of damage from marine borers should be taken into account when specifying the timber for any maritime structure.

The choice of timber should be selected from species with a proven resistance to marine borers.

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14 Functional suitability

14.1 Piling

*COMMENTARY ON **14.1***

The principal species of timber used for piling are greenheart, ekki (azobe), balau and basrolocus. Many other species can be used, however, and choice depends largely on availability in the region in which the works are situated, together with the length of piles required.

The selection of timbers for piling should take into account the ability of the chosen timber to withstand the impact actions expected to be sustained during installation. Head bands or caps and toe shoes should be used to assist in protecting the timber whilst driving, if the soils into which the piles are being driven are found to have a significant resistance.

14.2 Superstructures

*COMMENTARY ON **14.2***

The timbers commonly used for the main structural elements in superstructures are similar to those used for piling. Timbers vary in their wear resistance to pedestrian and other traffic when employed as decking. The use of species such as Baltic redwood, dahoma, Douglas fir and Western hemlock are best confined to areas of light traffic. Species such as dark red meranti, jarrah, kapur, karri, keruing, opepe and pitch pine have sufficient resistance against wear to justify a general use for decking, except where abrasion from heavy pedestrian traffic is considered severe.

The design of deck structures should take into account that horizontal surfaces can retain rainwater in positions where it cannot be quickly removed by evaporation.

14.3 Kerbs and capping pieces

Kerbs and capping pieces should be large enough to provide effective protection.

NOTE Sections in excess of 250 mm square are common.

14.4 Fendering and rubbing strips

The sustainability, or otherwise, of classic timbers should be taken into account when selecting a timber for fendering purposes.

Close-grained timbers such as greenheart have been used for fender piles in the past, but for new projects this species of timber should be used only where rubbing strips are provided to take the impact and abrasion from berthing vessels.

NOTE 1 Recycled plastic rubbing strips might be a suitable alternative to traditional timber rubbing strips, as they might prove to be more sustainable, either on a whole life or carbon footprint basis.

NOTE 2 Guidance on fender design is given in BS 6349-4.

14.5 Sea defences

Timbers for use in sea defences should be selected principally on their resistance to abrasion.

NOTE Timbers that are found to be satisfactory in sea defence works such as groynes are ekki, greenheart, jarrah, opepe, pitch pine and pynkado. Of the UK-grown timbers, oak has the best resistance to abrasion. Timbers requiring protective treatment are not suitable in sea defences, as the preservative treatment is only effective in the surface zone of the treated material.

14.6 Dock blocks

*COMMENTARY ON **14.6***

Timbers used for the contact surfaces of keel and bilge blocks in dry docks are subject to very high intensity loads.

Data on the properties of various species of timber is given in the TRADA publication Timber for marine and fresh water construction [16]. Further guidance on the selection of hardwood timbers for dock blocks is given in BS 6349-3.

Expendable softwood capping pieces should be used in conjunction with a hardwood block.

Hardwoods should be selected principally on their resistance to splitting and hardwoods species with an interlocked grain should be specified.

14.7 Other applications

Timbers for use in lock gates and sluices paddles should be selected for their dimensional stability, as well as other properties such as durability, abrasion resistance and strength.

NOTE Species commonly employed on inland waterways include Dutch elm, greenheart, oak, pitch pine or Wych elm where extra strength, abrasion resistance or long lengths are required.

15 Fastenings

All steel fastenings materials should be corrosion-resistant and should conform to BS EN 912, BS EN ISO 898-1, BS EN ISO 898-2 and/or BS EN 14545 as appropriate.

All bolts, nuts and washers that are not manufactured of stainless steel should be hot dipped galvanized in accordance with BS 7371-6 or BS EN ISO 10684. They should be subjected to post galvanizing heat treatment to release hydrogen and prevent hydrogen cracking.

All fastenings should be subjected to batch testing of their physical and mechanical properties. This should include micro hardness testing and expert assessment to determine stress corrosion cracking (SCC) susceptibility. The extent and detail of testing should be related to function of the fixings.

Test laboratory accreditation*. Users of this part of BS 6349 are advised to consider the desirability of selecting test laboratories to undertake physical and mechanical testing of the fixings that are certified as meeting the requirements of BS EN ISO 9001 and accredited to BS EN ISO 17025.*

The use in timber maritime structures of other fastenings such as screws, coach screws and spikes should be confined to the fixing of planking and rubbing strips and similar connections of secondary importance.

For fastening timber work to the face of concrete structures, stainless steel should be used where practicable (see Clause **13**), although rag bolts or indented bolts may be used if necessary. Non-stainless steel parts which are not embedded in concrete should be coated with suitable bituminous compounds or paint.

All bolts and fixing screws threads, whether of stainless steel or galvanized steel, should be coated with waterproof grease prior to assembly.

Section 5: Polymers

16 Elastomers

*COMMENTARY ON CLAUSE **16***

This clause applies primarily to elastomeric fenders fixed to maritime structures and used for the purpose of absorbing the kinetic energy of berthing or moored vessels. It also provides recommendations on elastomeric structural bearings used on maritime structures.

16.1 Rubber

*COMMENTARY ON **16.1***

The vocabulary used in this subclause is consistent with BS ISO 1382. Specific definitions of the rubber industry terms used in this subclause are given in BS ISO 1382.

Rubber products used in maritime works are made from compounds of raw/virgin rubber (which can be natural or synthetic or a blend of both), mixed with reinforcing fillers and various compounding ingredients and vulcanizing agents.

Rubber is a thermosetting elastic polymer and is difficult to separate out into its constituent components once vulcanized, although it is possible to devulcanize compounds.

16.1.1 General

Recycled rubber should not be used unless its use is proven to provide adequate durability and performance of the elastomeric product over the product's design working life.

NOTE 1 Recycled rubber is also known as reclaimed rubber, recyclate rubber and devulcanizate.

Vulcanized waste rubber should not be used.

NOTE 2 Vulcanized waste rubber is also known as recycled vulcanized particulate rubber, chip rubber, crumb rubber, ground vulcanized rubber, powdered rubber, fine powered rubber, granulated rubber, elongated fibre-like rubber particles, scrap rubber and factory scrap.

16.1.2 Rubber material (raw)

Natural rubber used to manufacture elastomeric products should conform to BS ISO 2000.

There are many different types of natural and synthetic rubber, and advice should be obtained from the product manufacturer or by a rubber materials specialist to determine which specific rubber or blend of rubber will be most appropriate.

16.1.3 Fillers

*COMMENTARY ON **16.1.3***

There are three types of filler used in rubber production:

a) reinforcing fillers, used to enhance the stiffness and mechanical properties of the rubber compound;

b) semi-reinforcing fillers, used to provide a limited enhancement of the compound stiffness and mechanical properties; and

c) inert or extending fillers, which offer no reinforcing effect but are added for economic purposes.

The most common reinforcing filler used in rubber compounding is carbon black. Other reinforcing fillers used in rubber compounding are colloidal mineral fillers such as silica. It is not only the quantity *of filler(s) added, but also the particle size of the filler and the dispersion of the filler within the rubber matrix that can affect the physical properties of the compound.*

Common semi-reinforcing fillers are mineral fillers, and other fillers such as processed calcium carbonate, with particle sizes larger than colloidal dimensions (0.001 µm to 1.0 µm). Semi-reinforcing fillers are typically used when non-marking and/or non-black elastomeric units are required.

The most common inert or extending fillers are unprocessed calcium carbonates and other mineral fillers of large particle dimensions (i.e. >1.0 µm).

The type, quantity, particle size and target dispersion of a reinforcing filler should be selected to suit the specific project requirements.

Carbon black used as a reinforcing filler should be a rubber-grade, colloidal carbon black and should conform to ASTM D1765.

Where semi-reinforcing fillers are to be used, specialist advice should be sought from the product manufacturers.

The designer should specify a manufactured rubber product where inert or extending fillers are restricted to a maximum of 5% inert or extending filler content, unless it has been demonstrated that their inclusion at a higher dosage does not negatively impact the product's performance or durability.

16.1.4 Compounding ingredients and vulcanizing agents

COMMENTARY ON ***16.1.4***

There are numerous compounding ingredients, anti-degradant agents, plasticizers, etc. that manufacturers use to improve the durability or performance of their products or to suit their specific manufacturing methods. Similarly, there are numerous vulcanizing agents, curing agents and accelerators, etc. which manufacturers use to improve the vulcanization process to achieve optimum cure of their products.

The product designer, which might be the manufacturer, should select the most suitable compounding ingredients and vulcanizing agents to suit the manufacturing methods, subject to the elastomer product achieving the specified performance and durability characteristics.

16.1.5 Physical and mechanical properties of rubber compounds

The physical and mechanical properties of vulcanized rubber compounds should be in accordance with Table 8.

NOTE 1 Vulcanization of rubber compounds is achieved through the application of heat and pressure to the unvulcanized mass. To achieve optimum cure through the full depth of a section, the amount of heat and pressure, and the duration over which each are applied, vary depending on the thickness of the sample. The thickness of the samples required by the applicable standards for each mechanical property test is much less than the wall thickness of a typical elastomeric product used in the maritime environment. Hence the samples tested, even if prepared from the same compound batch, will have a different cure history to the procured products and will likely exhibit different test results. Rubber compound taken from the product is not required to meet the test criteria in Table 8.

NOTE 2 The purpose of the mechanical property tests is to confirm that the compound selected by the manufacturer can achieve the specified mechanical properties under test conditions, and to provide a set of reference values for quality control testing to check tolerances with regard to batch to batch variation.

The test temperature for low temperature resistance in Table 8 should be selected taking into account the geographic and macroclimatic conditions at the location where the elastomeric product is expected be used during its design working life.

NOTE 3 The low temperature resistance test is only required where the project location experiences low temperatures.

Table 8 — *Vulcanized rubber compound physical and mechanical properties*

Physical/mechanical property	Relevant test standard	Condition	Criteria
Tensile strength	BS ISO 37	Shape Original After being aged for 96 h at 70 °C	Dumbbell type 1 ≥16 N/mm² Not less than 80% of the original property
Elongation at break	BS ISO 37	Original After being aged for 96 h at 70 °C	≥400% Not less than 80% of the original property
Hardness	BS ISO 48-4	Original After being aged for 96 h at 70 °C	≤78 (durometer hardness, shore type A) Not to exceed original property by more than 8 hardness units
Compression set	BS ISO 815-1	After being aged for 24 h at 70 °C Test method: Method A Sample size: Type A	≤30%
Tear resistance	BS ISO 34-1	Method C	≥70 kN/m
Ozone resistance	BS ISO 1431-1	20% static strain and exposure to 50 pphm at (40 ±2) °C for 96 h	No cracking
Seawater resistance	BS ISO 1817	After being submerged for 28 days at 95 °C	Maximum change of durometer hardness shore type A ±10 hardness units Maximum change in volume %
Abrasion resistance	BS ISO 4649	Method A	≤100 mm³ where fender is in direct contact with vessel ≤150 mm³ where fender is not in contact with vessel
Bond strength	BS ISO 813	Method B	≥7 N/mm²
Dynamic fatigue	BS ISO 132	15 000 cycles	Grade 0 to Grade 1
Low temperature resistance	BS ISO 812	Procedure C	No failure
Density	BS ISO 2781	Method A	≤1.250 Mg/m³

NOTE 1 Unless otherwise stated in the project specification, the criteria values stated in the fourth column apply.

NOTE 2 Ozone resistance is measured in parts of ozone per hundred million of air by volume.

Test laboratory accreditation*. Users of this part of BS 6349 are advised to consider the desirability of selecting test laboratories to undertake physical and mechanical testing of the rubber compound that are certified as meeting the requirements of BS EN ISO 9001 and accredited to BS EN ISO 17025.*

16.1.6 Deterioration and hardening

COMMENTARY ON ***16.1.6***

Two material mechanisms are known to occur within rubber compounds over their design working lives: degradation and re-hardening. Degradation due to oxidation or exposure to heat and/or *ultraviolet tends to soften the compound, whereas re-hardening, due to delayed vulcanization of free sulfur remaining after initial cure, tends to harden the compound. It has been found that the re-hardening process typically outpaces the degradation process and so rubber elastomeric units tend to harden with time.*

The design of rubber elastomeric units should take into account the effects of ageing, recovery, re-hardening and creep, as applicable to the specific project.

NOTE An updated version of BS 6349-4 is in preparation which is expected to make recommendations to account for ageing, recovery, re-hardening and creep within the design process of rubber elastomeric fender units. Guidance on these phenomena is given in Guidelines for design and testing of rubber fender systems [17].

16.2 Polyurethane

*COMMENTARY ON **16.2***

The vocabulary used in this subclause is consistent with BS ISO 37 and BS EN ISO 14896.

Polyurethane products used in maritime works typically consist of polyether or polyester compounds. Polyester polyurethanes typically have higher mechanical properties but have a lower resistance to hydrolysis/wet environments. Polyether polyurethane elastomers are most commonly used for maritime works.

They are best suited to applications where flexibility, elasticity and abrasion resistance are required. They are particularly suited to dynamic/high stress environments.

Physical properties, when compared with rubber, in general have a lower coefficient of friction and retain their properties in high and low temperature environments. However, they are limited in the size that can be manufactured due to the manufacturing process and curing nature of polyurethane.

16.2.1 General

Recycled polyurethane should not be used in elastomers for maritime works unless its use is proven to provide adequate durability and performance of the elastomeric product over the product's design working life.

NOTE 1 Polyurethane products tend to be manufactured from thermosetting compounds and hence do not soften or remould when heated. Nonetheless, recycling of polyurethane products where practicable either by mechanical means, in which the material undergoes mechanical destruction but is reused in its compound form, or by chemical means, in which the material is returned to its constituent components, is used in the manufacturing industry.

NOTE 2 For marine environments, a polytetramethylene ether glycol (PTMEG) polyurethane elastomer has good mechanical properties, particularly in dynamic applications. Polypropylene glycol (PPG) polyurethane elastomers are a lower grade polymer, with lesser durability and lower mechanical properties than PTMEG.

16.2.2 Polyurethane elastomers

There are many different types of polyurethane elastomers, and advice should be obtained from the product manufacturer or by a polyurethane materials specialist to determine which specific polyurethane compound will be most appropriate.

16.2.3 Fillers

*COMMENTARY ON **16.2.3***

Typically, polyurethane elastomers are unfilled. The polyurethane products with the highest mechanical properties tend to be manufactured from compounds without fillers.

Bulking fillers are added to some polyurethane compounds, but these fillers are added for economic purposes and can reduce the mechanical properties of the elastomeric product.

Density/weight reducing fillers, such as glass microspheres that might be used in the more rigid compounds, should not be used where the polyurethane elastomer might be subject to dynamic and/or impact loads.

16.2.4 Performance enhancing additives

COMMENTARY ON ***16.2.4***

Polyurethane elastomers are typically processed using a blend of two or three base components to generate the required hardness/physical properties for a particular application.

Polyurethane materials typically have a coefficient of friction from 0.2 to 0.9. The coefficient of friction is directly related to the shore hardness with the softer polyurethane compounds giving the highest coefficient of friction.

In applications requiring the most severe resistance to abrasion, additives should be added to lower the coefficient of friction and further increase abrasion resistance.

In applications where a colour is specified other than black, additional UV stabilizers should be added to improve the long-term colour fastness.

16.2.5 Physical and mechanical properties of elastomer compounds

The physical and mechanical properties of polyurethane elastomer compounds should be in accordance with Table 9.

NOTE This does not apply to PU skins of foam fenders.

Table 9 — *PTMEG polyurethane elastomer compound physical and mechanical properties*

Physical/ mechanical property	Relevant test standard	Condition	Criteria
Tensile strength	BS ISO 37	Dumbbell type 1	≥22 N/mm²
Elongation at break	BS ISO 37	—	≥590 %
Hardness	BS ISO 48-4	At 20 °C	≤60 (durometer hardness shore type A)
Compression set	BS ISO 815-1	After being aged for 24 h at 70 °C Test method: Method A Sample size: Type A	≤14%
Tear resistance	BS ISO 34-1	Method B	≥12 kN/m with nick ≥35 kN/m without nick
Abrasion resistance	BS ISO 4649	Method A	≤35 mm³
Bond strength	BS ISO 813	Method B	≥7 N/mm²
Dynamic fatigue	BS ISO 132	15 000 cycles	Grade 0 to Grade 1
Specific gravity	—	—	≥1.05

NOTE 1 Unless otherwise stated in the project specification, the criteria values stated in the fourth column apply.

NOTE 2 Tear resistance "nick" is defined in BS ISO 34-1.

In addition to the recommendations in Table 9 for the maximum elongation at break, the stress at increments of 50% strain should also be determined.

Test laboratory accreditation*. Users of this part of BS 6349 are advised to consider the desirability of selecting test laboratories to undertake physical and mechanical testing of the polymer compound that are certified as meeting the requirements of BS EN ISO 9001 and accredited to BS EN ISO 17025.*

16.3 Elastomers for fenders

*COMMENTARY ON **16.3***

There are three types of fenders used on maritime structures:

a) moulded/extruded fenders – the vessel's kinetic energy is primarily absorbed through strain of the elastomeric material (usually compression and/or buckling of the fender body);

b) pneumatic fenders – the vessel's kinetic energy is primarily absorbed through compression of air contained within a cylindrical elastomeric bag;

c) foam-filled fenders – the vessel's kinetic energy is primarily absorbed through compression of a foam core.

16.3.1 Design and specification

*COMMENTARY ON **16.3.1***

Fenders differ from typical civil engineering applications as they are subject to short duration, high frequency, high strain actions. They are principally specified for their energy absorption qualities rather than their ability to resist static loads. Consequently, the design and specification of elastomers used in elastomeric fenders does not follow the typical Eurocode limit state philosophy of determining characteristic material properties and partial material factors.

16.3.1.1 General

Elastomeric fenders should be designed in accordance with BS 6349-4 and the manufacturing tolerances and design factors stated therein.

The choice of elastomeric materials for fenders should focus on achieving a durable compound which can accommodate repeated high strains without cracking, splitting or otherwise deteriorating for the duration of the specified design working life. The elastomer should be homogeneous, free from foreign materials (except for reinforcing plates), voids, delamination, cuts, cracks and other detrimental defects.

The designer of the fendering system should specify the fender properties and appropriate testing.

NOTE Guidance on the specification of materials for elastomeric fenders is given in Annex D. Further guidance on the specification of elastomeric fenders is given in PIANC WG33 [18].

***Production control**. Users of this part of BS 6349 are advised to consider the desirability of specifying that the production control system for the manufacture of elastomeric fenders is as described in Annex E.*

16.3.1.2 Traceability testing

*COMMENTARY ON **16.3.1.2***

Typically, elastomer compounds are batched daily in quantities suitable for each day's planned production.

Compositional analysis should be used to verify that the same elastomer compound has been used throughout the manufacture and testing of a production run/project. Samples for compositional analysis should be selected as follows.

a) Samples should be selected at random, from the pre-prepared material samples used for the physical and mechanical testing.

b) Samples should be taken from a fender unit which has been performance tested.

c) Samples should be taken from a fender unit which has been durability tested (if durability testing has been specified).

d) Samples should be taken at random from completed fender units which have not been performance or durability tested.

e) When samples are taken from completed fender units, these should be taken from the main body of the fender and not the flanges.

f) The number of samples should be chosen by the designer.

The polymers present in each compound sample and their respective proportions should be identified through infrared spectrometric methods in accordance with BS ISO 4650. The spectrometric examination should verify that the same polymers and proportions of polymers are present in each sample.

The respective proportions of each compound constituent within each sample should be determined through thermogravimetric analysis (TGA) in accordance with BS ISO 9924-1. The TGA should verify that the same proportions of constituent materials are present in each sample. The variation in proportions between samples should be no greater than ±3% by mass, e.g. if one constituent comprised 10% of the total mass of sample 1, the same constituent should comprise no less than 7% or no more than 13% of the total mass of sample 2.

When undertaking TGA, and when methods requiring solvent extraction are used for infrared spectrometric examination, the extractable material should be removed from the sample through solvent extraction in accordance with BS ISO 1407.

Due to the sensitivity of an elastomeric compound to its manufacturing and cure history, compositional analysis alone cannot guarantee a high performing and durable elastomeric unit and hence compositional analysis should be carried out together with performance testing of the completed fenders and, where specified, durability testing.

Traceability testing*. Users of this part of BS 6349 are advised to consider the desirability of selecting test laboratories to undertake traceability testing in laboratories that are certified as meeting the requirements of BS EN ISO 9001 and accredited to BS EN ISO 17025.*

16.3.2 Additional recommendations for pneumatic fenders

In addition to the recommendations of this part of BS 6349-1-4, pneumatic fenders should conform to ISO 17357.

16.4 Elastomers for structural bearings

Elastomeric structural bearings used on maritime structures should conform to BS EN 1337-3.

Where elastomeric structural bearings are exposed to the maritime environment, in addition to meeting the requirements in BS EN 1337-3, the elastomer used to manufacture the bearings should also meet the recommendations given in the present section of BS 6349-1-4.

Bearings Type C and Type E, as detailed in BS EN 1337-3:2005, Table 2, should not be used on maritime structures.

16.5 Embedded/integral steel reinforcing plates

Where steel reinforcing plates are embedded within elastomeric units, the reinforcing plates should be fully encapsulated by the elastomer compound to protect the steel from corrosion, and the elastomer compound should be fully bonded to the plate(s). The thickness of elastomer compound surrounding the reinforcing plates should be not less than 5.0 mm for any fenders 500 mm in height/diameter or larger.

Steel reinforcing plates should be of steel grade S235 or higher and should conform to BS EN 10025. The minimum impact strength or subgrade should be selected in accordance with BS EN 1993-1-10.

17 Plastics

17.1 General recommendations for plastics

*COMMENTARY ON **17.1***

Historically, plastics have had limited use in maritime works. Typical applications have been ancillary element replacing timber or steel elements. For example, glass-reinforced plastic (GRP) and fibre-reinforced plastic (FRP) have been used for open mesh decking, service trays, pipes and ducts, ladders and, more rarely, sheet piles. Other plastics have been used in coatings and decking. The principal use of plastics has been in the provision of surfaces for fender systems.

Ultra-high-molecular-weight polyethylene (UHMW-PE) should be selected in accordance with **17.2**.

Specialist advice should be obtained on the use of other plastics according to the specific application.

NOTE Guidance on the use of FRP for bridge applications is given in CIRIA C779 [19]. This guidance is applicable to some maritime structures.

17.2 UHMW-PE

*COMMENTARY ON **17.2***

UHMW-PE is generally used within maritime works to provide a low friction, durable surface to fendering.

17.2.1 General

UHMW-PE materials should be UV stabilized, and unfilled except for carbon black and colouring agents. UHMW-PE surfaces should be isotropic.

NOTE Anti-static UHMW-PE might be required for oils and gas terminals.

Where reclaimed UHMW-PE is used, it should be uncontaminated.

A grade of UHMW-PE suitable for the chosen application should be used.

Where UHMW-PE sheets are fixed to panels or structures by fixings, the sheets should be of sufficient thickness to accommodate:

- a minimum of 20 mm of wear until the recessed fixings become level with the wearing surface;
- the actions arising from the fixing within the recess; and
- the thickness of the fixing head.

All seaward edges of the UHMW-PE board should be bevelled/splayed to reduce possible damage or risk of chafing or snagging.

The size of the boards should be such that they can be easily replaced.

17.2.2 Material properties

The properties of UHMW-PE materials should be in accordance with Table 10.

Table 10 — *Material properties for UHMW-PE*

Property	Test method	Unit	Recommended value
Density	BS EN ISO 1183-1	g/cm^3	0.920 to 0.945
Molecular weight	BS EN ISO 1628-3	g/mol	≥3.5 × 10^6
Tensile strength at yield	BS EN ISO 527-2	MPa	≥20
Elongation at break	BS EN ISO 527-2	%	≥150
Wear resistance	BS EN ISO 15527	%	≤140
Shore hardness	BS EN ISO 868	HDD	61 to 70
Friction coefficient (static, dry)	ISO 6601	—	≤0.2
Charpy impact strength	BS EN ISO 179-1	—	No break
Melt mass flow rate	BS EN ISO 1133	g/10 min	0 to 0.1

The wear resistance should be referenced to a standardized virgin grade UHMW-PE with a molecular weight of 3.5 ×10^6 g/mol.

Test laboratory accreditation*. Users of this part of BS 6349 are advised to consider the desirability of selecting test laboratories to undertake physical and mechanical testing of the polymer compound that are certified as meeting the requirements of BS EN ISO 9001 and accredited to BS EN ISO 17025.*

Testing, inspection and traceability of materials. *Users of this part of BS 6349 are advised to consider the desirability of selecting materials that are certified following the principles of BS EN 10204:2004, Type 3.1 certification.*

Density, wear resistance, charpy impact strength and melt flow index (MFI) properties of delivered materials should be verified by testing.

Section 6: Stone for armouring or protection works

*COMMENTARY ON SECTION **6***

Natural stone has been used traditionally in the construction of protection works in marine conditions. It is used in such structures as breakwaters, training walls and groynes and in pitched and revetted slopes.

18 General recommendations for stone

Stone for protection works should conform to the requirements specified in BS EN 13383.

NOTE BS EN 13383-1 specifies requirements for grading of the armourstone stone, the geometrical requirements for individual pieces of armourstone and any physical and chemical requirements. Assessment of these requirements is by test methods, the majority of which are described in BS EN 13383-2 together with requirements for sampling for testing. The remaining test methods specified use European standard test methods for aggregates. Guidance on these test methods and the appropriate selection of requirements and requirement levels is given in PD 6682-7. Further guidance on the identification and selection of rock is given in The Rock Manual [N4]. BS EN 13383 does not provide any guidance for the workmanship of placing armourstone in engineering works. Guidance on this aspect is given in The Rock Manual [N4], which includes a model construction specification as well as a chapter devoted to construction.

19 Grading

19.1 General

Wherever possible, gradings should be selected from the standard gradings given within BS EN 13383-1 such that they fulfil the design requirements for mass, in the case of cover layers, and filtration/support, in the case of underlayers.

NOTE 1 Gradings given in BS EN 13383-1 are summarized as:

- *a selection of standard coarse gradings which are specified by the size of the armourstone pieces, the nominal upper limit for which does not exceed 250 mm;*
- *a selection of standard light gradings which are specified by the mass of the individual pieces. The nominal lower limit for these gradings is not lower than 5 kg and the nominal upper limit not greater than 300 kg; and*
- *a selection of standard heavy gradings which are specified by the mass of the individual pieces. The nominal lower limit for these gradings is not lower than 300 kg.*

NOTE 2 The use of standard gradings is particularly important for coarse and light gradings which are produced using standardized equipment (screens and crushers), and these procedures are difficult to modify without incurring significant cost.

Where non-standard gradings are required, these should be specified following the guidance in BS EN 13383-1 and *The Rock Manual* [N4].

NOTE 3 Where quarries are set up dedicated to a particular large project, non-standard gradings might be appropriate in order to ensure that the design matches the quarry yield.

19.2 Cover layer underlayer and filter applications

*COMMENTARY ON **19.2***

There are two types of grading quality for heavy and light gradings applicable to the cover layer: category A, where the average mass is controlled, and category B, where it is not.

Category A gradings should normally be used for the cover layer.

NOTE 1 When selecting the appropriate category for underlayer or filter applications, Category B materials may be selected when there is no requirement for a control on the average mass.

When assessing the average mass required for hydraulic stability, an allowance should be made for the fact that the design value of M_{50} (and the associated value of D_{n50}), calculated when using armour stability formulae, is greater than the corresponding average mass, M_{em}.

NOTE 2 Conversion factors between M_{50} and M_{em} are given in The Rock Manual [N4].

NOTE 3 The grading $LMA_{15/300}$ is typically too wide for cover layer applications.

19.3 Volume filling materials

*COMMENTARY ON **19.3***

Volume filling materials are often used in the core of rubble structures.

The property requirements of the core material for a breakwater or revetment vary depending on the functional use of the core and/or the rubble structure. If the core material is primarily for volume filling, the material might not require specification to international standards, and it might be acceptable to use lower quality materials compared to armour and filter layers.

When selecting material for the core, the following factors should be taken into account in determining the most appropriate material:

a) internal and external loads acting on the core material;

b) acceptable post-construction settlement limits;

c) construction techniques; and

d) potential for loss of fines during construction.

NOTE 1 The placed bulk density is an important indicative material parameter, as it relates closely to shear strength and possible settlement as well as to permeability.

Measures should be taken to prevent core material from being washed out through the overlying layers and thereby being lost.

NOTE 2 To limit washout, the fines content within the core grading can be restricted to 1%.

The fill material should be of a wide grading, such that the overall degree of permeability meets the design requirements of the structure.

NOTE 3 The permeability of the core has an effect on the stability of the protective layers, and the grading of the core has to be compatible with the permeability assumed in the design to ensure that wave transmission is limited to the design requirements.

20 Geometrical parameters

The shape of stone should be assessed by length to thickness (LT) ratio for cover layers, underlayers and the core.

NOTE Guidance on the LT ratio is provided in The Rock Manual [N4].

The proportions of crushed or broken surfaces should be determined in accordance with *The Rock Manual* [N4] as appropriate.

21 Physical and chemical parameters

In calculations for hydraulic stability of armourstone used in cover layers, the apparent density should be used rather than the oven dry density.

NOTE 1 Guidance on calculating the apparent density from the oven dry density and percentage water absorption is provided in The Rock Manual [N4].

In the design, the selection of stone density should allow for the potential reduction in density in stone from the quarry compared with the declared density as permitted in BS EN 13383-1.

NOTE 2 BS EN 13383-1:2002, Table 8, specifies the following values:

- *average density of 10 pieces ≥ x Mg/m^3; and*
- *density of at least 36 pieces of 40 pieces tested ≥ x −0.10 Mg/m^3.*

BS EN 13383-1:2002 requires that the value for x is declared by the producer and stated to two decimal places, and is not less than 2.30.

NOTE 3 The requirement in BS EN 13383-1 for the density of at least 36 pieces of 40 tested permits a significant proportion of rocks to be below the density declared by the producer which might not be in accordance with the design requirements.

Resistance to breakage should be assessed by compressive strength (CS). For cover layer applications, category CS_{80} should be selected (equivalent to a compressive strength of 80 MPa) in order to avoid excessive breakage of the rock through the mineral fabric.

NOTE 4 For underlayers and filter layers, category CS_{60} is expected to be sufficient, and for volume filling applications it is not necessary to set any requirements for resistance to breakage.

Armourstone selection should include block integrity testing using the destructive testing techniques and assessment criteria as set out in *The Rock Manual* [N4].

NOTE 5 Additional guidance on armourstone integrity using destructive and non-destructive testing techniques is provided in The Rock Manual [N4].

Armourstone selection should include destructive testing. The destructive testing should include a combination of the drop test, full-scale crushing test and full-scale splitting test as appropriate, as set out in *The Rock Manual* [N4].

NOTE 6 Additional guidance is provided in BS EN 13383-1:2002, Annex B and in The Rock Manual [N4].

Resistance to wear should be assessed by abrasion losses determined by the Micro-Deval wear test in BS EN 1097-1. For many situations, it is not necessary to set a wear requirement; however, for cover layers and dynamic structures (such as beaches), Micro-Deval coefficients, M_{DE}, should be set as follows:

a) M_{DE}10 for very highly abrasive environment (e.g. frequently stormy seas with shingle-structure interaction, fluvial torrents, and dynamic armour layers including berm breakwaters);

b) M_{DE}20 for highly abrasive environment (e.g. occasionally stormy seas with shingle or sandy foreshore); and

c) M_{DE}30 for moderately abrasive environment (e.g. occasional wave or current action with suspended sediment load).

NOTE 7 If there are insignificant sediment loads present in the water, a wear requirement may be omitted. Similarly, for filtering and volume filling applications, no wear requirement is necessary.

Water absorption (WA) should be determined in accordance with BS EN 13383-2.

NOTE 8 The results from the water absorption test are needed for two reasons:

- *for apparent density calculations for hydraulic stability (see Note 1);*
- *as a screening test for durability against salt crystallization and/or freeze-thaw attack.*

The guidance on resistance to freezing and thawing provided in *The Rock Manual* [N4] should be followed where appropriate.

NOTE 9 Freeze–thaw testing is not normally considered necessary for coastal applications in the UK.

Resistance to salt crystallization should be assessed where WA is determined to be greater than 0.5%. In such situations, category MS_{25} should be selected (equivalent loss of mass should be less than 25%).

NOTE 10 Where armourstone is permanently submerged, salt crystallization processes are likely to be limited in effect and no requirement is necessary.

NOTE 11 Additional guidance is provided in The Rock Manual [N4].

22 Particular armourstone sources

Where steel slags and natural basalts are to be used as armourstone, they should be selected following tests for disintegration and signs of "Sonnenbrand" respectively.

Acceptable disintegration and Sonnenbrand properties should be in accordance with BS EN 13383.

NOTE Additional guidance is provided in The Rock Manual [N4].

23 Use of stone with concrete armour units

Some concrete armour unit licence holders have minimum properties for stone when used in conjunction with the concrete armour units. The design should specify the higher of the minimum rock properties given in the appropriate British Standard and those given by the licence holder.

Section 7: Bituminous materials

*COMMENTARY ON SECTION **7***

Bituminous materials are used in maritime works for:

- *pavements;*
- *coatings;*
- *waterproofing;*
- *sealing compounds; and*
- *coast and bank protection.*

The use of bituminous materials for pavements, coatings, waterproofing and sealing compounds is the same as or similar to their applications in non-maritime works, and no special recommendations are given in this part of BS 6349.

*The uses, mixes and application techniques of bituminous materials for coast and bank protection are described in Clause **24** to Clause **27**. Guidance on uses of bituminous materials is given in Annex F.*

Bitumen is employed in a number of ways for coast and bank protection work, but not all bituminous materials used for other hydraulic applications can be used for this purpose. Pure bitumens, cutbacks and emulsions are only applied for tack coats and surface treatments.

Aggregate/cutback or emulsion mixtures are rarely used, but extensive use is made of hot mixtures of bitumen and aggregate. These mixes are normally dense, and their lack of permeability can be a disadvantage from the design point of view. A low void content is nevertheless advisable owing to the difficulty in constructing strong and durable open mixtures. Open stone asphalt is the one exception. Hot mixtures in common use are:

- *asphaltic concrete (gravel and stone filled sheet asphalt also belong to this group);*
- *sand mastic or asphalt mastic;*
- *dense stone asphalt;*
- *open stone asphalt; and*
- *lean sand asphalt.*

24 Asphaltic concrete

*COMMENTARY ON CLAUSE **24***

Asphaltic-concrete types of mixtures consist of crushed stones or gravel with a maximum size of 32 mm, graded sand, filler and bitumen. These mixes usually need to be compacted after spreading and have a certain amount of stability. Normally they are applied under dry conditions.

Asphaltic concrete should be durable and of low permeability, have adequate stability to resist flow down a slope, where applicable, and be of good workability to facilitate compaction.

The following specific recommendations should be met.

a) A bitumen content of 6% to 9% should be used.

NOTE 1 The bitumen content is normally higher than for highway use in order to obtain low permeability and durability.

b) The softer grades should be used on slopes because compaction is difficult.

NOTE 2 Penetration grade bitumen, 40/60 pen, 50/70 pen, 70/100 pen or 100/150 pen, conforming to BS EN 12591, are normally used to facilitate compaction. 40/60 pen and 100/150 pen grades are most commonly available.

c) The laid thickness should not be less than 2.5 times the maximum aggregate size. Aggregates should have good adhesion characteristics and be angular or crushed for revetments that are placed on slopes steeper than 1:2.5.

NOTE 3 A continuous aggregate grading with a maximum stone size of 14 mm, 20 mm or 32 mm is commonly used. Gap-graded mixes, which need less compactive energy, are sometimes used.

d) A well-graded sand should be used because otherwise high percentages of filler would have to be added in order to reduce the voids content.

NOTE 4 High percentages of filler can lead to the production of mixes that are difficult to handle.

e) Filler contents, i.e. materials smaller than 63 µm, should be between 7% and 13%, limestone or cement being preferred.

f) The void content should be below 4%.

NOTE 5 For mix design, use can be made of the Marshall test procedure [20]. It is, however, essential that the state of compaction achieved in the laboratory-made specimens is comparable with that obtained in the field.

The design procedure should be to select an aggregate grading, make mixes at varying bitumen contents and determine the void content after five to ten blows. The aim should be to obtain a mix with minimum void content in the mineral aggregate and a total void content of 5% to 6% with a bitumen content between 6% and 9%.

Asphaltic concrete should be manufactured in accordance with BS EN 13108-1, which includes quality control procedures.

When a suitable mix has been selected, an uncompacted sample should be subjected to a flow test at the compaction temperature.

NOTE 6 A suitable form of test is to place the mix in a wooden form held at the same slope as the structure.

The mix should remain in the form for half an hour without flow. A similar test should be carried out on a compacted specimen kept at a temperature of 40 °C to 70 °C, as appropriate, for 48 h. Any movement should be small, i.e. 3 mm maximum over a length of 300 mm, and should cease after 24 h. In both tests the sample depths should be representative of those to be used in the field.

NOTE 7 Asphaltic concrete is normally made in a hot-mix plant and transported to the site by trucks or lorries.

Asphaltic concrete should be placed in the dry, and various methods are used for spreading the mixture over the revetment.

NOTE 8 The simplest placement method is by tipping the mix directly from a truck on the formation and spreading it to the desired thickness with hand rakes. Another possibility is to tip the mix into a shallow container, from which it is picked up and divided over the revetment by means of a crane, spreading usually being carried out by hand.

Unless slopes are very shallow, compaction rollers should be operated by a winch system.

NOTE 9 A modern trend is to lay asphaltic concrete revetments 200 mm to 300 mm thick, in one layer, the thicker layer retaining heat and thus facilitating compaction. This method also eliminates problems related to adhesion between different layers.

25 Sand mastic

*COMMENTARY ON CLAUSE **25***

Sand mastic consists of sand, filler and bitumen. The voids in the sand/filler mixture are overfilled with bitumen so that the mix is pourable in its hot state and does not require any compaction. Larger aggregate is sometimes added but this has no effect on the viscous behaviour of this type of mix.

Sand mastic is used above and below water, either as a grouting material for stone revetments or as a carpet. The material can also be used for the construction of prefabricated mattresses.

For a number of applications, it is desirable to limit the penetration depth of the sand mastic grout without affecting the viscosity appreciably and this can be done by adding finely rounded gravel to the mix.

The sand mastic is usually made in a hot-mix plant in accordance with BS EN 13108-5 and transported to the site in 5 t special containers or transporters, which are fitted with stirrers to prevent settlement of the mineral particles. At the site, the hot mastic is poured through open channels or chutes and guided over the stone surface and into the voids with the aid of squeegees or shovels. In some cases, the containers are lifted from the truck by crane so that the mix can flow directly into the work.

It is possible to apply sand mastic in deep water using a special apparatus that can lay an impermeable sand mastic carpet continuously on the seabed at depths of up to 30 m. It is also possible to carry out stone grouting continuously and evenly at these depths. Prefabricated mattresses of sand mastic, which are easy to construct, may be used for toe protection, but in order to make transport and placing possible they are often reinforced with wire netting and steel cables.

The composition of sand mastic can vary within wide limits and thus extensive use of local materials can be made.

Sand mastic should meet the following recommendations.

a) During application, the mastic should be pourable, with viscosity low enough to permit sufficient penetration into the interstices between the stones, but high enough to prevent excessive flow when applied hot on a slope.

b) During service conditions, the viscosity should be high enough, i.e. over approximately 10^9 Pa to 10^{10} Pa, to keep long-term flow within acceptable limits.

26 Open stone asphalt

*COMMENTARY ON CLAUSE **26***

*Open stone asphalt consists of bitumen and a mineral aggregate having a large maximum stone size, and is characterized by a double mixing procedure. Firstly, a slightly overfilled asphaltic mixture is made in a normal hot mix plant, and secondly, this mix is blended with dried preheated large stones. By this means, the mix coats the large stones and binds the whole together but without destroying the permeability (see Commentary on Section **7**). Due to this special manufacturing process, open stone asphalt possesses some unique properties. For example, the aggregate is gap graded, the mix is just pourable and no compaction is required.*

It is very important to have a good asphaltic mixture in which there is a good affinity of the bitumen and the aggregates. This can be tested by means of:

- *the rolling bottle test; or*
- *the boiling test.*

A good open stone asphalt mixture contains few <2 mm materials in the supplied aggregates. Too much fine material leads to a poor mastic, which results in low strength. If the aggregates contain too much fine material, it needs to be washed or sieved.

Open stone asphalt can be used below water but only in the form of prefabricated mats.

The dimensions of the prefabricated mattresses depend on the contractor and the placing method. The size of the mattresses can be as big as 10 m × 36 m.

Due to the use of bitumen, the mattresses are known to be very flexible. The mattresses can follow the deformations of the seabed very easily or can be placed on a bottom with various slopes.

As asphalt is structurally not suited to be lifted due to induced bending moments, reinforcement is placed in the asphalt mattresses. This reinforcement also contains the reinforcement for the lifting.

Above water it can be applied as a monolithic revetment or as a grouting material for very large stones. Because of its high stability, open stone asphalt can be applied on slopes in much thicker layers than normal asphaltic concrete. Open stone asphalt is transported and laid in a similar manner to asphaltic concrete.

Open stone asphalt (OSA) consists of the following material:

- *sand;*
- *filler;*
- *bitumen;*
- *coarse aggregates; and*
- *optional: fibre glass wires.*

The composition of open stone asphalt can vary between certain limits, depending on the type of application, and it is capable of making strong, porous yet durable revetments. In addition, fibre glass wires can be added to the open stone asphalt mixture, which gives so called fibred open stone asphalt (FOSA). Laboratory tests in 2008 in the Netherlands showed that these fibres give the following advantages:

- *the bending strength is two times higher; and*
- *resistance against fatigue is higher.*

Dense (or heavy) stone asphalt can be considered as consisting of large stones (maximum 500 mm) in that the interstices are filled with a slightly overfilled asphaltic mastic or concrete.

Open stone asphalt is used as dyke revetment and as bed protection. For both situations, specialist advice should be obtained on the design and life expectancy, as this is different for the two situations due to the specific induced forces and environmental conditions.

NOTE 1 Depending on the asphalt quality and location, the expected lifetime can vary from 15 years to 50 years.

When open stone asphalt is applied as a revetment on relatively steep slopes above and below water level, the stone content should be selected to provide adequate stability, taking into account that near the tidal zone this part is generally subjected to high wave forces. Above water level the stone asphalt can be subjected to high temperature differences, due to direct sunlight, and this should be allowed for in the design.

Where this material is used for surface-grouting very large stones, the composition should be modified in such a way that sufficient penetration is obtained, but at the same time limiting the depth of penetration to prevent excessive loss of material.

NOTE 2 When using open stone asphalt as scour protection on the bed, the open stone asphalt is subjected to much less critical loading that above water. Ageing of the bitumen is retarded due to the small amount of oxygen that is *present under water. The temperatures underwater are more constant, which leads to minimum thermal stresses. Generally, the temperature is also very low, providing a low viscosity and high tensile strength of the bitumen. The only degradation of submerged open stone asphalt is due to stripping.*

27 Lean sand asphalt

*COMMENTARY ON CLAUSE **27***

Lean sand asphalt consists of a mixture of locally available sand and bitumen, and is therefore a relatively economical material. It is a greatly underfilled mix, the function of the bitumen being to coat the sand particles and bind them together. Usually, when applied underwater, no compaction is carried out, so the void content is very high, but even when dry applications are carried out and compacted, the void content is rather high in most cases, due to the single-sized grading of most sands and the low binder content. After some time, the permeability is very similar to that of the sand from which it is made. Lean sand asphalt can be used as a filter layer, core material or temporary protective covering.

Lean sand asphalt can be made in a conventional hot-mix plant and transported to the site by lorry, where it is dumped, either above or below water. It can be handled and spread by means of a back-acter excavator, bulldozers or barge.

Despite the relatively high void content of lean sand asphalt, it is well able to resist the scouring effect of water up to velocities of 3 m/s. Because of the high void content, durability and bearing capacity are limited, but if the material is applied correctly it can form a reasonably economical substitute for conventional materials.

The composition of lean sand asphalt can vary within wide limits and thus extensive use of local sands can be made.

Lean sand asphalt should have a bitumen content of 3% to 6%.

Annex A (informative)
Factors affecting the design of maritime concrete

A.1 General

There are a number of deterioration processes that are specifically recognized in relation to concrete in or adjacent to seawater.

Explanation and guidance on the different mechanisms are given in the CEB publication *Durable concrete structures – Design guide* [21] and in the PIANC *Recommendations for the construction of breakwaters with vertical and inclined concrete walls* [22]. Other useful publications include CIRIA C674 [2] and the Concrete Society Technical Report 61 [4].

A.2 Corrosion of reinforcement and other embedded metallic items

The most serious process affecting maritime structures is that of chloride induced corrosion of reinforcement or prestressing steel, with consequent cracking and bursting of the concrete cover and loss of steel cross section due to corrosion.

Corrosion only occurs when the amount of chlorides in the concrete at the surface of the steel reaches a threshold value, typically known as the critical chloride threshold.

The chlorides migrate into the structure from the surface and therefore the time to the onset of corrosion is strongly influenced by the speed with which the chloride ions can penetrate the concrete cover. In water saturated concrete, chloride ions are transported by the slow process of diffusion. In dry concrete, chloride ions are transported into the cover zone much more quickly by the processes of absorption, wick action and hydration suction. Rates of ingress are also higher for concrete with a higher internal temperature. In both incidences the rate is greater at the edges or corners of a structural member as chloride enters from more than one face simultaneously. Consequently, a flat-slab type construction typically provides better durability performance than beam-and-slab.

The critical chloride threshold is not a constant value, with a higher amount being required in saturated concrete than in unsaturated concrete to cause corrosion. The value is also affected by the quality of the interface between the steel and concrete, so is likely to be negatively impacted by presence of voids or non-cementitious material on the surface of the steel. Consequently, inadequate compaction, bleed water becoming trapped on the underside of the bars, and the presence of other materials and debris on the surface of the steel prior to concrete placement, such as bentonite or general construction debris, is likely to accelerate the initiation of corrosion.

Even once the chloride threshold level has been reached, oxygen is required at the surface of the steel for the corrosion to proceed, although in partially oxygen depleted concrete such as in the upper tidal zone or under coatings, anaerobic influenced corrosion can occur and the corrosion rate can be rapid, but with little external evidence in the form of concrete cracking and delamination as the corrosion products formed are not sufficiently expansive. This is colloquially known as “black rust”.

The zones most at risk from chloride induced corrosion are those subject to an unbalanced wetting and drying cycle, such as can occur in the following situations:

a) locations subject to annual changes in mean sea level and tidal range due to seasonal, barometric or other reasons;

b) locations such as dry docks, locks and slipways;

c) areas adjacent to bollards, mooring winches and salt water hydrants;

d) areas at and just above high water level, which are subject to splash and irregular inundation;

e) concrete exposed to seawater conditions in bridge piers, and underground structures and tunnels; or

NOTE Underground structures can be subject to irregular inundation due to flooding and immersion during the construction process, and direct leakage and transport of moisture through joints, construction joints or the concrete.

f) arid conditions, natural or artificial, which exacerbate all of the previous conditions.

Concrete that is continually submerged, or regularly wetted and only surface-dried within the tidal range, remains essentially water saturated which stifles the transport of chloride ions and the availability of oxygen. As a result, these areas are less at risk from chloride induced corrosion. The one exception to this is with hollow immersed structures. This phenomenon has been traditionally linked to the hollow legs of concrete oil production platforms, but could similarly affect quay walls where there are service galleries below water level, or in floating concrete pontoons or jetties. In this situation, galvanic corrosion cells can be established between the reinforcement located close to the immersed face in saturated concrete (once sufficiently chloride contaminated) and the reinforcement in the non-water saturated concrete adjacent to the air-filled void. In these incidences it is possible for the reinforcement in the saturated chloride contaminated concrete to corrode to form “black rust” with significant loss of steel reinforcement cross-sectional area but with little or no cracking or bursting of the concrete.

The relative influence of the various transport mechanisms for chlorides, i.e. diffusion, absorption, wick action, permeation by pressure head, and the conditions in which salt concentration occurs, are illustrated for a schematic maritime structure in Figure A.1, which includes the assignment of XS exposure classes to enable durability design. The qualitative effect of different macroclimates is shown in Figure A.2.

Exposure conditions for airborne chlorides are particularly site-specific and depend on the microclimate and the macroclimate. Airborne chlorides are transported in the form of aerosols that can be wet or dry. In some regions, these effects can extend kilometres from the coast. The risk of corrosion of reinforcement depends on there being sufficient water to carry the chlorides into the concrete and the degree of dilution by rain on the surface.

Where concrete remains in direct contact with chloride-bearing water or is in frequent contact with such water, the main local transport process is likely to be diffusion. In other locations, such as in the irregularly wetted upper part of the structure as illustrated in Figure A.1, other, more damaging, processes can occur. The zones most at risk, as itemized in a) to f), correspond with the latter situation.

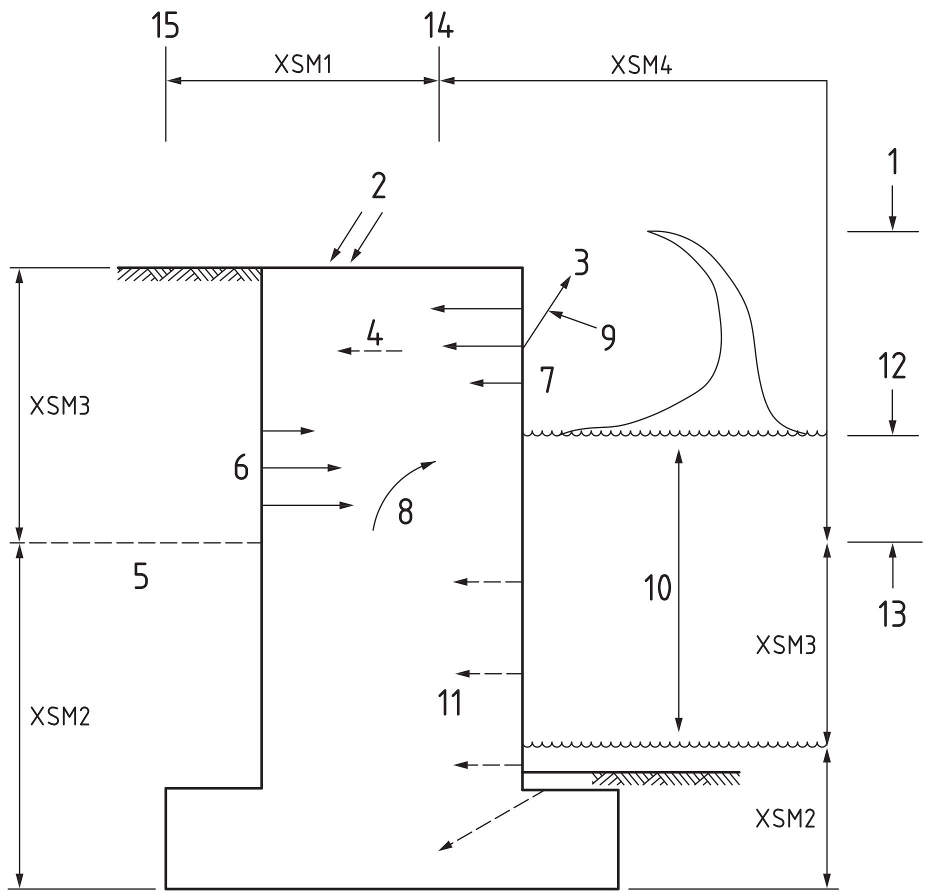
The range for XS3 under most conditions includes overtopping of quay walls from storm waves and seawater run-off from moorings.

Further information on severity ratings and the assessment for site- and climate-specific environmental conditions is given in *The design of coastal structures* [1].

In some structures, such as tunnels or ducts, internal temperatures can get much higher due to the heat from the electrical equipment or piping, etc. Where there are leaks from seawater into these structures, hot wet conditions and even hot dry conditions along the extremes of the wetted zones might apply. The severity condition can therefore exceed the XS3 rating, and thus particular assessment of the concrete specification is required.

The surface of reinforced concrete has the same design requirements as for unreinforced or mass concrete, together with the selection of cement type in conjunction with cover to reinforcement appropriate to that cement type, for a given exposure condition.

Figure A.1 — *Schematic diagram of the chloride transport processes in a maritime structure*

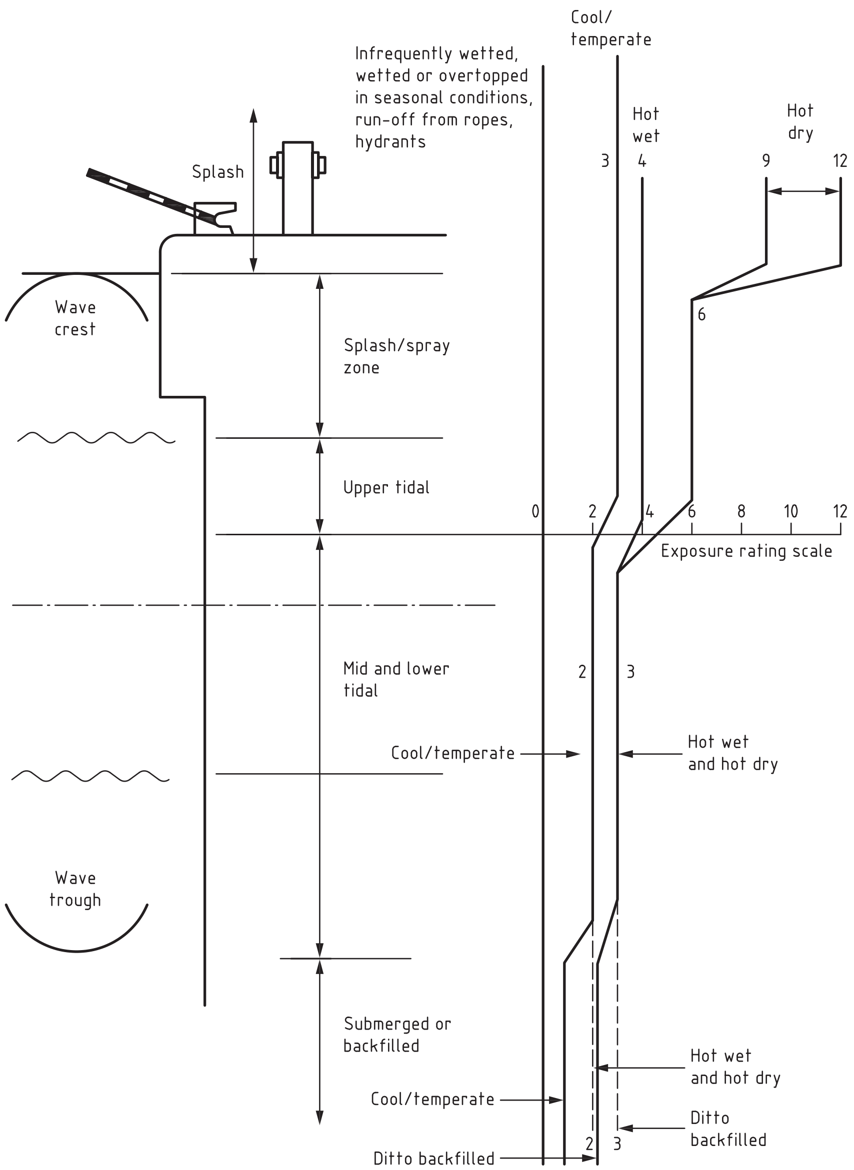


NOTE XSM1 exposure class applies to elements not directly in a wetted zone, including superstructures and buildings adjacent to the coast, but not subjected to frequent daily aerosol/mist.

Key

1 Extreme water level plus maximum wave height
2 Rain-reducing surface salt concentration
3 Evaporation giving a salt concentration
4 Diffusion in response to salt concentration
5 Water table
6 Permeation by pressure head
7 Capillary absorption into partially saturated concrete
8 Wick action, drawing water from wet concrete to the exposed face
9 Splash/spray
10 Tidal range between MHWS and MLWS
11 Diffusion of salt from seawater
12 Mean high water springs (MHWS)
13 Level approximately one quarter of tidal range between MHWS and MLWS below MHWS
14 Airborne chlorides only from aerosol/mist and beyond reach of contact with seawater through wave or tidal action
15 Extent of saline aerosol reach which is dependent on wave and wind climate

Figure A.2 — *Effect of macroclimate on chloride ingress/induced corrosion*



NOTE This is a reproduction of Figure 6.2 in Concrete in coastal structures [1]. It is reproduced with the kind permission of ICE Publishing, 8 Storey's Gate, London SW1P 3AT.

A.3 Chemical and physical attack of the concrete

Incorrectly specified concrete mixes can also be weakened by the action of sulfates and by salt weathering of the surface.

In situations where chloride induced corrosion has been avoided by appropriate design and specification, or by designing with unreinforced concrete or non-ferrous reinforcement, the effects of sulfates could prove to be a critical factor in the longer term. However, in the medium term, sulfate attack is reduced in the presence of chlorides and is less of a risk in warm water conditions than cold water conditions.

In colder climatic regions, freeze–thaw damage is an important consideration, the risk of damage being greater in concrete saturated by salt water.

Sulfate attack is more likely to present a risk in continually wetted concrete and is greater in colder water conditions. Salt weathering and freeze–thaw damage is more likely to present a risk in the inter tidal and splash zone areas, and on horizontal surfaces rather than vertical.

Concrete can also be damaged due to deficiencies in choice of raw materials by the processes of alkali-silica reaction and delayed ettringite formation. Alkali-silica reaction can occur when alkali-susceptible aggregate is used in the production of the concrete due to the chemical reaction with the alkalis in the cement in the presence of water. The likelihood of damage is increased when the water is saline. A gel is formed as a result of a chemical reaction which imbibes water present within the concrete and tries to expand inducing tensile pressures within the concrete which eventually leads to cracking. The reaction is more rapid in warm conditions.

Delayed ettringite formation is a result of the hydrating cement being heated to too high a temperature during curing. Ettringite is a mineral produced as a normal reaction product of cement hydration at early ages and under moderate temperature conditions, and is not damaging to concrete. Delayed ettringite formation (DEF) occurs in concrete which has experienced high temperature during its early hydration, such as occurs in thick sections or steam-cured concrete. The high temperature suppresses the formation of ettringite, which can re-form later in the life of the concrete when sufficient water is available, leading to expansion and cracking. Damage generally arises typically within 5 years to 25 years after construction. The likelihood of these temperatures being reached initially is greater in hot environments.

Although there is uncertainty over the precise mechanism of deterioration, there appear to be a number of commonly repeated risk factors, principally:

a) high temperatures (70 °C or higher) in the concrete during curing;

b) cement with high sulfate (>3.6% total SO_3 by mass of cement) and/or alkali content (>0.85% Na_2O_{eq} by mass of cement) in the concrete;

c) exposure to moisture in service; and

d) presence of pre-existing cracks (e.g. early thermal or plastic cracks) allowing external water to more readily access the body (and most heat affected part) of the concrete. See CIRIA C766 [3] for further information on assessing the risk and mitigation of early age cracking.

Further information is given in BRE IP11/01 [23].

Annex B (informative)
Enhanced protection of reinforcement

Measures to enhance the durability of reinforced concrete are available and form a valuable function where, for example:

- the risk of reinforcement corrosion is likely to be extreme;
- extended service lives or structurally critical/prestige structures (e.g. major crossings) are required; or
- structural and detailing feasibility rules out large values of cover.

The selection of additional protective measures can either provide an increase in concrete quality to resist ingress of chlorides, or improve the threshold at which corrosion initiates. A combination of measures is a valid approach, particularly for critical structures. Careful selection of measures is necessary to ensure compatibility within the design along with a practical construction methodology.

Stainless steel reinforcement provides improved corrosion resistance properties but at increased initial cost when compared to carbon steel reinforcement. Austenitic stainless steels are appropriate for embedded reinforcement, but higher, more corrosion resistant, grades are likely to be required for exposed items (i.e. PREN values >40). Immersed items with crevices (e.g. mating faces of fastenings) typically have PREN values >40.

Reinforcement protected by fusion bonded epoxy coatings has been used. However, it is critical that good control and inspection procedures are in place to ensure that the coating is not damaged as this could cause accelerated local corrosion. Historically, this solution has proven to be problematic, partly due to variable coating quality and partly due to damage on site during construction. It has the disadvantage of precluding the subsequent application of cathodic protection if corrosion damage does occur. It has not been widely used in Europe since circa 2000.

Galvanized steel reinforcement is covered within BS EN 10348-2. It has not been widely used in the UK and it is advisable to seek specialist guidance prior to its use.

Integral admixtures such as corrosion inhibitors and integral waterproofing admixtures may be used, to enhance concrete quality or increase the threshold to corrosion. The use of high range water reducers (previously known as superplasticizers) allows a lower water cement ratio to be achieved than would otherwise be the case.

Controlled permeability formwork may also be used as this densifies the concrete at the cover zone, increasing the resistance to chloride ingress.

Cathodic protection can be used for the protection of concrete reinforcement as well as the conventional protection of steel structures. This is classed as a prevention system, installed during construction or a protection system, which is retrofitted during the structure service life.

NOTE Corrosion of adjacent structures (either reinforced concrete or steel) is theoretically possible by stray currents from an impressed current system. In practice this is only likely if the cathodic protection system includes anodes that are buried in soil or immersed in waters; for atmospherically exposed concrete in which anodes are incorporated into or onto the concrete, such stray current effects are virtually impossible. BS EN ISO 12696 covers the design, installation and operation of such systems.

Further information is given in CIRIA C674 [2], Concrete Society Technical Report 61 [4] and *The design of coastal structures* [1].

None of the above, with the exception of the use of high range water reducing admixtures, are considered in Table 3 to Table 5 of this part of BS 6349, and a service life design is needed to assess the benefit.

Annex C (informative)
Historically measured corrosion rates

Table C.1 gives historically measured corrosion rates extracted from Report EUR 8492 [24] generally and CIRIA C634 [13] for data related to MIC/ALWC.

Table C.1 — *Measured corrosion rates for non-alloy structural steels in temperate climates*

Exposure zone	**BS EN 1993-5 descriptor**	**Corrosion rate (mm/year/side)** A)		
		Mean	**Upperbound (excl. localized corrosion)**	**Upperbound (incl. localized corrosion)**
Splash zone: Above mean high water to a height depending on mean wave height and exposure to wind; direct wave or spray impingement frequent	Sea water in temperate climate in the zone of high attack (splash zones)	0.04 to 0.13 (0.09)	0.08 to 0.24 (0.18)	0.10 to 0.32 (0.25)
Tidal zone: Between MHW and MLWS	Sea water in temperate climate in the inter-tidal zone	0.02 to 0.09 (0.04)	0.04 to 0.14 (0.11)	0.05 to 0.17 (0.14)
Intertidal low water zone: Between MLWS and 0.5 m below LAT	Sea water in temperate climate in the zone of high attack (low water)	0.03 to 0.14 (0.07)	0.06 to 0.23 (0.14)	0.07 to 0.52 B) (0.45)
Continuous seawater immersion zone: From 0.5 m below LAT to seabed	Sea water in temperate climate in the zone of permanent immersion	0.03 to 0.09 (0.05)	0.05 to 0.30 (0.14)	0.06 to 0.38 B) (0.28)
Below seabed or in contact with uncontaminated soil	Undisturbed natural soils (sand, silt, clay, schist)	0.02	0.05	— C)

A) Values in parenthesis are the mean values across all survey sites.

B) Where MIC/ALWC occurs above bed level, localized corrosion rates of up to 2 mm/year have been recorded.

C) MIC can occur in seabed silts, up to 2 m to 3 m below bed level. Where this occurs, localized corrosion rates of up to 0.8 mm/year have been recorded.

Annex D (informative)
Guidance on the specification of materials for elastomeric fenders

D.1 General

A specification for elastomeric fenders generally includes the basic requirements given in **D.2**, and the information listed in **D.3**. The manufacturer selects/designs the most suitable elastomeric compound for the project cognizant of these requirements and this information.

D.2 Basic content of the specification

The specification for elastomeric fenders generally includes material, performance and durability requirements such as:

- a requirement to conform to BS 6349-1-4 and BS 6349-4;
- the minimum performance requirements of the fender product(s);
- the minimum durability requirements of the fender product(s);
- the required design working life of the fender product;
- the information from the specifier listed in **D.3**;
- a requirement for a quality management system in accordance with BS EN ISO 9001;
- confirmation of whether the manufacturer's quality management system is required to be certified by an accredited third-party certification body as conforming to BS EN ISO 9001;
- confirmation of whether the manufacturer's production control system is required to be certified by an accredited third-party certification body as conforming to Annex E of this standard,
- the number of production run fenders to be performance tested;
- the number of supplementary fenders to be manufactured and durability tested;
- the number of material samples to be retrieved for traceability testing;
- any requirements for user/specifier witnessed testing (e.g. witnessing of the physical and mechanical property testing, performance testing, durability testing and/or traceability testing); and
- any requirements for independent third-party verification testing (e.g. independent third-party verification of the physical and mechanical property testing, performance testing, durability testing and/or traceability testing).

D.3 Information from the specifier of the elastomeric fender to the manufacturer

The following information is typically provided by the specifier to the manufacturer within the specification:

- the geographic and climatic location of where the elastomeric fender is to be located during its design working life;

- the type of maritime terminal where the elastomeric fender is to be used and what cargo is to be handled at that terminal;
- the number of berthing events that the fender(s) is to be expected to endure during its design working life;
- the expected frequency of berthing events that the fender(s) is to be subjected to;
- tidal range and berth geometry where the fender(s) is to be installed;
- the design vessel(s) data, geometry and berthing criteria; and
- any other project specific data.

D.4 Information from the manufacturer of the elastomeric fender to the specifier/ user

The following information is typically provided by the manufacturer to the specifier/user:

- confirmation that the fenders meet the specification;
- confirmation of the uncorrected performance of the fender unit(s) including the associated performance curve(s);
- the applicable factors relevant to the design of the fender units, including temperature factors, angle factors and velocity factor(s);
- the applicable factor relevant to testing of the fender units, i.e. the conversion from constant velocity to decreasing velocity;
- the applicable manufacturing tolerance;
- confirmation that each fender unit has received at least one break-in compression up to its rated deflection and the associated performance curve from that break-in compression for each fender;
- the manufacturing data report (MDR), which typically includes at least the following information:
  - the project name, date and name of manufacturer;
  - a general arrangement drawing of the fender(s);
  - a record of the dimensional checks of each fender;
  - a record of the weight check of each fender;
  - a record of the temperature of the fenders during the temperature stabilization process;
  - a record of the results of the break-in compressions and the associated break-in performance curve of each fender;
  - a record of the results of the performance testing and the associated performance curves of each fender;
  - a record of the compression speed of each fender compression;
  - a record of the duration of each recovery period each fender was subject to between compression cycles;
  - a record of the physical and mechanical material test results;
  - a summary of the durability test and its results;

- a summary of the traceability tests and their results; and
- copies of all relevant test equipment calibration certificates.

D.5 Physical and mechanical property testing

For each physical and mechanical property listed in either Table 8 or Table 9, a minimum of five test samples, from each batch source, is typically prepared and tested in accordance with the relevant standard. The mean value of the five test results is taken as the test result to be compared with the specified criteria.

D.6 Performance testing

The number of fenders to be performance tested within a single production run/project is specified.

The relevant standard for undertaking performance testing of fenders units is ASTM F2192.

NOTE An updated version of BS 6349-4 is in preparation which will recommend updated procedures for performance testing of elastomeric fenders, and this will be the applicable standard once published.

D.7 Durability testing

Durability testing is not typically undertaken on production run fenders which are to be subsequently installed on maritime structures. An additional supplementary fender(s) is typically manufactured from the same compound and grade (see **16.3.1.2**), following the same manufacturing procedures for the purpose of durability testing.

The number of supplementary fenders to be durability tested within a single production run/project is specified.

Appendix A of the PIANC (2002) Working Group 33 Report [18] is the applicable procedure for undertaking durability testing of fender units.

NOTE An updated version of BS 6349-4 is in preparation which will recommend updated procedures for durability testing of elastomeric units, and this will be the applicable standard once published.

Annex E (informative)
Typical production control system for elastomeric fenders

E.1 General

NOTE 1 The following production control system has been adapted from the production control requirements for concrete set out in BS EN 206.

The manufacture of elastomeric fenders is typically subject to production control under the responsibility of the manufacturer.

Production control comprises all measures necessary to maintain the properties of the elastomer product in conformity to the specified requirements. The production control system typically includes the following non-exhaustive list of general requirements:

- the management of the production control system;
- production control procedures;

- personnel;
- selection of constituents;
- compound composition;
- storage of constituents;
- mastication;
- compound production;
- curing;
- inspections and tests;
- the use of the results from the inspections and tests on the constituents, the compounds and the fender product;
- calibration of equipment;
- design, fabrication and maintenance of moulds; and
- conformity control.

Further specific details for production control are given in the following subclauses. Where production control within a manufacturer's place of production differs from that described in this annex, the differences and justifications for such differences need to be documented.

NOTE 2 Additional requirements might be necessary for special circumstances at the place of production or for specific requirements.

E.2 Production control systems

The manufacturer is expected to have a production control system that is documented and followed.

The responsibility, authority and the interrelation of all personnel who manage, perform and verify work affecting the quality of elastomeric fenders are defined in the production control system. This particularly concerns personnel who need the organizational freedom and authority to minimize the risk of non-conforming products and to identify and record any quality problem.

The production control system is typically reviewed at least every two years by the management of the manufacturer to ensure the suitability and effectiveness of the system. Records of such reviews are typically retained for at least three years unless legal obligations require a longer period.

The production control system contains adequately documented procedures and instructions. These procedures and instructions establish the intended frequencies of tests and inspections by the manufacturer. The results of tests and inspections are recorded.

E.3 Recorded data and other documents

All relevant data from the production control are recorded. The records of the production control are typically retained for at least three years unless legal obligations require a longer period.

E.4 Production control procedures

The constituents, equipment, moulds, production procedures and elastomeric compounds are controlled with regard to their conformity with the relevant specifications and the recommendations of this part of BS 6349. The control is such that significant changes that influence the properties are detected and appropriate corrective action taken.

A procedure is in place to enable the correct delivery, storage and use of constituents, including:

- checking that the delivered material is what was ordered;
- checking that it is being stored in the correct location;
- preventing use of any materials that are clearly non-conforming;
- storing materials in a way that minimizes the risk of contamination or deterioration;
- keeping records of deliveries; and
- testing of suspect deliveries for all properties for which conformity with the relevant standard or other specification is in doubt.

If a manufacturer produces its own constituent materials, the manufacturer is regarded as a constituent materials producer, and is expected to comply with the technical aspects of the relevant international standards for producing that constituent material.

The control of equipment is expected to be such that the storage facilities, the weighing and gauging equipment, the mixers, the vulcanizers/autoclaves, and all other equipment and control apparatus are in good working condition and meet the recommendations given in this part of BS 6349.

Manufacturers are permitted to purchase pre-masticated polymers or undertake in-house mastication. Where a manufacturer purchases pre-masticated polymers, it needs to undertake procedures to verify the level of mastication prior to using the materials in fender production. Where the manufacturer undertakes in-house mastication, it is expected to implement procedures to control the level of mastication, and to undertake procedures to verify the level of mastication achieved prior to using the materials in fender production.

Manufacturers need to implement procedures to control batching and compound production, and to establish procedures to control the level of constituent dispersion achieved at each stage of batching and compound production prior to progressing to the next stage of production.

Plant, equipment, moulds and transport facilities need to be subject to a planned maintenance system and to be maintained in efficient working conditions, so that the properties and the quality of the fenders are not adversely affected.

If the specification has defined additional requirements for the fender products, the production control needs to include appropriate actions, and these actions need to be documented.

E.5 Personnel

The knowledge, training and experience of personnel involved in production and production control needs to be appropriate to the type of elastomer and the elastomeric product.

Appropriate records of the training and experience of the personnel involved in production and production control need to be maintained.

E.6 Storage of constituents

Constituents need to be stored and handled so that their properties do not change significantly, e.g. by action of climate, intermingling or contamination, and so that conformity with the respective standard is maintained.

Storage compartments need to be clearly marked in order to avoid errors in use of the constituents.

Special instructions from the suppliers of the constituents need to be taken into account.

Facilities need to be provided to enable representative samples to be taken for testing, e.g. from stockpiles, silos, racking and bins.

E.7 Mastication

Mastication of natural rubber needs to be carried out using equipment appropriate for the type/grade of rubber, the required rate of production, and the quality requirements of the compound and the fender product. Mastication needs to ensure homogeneity of the rubber and provide appropriate viscosity and plasticity for compound production.

Mastication equipment needs to be loaded such that it does not exceed its rated capacity. The rotation speed of the equipment motors and the temperature of the polymer(s) being masticated needs to be monitored and controlled during mastication.

E.8 Batching

A documented batching instruction giving details of the type and quantity of the constituents is typically available at the place of batching of the compound. Maximum tolerances on constituent quantities need to be established and recorded, and not exceeded during batching. The exact quantity of each constituent added to each batch needs to be recorded to aid the identification of non-conformities in batch to batch variations.

The batching instructions need to make clear whether each constituent material is to be batched by volume or by mass.

All equipment used to batch constituents of elastomeric compounds is typically subject to a calibration check at intervals of not more than three months.

Equipment needs to be tested, calibrated and certified over its full working range by a relevant specialist.

E.9 Compound production

The manufacturer is expected to establish the optimum sequence in which each constituent material is added to the mix, the optimum mixing time between each addition, the optimum mixing temperature and the appropriate mixing equipment for each stage of the compound production. This mixing procedure needs to be documented and is typically available at the place of mixing the compound.

Compound mixing is carried out using equipment appropriate for the compound type, the required rate of production, and the quality requirements of the compound and the fender product. Mixing needs to ensure uniform dispersion of the constituent materials.

Mixing equipment needs to be loaded such that it does not exceed its rated capacity. The rotation speed of the equipment motors and the temperature of the compound being mixed need to be monitored and controlled during mixing.

E.10 Curing

The manufacturer needs to establish the optimum curing procedures for each fender type and compound allowing for batch to batch variations. The curing procedures need to establish the appropriate equipment and optimum pressure, time and temperature for curing. The curing procedures are documented and are typically available at the place of curing.

Curing needs to be carried out using equipment appropriate for the compound type, the size of the fender, and the quality requirements of the compound and the fender product. Curing is carried out to enable vulcanization of the elastomer compound and adequate bonding of the compound to the integral reinforcing plates.

Curing equipment needs to be used such that it does not exceed its rated range (temperature, pressure, volume of compound). The variation in pressure and temperature applied to the compound during curing needs to be continuously monitored and recorded. The duration that each pressure and/or temperature step that is applied to the compound also needs to be monitored and recorded.

E.11 Moulds

Moulds used for manufacturing fenders need to be designed, fabricated and constructed to national or international standards. They need to be suitable for repeated use over the high temperature and high pressure ranges imposed by elastomeric fender manufacture.

Moulds need to be suitably rigid so as not to deflect significantly under pressure, heat or load, to enable the elastomeric fenders to be constructed to accurate dimensional and geometrical tolerances.

Moulds typically include fastenings designed to withstand the internal pressure of the compound during vulcanization, or are designed to receive bearing loads from a mechanical press.

The moulds need to be easily maintained and repaired. The manufacturer typically implements an inspection and maintenance regime to enable the moulds to be maintained in efficient working condition, so that the properties and the quality of the fenders are not adversely affected.

Where a manufacturer's production method requires the lifting of moulds and/or the lifting of mould components, the moulds or mould components typically have specifically designed lifting points. The lifting points are designed, fabricated and tested in accordance with the relevant national standard, and are designed to avoid bending, warping or excessive deflection of the mould or mould component during lifting.

E.12 Testing

Testing equipment needs to be used such that it does not exceed its rated range. The test equipment needs to be in calibration at the time of testing, and the manufacturer typically operates a calibration programme.

E.13 Conformity control

*COMMENTARY ON **E.13***

Conformity control comprises the combination of actions and decisions to be taken in accordance with conformity rules adopted in advance to check the conformity of the compound and the product with the specification.

The manufacturer is expected to establish, document and follow a conformity control plan, which typically includes:

- a sampling and testing plan;
- the methods of testing;
- the conformity criteria; and
- actions to be taken in the event of non-conformity.

NOTE The manufacturer is responsible for the evaluation of conformity to their own conformity control plan. The tests and inspections required by the manufacturer's conformity control plan are separate to the tests and inspections which might be required by the specifier.

E.14 Assessment, surveillance and certification of production control

Where it is required by the specifier that the manufacturer's production control be assessed and inspected by an accredited inspection body and then certified by an accredited certification body, the processes given in BS EN 206:2013+A1, Annex C are suitable for use, with the following amendments:

- where BS EN 206:2013+A1, Annex C refers to the producer, this is to be read as the fender manufacturer;
- where BS EN 206:2013+A1, Annex C refers to concrete, this is to be read as the elastomeric compound;
- where BS EN 206:2013+A1, Annex C refers to BS EN 206:2013+A1, Clause **9**, this is to be read as BS 6349-1-4:2021, Annex E;
- where BS EN 206:2013+A1, Annex C refers to testing of concrete for strength, water/cement ratio, etc. these tests need to be replaced with the testing undertaken by the fender manufacturer necessary for production control in the manufacturing of elastomeric fenders.

Where a manufacturer has multiple manufacturing facilities, or subcontracts the manufacture of fenders, each individual facility is expected to hold its own accreditation.

Annex F (informative) Uses of bituminous materials

F.1 General

The choice of the various materials available for different maritime protection works is summarized in Table F.1.

F.2 Revetments for dykes, closure dams, dunes and sea walls

Asphaltic concrete and sand mastic grouted stones are extensively used for dykes, closure dams, dunes and sea walls; asphaltic concrete mainly for sealing and for protection against heavy wave attack, and in those cases where a heavy layer is needed to withstand uplift pressures.

The problem of uplift pressures is one of the main reasons for asphaltic concrete seldom being used below the high water level, the thickness required in some cases normally being uneconomic.

F.3 Underwater seabed protection

Sand mastic in the form of a carpet is suitable material for the protection of sandy seabeds. In general, waves do not play a significant role in the loading conditions. Uplift pressures can develop when the carpet is applied in a closure gap of an estuary or sea arm.

Table F.1 — *Possible uses of bituminous materials in maritime protection works*

Types of bituminous materials	Dykes and closure dams	Dune protection and sea walls	Protection of seabed	Groynes	Breakwaters	Sills in closure gaps
Asphaltic concrete	Revetment above high-water level	Revetment above high-water level	Aprons placed in the dry	Special cases (capping)	—	—
Sand mastic grouting	Grouting of stone revetment	Grouting of stone revetment	—	Revet-ment and capping Grouting up stone	Moderate-ly attacked revetment only	Heavily attacked sill
Sand mastic carpet (placed in situ)	Toe protection	Toe protection	Plain or stone weighted or stone roughened	Toe protection	Toe protection	—
Prefabricat-ed mattresses	Toe protection Revetment	Toe protection Revetment	Special cases	Toe protection	Toe protection	—
Open stone asphalt	Revetment	Revetment either direct or by grouting of heavy rubble	Only as prefabri-cated mattresses	Revetment either direct or by grouting of heavy rubble	Grouting of heavy rubble	—
Dense stone asphalt	—	Revetment	—	Revetment	Revetment	—
Lean sand asphalt	Core, fill, filter layer	Core, fill, filter layer	—	Core	Special cases (core) filter layer	Core

F.4 Groynes and breakwaters

These structures are frequently the subject of heavy wave attack and in many cases they reach far into the open sea where the water depth can be considerable.

The cost of obtaining, transporting and placing large stones is often very high and it is therefore sometimes more economical to use smaller stone or rubble and to bind these together to form monolithic structures that have sufficient mass to resist movement and displacement by wave action.

One of the most satisfactory methods of binding stones together is to apply a grouting with a bituminous mixture. The monolithic mass thus formed is not only heavy but also flexible and can accommodate differential movement due to settlement without cracking.

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