BS 6349-1-4:2013

BSI Standards Publication

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 28 February 2013. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

Together with BS 6349-1-1, BS 6349-1-2 and BS 6349-1-3, this part of BS 6349 supersedes BS 6349-1:2000, which will be withdrawn when all four of the new subparts have been published.

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*; [1)]
- Part 1-2: *General – Code of practice for assessment of actions*; [1)]
- 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: *Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates*;
- 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

A full revision of BS 6349-1:2000 has been undertaken and the principal change is to split the document into four smaller parts:

- BS 6349-1-1: *Code of practice for planning and design for operations*;
- BS 6349-1-2: *Code of practice for assessment of actions*;
- BS 6349-1-3: *Code of practice for geotechnical design*;
- BS 6349-1-4: *Code of practice for materials*.

The principal change in respect of the materials content is that the document has been edited to be compatible with relevant Eurocodes. The concrete clause has been significantly revised to reflect current industry practice and to bring the recommendations in line with comparable British and European standards.

Subclause **4.3.3.3** is adapted from Concrete Society publication CS 163, *Guide to the design of concrete structures in the Arabian Peninsula* [1], with the kind permission of the Concrete Society.

[1)] In preparation.

Use of this document

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

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.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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.

Some elements of maritime construction, such as pavements and piling, which can utilize a variety of materials, are also included, because the special requirements of the maritime situation have a bearing on the choice of materials that are the most appropriate.

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

a) concrete;

b) structural steel and other metals;

c) piles;

d) rails;

e) pipes;

f) timber;

g) stone for armouring or protection works;

h) pavements;

i) bituminous materials.

Protective measures and treatments cover a wide range of methods that can be applied in the construction, operation and maintenance of maritime structures. Those covered in this part of BS 6349 include the following:

1) coating systems;

2) concrete protection;

3) sheathing;

4) steel wear plates;

5) wrappings;

6) cathodic protection.

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 inshore structures, and thus special attention is given to the use of durable materials to provide the specified performance and design life.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

ASTM B127, *Standard specification for nickel-copper alloy (UNS N04400) plate, sheet, and strip*

BS 11 (obsolescent), *Specification for railway rails*

BS 500 (all parts), *Mobile road construction machinery – Safety*

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*

BS 6349-1:2000, *Maritime structures – Part 1: Code of practice for general criteria*

BS 6744:2001+A2:2009, *Stainless steel bars for the reinforcement of and use in concrete – Requirements and test methods*

BS 8500-1, *Concrete – Complementary British Standard to BS EN 206-1 – Part 1: Method of specifying and guidance for the specifier* [2)]

BS 8500-2, *Concrete – Complementary British Standard to BS EN 206-1 – Part 2: Specification for constituent materials and concrete* [3)]

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

BS EN 197-1, *Cement – Part 1: Composition, specifications and conformity criteria for common cements* [4)]

BS EN 206-1:2000, *Concrete – Part 1: Specification, performance, production and conformity*

BS EN 206-9, *Concrete – Part 9: Additional rules for self-compacting concrete (SCC)*

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

BS EN 934-2, *Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling*

BS EN 1008, *Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete*

BS EN 1011-1, *Welding – Recommendations for welding of metallic materials – Part 1: General guidance for arc welding*

BS EN 1011-2, *Welding – Recommendations for welding of metallic materials – Part 2: Arc welding of ferritic steels*

BS EN 1090-2, *Execution of steel structures and aluminium structures – Technical requirements for steel 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 1097-2, *Tests for mechanical and physical properties of aggregates – Part 2: Methods for the determination of resistance to fragmentation*

BS EN 1537, *Execution of special geotechnical work – Ground anchors*

BS EN 1744-1, *Tests for chemical properties of aggregates – Part 1: Chemical analysis*

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

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

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2) This standard also gives informative references to BS 8500-1:2006+A1:2012.
3) This standard also gives an informative reference to BS 8500-2:2006.
4) This standard also gives an informative reference to BS EN 197-1:2011.

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BS EN 1993-1-8, *Eurocode 3 – Design of steel structures – Part 1-8: Design of joints*

BS EN 1993-1-10, *Eurocode 3 – Design of steel structures – Part 1-10: Material toughness and through-thickness properties*

BS EN 1993-5:2007, *Eurocode 3 – Design of steel structures – Part 5: Piling*

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

BS EN 1999-1-1:2007+A1:2009, *Eurocode 9 – Design of aluminium structures – Part 1-1: General structural rules* [5)]

BS EN 1999-1-3, *Eurocode 9 – Design of aluminium structures – Part 1-3: Structures susceptible to fatigue*

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

BS EN 10088 (all parts), *Stainless steels*

BS EN 10160, *Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)*

BS EN 10210 (all parts), *Hot finished structural hollow sections of non-alloy and fine grain steels*

BS EN 10219 (all parts), *Cold formed welded structural hollow sections of non-alloy and fine grain steels*

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 12063, *Execution of special geotechnical work – Sheet pile walls* [6)]

BS EN 12163, *Copper and copper alloys – Rod for general purposes*

BS EN 12164, *Copper and copper alloys – Rod for free machining purposes*

BS EN 12165, *Copper and copper alloys – Wrought and unwrought forging stock*

BS EN 12166, *Copper and copper alloys – Wire for general purposes*

BS EN 12167, *Copper and copper alloys – Profiles and bars for general purposes*

BS EN 12449, *Copper and copper alloys – Seamless, round tubes for general purposes*

BS EN 12513, *Founding – Abrasion resistant cast irons*

BS EN 12591, *Bitumen and bituminous binders – Specifications for paving grade bitumens*

BS EN 12620:2002+A1:2008, *Aggregates for concrete*

BS EN 12954, *Cathodic protection of buried or immersed metallic structures – General principles and application for pipelines*

BS EN 13055-1, *Lightweight aggregates – Part 1: Lightweight aggregates for concrete, mortar and grout*

BS EN 13383 (all parts), *Armourstone* [7)]

BS EN 13674 (all parts), *Railway applications – Track – Rail*

BS EN 13835, *Founding – Austenitic cast irons*

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5) This standard also gives an informative reference to all parts of the BS EN 1999 series.
6) This standard also gives an informative reference to BS EN 12063:1999.
7) This standard also gives an informative reference to BS EN 13383-1:2002.

BS EN 14216, *Cement – Composition, specifications and conformity criteria for very low heat special cements*

BS EN 14399-1, *High-strength structural bolting assemblies for preloading – Part 1: General requirements*

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

BS EN 15048-1, *Non-preloaded structural bolting assemblies – Part 1: General requirements*

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 2560, *Welding consumables – Covered electrodes for manual metal arc welding of non-alloy and fine grain steels – Classification*

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

BS EN ISO 14171, *Welding consumables – Solid wire electrodes, tubular cored electrodes and electrode/flux combinations for submerged arc welding of non alloy and fine grain steels – Classification*

BS EN ISO 14174, *Welding consumables – Fluxes for submerged arc welding and electroslag welding – Classification*

BS EN ISO 14341, *Welding consumables – Wire electrodes and weld deposits for gas shielded metal arc welding of non alloy and fine grain steels – Classification*

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 17632, *Welding consumables – Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of non-alloy and fine grain steels – Classification*

BS ISO 14656, *Epoxy powder and sealing material for the coating of steel for the reinforcement of concrete*

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

Other publications

[N1] BUILDING RESEARCH ESTABLISHMENT. *Concrete in aggressive ground*. BRE Special Digest 1. Watford: BRE, 2005.

[N2] CIRIA, CUR, CETMEF. *The rock manual – The use of rock in hydraulic engineering*. C683. 2nd edition. London: CIRIA, 2007.

3 Terms and definitions

For the purposes of this part of BS 6349, the terms and definitions given in BS 6349-1:2000 apply. [8)]

[8)] The terms and definitions in BS 6349-1:2000 are expected to form part of the new BS 6349-1-1, which is currently in preparation.

4 Concrete

*COMMENTARY ON CLAUSE **4***

This clause applies primarily to concrete structures in the UK, and caution is needed if the guidance on durability is used outside temperate climate regions, where it is advisable to seek further specialist advice for specific requirements for other climate regions. Many maritime and estuarine structures can be classed as "special structures" and demand specific requirements due to combinations of environmental loads imposed on them. For this reason it is necessary to maintain an overview of environmental conditions of exposure (such as conditions of aridity and higher or lower temperatures).

The general principles for specification, production and assessment of conformity of concrete are set out in BS EN 206-1:2000, BS 8500-1 and BS 8500-2. These standards include normative provisions for concrete in structures in a seawater environment. Designers and constructors need to be aware of these standards and of the latest published authoritative advice on the effects of sulfates, chlorides and general deterioration processes.

Further guidance on design and construction can also be found in CIRIA C674 [2].

4.1 General

The environmental conditions affecting maritime structures are usually much more severe than for land-based structures. Consequently, the specification for concrete, in terms of both materials and workmanship, should focus on the concrete being constructible and durable, as well as having structural strength. The same factors apply to design and detailing. The structural design of the elements of maritime structures should be carried out in accordance with the principles of relevant design standards, such as BS EN 1992, as is appropriate to the contract and to the application of the structure.

The environmental conditions should be researched and predicted for all stages of construction 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.

The specification of maritime concrete in the UK should conform to BS 8500-1 and BS 8500-2 as a minimum. Notwithstanding this, guidance provided in the present part of BS 6349 should be used to supplement the design of maritime structures where appropriate.

4.2 Design and construction

Several factors affect both design and construction in the maritime environment and, as a minimum, the following factors should be taken into account.

a) The work might be 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) 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.

h) 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 be avoided, as should thin cross-sections in which the cover to reinforcement is sensitive to the accuracy of steel fixing.

i) Steel reinforcement should be carefully detailed so 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.

j) 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 Report C660 [3].

NOTE 2 Further guidance on construction considerations can be found in CIRIA C674 [2].

NOTE 3 Additional information on execution of construction can be found in BS EN 13670.

4.3 Durability

4.3.1 General

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

a) Design for durability of concrete in maritime structures (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, 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. It is not prudent to produce structural design and details without parallel 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 is a fundamental part of the design process.

c) The durability of concrete is governed primarily by the pore structure of the concrete, its permeation characteristics and chemical nature. These in turn are dependent on appropriate mix design, a sufficiently low water/cement ratio and appropriate cementitious materials together with selection of cover to reinforcement appropriate to the mix and the specific cement type.

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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.

Most current design codes and standards do not state explicitly the rationale behind the provisions for specific life periods, but simply provide the prescriptive rules. For concrete maritime structures, systematic durability design methods should, where appropriate, be adopted as a basis for achieving specific required design working lives. Appropriate factors of safety should be applied to the method. In order for the design life (see BS 7543) to meet the requirements of the design working life, the former should exceed the latter by a rational margin.

In a systematic durability design method, the designer should categorize elements of the structure in relation to the severity of exposure, the performance required for the elements and the maintenance strategy to be employed. In addition to an acceptable model of the deterioration process, the designer should identify the parameters to be defined for durability failure or limit state.

The acceptable risks and the likely probability of failure should be taken into account, as these affect the design choices. From an economic and practical standpoint, the consequences of deterioration to the type of structure and the capability for repair or replacement are key considerations that should be assessed when defining a structure's design working life (see Notes 1 to 3).

NOTE 1 The phrase "design working life" is explained in BS EN 1990. The definition is similar to that for "required service life" in BS 7543.

NOTE 2 In the case of reinforcement corrosion, the definition of durability failure can include any or all of the following, leading to either the serviceability or the ultimate limit states being exceeded:

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

NOTE 3 Systematic (or explicit) design methods are developing, but are still 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 4 Guidance on enhanced protection of reinforcement is given in Annex A.

4.3.2 Deterioration processes

All concrete structures should be designed to account for the actions of chloride-induced corrosion, corrosion induced by carbonation, freeze–thaw and sulfate attack, where applicable.

Physical processes of weathering and abrasion should also be taken into account.

NOTE Annex B gives further information on the deterioration processes for concrete in a marine environment.

4.3.3 Exposure classification

*COMMENTARY ON **4.3.3***

*The various exposure condition classifications specific to the various separate deterioration mechanisms are described in BS 8500-1. In most situations and in seawater, a combination of more than one mechanism has to be taken into account. Classifications given in BS 8500-1 for chloride-induced corrosion of reinforcement are developed within **4.3.3.1** in the present part of BS 6349 to consider conditions specific to the maritime environment, including an additional class. Thus the structures that are covered by this part of BS 6349 can be often be regarded as "special structures", defined as being in more aggressive exposure conditions than those that fall within the scope of other standards, e.g. a combination of abrasion and wave loading.*

*The specific exposure conditions for maritime structures in the UK are explained in **4.3.3.1** to **4.3.3.4**. An additional exposure class (XS2/3) has been incorporated in this part of BS 6349 to include a specific maritime condition.*

4.3.3.1 Chloride ingress

*COMMENTARY ON **4.3.3.1***

The moisture state, as explained in Annex B, is critical to the processes of chloride penetration and subsequent electrochemical corrosion. The most important macro-climatic factors are temperature and rainfall, which control the rate of chemical reactions and the drying out characteristics of the cover concrete. Rainfall, humidity and the location of a member in relation to seawater level fluctuation control the wetness of the concrete and thus the mechanisms for the penetration of chlorides and of oxygen. The wetting and drying depth in a temperate climate might not exceed 20 mm.

There are four main subdivisions of macroclimate that affect chloride-induced corrosion, and the correct application of microclimate should be chosen to assess the durability category:

- cold with freezing;
- temperate;
- hot wet;
- hot dry.

There are four levels of micro-environmental classification for chloride-induced corrosion, and the correct classification should be assessed to determine the factors for the concrete specification and cover requirements:

- XS1: exposed to airborne salt but not in direct contact with seawater;
- XS2: permanently submerged;
- XS2/3: frequently wetted (e.g. mid and lower tidal zone and backfilled);
- XS3: infrequently wetted (e.g. upper tidal, splash/spray, "dry" internal faces of submerged structures).

4.3.3.2 Sulfate attack

*COMMENTARY ON **4.3.3.2***

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.

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Where sulfates are present, the appropriate cement type should be assessed in accordance with one of the following documents.

- BS EN 206-1:2000, Table 1 and Table 2 list a classification for various causes of chemical attack (XA classes) with subdivisions. This approach however is not commonly used in the UK.
- More commonly used in the UK is reference to the design sulfate class, aggressive chemical environment for concrete (ACEC) class, and design chemical class as detailed in BRE Special Digest 1 [N1], along with other considerations such as assessment of brownfield sites, the effect of magnesium, pH, hydraulic gradient and special precast items. This guidance allows the selection of appropriate cement types and limiting proportions for a given condition, and allows the use of additional protective measures (APMs) to enhance chemical resistance for the intended service life.

NOTE In addition to guidance given in BRE Special Digest 1 [N1], the selection of DC-class designated concretes for aggressive ground conditions is given in BS 8500-1:2006+A1, Table A.9. Cement type selection and limiting proportions for DC-class designed concretes are given in BS 8500-2:2006, Table 6.

4.3.3.3 Delayed ettringite formation (DEF)

(Adapted from Concrete Society publication CS 163, *Guide to the design of concrete structures in the Arabian Peninsula* [1], with the kind permission of the Concrete Society.)

*COMMENTARY ON **4.3.3.3***

Ettringite, or calcium sulphoaluminate, is 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 is believed to follow an S-shaped progression with time, with damage generally becoming serious once the expansion reaches 0.5 mm/m, typically within 5 years to 25 years after construction.

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

- high temperatures (65 °C or higher) in the concrete during curing;
- exposure to moisture in service;
- high sulfate and alkali content in the concrete mix;
- presence of pre-existing cracks (e.g. early thermal or plastic cracks).

DEF should be prevented by limiting the peak temperature achieved during the early thermal cycle and by controlling the chemistry of the cement and concrete mix.

NOTE 1 The risk may be reduced effectively by the use of cements or combinations containing ground granulated blastfurnace slag (ggbs) or fly ash in suitable proportions, which will have the combined effect of reducing the temperature rise and increasing the temperature at which DEF will occur, and by limiting the total SO_3 in the mix to <3.6% by mass of cement.

The precautions that should be taken for thick sections are:

a) use blastfurnace cement, Portland fly ash cement or equivalent combinations containing at least 50% ggbs or 25% fly ash or equivalent combinations;

b) use the highest size of aggregate practicable, e.g. 40 mm size, in order to reduce cement content and therefore reduce the heat of hydration;

c) limit the sulfate content (SO_3) of the mix, to 3.6% SO_3 to mass of cement;

d) develop a detailed method statement to control the risk of early-age thermal cracking, including estimates of peak and differential temperatures from core to surface;

e) monitor the temperature in trial pours and during the works, and limit the maximum fresh concrete placing temperatures as follows:

- fresh concrete placing temperature 30 °C;
- peak temperature 65 °C (higher peak temperatures are possible when CEMII/B, CEMIII, CEMIV or equivalent combinations are used; see BRE IP11/01 [5]);
- differential temperature: 20 °C or greater (dependent on aggregate type).

NOTE 2 Higher temperatures can be tolerated depending upon aggregate type; see CIRIA C660 [3] for further information.

4.3.3.4 Freeze–thaw

The exposure classes specific to freeze–thaw damage should be selected from the following:

- XF1: moderate water saturation without de-icing salt;
- XF2: moderate water saturation with de-icing salt;
- XF3: high water saturation without de-icing salt;
- XF4: high water saturation with de-icing salt or sea water.

Although serious freeze–thaw exposure conditions are not generally experienced by parts of structures in UK maritime waters, freeze–thaw damage is associated with either colder temperatures than are found in the sea around the UK or the application of de-icing salts. Designers need to be aware of freeze–thaw for sea conditions outside the UK and for road and approach surfaces in the UK subject to de-icing salts. In either case, appropriate guidance should be followed.

NOTE Further guidance for the design of resistance to freeze–thaw is given in BS 8500-1 and CIRIA C674 [2].

4.4 Specification for materials and workmanship

4.4.1 Cement

Cements should conform to BS EN 197-1 and combinations should be selected on the basis of their suitability from BS 8500-1. The choice of cement or combination for reinforced concrete should ensure that the appropriate composition correlates with the composition given in Table 1, Table 2 and Table 3. The cement or combination type necessary for mass (or unreinforced) concrete should be selected from Table 4.

Whether or not the design of a structure is supplemented by guidance given in this part of BS 6349, concrete in the UK should always be specified in accordance with BS 8500-1.

NOTE 1 BS EN 197-1:2011, Table 1 gives the various products in the family of cements. The various proportions of ggbs or fly ash that are given in this table are not necessarily in line with the percentages given in Table 1, Table 2 and Table 3 of the present part of BS 6349, and it is necessary for the engineer to ensure that the specific make-up of the cement is known.

NOTE 2 Not all the cement combinations listed in BS EN 197-1 are applicable for maritime concrete, e.g. CEM III/C.

Where Portland cement (CEM I) alone is used in UK waters, a maximum of 10% C_3A, when determined by the Bogue method, is recommended. The C_3A should be not less than 5% for reinforced concrete in order to reduce the risk of attack of steel reinforcement by chlorides.

NOTE 3 One of the most expedient methods to combine sulfate resistance with chloride resistance is to use CEM II/B, CEM III/A, IIIB or IV/B-V or combinations of CEM I with at least 21% fly ash or 35% ground granulated blastfurnace slag (ggbs). Higher levels of addition (e.g. 25% to 40% fly ash or 66% to 80% ggbs) produce significantly reduced rates of chloride ingress. The choice of fly ash or ggbs content depends on both climatic and site conditions, e.g. the lower range of replacement proportions is suitable for slender members and/or colder climatic conditions if early set and strength is required by construction logistics.

NOTE 4 Silica fume can also be beneficial when added to Portland cement in doses up to 10% of the total cementitious content, or 5% in conjunction with fly ash or ggbs and Portland cement (i.e. ternary blends). See Concrete Society publications CS 163 [1] and Technical Report 41 [6].

NOTE 5 Cover to reinforcement is dependent upon cement/combination type and w/c ratio, as set out in Table 1, Table 2 and Table 3.

NOTE 6 Concrete made with cements and combinations containing fly ash and ggbs and aggregates with low coefficients of thermal expansion will reduce free strain in thick sections and thus the risk of early thermal cracking is also reduced. Guidance for the control of early thermal cracking can be found in CIRIA C660 [3], which details considerations such as materials selection and mix design, good construction practice and crack control reinforcement design.

4.4.2 Concrete cover

For reinforced concrete, limiting values, cement composition and cover to reinforcement for 30-year, 50-year and 100-year design working lives should either be derived by systematic durability design methods, or conform to the prescriptive limits given in Table 1, Table 2 and Table 3.

When assessing the minimum cover for prestressing strand, an additional 10 mm should be added to the figures given in Table 1, Table 2 and Table 3.

Table 1 Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 30 years *(1 of 2)*

Compressive strength class [A)], maximum water/cement ratio [B), C)] and minimum cement or combination content (kg/m^3) [D)]											Permissible cement and combination designations with additional restrictions (where appropriate)
Nominal cover, in millimetres [E), F)]											
30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	55 + Δc	60 + Δc	65 + Δc	70 + Δc	75 + Δc	80 + Δc	
XS1 – Airborne salt environment – exposed to airborne salt but not in contact with seawater or splash											
C28/35 0.50 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA IIIB IIB-V+SR (25% to 35% fly ash) [G)] IVB-V IIB-V with 21% to 24% fly ash [G)]
—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	CEM I CEM II/A-L(LL), II/A, II/B-S
XS2 – Submerged environment – permanently submerged											
C32/40 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 56% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G)]
C35/45 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 55% ggbs IVB-V
C40/50 0.40 360	C35/45 0.45 360	C32/40 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash [G)]
—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	CEM I CEM II/A-L(LL), II/A, II/B-S
XS2/3 – Frequently wetted lower tidal, backfilled											
C40/50 0.35 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G)] IVB-V
—	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash [G)]
—	—	—	—	—	C40/50 0.35 360	C35/45 0.40 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.45 360	C25/30 0.50 360	CEM I CEM II/A-L(LL), II/A, II/B-S

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Table 1 **Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 30 years** *(2 of 2)*

Compressive strength class A), maximum water/cement ratio B), C) and minimum cement or combination content (kg/m³) D)											**Permissible cement and combination designations with additional restrictions (where appropriate)**
Nominal cover, in millimetres E), F)											
30 + Δc	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	**55 + Δc**	**60 + Δc**	**65 + Δc**	**70 + Δc**	**75 + Δc**	**80 + Δc**	
XS3 – Infrequently wetted upper tidal, splash/spray, "dry" internal faces of submerged structures											
—	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C28/35 0.55 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 56% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) G)
—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 55% ggbs IVB-V
—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash G)
—	—	—	—	—	—	C40/50 0.35 360	C35/45 0.35 360	C35/45 0.40 360	C35/45 0.45 360	C32/40 0.45 360	CEM I CEM II/A-L(LL), II/A, II/B-S

A) Characteristic strength class: cylinder/cube (MPa). Lightweight aggregate concrete should conform to the equivalent strength classes.

B) Maximum free water/cement ratio in accordance with BS EN 206-1:2000.

C) Where there is difficulty in conforming to the strength required at 28 days because of the characteristics of the cement type or the combination then, provided that a systematic regime of checking is established to ensure conformity to the free water/cement ratio recommendation, the 28 day strength recommendation may be relaxed.

D) Minimum cement content depends on maximum aggregate size (see Notes on Table 1, Table 2 and Table 3).

E) Expressed as the minimum cover to reinforcement plus an allowance for deviation, Δc, to allow for workmanship and tolerance. An additional 10 mm should be allowed for prestressing strand.

F) A dash (—) signifies that greater cover is recommended.

G) The designation of cement type CEM IIB-V is deemed to contain 21% to 24% fly ash for the purposes of this table. The designation of IIB-V+SR contains 25% to 35% fly ash and is thus equivalent to a CEM IIB-V containing 25% to 35% fly ash as specified in BS EN 197-1.

Table 2 **Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 50 years** *(1 of 2)*

Compressive strength class [A], maximum water/cement ratio [B), C] and minimum cement or combination content (kg/m³) [D]											**Permissible cement and combination designations with additional restrictions (where appropriate)**
Nominal cover, in millimetres [E), F]											
30 + Δc	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	**55 + Δc**	**60 + Δc**	**65 + Δc**	**70 + Δc**	**75 + Δc**	**80 + Δc**	
XS1 – Airborne salt environment – exposed to airborne salt but not in contact with seawater or splash											
C35/45 0.40 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G] IVB-V
C40/50 0.35 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIB-V with 21% to 24% fly ash [G]
—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	CEM I CEM II/A-L(LL), II/A, II/B-S
XS2 – Submerged environment – permanently submerged											
—	C40/50 0.35 360	C35/45 0.45 360	C32/40 0.50 360	C28/35 0.55 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G] IVB-V
—	—	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash [G]
—	—	—	—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.40 360	C32/40 0.45 360	C28/35 0.50 360	CEM I CEM II/A-L(LL), II/A, II/B-S
XS2/3 – Frequently wetted lower tidal, backfilled											
—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G]
—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash [G]
—	—	—	—	—	—	—	—	C40/50 0.35 360	C35/45 0.40 360	C35/45 0.40 360	CEM I CEM II/A-L(LL), II/A, II/B-S

Table 2 **Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 50 years** *(2 of 2)*

Compressive strength class A), maximum water/cement ratio B), C) and minimum cement or combination content (kg/m³) D)											**Permissible cement and combination designations with additional restrictions (where appropriate)**
Nominal cover, in millimetres E), F)											
30 + Δc	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	**55 + Δc**	**60 + Δc**	**65 + Δc**	**70 + Δc**	**75 + Δc**	**80 + Δc**	
XS3 – Infrequently wetted upper tidal, splash/spray, "dry" internal faces of submerged structures											
—	—	—	C40/50 0.35 380	C35/45 0.45 360	C32/40 0.50 360	C28/35 0.55 340	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB with >66% ggbs IIB-V+SR (25% to 35% fly ash) G)
—	—	—	—	C40/50 0.35 380	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C25/30 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash G)
—	—	—	—	—	—	—	—	—	—	C40/50 0.35 360	CEM I CEM II/A-L(LL), II/A, II/B-S

A) Characteristic strength class: cylinder/cube (MPa). Lightweight aggregate concrete should conform to the equivalent strength classes.

B) Maximum free water/cement ratio in accordance with BS EN 206-1:2000.

C) Where there is difficulty in conforming to the strength required at 28 days because of the characteristics of the cement type or the combination then, provided that a systematic regime of checking is established to ensure conformity to the free water/cement ratio recommendation, the 28 day strength recommendation may be relaxed.

D) Minimum cement content depends on maximum aggregate size (see Notes on Table 1, Table 2 and Table 3).

E) Expressed as the minimum cover to reinforcement plus an allowance for deviation, Δc, to allow for workmanship and tolerance. An additional 10 mm should be allowed for prestressing strand.

F) A dash (—) signifies that greater cover is recommended.

G) The designation of cement type CEM IIB-V is deemed to contain 21% to 24% fly ash for the purposes of this table. The designation of IIB-V+SR contains 25% to 35% fly ash and is thus equivalent to a CEM IIB-V containing 25% to 35% fly ash as specified in BS EN 197-1.

Table 3 **Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 100 years** *(1 of 2)*

Compressive strength class [A)], maximum water/cement ratio [B), C)] and minimum cement or combination content (kg/m³) [D)]											Permissible cement and combination designations with additional restrictions (where appropriate)
Nominal cover, in millimetres [E), F)]											
30 + Δc	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	**55 + Δc**	**60 + Δc**	**65 + Δc**	**70 + Δc**	**75 + Δc**	**80 + Δc**	
XS1 – Airborne salt environment – exposed to airborne salt but not in contact with seawater or splash											
—	—	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G)] IVB-V
—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIV-B with 21% to 24% fly ash [G)]
—	—	—	—	—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	CEM I CEM II/A-L(LL), II/A, II/B-S
XS2 – Submerged environment – permanently submerged											
—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	C20/25 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G)] IVB-V
—	—	—	—	C40/50 0.35 360	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	IIIA with 36% to 45% ggbs IIV-B with 21% to 24% fly ash [G)]
XS2/3 – Frequently wetted lower tidal, backfilled											
—	—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 360	C25/30 0.55 340	C20/25 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) [G)] IVB-V
—	—	—	—	—	—	C40/50 0.35 380	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	C28/35 0.50 360	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash [G)]

Table 3 **Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 100 years** *(2 of 2)*

Compressive strength class A), maximum water/cement ratio B), C) and minimum cement or combination content (kg/m³) D)											**Permissible cement and combination designations with additional restrictions (where appropriate)**
Nominal cover, in millimetres E), F)											
30 + Δc	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	**55 + Δc**	**60 + Δc**	**65 + Δc**	**70 + Δc**	**75 + Δc**	**80 + Δc**	
XS3 – Infrequently wetted upper tidal, splash/spray, "dry" internal faces of submerged structures											
—	—	—	—	—	—	C40/50 0.35 380	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.55 360	C25/30 0.55 340	IIIA with 46% to 65% ggbs IIIB IIB-V+SR (25% to 35% fly ash) G) IVB-V
—	—	—	—	—	—	—	C40/50 0.35 380	C35/45 0.40 360	C32/40 0.45 360	C28/35 0.50 360	IIIA with 36% to 45% ggbs IIB-V with 21% to 24% fly ash G)

A) Characteristic strength class: cylinder/cube (MPa). Lightweight aggregate concrete should conform to the equivalent strength classes.

B) Maximum free water/cement ratio in accordance with BS EN 206-1:2000.

C) Where there is difficulty in conforming to the strength required at 28 days because of the characteristics of the cement type or the combination then, provided that a systematic regime of checking is established to ensure conformity to the free water/cement ratio recommendation, the 28 day strength recommendation may be relaxed.

D) Minimum cement content depends on maximum aggregate size (see Notes on Table 1, Table 2 and Table 3).

E) Expressed as the minimum cover to reinforcement plus an allowance for deviation, Δc, to allow for workmanship and tolerance. An additional 10 mm should be allowed for prestressing strand.

F) A dash (—) signifies that greater cover is recommended.

G) The designation of cement type CEM IIB-V is deemed to contain 21% to 24% fly ash for the purposes of this table. The designation of IIB-V+SR contains 25% to 35% fly ash and is thus equivalent to a CEM IIB-V containing 25% to 35% fly ash as specified in BS EN 197-1.

NOTES ON TABLE 1, TABLE 2 AND TABLE 3

Table 1, Table 2 and Table 3 are based on 20 mm maximum aggregate size. Refer to BS 8500-1:2006+A1, Table A.7 for minimum cement contents for aggregate sizes other than 20 mm.

The tables provide rationalized durability recommendations with respect to the type of cement used, its performance and the application for which the concrete will be used.

Improved resistance to chloride ingress and reinforcement corrosion is afforded by the use of cements containing fly ash or ggbs or the use of Type II additions in combination with CEM I. It also follows that increasing the level of second main constituents or Type II addition in a combination increases this resistance to an optimum value.

BS 8500-1 and BS EN 197-1 give the overall cement and combination classifications. However, not all are applicable for maritime concrete. The most commonly selected cement types and compositions are given in the tables.

Table 1, Table 2 and Table 3 are considered to provide more reliable and sustainable concretes with regard to the durability of marine works than the classifications given in BS EN 206-1:2000 and BS 8500-1, as these tables focus on restrictions to cement and combination designations that are sometimes too broad to allow for the most durable concretes.

CEM I concretes previously have been over-specified in aggressive environments, and the levels of second main constituents or Type II additions within these classifications in these earlier standards do not always follow a logical progression in terms of durability.

The computer modelling used to derive these tables comprises a comprehensive assessment of concretes of different quality with varying levels of ggbs and fly ash. The modelling assumes the benefits that ggbs and fly ash provide for resistance to chlorides, up to well established optimum levels of combinations.

Modelling was carried out using established solutions to Ficks laws of diffusion. Chloride diffusion coefficients were estimated on the basis of their relationship with the water/cement ratio of the concrete, and adjusted by the level of cement or combination type in accordance with guidance provided in Concrete Society Technical Report 61 [4].

Modelling was undertaken for 30-year, 50-year and 100-year service lives.

The modelling undertaken comprised over 4 000 individual modelling cases. The serviceability limit state used in the modelling was to initiation of reinforcement corrosion.

Each result (i.e. the time to initiation of corrosion) was categorized into each load case (i.e. exposure condition) to assess each concrete type against a given exposure.

The outcome of the analysis provides minimum cover values for different concrete types based on the four environmental classes. Nominal values for construction are derived by adding an allowance in design deviation to the minimum values (default 15 mm for cast in situ construction, 10 mm for precast construction).

Minimum concrete cover values are given for concretes that contain different types and levels of fly ash or ggbs to provide equivalent levels of durability.

The findings of the analysis show two key observations.

The first observation is that CEM I concretes are limited to relatively low exposure conditions only, in recognition that CEM I concretes are less resistant to chloride ingress than concretes containing ggbs or fly ash. In addition, they are often less sustainable, containing a higher embodied carbon content than concretes containing cements or combinations with high proportions of ggbs or fly ash.

The second observation is that increasing durability is provided with increasing ggbs and fly ash up to an optimum limit. The more durable concretes in the more aggressive environments contain 55% to 70% ggbs or 30% to 35% fly ash.

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 available for a known minimum cover.

4.4.3 Plain and mass concrete

Plain (unreinforced) concrete and mass concrete (defined as massive concrete sections either unreinforced or reinforced) are used in numerous applications and require minimum standards of quality to ensure long-term durability. The limiting values for these concretes should be in accordance with Table 4 for all environments (abrasive and non-abrasive).

NOTE Reinforced concrete in abrasive conditions can be specified using a combination of Table 1, Table 2, Table 3 and Table 4.

Table 4 **Limiting values for composition and properties of plain or mass (unreinforced) concrete with normal weight aggregates of 20 mm nominal maximum size exposed to UK seawater conditions for a required design working life up to 100 years** A)

Inter-tidal, tidal submerged, splash	**Limiting values**	
	Non-abrasive	**Abrasive** B)
Min. strength class cylinder/cube (MPa) C)	C25/30	C40/50
Max. w/c ratio D)	0.55	0.45
Min. cement content/combination (kg/m^3) C)	320	350
Permitted cements and combinations E)	BS EN 197-1, BS EN 14216 CEM I, IIA, IIIA, IIIB, II/B-S, II/B-V, IIB-V+SR, IVB-V	
Additional (optional) measures	N/A	Steel fibres
	N/A	Abrasion resistant aggregate (Los Angeles Abrasion <30 (LA$_{30}$) to BS EN 1097-2/BS EN 12620:2002+A1)
	N/A	IIA-D cement
	N/A	Controlled permeability formwork

A) Minimum cement content depends on maximum aggregate size (see BS 8500-1:2006+A1, Table A.7). Water/cement ratio limits are the ruling parameters over minimum strength class and minimum cement content.

B) Abrasion is defined as locations subject to aggressive wave action, cavitations, and beach sediments. (See CIRIA C674 [2] for further information.)

C) Where there is difficulty in conforming to the strength recommendations at 28 days, because of the characteristics of the cement type or combination, then, provided that a systematic regime of checking is established to ensure conformity to the free water/cement ratio and cement content recommendations, the 28-day strength recommendations may be relaxed. However, this relaxation is permitted only if the specified compressive strength on the concrete is not a structural requirement. A similar relaxation may be applied in the case of abrasion, provided the concrete mix is expected to meet the strength requirement within an agreed period.

D) Maximum free water/cement ratio, in accordance with BS EN 206-1:2000.

E) For thick concrete sections (typically, but not limited to, >600 mm thickness), cement types should be specified that ensure the effects of heat of hydration are controlled. Normally, increased proportions of ggbs or fly ash may be used to mitigate risks of early thermal cracking for these elements. CIRIA C660 [3] provides further guidance.

4.4.4 Aggregates

Aggregates should conform to BS EN 12620:2002+A1, or BS EN 13055-1 for lightweight aggregates. As a bulk materials resource, it might be necessary to make the best use of locally available and/or recycled materials of varying standards. In that case, studies of petrography, appropriate physical and chemical tests and trial mixes should be made.

NOTE 1 The quality of aggregates has a lesser impact on the strength of concrete than is often supposed (other than effects of water demand, which might affect the water/cement ratio), but it does affect resistance to abrasion, freeze–thaw and surface weathering.

Where aggregates resistant to freezing and thaw are required then BS EN 12620:2002+A1, Class M_{18} should be specified.

*NOTE 2 For guidance on the use of the water absorption test as a screening test for assessing freeze–thaw resistance of aggregates, see BS EN 12620:2002+A1, **F.2.3**.*

The water soluble chloride ion content (see BS EN 1744-1) and testing frequency should conform to BS EN 12620:2002+A1. This is subject to the overriding limits of chloride ion in the concrete as cast, as given in Table 5 of the present part of BS 6349 (see **4.4.7**).

Chloride ion limits should be taken into account for both corrosion of reinforcement and their contribution to the alkali level, as they affect alkali–aggregate reactivity.

If severe abrasion of the concrete by pebbles or sand is expected, the coarse aggregate should be at least as hard as the material causing the abrasion, and the fines aggregate of the mix should be kept as low as is compatible with appropriate mix design. Abrasion resistance should be expressed as Los Angeles abrasion in accordance with BS EN 12620:2002+A1, and should be no greater than LA_{30} to provide adequate resistance.

NOTE 3 If there is an aggregate available with a documented history of satisfactory performance in marine structures then it may be considered to be suitable, even without wear resistance testing. Alternative means of measuring abrasion are available, e.g. the performance measured using the micro-Deval test procedure may be considered to be appropriate.

4.4.5 Water

Water should be free from harmful matter. Where tests are required, these should be as described in BS EN 1008. Seawater should not be used in reinforced concrete.

NOTE Seawater may be used in unreinforced concrete, although this increases the alkali content and risk of alkali–aggregate reaction, and also accelerates set and enhances the risk of early thermal cracking.

4.4.6 Admixtures

Admixtures should conform to BS EN 934-2. The use of appropriate admixtures should be encouraged to achieve the required consistence for placing at the lowest water/cement ratio and unit water content as necessary for the mix to resist the exposure conditions. Other, proven admixtures for specialist and underwater concrete may be used. Admixtures containing chlorides should not be used.

The use of air-entraining admixtures should be considered for the splash and inter-tidal zone and for any part of the structure that might be subject to freezing and thawing when in a saturated condition, although serious freeze–thaw exposure conditions are not usual in UK waters. Design for freeze–thaw conditions should be considered for pavement surfaces, especially those that are subject to the application of de-icing salts (see **4.3.3.4**).

NOTE 1 Controlling the required amount of air is often difficult in stronger mixes where the cement content is of the order of 400 kg/m³ and above. In this case, resistance to freeze–thaw in UK conditions may be obtained with more confidence by the use of richer non-air-entrained mixes. Air entrainment does not enhance resistance to chlorides.

NOTE 2 Cement-rich non-air-entrained concrete does not always provide the same freeze–thaw resistance as properly air-entrained concrete.

4.4.7 Hardened concrete

The minimum requirements for the strength of concrete in the hardened state should be determined from the limit state requirements of BS EN 1992-1.

NOTE 1 The requirements for achieving durability usually outweigh structural considerations of strength. For each cement type, higher strength concretes (i.e. with a lower water/cement ratio) normally have a higher durability than lower strength concretes. Provided that the concrete is of a quality that is adequate to resist the degree of exposure to chemical attack, freeze–thaw and abrasion, a trade-off can be made between concrete quality and cover to provide appropriate resistance to corrosion of reinforcement. Selection of cover to reinforcement depends on concrete quality and cement chemistry.

Procedures for testing for conformity and identity testing should conform to BS 8500-1.

NOTE 2 The strength and closed pore structure required for durability are primarily controlled by the water/cement ratio. The cement content of a mix is a secondary consequence of the water demand for a given set of materials, i.e. it is the product of the water demand required for consistence divided by the designed water/cement ratio. The water demand of a mix depends upon the size and grading of aggregate and of the fines content, and it can be reduced by the use of admixtures. Cement content can also be reduced by increasing the aggregate size and/or reducing the fines content. Excessive cement contents exacerbate the risks of early age thermal cracking and alkali–aggregate reactivity and, even at equal water/cement ratios, involve higher unit water contents that increase moisture movement and air and water permeability and decrease freeze–thaw resistance. Nevertheless, for concrete in maritime conditions, it is prudent to specify a minimum cement content, as well as the maximum water/cement ratio, in order to guarantee an appropriate volume and richness of cement paste for chloride binding and chemical resistance.

In the specific cases of concrete exposed to seawater in the UK, unreinforced concrete mixes for design working lives up to 100 years should conform to the limits given in Table 4.

Chloride limits given for mix constituents are subject to the overriding limits for the designed mix, which should be confirmed by measurement on the hardened concrete.

The chloride ion content (percentage by mass of cement or combination), as calculated by the procedure given in BS 8500-2 from the constituents, should not exceed the limits given in Table 5.

Table 5 **Chloride content class of concrete for maritime structures**

Concrete type	Chloride ion % by mass of cement
Prestressed and heat-cured in contact with concrete	0.10% (Cl 0.10)
Containing steel reinforcement or other embedded metal	0.20% (Cl 0.20)
Plain (unreinforced) concrete	0.50% (Cl 0.50)

For tests on hardened concrete (e.g. BS 1881-124), the limits of chloride ion content (prior to exposure to seawater) should not exceed those given in Table 6.

Table 6 **Total chloride ion content of hardened concrete**

Concrete type	Limit of 95% of results	No results more than
Prestressed and heat-cured in contact with concrete	0.10%	0.15%
Containing steel reinforcement or other embedded metal	0.20%	0.25%
Plain (unreinforced) concrete	0.50%	0.65%

4.4.8 Steel reinforcement

Black, uncoated, steel reinforcement should conform to BS 4449, BS 4482 and BS 4483.

Cutting and bending of reinforcement should conform to BS 8666. Measures should be taken to ensure that reinforcement is maintained free from salt deposits in transit, in storage and during fixing.

Where, during the construction process, exposed reinforcement is immersed in seawater, it should be checked for salt contamination and pitting corrosion other than surface rusting, and cleaned if necessary.

Stainless steel reinforcement should be grade 1.4301 austenitic steel in accordance with BS 6744:2001+A2.

Fusion-bonded epoxy coated reinforcement should conform to BS ISO 14656.

NOTE The use of fusion-bonded epoxy coating needs careful consideration. Normally it is used when cover needs to be restricted or protection from damage from de-icing salts is required. The construction procedure can ensure that the surface of the bar prior to and during concreting remains undamaged, as accelerated local corrosion could occur at points where the surface has been chipped or cracked.

4.4.9 Prestressing tendons, sheathing and grouting

The use of prestressing steels, sheathing and grouts, and procedures to be followed when storing, making up, positioning, tensioning and grouting tendons, should be in accordance with BS EN 1992-1.

4.4.10 Cover to reinforcement

Cover to reinforcement refers to 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 required cover to reinforcement for a specific exposure condition and a specific design working life is dependent upon:

- the quality of the concrete as determined by the water/cement ratio;
- the cement or combination type.

The nominal cover (i.e. the figure used in the design and detailing and shown on the drawings for construction) should be the minimum cover value (either calculated by an explicit durability method or from the tables herein) together with an allowance for deviation, Δc.

NOTE 1 For Δc as described here and in BS 8500, see Δ_{dev} in BS EN 1992-1-1.

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NOTE 2 There are two recommended methods for calculating the minimum cover (before addition of tolerance or placing allowance) to minimize the risk of corrosion to reinforcement for a 30-year, 50-year or 100-year minimum design working life. The first is an analytical method and the second is to select according to the exposure conditions, type of cement and maximum water/cement ratio, as given in Table 1, Table 2 and Table 3. The information given in these tables is suitable for use in initial design, as a check on analytical methods or to provide prescriptive values.

The required tolerance (i.e. allowance in design for deviation) ranges from between ±10 mm and ±15 mm for normal in-situ construction, to between ±5 mm and ±10 mm for more precise or factory-controlled work. Tolerances of ±5 mm and below should be used only when conformity is demonstrated by trials and quality control procedures. Where problems exist, e.g. difficulties of access, visibility, or opportunity for inspection and maintenance, cover should be increased. Increased cover is required in particularly vulnerable positions, e.g. horizontal surface tops. Cover tolerance to piles or for ground-bearing members should be increased to at least 50 mm to accommodate the greater difficulty in fixing reinforcement in these elements.

Increased cover might conflict with a requirement to control the size and spacing of flexural cracks. In maritime conditions, however, the requirement for cover usually governs, and cover should not be reduced in order to control flexural crack widths. Any limiting values should rather be increased pro rata to the greater cover, as allowed by expressions that relate acceptable flexural crack widths to a proportion of the cover thickness. It is not necessary to sum the effects of early thermal and flexural cracking.

4.4.11 Curing

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 be too difficult to carry out.

Curing is an important aspect of the construction phase and should be well planned in advance of construction.

Saline water should not be used for curing reinforced concrete.

Concrete should be cured for a period not less than those shown in Table 7 when the mean ambient temperature is 15 °C or greater. The curing methods should ensure that cracking, distortion and efflorescence are minimized.

Table 7 **Minimum curing periods for different cement types in ambient temperatures at or above 15 °C**

Cement or combination type	Minimum period (days)
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

NOTE 1 Where the mean ambient temperature is below 15 °C, the curing period can be calculated using the following equation:

$$\text{curing period} = \text{min. period} \times \left(\frac{36}{\text{mean ambient temperature} + 16} \right)^2 \text{days}$$

During the curing period, measures should be taken to prevent the loss of moisture and to minimize thermal stresses caused by the difference in temperature between the surface of the concrete and the core of the concrete mass, and to promote sustained hydration of the concrete. Well-executed wet curing should be carried out on critical structures where practical, although indiscriminate wet curing with cold water and/or the premature removal of formwork can lead to thermal shock.

NOTE 2 Attention is drawn to the necessity for thorough and continuous curing, particularly in the case of concrete containing fly ash or ggbs.

NOTE 3 In dry conditions, water loss from the surface can result in incomplete curing and poor surface properties. Where wet curing is not possible, high-efficiency spray-applied curing membranes can be used as long as they can be protected from removal by the marine environment.

NOTE 4 For formed surfaces it is advisable to leave forms in place as long as is feasible. Controlled permeability formwork can be used, as it also densifies the surface and reduces locally high water/cement ratios.

NOTE 5 As a related topic, excess bleeding can result in an excessive water/cement ratio at the top surface, whereas some bleeding can be beneficial in avoiding desiccation and plastic cracking. Bleeding performance needs to be checked in concretes containing ggbs.

4.4.12 Underwater concrete

*COMMENTARY ON **4.4.12***

Underwater concreting can be carried out in situ by placing conventionally mixed fresh concrete by the methods listed here or by the process of pumping cement grout into previously placed aggregate.

Guidance on developments in underwater concreting is given in Concrete Society Technical Report 35 [7].

The principal methods of placing fresh concrete under water are:

a) 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;

b) 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;

c) by introducing admixtures and/or additives that give enhanced cohesive, self-levelling and self-compacting properties. These methods are suitable for reinforced sections;

d) 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, while bearing in mind that 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 8500-1:2006+A1).

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 206-9.

NOTE Guidance on slump flow can be found in EFNARC publication Specifications and guidelines for self-compacting concrete *[8].*

c) Concrete can be placed underwater as precast units and used either as structural units or as permanent shuttering for freshly placed concrete underwater.

d) Patented processes are usually employed for the grouted aggregate method of placing underwater concrete, where the forms are first filled with coarse aggregate and then grouted by sand–cement grout with colloidal characteristics being injected to fill the voids completely. Portland cement grouts are normally used, together with fly ash or ggbs to improve the fluidity of the grout. Admixtures are often used.

5 Structural steel and other metals

*COMMENTARY ON CLAUSE **5***

*The most commonly used metals in maritime structures are weldable structural steels (see **5.2**). Other metals that are sometimes used in maritime structures, usually for special reasons, are copper alloy steels, stainless steels, cast steels, cast irons, wrought irons, brasses, bronzes, aluminium alloys and copper nickel alloys (see **5.4**).*

All metals suffer more from corrosion in a maritime environment than inland. This is mainly due to:

a) the formation of galvanic cells, with anodes and cathodes being formed between different metals (e.g. with weld metal), or within the one material due to varying conditions (e.g. differential aeration), or because of the presence of strong currents and the solution of salts in the seawater acting as the electrolyte, particularly in the splash zone;

b) the steady erosion of the corrosion products, such as rust in the case of structural steels, by wave action and cyclic deflections, especially if the structure is designed to absorb energy by deflection;

c) the inadequacy of planned preventative measures and/or maintenance by owners.

The need to control corrosion and to predict losses of metal due to corrosion plays a major part in the selection of the most suitable metal. As an example of this, it might be preferable to provide grade S 355 steel designed at the stress levels appropriate for grade S 270 steel. This yields a thicker section with a greater allowance for corrosion before the structure is endangered. It might, however, be more appropriate to quantify a specific corrosion allowance from corrosion rates forecast from knowledge of local conditions.

5.1 General

Fabrication details should be kept as simple as possible and be designed to avoid corrosion and facilitate maintenance. This applies especially to on-site connections where bi-metallic contacts should be avoided and tolerances should be generous, because of the difficulties associated with working in a maritime environment. For the same reason, as much prefabrication should be undertaken as possible, taking advantage of mechanized welding and pre-installation painting under factory-controlled conditions, provided that these operations are carried out where adequate inspection and supervision are possible.

NOTE 1 Inadequate or construction-damaged coatings (e.g. from pile driving) could exacerbate corrosion conditions.

NOTE 2 It is recommended that a maintenance strategy is developed for all marine structures to ensure that periodic inspection is carried out, enabling corrosion or other deterioration to be identified and dealt with at an early stage before it affects the integrity of the structure.

5.2 Structural steel

5.2.1 General

The steels most commonly used in maritime structures are weldable structural steels, which should conform to BS EN 10025 for structural sections and flat products, BS EN 10210 and BS EN 10219 respectively for hot and cold formed tubular sections, BS EN 10248 for hot rolled sheet piling and BS EN 10249 for cold formed sheet piles.

NOTE The steel grades are shown in Table 8.

Table 8 **Structural steel grades**

Standard	Steel grade	Minimum yield stress N/mm^2
BS EN 10025-1:2004	S 235	235
	S 275	275
	S 355	355
	S 450	450
BS EN 10210-1:2006	S 275	275
	S 355	355
	S 420	420
	S 460	460
BS EN 10219-1:2006	S 235	235
	S 275	275
	S 355	355
	S 420	420
	S 460	460
BS EN 10248-1:1996 [A)]	S 240	240
	S 270	270
	S 320	320
	S 355	355
	S 390	390
	S 430	430
BS EN 10249-1:1996 [B)]	S 235	235
	S 275	275
	S 355	355

A) A new grade, S460, is expected to be included in the revision of BS EN 10248, currently in preparation.

B) A new grade, S420, is expected to be included in the revision of BS EN 10249, currently in preparation.

5.2.2 Corrosion rates

*NOTE 1 Marine environments usually include several exposure zones with differing degrees of aggressiveness. The corrosion performance of marine structures therefore requires separate consideration in each of these zones. Recommended thickness losses applicable to steel exposed to marine environments for different life expectancies are given in BS EN 1993-5:2007, Section **4**.*

The figures given in BS EN 1993-5:2007, Section **4** are applicable to uniform or general corrosion and, in the absence of site-specific data, should be used to assess the (theoretical) design life of a structure.

*NOTE 2 Localized higher rates of corrosion can occur due to several mechanisms; these conditions, applicable corrosion rates and preventative measures are discussed in **5.2.3**.*

5.2.3 Concentrated corrosion

The following factors should be taken into account when determining means of minimizing concentrated corrosion.

a) In marine environments, accelerated corrosion can be caused locally by several mechanisms, which are outlined in the following list. These forms of accelerated or localized corrosion are referred to as "concentrated corrosion".

   1) 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 repeated stresses. The area where the rust layer is repeatedly removed becomes anodic to the unaffected areas.

   2) Bi-metallic corrosion, where steel is electrically connected to metals having nobler potentials or where weld metals are significantly less noble than the parent material.

   3) Accelerated corrosion in the low water zone associated with microbiological activity, often referred to as microbiologically induced corrosion (MIC) or accelerated low water corrosion (ALWC), which has been found in British estuarial waters since the 1980s and also in other parts of the world. Its effect is normally concentrated in discrete areas, within a 1 m range, centred between mean low water level and lowest astronomical tide (LAT). It is often randomly located along a structure, but where it occurs on sheet piles, attack 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. Because of the differences in pile section thickness at these corrosion sites, a similar strength section could yield a different life if ALWC occurs.

      NOTE Further information is available in CIRIA publication C634 [9] and the PIANC report Accelerated low water corrosion *[10].*

   4) Forms of concentrated corrosion also occur just above seabed level.

b) Concentrated corrosion is unlikely to cause catastrophic global failure of a sheet-piled structure, owing to the continuous nature of such a structure. It might be more critical on a king pile or other structural member.

c) If corrosion of a sheet-piled wall were allowed to continue to the point of perforation, loss of retained material could lead to collapse of adjacent surfacing or structures supported on the backfill.

d) Corrosion rates for concentrated corrosion can be typically 0.5 mm/side/year, averaged over time, to the point of perforation of the member. The corrosion is often of a pitting form, and can be increased, e.g. by repeated removal of the corrosion products. Rates of 0.8 mm/side/year have been recorded in UK coastal waters.

5.2.4 Measures against corrosion

It is uneconomic to design an entire wall on the basis of concentrated corrosion rates. In situations where concentrated corrosion is likely, therefore, the high rates of corrosion within the affected area should be evaluated and a specific solution developed, using one of the following methods:

a) use of a thicker steel section, a higher grade of steel or an increase in pile thickness locally by the addition of steel plates;

b) use of a high quality protective coating;

c) use of an electrical bonding system and cathodic protection (see **13.5.6**);

d) optimization of the design to ensure that high bending moments do not occur where corrosion rates are highest.

*NOTE Further detailed measures are given in Clause **13**.*

It is recommended that, where appropriate, one or more of the measures in items a) to d) is adopted to provide the desired effective life; or alternatively, a practical in-service repair is designed for implementation after a planned period. Structures should be inspected at regular intervals in order that any unusual corrosion activity can be detected at an early stage. It is also possible that physical inspection could encourage corrosion by the removal of localized fouling [see **5.2.3**a)].

Pitting corrosion to elements in tension, i.e. ties and anchors, can have serious consequences. In such cases, even small corrosion pits can cause stress concentrations that could promote failure below the nominal design and/or yield stress of the material. Allowance should be made for this.

5.2.5 Type of steel

Welded connections between structural elements are in common use on maritime structures, either exclusively or in conjunction with bolted connections, so only steels that are suitable for welding should be used. In most cases, welding by manual metal arc is favoured and the steels referred to in **5.2.1** should be selected, rather than other steels, which might require more specialized welding techniques.

5.2.6 Fracture toughness

Steel subgrade should be selected in accordance with BS EN 1993-1-10 for structural elements and BS EN 1993-5:2007 for steel piling to ensure that it possesses adequate fracture toughness.

5.2.7 Chemical composition

*NOTE The chemical composition limits and carbon equivalent values specified in the relevant British Standard (see **5.2.1**) will provide satisfactory weldability for maritime construction where lamellar tearing risks are low. Weather-resistant steels are not recommended for maritime structures, because their enhanced resistance to inland atmospheric corrosion is not realized in the presence of continuously damp or humid chloride-contaminated maritime environments.*

Steel embedded in concrete is cathodic relative to the same steel in seawater. Rapid corrosion therefore occurs at the interface of a partly embedded member. In such cases, special precautions should be taken.

Chemical composition of steel has less influence on corrosion rates in maritime environments than physical factors, such as the roughness of the surface finish of the steel and the presence of holes and corners that allow re-entry, all of which tend to promote the formation of galvanic corrosion cells. It should be recognized that heterogeneity of any kind in the materials of a structure can lead to the formation of electrolytic cells and to one material being sacrificed to the other. For example, cold worked metals have a higher potential than unworked metals of the same chemical composition and are, therefore, anodic to the latter. Cold working can result from impact damage and this should be taken into account when making repairs to existing structures.

Where set-on connections are made by welding, lamellar tearing can occur. In such cases, requirements additional to the properties specified in the relevant British Standard (see **5.2.1**) should be added to the steel specification. These usually take the form of guaranteed through-thickness properties.

When the steel is to be painted with anything other than a simple coating, the mill scale that normally coats steel sections, plates and bars on delivery should be removed. If it is not removed and is allowed to weather off, galvanic corrosion is promoted by cells formed between the mill scale and the parent material, and deep pitting can result (see **5.2.3**).

5.2.8 Quality of material

The presence of discontinuities, such as laminations in plates and forgings, and blowholes and sand inclusions in castings, should be taken into account when specifying the quality of steel. The appropriate design requirements in relation to service stresses and fabrication procedure should also be taken into account.

Plate material required to have a quality level in respect of laminations and inclusions should be examined in accordance with BS EN 10160.

Castings and forgings can be examined by radiography, ultrasonic methods or both, depending on the size and shape of the component. Such examinations should be carried out after any heat treatment but before any machining or welding takes place.

5.2.9 Connections

Connections should conform to the requirements of BS EN 1993-1-8 and BS EN 1090-2.

Welding should be a metal arc process in accordance with BS EN 1011-1 and BS EN 1011-2 as appropriate. Consumable materials for metal arc welding of steel in maritime structures should conform to BS EN ISO 2560, BS EN ISO 14171, BS EN ISO 14174, BS EN ISO 14341 or BS EN ISO 17632.

Fastener assemblies should be in accordance with BS EN 15048-1 (non-preloaded) or BS EN 14399-1 (preloaded).

5.3 Aluminium and its alloys

*COMMENTARY ON **5.3***

Aluminium in its pure state has a low tensile strength, but because of its ductility and 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 magnesium, manganese or silicon or combinations of some or all of these elements. The current standards classify alloys of aluminium according to their chemical composition, denoted by a number that is greater with increasing strength and various letters denoting whether the alloy has been heat treated or not and what method of fabrication has been used. This classification in addition to product form and tolerances are fully described in BS EN 515, BS EN 485, 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.

5.3.1 Selection of alloy

Aluminium structures should be designed in accordance with BS EN 1999-1-1:2007+A1.

NOTE BS EN 1999-1-1:2007+A1, Annex C gives guidance on the selection of alloys based on strength, weldability and decorative anodizing.

5.3.2 Structural properties

The use of aluminium in structures requires the same consideration as steel, but closer attention should be paid to the stability of parts in compression, deflections, vibrations and expansion.

Aluminium has an elastic modulus that is one third of that for steel, which means that particular attention should be paid to deflection of laterally loaded structural elements and the buckling of structural elements loaded in-plane.

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. Consequently, care should be taken to ensure that forces arising from temperature effects are allowed for in design.

NOTE Full details of the engineering properties of the principal alloys for structural use are given in BS EN 1999-1-1:2007+A1.

5.3.3 Protection from environment

The recommendations in BS EN 1999-1-1:2007+A1, Annex D concerning durability and BS EN 1999-1-3 concerning fatigue should be taken into account in design.

Pockets and crevices likely to trap water, dirt or condensation should be avoided. The greatest care should be exercised in structures containing other metals, such as steel- and copper-based alloys, to ensure that water cannot flow from the metals on to the aluminium and that the aluminium elements are electrically insulated from the other metals.

5.4 Other metals

Other metals used in maritime structures (see Commentary on Clause **5**) should conform to the relevant standards where appropriate, as follows:

a) stainless steel: BS EN 10088 for sheet, plate, strip, bars, rods and sections. Molybdenum-bearing, corrosion-resistant steels are preferable. Grade 316 is the minimum anti-corrosion grade that should be used. Austenitic stainless steels are liable to pitting corrosion in seawater in conditions where oxygen is excluded;

b) cast iron: BS EN 13835 and BS EN 12513;

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c) brass and bronze: BS EN 12163, BS EN 12164, BS EN 12165, BS EN 12166, BS EN 12167, and BS EN 12449. Brasses usually suffer from dezincification in seawater and should be avoided;

d) nickel alloy (e.g. Monel® 400 [9)]): ASTM B127 for plate and sheet. This has high corrosion resistance but is expensive (see **13.5.1**).

Wrought iron is also used and has good corrosion resistance, but there are no current manufacturing standards applicable to this material.

6 Piles

*COMMENTARY ON CLAUSE **6***

Piles in maritime works can be divided into two groups:

a) bearing piles as used in foundations, wharf, jetty and dolphin construction, or in fendering systems;

b) sheet piles as used in retaining walls or for wave protection.

Materials used for bearing and sheet piles include timber, concrete and steel. Fender piles are designed primarily to withstand or transmit horizontal impact forces and, for toughness, timber or steel is normally used. There are a number of specialized piling systems, some of which use combinations of materials.

6.1 Bearing piles

*COMMENTARY ON **6.1***

*Descriptions of bearing piles are given in BS EN 1993-5:2007 and particular considerations relevant to the maritime environment are given in **6.1.1** to **6.1.4**.*

Detailed guidance on pile design and construction is given in Pile design and construction practice, *5th ed. [11].*

6.1.1 Selection of bearing piles

In addition to availability, the following factors should be taken into account when selecting the most suitable pile type.

a) **Location and type of structure**. For a structure built over water, either tubular, box or H-section steel piles, or tubular precast or prestressed concrete piles are likely to be most suitable. Solid precast or prestressed concrete piles can be used in fairly shallow water, but in deeper water a solid pile becomes too heavy to handle. Timber piles might be suitable, but are limited by considerations of length and cross-section. In exposed maritime conditions, steel tube or box piles are preferable to H-sections because of the smaller drag forces from waves and currents. Large diameter steel tube or box piles are also an economical solution to the problem of dealing with impact forces from waves and berthing ships.

   Bored and cast-in-place piles should not be used for maritime or river structures unless used in a composite form of construction, such as extending the penetration of a tubular pile, driven through water and soft soil, to a firm stratum.

9) Monel® 400 is a trade mark owned by Special Metals Wiggin Limited, Holmer Road, Hereford, HR4 9SL and is an example of a suitable product available commercially. This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of this product.

Piles for inshore or land work can be selected from any of the three bearing pile categories, namely large displacement, small displacement or non-displacement. Of these, bored and cast-in-place piles are often the most economical, and large diameter bored piles, sometimes with enlarged bases, are capable of carrying very high loads. Bored piles are often specified in environments where ground heave, noise and vibration are to be avoided, but great care should be exercised in their use in waterside situations, in that ingress of water to the pile excavation can cause very serious structural defects.

Silent and vibration-free installation techniques are available for steel piles including large diameter tubes, and it is also possible to install steel piles into rock using these methods.

b) **Ground conditions**. This factor influences both the choice of material forming the pile and the method of installation.

Auger bored piles are suitable for firm to stiff cohesive soils, but augering is not possible in very soft clays or in loose or water-bearing granular soils, and in these cases driven or driven-and-cast-in-situ piles would be preferable. Concrete driven and driven-and-cast-in-situ piles are not suitable for ground containing boulders, nor should they be used in soils where ground heave is to be avoided.

Driven-and-cast-in-situ concrete piles, which use a retractable tube, should not be used for very deep penetrations, because of the limitations of jointing and retrieving the driving tube. A driven pile or a mandrel-driven thin-walled steel pile would be suitable in these conditions. Thin-walled steel piles are liable to tearing when being driven through soils containing boulders. For hard driving conditions in boulder clays or gravelly soils, a thick-walled steel tube pile or a steel H-section is preferred to a precast or prestressed concrete pile of solid or hollow section. Some form of drilled pile, such as a drilled-in steel tube, would be appropriate for piles taken down into rock for the purpose of mobilizing resistance to uplift from lateral loads.

c) **Durability requirements**. This factor affects the choice of material for a pile.

Steel-bearing piles in normal undisturbed soil conditions usually have an adequate resistance to corrosion. The portion of the piles above the seabed in maritime structures, in disturbed ground or in corrosive soils can be protected by cathodic protection or other methods, as described in Clause **13**, or be specified with a thickness which takes into account anticipated corrosion losses over the life of the structure.

Precast concrete piles are not expected to suffer corrosion in saline water below the splash zone, and well compacted concrete can normally withstand attack from quite high concentrations of sulfates in soils and groundwater (see Annex B). Cast-in-place concrete piles are not so resistant to aggressive substances because of difficulties in ensuring complete compaction of the concrete, but protection can be provided against attack by, for example, placing the concrete in permanent linings of coated light gauge metal or plastics.

Timber piles are liable to decay above groundwater level and in some situations they are damaged below water level by marine borers (see **9.2**). Piles can also be damaged by abrasion [see **4.2**d) and **9.2.1**] and protective measures are necessary, depending on the particular circumstances.

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6.1.2 Steel-bearing piles

The following factors should be taken into account when using steel-bearing piles.

a) Types of steel-bearing piles include tubes, box sections, H-sections and tapered and fluted tubes. They can be designed as large or small displacement piles which, in the latter instance, is advantageous in situations where ground heave and lateral displacement have to be avoided. Steel piles can be readily cut down or extended where the level of the bearing stratum varies, and the head of a pile that buckles during driving can be cut down and re-trimmed for further driving. They have a good resilience and high resistance to buckling and bending forces. They are light to handle compared with precast concrete piles and this can be particularly advantageous in maritime construction over water, but their cost per metre run is greater. Their lightness facilitates their use as raking piles.

b) Extending steel piles for driving to depths greater than originally predicted is carried out easily by welding. The practice is satisfactory in the leaders of a piling frame for land structures. It might, however, need considerably more care in maritime works, where the section of the pile above seabed level is subjected to high lateral forces and corrosive influences, and where the highest strength and best protective treatment are therefore required. Conditions are not conducive to first class welding when the extension pile is held in leaders or guides on a floating vessel, or on staging supported by piles swaying under the influence of waves and currents.

c) Hollow-section piles can be driven with a closed end in order to develop increased resistance over the pile base area. Where deep penetrations are required they can be driven with open ends, possibly with driving shoes up to 1 m long welded on the toes, and then filled with concrete after cleaning out the soil. In some circumstances, the solid plug within the pile can itself develop the required base resistance. A possible subsequent loss of resistance, particularly as a result of boiling in granular soils, can be prevented by filling the pile with water immediately after driving.

d) If the base resistance has to be eliminated when driving hollow-section piles to a deep penetration or to avoid ground heave, the soil within the pile can be progressively cleaned out by augers, by reverse water circulation drilling or by airlift. It is not always necessary to fill hollow-section piles with concrete, and each case should be assessed in relation to its circumstances.

e) Hollow-section piles have an advantage over solid types when inspecting a pile for buckling. A light can be lowered down the pile and if it remains visible when lowered to the bottom, no deviation has occurred. If a large deviation is shown by complete or partial disappearance of the light, measurements can be made and measures taken to strengthen the buckled section by, for example, inserting a cage of reinforcement and placing concrete.

f) Circular-section piles have considerable strength as columns, where piles project above the ground or seabed, and are preferred when soil has to be cleaned out for subsequent placement of concrete, because there are no corners from which the soil might be difficult to remove. The circular shape is also advantageous in minimizing drag and oscillation from waves and currents.

g) Steel tubes for piles can be seamless, longitudinally welded or spirally welded. There is nothing to choose between the latter two types of welding from the point of view of strength to resist driving stresses.

6.1.3 Concrete-bearing piles

Concrete in piles should be in accordance with Clause **4**.

NOTE 1 Precast concrete piles are often used in maritime structures because of the simplicity of manufacture and their suitability in a wide range of applications. Their main disadvantage is the difficulty of extending them when necessary.

NOTE 2 Particularly in maritime works, prestressed concrete piles are normally preferable to ordinary reinforced concrete piles because they are able to tolerate larger bending loads and are more durable. Their higher bending strength permits manufacture and handling in a wider range of lengths and greater resistance to lateral forces in operation. They have a greater resistance to tensile stresses caused by uplift forces. A further advantage of prestressed concrete is that any cracks that occur during handling and driving are likely to close up. This, combined with the high quality concrete necessary for prestressing, gives the prestressed pile increased durability in the maritime environment. However, prestressed piles are less resistant to impact from harbour craft or lighters than reinforced concrete piles.

The working stresses in the concrete during lifting, handling and pitching of precast piles should not exceed those given in BS EN 1992-1-1. High stresses, which can exceed the handling stresses, can occur during driving, and the serviceability limit of cracking should be taken into account. The cover to reinforcement for piles exposed directly to seawater should be in accordance with **4.4.2** and **4.4.10**.

6.1.4 Timber-bearing piles

Round log or hewn piles are often acceptable in lieu of sawn piles, but only certain timbers are suitable for maritime piling (see **9.3.1**). The resilience of such timbers with their high strength to weight ratio make them very suitable for bearing and fender piling, but to obtain adequate durability, the correct species and grading should be used, connections should be carefully detailed (see **9.4**) and appropriate preservative treatments should be adopted where necessary.

Timber piles should be designed in accordance with BS EN 1995. When calculating the working stress on a pile, allowance should be made for bending stresses due to eccentric and lateral loading, and to eccentricity caused by deviations in the straightness and inclination of a pile.

Allowance should also be made for reductions in the cross-sectional area due to drilling or notching and to the taper on a round log.

6.2 Sheet piles

6.2.1 Steel sheet piles

Steel sheet piling for use in all types of temporary works and permanent structures, including cofferdams, retaining walls, river frontages, quays, wharves, dock and harbour works, permanent foundations, land reclamation and sea defence works, should be designed in accordance with BS EN 1993-5:2007 and installed in accordance with BS EN 12063.

The most appropriate type of pile should be selected on the basis of section type, strength, driveability and durability. Piles are available in various shapes and the stiffer sections are capable of being driven to a considerable depth in a wide range of ground conditions and, when necessary, into rock. Silent and vibration-free installation of sheet piles is widely available and should be adopted where pile installation using impact or vibratory techniques is expected to result in disturbance in the vicinity of the site. It is also possible to use these techniques to install steel sheet piles into reasonably competent rock. The interlocks between adjacent piles are relatively watertight but introduction of an interlock sealant might be advantageous when water exclusion is desirable.

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The most appropriate type of piling should be selected from the following options:

a) U-section;

b) Z-section.

Retaining wall structures can also involve:

c) straight web piles;

d) H or I sections;

e) tubular sections.

NOTE 1 Types a) to c) are rolled sections which are manufactured to interlock together, but types d) and e) require the introduction of interlocking devices to form a continuous structure. It is also possible to combine sheet piles with structural sections or tubes to create a wall with enhanced stiffness and bending resistance. Such systems are referred to as high modulus or combined walls. The difference between these two wall forms is that a high modulus wall comprises interlocking steel elements that have the same geometry, whereas a combined wall is composed of primary and secondary elements.

The primary elements should normally be steel tubular piles, I-sections or built-up box types, spaced uniformly along the length of the wall. The secondary elements should normally be steel sheet piles of various types installed in the spaces between the primary elements and connected to them by interlocks.

Type c) sections are designed to act primarily in tension across the webs and should be used in cellular configurations.

NOTE 2 Cross-sections of the various types of sheet pile in common use are shown in BS EN 1993-5:2007.

NOTE 3 Steel sheet piling can be rolled in lengths up to approximately 35 m, though handling facilities do not always permit the use of such long lengths. This is especially so with straight-web piling. Where it is necessary to increase the pile length during driving, site-welded joints can be used.

*NOTE 4 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 inter-tidal zone (see **5.2.2**). The additional cost of specifying copper-bearing steel will therefore only be justified if corrosion in the atmospheric zone governs performance of the piles. Information on concentrated corrosion on sheet piles is given in **5.2.3** and methods of protection in **5.2.4**. Other systems for protecting steel piling against corrosion are given in Clause **13**.*

6.2.2 Concrete sheet piles

*COMMENTARY ON **6.2.2***

Reinforced concrete sheet piles are used in retaining walls in canal banks, where they are quite short and therefore of acceptable thickness. The height of any earth-retaining structure is limited by the depth to which it is possible to drive the piles without breakage in order to achieve the required passive resistance to earth pressure. It is difficult to achieve a tight interlock because of warping and shrinkage in individual piles. In addition, with increasing length the thickness of concrete piles, even if prestressed, becomes excessive, making them very heavy and therefore expensive to manufacture and handle. Their use in UK conditions is generally regarded as uneconomic, but they remain in use in developing countries in structures of modest size.

Steel shoes are not normally required on the toes of concrete sheet piles driven through soft or loose soils into dense sands and gravels or firm to stiff clays. A blunt pointed end is all that is required to achieve the desired penetration in these soils, and if the blunt point is cast on a longitudinal rake it assists in the close driving of adjacent piles.

Concrete mixes, working stresses, cover to reinforcement, use in aggressive conditions and the use of prestressed concrete in concrete sheet piles should conform to Clause **4**.

6.2.3 Timber sheet piles

Timber sheet piles should only be used for low earth-retaining structures and beach groynes, for replacing damaged sheet piles in existing timber structures, or for temporary works such as cofferdams.

NOTE 1 Interlock can be achieved by tongue and groove joints or by lapping the joints of a double row of planks. Typical details are shown in BS EN 12063:1999, Figure F.1.

Materials should be in accordance with Clause **9**.

NOTE 2 Timber sheet piles are often fitted with steel shoes to prevent splitting of the toe and to assist in driving. Cutting of the toe on a longitudinal rake assists in close driving.

7 Rails

*COMMENTARY ON CLAUSE **7***

Rails are used in maritime facilities both as permanent way for rail traffic and as track for special rail-mounted equipment including cranes, hoppers, slipway carriages and lock and dock gates.

7.1 General

Requirements for materials for permanent way in port facilities are not normally different from those applying to permanent way, and materials should conform to BS EN 13674, BS 11 and BS 500, as appropriate.

NOTE 1 These standards also specify requirements for fittings, including fishplates and fishbolts, with appropriate references.

NOTE 2 A large proportion of permanent way in port areas is constructed flush with pavements. Care is necessary in the detailing of pavements and in the specification of foundations, drainage and method of installation, because problems can arise due to differential settlement and movement between tracks and pavement.

Crane rails and rail track for special equipment can be required for a wide range of duties including the carriage of wheel loads much heavier than those used on permanent way. The materials and details for special rail tracks should therefore be selected and specified according to the needs of each application.

NOTE 3 The rail section selected is a function of the maximum wheel loading and the method proposed for supporting the rail. There are numerous methods for bedding, positioning and holding down crane rails, and these are frequently supplied as proprietary systems.

7.2 Crane rails

The following factors should be taken into account when using crane rails.

a) The correct selection of bedding system and holding-down bolt arrangement is most important, because many failures of container crane rails have been reported.

b) The main problem is the bow wave that is induced in the rail by a heavy moving wheel. This causes cyclic loads in the fixings and a pumping action on the bedding layer due to the inevitable presence of water.

NOTE There are two bedding fixing systems in general use:

- *a continuous support, involving a continuous rubber pad between the rail and a steel base plate, which is bedded on a pourable cement or epoxy based material;*
- *an intermittent support, as in permanent way.*

7.3 Adjustment of crane rails

Crane suppliers demand tight tolerances on rail straightness, track alignment and level. The bedding and fixing system selected should allow vertical adjustment to be made after the crane has been put into service.

7.4 Holding-down bolts

Where a bedding medium that is placed in situ is used, the holding-down bolts that have been provided should allow the rails to be accurately adjusted to line, level and eliminate twist. The rails should also be rigid enough to maintain the correct alignment whilst the bedding materials are placed and cured.

7.5 Rail clips

Rail clips should give positive restraint to lateral and twisting displacements, while at the same time permitting some linear displacement of the rail due to thermal expansion.

7.6 Heavy-duty crane rails

Heavy-duty crane rails are normally continuous at structural expansion joints. The steel base plate should normally be discontinuous, and longitudinal movement between the rail and the base plate can be accommodated by the rail sliding under the rail clips, provided that these are of a suitable design to allow such movement.

7.7 Joints

Rails should normally be jointed by welding using methods employed for permanent way work.

8 Pipes

*COMMENTARY ON CLAUSE **8***

Pipes used in the maritime environment can be divided into four main categories:

a) pipelines laid on or under the seabed;

b) pipelines laid below ground on land in quays, piers, marginal and inland storage areas;

c) pipelines supported above ground;

d) flexible pipelines for ship-to-shore connection.

Selection of pipe material for a particular situation is governed by its suitability for the duty involved, taking account of availability, strength, durability and the construction methods to be adopted.

Pipes are manufactured in a wide variety of materials. The following is a list of pipe materials in general use, which should conform to the requirements of the appropriate standard where such exists:

a) concrete;

b) ductile spun iron;

c) glass reinforced plastics (GRP);

d) glazed vitrified clayware (GVC);

e) plastics:

   1) unplasticized polyvinyl chloride (PVC-U);

   2) polyethylene (PE) in various grades;

   3) polypropylene;

   4) acrylonitrile butadiene styrene (ABS);

f) steel.

9 Timber

9.1 General

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 TDRA publication Timber for marine and fresh water construction *[12].*

9.2 Resistance to environmental hazards

9.2.1 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.

*NOTE Recommendations are given in **9.3** for particular types of maritime structures.*

9.2.2 Biological attack

Resistance to biological attack is best achieved by the correct choice of timber for its position in the structure and the marine environment concerned. The need to provide protection against fungal decay for the superstructure of any structure should be taken into account in all marine environments.

NOTE 1 In freshwater situations, fungal decay is the major hazard, and the use of preservatives or timber having appropriate natural durability is essential.

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NOTE 2 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. Timbers are normally classified, in the UK, for their natural resistance to marine borers as follows:

a) very durable: suitable for use under conditions of heavy attack by Teredo and Limnoria (see Note 1 to ***9.2.4****), and expected to provide at least 20 years of life;*

b) moderately durable: suitable under conditions of moderate attack, mainly by Limnoria;

c) non-durable: suitable for only short service life.

NOTE 3 Guidance on the performance of various species of timber is given in literature from several sources such as TRADA and timber importers.

9.2.3 Fungal decay

In order to reduce the danger of fungal attack, structural detailing should ensure adequate drainage of surface water and avoid 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 avoid splitting. Embedment of timber in concrete or brick or its use in other situations that would encourage retention of moisture should be avoided.

9.2.4 Marine borers

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.

NOTE 1 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. Although shipworm in British waters has been found mainly in the sea around southern England, with climate change the increase in occurrences further north, within the British Isles, needs to be considered.

NOTE 2 See also Note 2 to ***9.2.2****.*

9.3 Functional suitability

9.3.1 Piling

The selection of timbers for piling should take into account the ability of the chosen timber to withstand the impact actions 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.

NOTE 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.

9.3.2 Structures

The timbers commonly used for the main structural elements in superstructures are similar to those used for piling. 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.

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

9.3.3 Kerbs and capping pieces

To be effective, kerbs and capping pieces should be of generous scantlings, and sections in excess of 250 mm square are common.

9.3.4 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 the continued use of this species of timber should only be where rubbing strips are provided to take the impact and abrasion from berthing vessels. With the greater availability of recycled plastics, plastics rubbing strips should be considered as an alternative to traditional timber rubbing strips, as these might prove to be more sustainable either on a whole life or carbon footprint basis.

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

9.3.5 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 jarrah, greenheart, pynkado, ekki, opepe, and pitch pine. 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.

9.3.6 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 oak, pitch pine, Dutch and Wych elm, or greenheart where extra strength, abrasion resistance, or long lengths are required.

9.4 Fastenings

All steel fastenings materials should be corrosion-resistant and should conform to BS EN 912, BS EN ISO 898-1 and BS EN 14545, as appropriate. All bolts, nuts, and washers that are not manufactured of stainless steel should be hot dip galvanized to at least 140 μm and should be dipped in a suitable bituminous material immediately prior to assembly.

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.

Rag bolts or indented bolts can be used for fastening timber work to the face of concrete structures, but preference should be given to the use of stainless steel. Non-stainless steel parts which are not embedded in concrete should be coated with suitable bituminous compounds or paint.

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

10 Stone for armouring or protection works

*COMMENTARY ON CLAUSE **10***

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, groynes and in pitched and revetted slopes.

10.1 General

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 conformity to 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 in much more detail than is possible in this part of BS 6349. Further guidance on the identification and selection of rock is given in The rock manual *[N2]. BS EN 13383-1 does not provide any specification for the workmanship of placing armourstone in engineering works. Guidance on this aspect is given in* The rock manual *[N2], which as well as a chapter devoted to constriction also includes a model construction specification. Whilst BS EN 13383 describes armourstone in a different manner to previous practice in some parts of Europe and the rest of the world, and in some cases uses different test methods to evaluate their properties, there is no change to the general quality of the armourstone in use.*

10.2 Grading

10.2.1 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 Gradings given in BS EN 13383-1 include:

- *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;*
- *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.*

Non-standard heavy gradings are also permitted (as the pieces of armourstone are generally handled individually), but the form in which any non-standard grading should be specified should follow the guidance in BS EN 13383-1 and *The rock manual* [N2].

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. However, when selecting gradings every opportunity should also be taken to optimize quarry yields, and where quarries are set up dedicated to a particular large project, non-standard gradings might be appropriate in order to make sure that the design matches the quarry yield.

10.2.2 Cover layer applications

There are two types of grading quality for heavy and light gradings: Category A, where the average mass is controlled, and Category B, where it is not. Category A gradings should normally be used for cover layers. When assessing the average mass required for hydraulic stability, designers should allow 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 their corresponding average mass M_{em}.

NOTE 1 Conversion factors are given in The rock manual *[N2].*

NOTE 2 The grading $LMA_{15/300}$ *is believed to be too wide for cover layer applications.*

10.2.3 Underlayer or filter applications

When selecting the appropriate category, Category B materials should be selected as there is no requirement for a control on the average mass.

10.2.4 Volume filling materials

Volume filling materials such as "quarry run" or "tout-venant" used in the core of breakwaters or revetments generally do not provide any significant protection or filtration function, and hence the grading system in BS EN 13383-1 is not appropriate. Any attempt to impose the BS EN 13383 system on them will lead to waste of resource and substantially increase cost. However, the core of a protective structure has to be capable of achieving a relatively high density without compaction when dumped in water. 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. The fines within the core grading can cause turbidity during construction, thus the grading should be controlled. Furthermore, scour of the core material by being washed out through the overlying layers should be limited. For these reasons, the fines content at the bottom of the grading will normally be restricted but the associated cost and resource penalty should be taken into account.

10.3 Other geometrical parameters

Shape should be assessed by length to thickness ratio, *LT*, but a requirement should only be specified for cover layers. Otherwise the "no requirement" category should be selected

NOTE A requirement for the proportion of crushed or broken surfaces, RO, is needed only where it is likely that naturally rounded boulders of riverine or glacial origin might be used in a situation in structures in which rounded stones could lead to instability.

10.4 Physical and chemical parameters

A minimum oven dry particle density may be selected by the designer/specifier in accordance with any requirement for hydraulic stability. 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 The apparent density can be calculated (Netherlands Ministry of Transport, Public Works and Water Management report [13]) by multiplying the (oven dry) particle density by the following factors:

- *(1 + 0.005WA) where the armourstone is to be used in a structure of which all, or part, is permanently submerged. This factor is based on half the pore volume within individual pieces of armourstone being filled with water;*
- *(1 + 0.0025WA) where the armourstone is to be used in a structure of which all, or part, is temporarily submerged. This factor is based on one quarter of the pore volume within individual pieces of armourstone being filled with water.*

In the above formulae, WA is the percentage water absorption of the armourstone determined in accordance with BS EN 13383-2.

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. 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.

Although BS EN 13383 states that block integrity is of particular importance and states that armourstone should be free from significant discontinuities which could lead to breakage during loading, unloading or placing, the property is difficult to control. However, to gain an estimate of the degree of breakage likely and whether it can be accommodated within the design, checks for block integrity should be carried out as part of initial type testing/product type determination.

NOTE 2 Guidance is provided in BS EN 13383-1:2002, Annex B and in The rock manual *[N2].*

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 will not be necessary to set a wear requirement. However, it is suggested that for cover layers and dynamic structures (such as beaches) Micro-Deval coefficients, M_{DE}, should be set as follows:

- M_{DE}10 for very highly abrasive environment (e.g. frequently stormy seas with shingle-structure interaction, fluvial torrents, dynamic armour layers including berm breakwaters);
- M_{DE}20 for highly abrasive environment (e.g. occasionally stormy seas with shingle or sandy foreshore);
- M_{DE}30 for moderately abrasive environment (e.g. occasional wave or current action with suspended sediment load).

NOTE 3 If there are insignificant sediment loads present in the water, a wear requirement can 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. No requirement level is necessary but the results are needed for two reasons:

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

NOTE 4 Resistance to freezing and thawing, FT, is assessed by loss of mass in testing but is only necessary where WA is determined to be greater than 0.5% and then only where it is relevant to the climate of end use for the armourstone. (For example, freeze–thaw testing is not normally considered necessary for coastal applications in the UK.) A requirement is also normally unnecessary where armourstone is permanently submerged, even in cool climates, as freezing and thawing processes are likely to be limited in effect.

Resistance to salt crystallization is assessed by the percentage loss of mass, *MS*, obtained in the magnesium sulfate soundness test, but is only necessary 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%). Where armourstone is permanently submerged, salt crystallization processes are likely to be limited in effect and no requirement is necessary.

10.5 Particular armourstone sources

If steel slags are proposed to be used for armourstone, they should be tested for disintegration. If natural basalts are proposed to be used for armourstone, they should be tested for signs of "Sonnenbrand". In both cases, the tests and results should be in accordance with BS EN 13383.

11 Pavements

*COMMENTARY ON CLAUSE **11***

Paved surfaces are required in port and dockyard complexes for roads, circulation areas, hardstanding areas for the parking of vehicles and storage of cargo and shed floors. Other pavings include breakwater cappings and sea walls where environmental conditions can be more damaging than traffic conditions.

Particular points to be considered in selecting materials for pavements are:

a) loadings;

b) durability;

c) settlement characteristics;

d) sustainability.

11.1 Loadings

*COMMENTARY ON **11.1***

*The wheel loadings imposed by mobile cargo handling equipment can be very large (see BS 6349-1:2000, Clause **45** [10)]) and the tendency is for such loadings to increase with the development of new cargo handling systems. Axle loads imposed by forklift trucks handling loaded containers frequently exceed 70 t. Systems in which four or more loaded containers are carried on a chassis can give rise to single bogie loads of 150 t. These loadings are quite different from those experienced because of highway traffic, where wheel loadings are more frequent, less intense and travel at higher speeds. The pavements required to withstand wheel loads of such high intensity are usually significantly heavier in design and more costly than highway pavements. To achieve economy in planning port layouts it might be necessary to confine the heavy-duty pavements to the working areas of the heavy equipment, the remaining areas being paved to a suitably reduced specification.*

Where available, loadings from wheeled equipment and stored cargoes pertinent to the pavement under consideration should be obtained for the design. In the event that this information is not readily obtainable, then generic loading data from similar applications should be applied.

10) It is expected that this clause will become part of the new BS 6349-1-2, currently in preparation.

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11.2 Durability

In addition to long-term loading due to various kinds of bulk and break bulk cargo, pavements should be capable of withstanding wear and tear by lorries and cargo-handling equipment. In hard-standing areas where the small jockey wheels of parked semi-trailers give rise to intensive point loading of the surface, and in areas where tight curves have to be negotiated by multi-axled vehicles, concrete construction should be adopted.

NOTE Modern cargo handling equipment can have solid rubber or plastics wheels or can use high-pressure pneumatic-tyred wheels. Plant is almost always power-steered. This combination can give rise to severe scuffing of the surface of pavements as the hard wheels are steered whilst the vehicle is at a standstill. Selection of an appropriate surface finish is necessary for such duties.

Another factor that, combined with the problem of scuffing (see Note), can give rise to rapid surface deterioration is attack by fuels, lubricating oils and hydraulic fluids dropped by mobile plant. Where such contamination cannot be avoided, susceptible paving materials such as asphalt should not be specified.

11.3 Settlement characteristics

Pavements in port and dockyard areas are frequently constructed on poor ground or in areas where land has recently been reclaimed and is subject to settlement. In such situations, appropriate means of accelerating settlement and/or strengthening the ground such as pre-loading, various drainage methods, vibroflotation or dynamic consolidation should be provided. In combination with those methods, a pavement type should be selected that is tolerant of settlement, can be regulated and repaired from the top, or can easily be taken up and re-laid. Rigid pavements that are not tolerant of settlement and that can only be repaired or replaced at considerable cost should be selected only where the foundation is reliable.

NOTE In situations where pavements have to be brought into use before the residual settlement is reduced to an acceptable amount, it might be desirable to provide a temporary pavement, which can serve operational needs for an interim period while settlement continues. Such a temporary pavement can be designed to form one of the lower courses of the final design pavement after regulation.

11.4 Sustainability

Pavements typically require the sourcing, transportation, and incorporation into the works of large quantities of aggregates. Non-primary sources should be used where appropriate, in particular, secondary aggregates, locally-sourced aggregates, site-won aggregates, and non-standard aggregates.

12 Bituminous materials

*COMMENTARY ON CLAUSE **12***

Bituminous materials are used in maritime works for:

a) pavements;

b) coatings;

c) waterproofing;

d) sealing compounds;

e) coast and bank protection.

*Their use for waterproofing and sealing compounds is similar to their applications in other structures and requires no special comment. The uses, mixes and application techniques of bituminous materials for coast and bank protection are described in **12.1** to **12.4**. Guidance on uses of bituminous materials is given in Annex C.*

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 impermeability is often a disadvantage from the design point of view. A low void content is nevertheless recommended owing to the difficulty in constructing strong and durable open mixtures. Open stone asphalt is the one exception, however. Hot mixtures in common use are:

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

12.1 Asphaltic concrete

*COMMENTARY ON **12.1***

Asphaltic-concrete types of mixtures consist of crushed stones or gravel with a maximum size of 25 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 is normally used for revetments.

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

The following specific recommendations should be met.

a) The bitumen content is normally higher than for paving mixes in order to obtain good impermeability and durability. A bitumen content of 6% to 9% should be used.
b) Penetration grade bitumens 40/60 pen, 50/70 pen, 70/100 pen or 100/150 pen, conforming to BS EN 12591, are normally used to facilitate compaction. The softer grades should be used, because compaction is difficult on slopes.
c) To minimize segregation, a continuous aggregate grading with a maximum stone size of 12 mm to 25 mm is commonly used. Gap-graded mixes, which need less compactive energy, are sometimes used. Aggregates should have good adhesion characteristics and be angular or crushed for revetments that are placed on slopes steeper than 1:2.5.
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. High percentages of filler can lead to the production of mixes that are difficult to handle.
e) Filler contents, i.e. materials smaller than 75 μm, should be between 8% and 13%, limestone or cement being preferred.
f) In order to ensure that the mix is impermeable, i.e. with the permeability less than 10^{-6} mm/s, the voids content should be below 4%.

   NOTE 1 For mix design, use can be made of the Marshall test procedure [14]. It is, however, essential that the state of compaction achieved in the laboratory-made specimens be 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%.

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

Asphaltic concrete is normally made in a hot-mix plant and transported to the site by trucks or lorries. It should be placed in the dry, and various methods are used for spreading the mixture over the revetment. The simplest is by dumping the mix directly from a truck on the formation and spreading it to the desired thickness with hand rakes. Another possibility is to dump 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 2 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.

12.2 Sand mastic

*COMMENTARY ON **12.2***

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 for grouting purposes is usually made in a hot-mix plant 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, can 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. It should, however, conform to the following two 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.

12.3 Open stone asphalt

*COMMENTARY ON **12.3***

*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 Clause **12**). 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. Open stone asphalt can be used below water but only in the form of prefabricated mats. 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.*

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.

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.

When open stone asphalt is applied as a revetment on relatively steep slopes above and below water level, the stability, and therefore stone content, for that part above water should be increased, because higher temperatures are expected in this area.

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.

12.4 Lean sand asphalt

*COMMENTARY ON **12.4***

Lean sand asphalt consists of a mixture of locally available sand and bitumen, and is therefore a relatively cheap 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 under water, 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 as a 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 cheap 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. It should, however, have a bitumen content of 3% to 6%.

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13 Protective measures

*COMMENTARY ON CLAUSE **13***

When designing structures that are especially vulnerable to deterioration, because of the aggressive environment in which they are sited, the life of the structure can be increased in one of two ways. Allowance can either be made for planned maintenance, as recommended in BS EN ISO 12944 and BS EN ISO 14713, or for increased initial structural strength, which will ensure the required amount of life without maintenance work.

*The detailed planning and selection of materials and workmanship for maritime structures, as recommended in Clause **5**, can minimize corrosion and the subsequent effects of corrosion. BS EN ISO 12944 and BS EN ISO 14713 give guidance on detailing to minimize corrosion.*

13.1 General

When selecting a protective system, the following factors should be taken into account.

a) Protective measures are repetitive in that the protective materials themselves deteriorate, and regular maintenance and the frequency of renewal of coatings should be assessed to ensure effective protection during the design life.

b) A maritime installation might need to be put out of commission during a maintenance period and thus the duration and frequency of the works should be taken into consideration when selecting the protective system.

c) Corrosion does not proceed at a uniform rate over the whole structure, and at certain corrosion points loss of the original material can be rapid. The corrosion allowance should be varied in order to allow for this difference (see **5.2.2**).

d) Access to areas to remove items such as marine growth and old paint, as well as the methods for removal, should be taken into account when assessing the renewal of a protective system.

e) Marine growth is prevalent on structures below mean high water level. Evidence exists that fouling can be protective against corrosion and thus it is not always necessary to remove it. The only exposure zones that should be assessed for marine growth removal prior to protection renewal are the splash and atmospheric zones.

f) If the potential for accelerated low water corrosion exists, the need for an upgraded or more durable protection system should be taken into account (see **5.2.2**).

13.2 Coating systems

The choice and specification of coating systems for maritime structures should be in accordance with BS EN ISO 12944 and BS EN ISO 14713. Primer coatings should be specified that protect the steel for extended construction periods and can withstand abrasion associated with handling and fabrication with a minimum of damage.

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

NOTE Discontinuities in the coating could encourage corrosion by forming galvanic cells with adjacent protected steel.

13.3 Concrete protection

COMMENTARY ON ***13.3***

Because of the low electrical conductivity of concrete, its alkalinity and its ability to exclude oxygen from the surface of the metal, it is common to encase steel members in the splash zone with a layer of dense concrete, usually reinforced with a light, welded cage of steel mesh. This method of splash zone protection is particularly applicable to structures where tidal ranges are small, i.e. 1.5 m to 3.0 m, and installation costs are acceptable. Concrete protection could also be used against concentrated corrosion (see ***5.2.3****), but see comments on interface corrosion in* ***5.2.7****.*

The placing of concrete for protection is often carried out underwater by use of a tremie inside prefabricated shutters. In all cases, careful cleaning of the steel piles should be carried out immediately prior to placing of the concrete.

NOTE In some cases, special woven polypropylene jackets are tied around piles and very wet concrete poured into the jackets, thus displacing the water inside. A hydrostatic head is maintained on the concrete within the woven jackets, which forces the excess water from the mix through the weave of the jacket material. A highly dense concrete can result from this procedure.

13.4 Steel wear plates

The beneficial effect of providing additional steel thickness in the form of steel wear plates in areas where corrosion and abrasion are expected should be taken into account when assessing the working life of the structure. In addition to providing a corrosion or abrasion allowance, wear plates add stiffness and strength, thereby providing greater impact resistance. Where appropriate, wear plates should be coated with the same protective coating system used for the remainder of the structure.

13.5 Sheathings and wrappings

13.5.1 General

Sheathings using metallic membranes or wrappings in non-metallic material are a suitable method to protect the underlying structural members from corrosion. The application of these products should be in accordance with the applicable standard and/or manufacturer's recommendations.

Where nickel alloy sheathing is used to clad steel structural members, the possibility of galvanic corrosion of the steel, as noted in PD 6484, should be taken into account when designing for corrosion.

NOTE 1 A typical example of a nickel alloy is Monel® 400 [11]*, which comprises Ni 67%, Cu 28%, Fe 2.5% max. and Mn 2%. It is as strong, tough and ductile as steel and resists corrosion better than copper, gunmetal or bronze. It machines readily and can be rolled, drawn, cast, forged, soldered, brazed and welded.*

Wrappings should be applied to structural members, preferably cylindrical, prior to installation below water. In the case of maintenance work, careful surface cleaning should be carried out if adhesion is to take place between the waterproofing compound and the structural member.

NOTE 2 Wrappings are described in BS EN ISO 12944 and BS EN ISO 14713, but in connection with maritime work the points given in ***13.5.2*** *to* ***13.5.5*** *require special consideration.*

[11] Monel® 400 is a trade mark owned by Special Metals Wiggin Limited, Holmer Road, Hereford, HR4 9SL and is an example of a suitable product available commercially. This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of this product.

13.5.2 Structural members

Structural members can be wrapped with glass fibre impregnated with a water-repellent compound of good adhesive properties. Hessian-reinforced wrappings should be used with caution, because these are susceptible to microbiological attack.

13.5.3 Tie rods and ground anchors

Corrosion protection systems for ground anchors and tie rods should conform to BS EN 1537.

13.5.4 Waterproofing compounds used for wrapping tapes

NOTE The wrapping tapes described in ***13.5.4.1*** *and* ***13.5.4.2*** *are used extensively for the protection of tie rods on anchored, sheet-piled structures. The tie rods and cables are also available with protective plastic sleeves applied during manufacture.*

13.5.4.1 Petroleum jelly and neutral mineral filler

Petroleum jelly and neutral mineral filler are used in conjunction with a petroleum jelly primer. This material is suitable for electrical insulation but is subject to damage by abrasion. Tapes impregnated with this compound should therefore not be used where they are liable to impact, such as near the berthing face of a maritime structure.

13.5.4.2 Two-pack epoxy or polyester compounds

Two-pack epoxy or polyester compounds can be applied with glass fibre tape, and this protective treatment is suitable for maritime protection both prior to installation of structural members and for long-term maintenance. The tape should be wrapped around the member immediately after it has been cleaned and primed with a two-pack resin compound and then several layers of resin should be applied over the tape and the final surface trowelled smooth.

13.5.5 Special measures

In flowing water, special measures should be taken to prevent wrappings being torn off by turbulence.

NOTE Flexible thick plastic jackets are available for protecting pile wrappings in the surf zone where abrasion from beach or seabed material adds to the problem.

13.5.6 Cathodic protection

Cathodic protection systems should be designed in accordance with BS EN 12954.

NOTE Cathodic protection can combat concentrated corrosion of the type described in ***5.2.3****.*

13.5.7 Protection in the buried zone

Where structural elements are driven into the buried zone (see Note 1), the rates of corrosion are negligible, irrespective of the presence of anaerobic sulfate-reducing bacteria, and this should be taken into account when assessing the need for corrosion protection for steel elements.

NOTE 1 The buried zone occurs below seabed or river bed level, minus an allowance for scour and over-dredging, or within structural earthworks such as soil dykes.

In filled ground, especially with certain clays, allowance should be made for bacterial corrosion which can occur locally and can be rapid.

NOTE 2 The presence of such bacteria is rare and can be detected by taking measurements of the redox potential of the soil (see BS 7361-1:1991, Annex A). By provision of adequate cathodic protection, this form of corrosion can be eliminated.

14 Maintenance

*COMMENTARY ON CLAUSE **14***

Maintenance includes:

a) regular inspections;

*b) in cases where planned maintenance is required to maintain durability (**13.1**):*

1) renewal of protective systems;

2) repair of structural components;

c) special inspections after a collision, severe storm or other extreme event;

d) repairs following such accident or event.

14.1 General

At the design stage, practical solutions should be identified for potential situations requiring maintenance or repairs (e.g. ship damage to fenders or the quay, or concentrated corrosion), which have not been allowed for in the original construction.

14.2 Records

Records of inspections and maintenance work carried out should supplement design and construction records. All such records should be maintained for the working life of the structure.

14.3 Access

In order to provide safe access, permanent fixings should be provided for mooring workboats and, where appropriate, for supporting temporary staging, so that inspection and maintenance can be facilitated.

NOTE Guidance on the inspection of rubble mound breakwaters is given in BS 6349-7.

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Annex A (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;
- 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 and carbon dioxide, 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 excellent corrosion resistance properties but comes at a high cost. Austenitic stainless steels are appropriate for embedded reinforcement, but higher, more corrosion-resistant, grades might be required for exposed items (i.e. PREN values >40).

Reinforcement protected by fusion-bonded epoxy coatings is another system, 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.

High-grade, high-build surface coatings are suitable for maritime work. These require first class surface preparation and will need replacing every 10 years to 30 years, depending on the location and the coating system.

Integral admixtures such as superplasticizers, corrosion inhibitors and integral waterproofing admixtures may be used, to enhance concrete quality or increase the threshold to corrosion.

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 or the conventional protection of steel structures. This may be classed as a prevention system, installed during construction, or a protection system, which is retro-fitted during the structure service life. Points to note are the dangers of corrosion of adjacent structures (either reinforced concrete or steelwork), and from issues caused by stray currents from an impressed current system.

Further information is given in CIRIA C674 [2], Concrete Society Technical Report 61 [4] and *The design of coastal structures* [17].

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

Design, specification and detailing with the objective of achieving a specific design working life within a range of probabilities requires a knowledge of the various deterioration mechanisms for concrete materials and recommended analytical models of the processes. Explanation and guidance on the different mechanisms are given in the CEB publication *Design guide – Durable concrete structures* [15] and in the PIANC *Recommendations for the construction of breakwaters with vertical and inclined concrete walls* [16]. Other useful publications include CIRIA C674 [2] and Concrete Society Technical Report 61 [4].

There are a number of deterioration processes that are specifically recognized in relation to concrete in or adjacent to seawater. The relative significance of various processes depends upon the macroclimate, i.e. the geographical location of the site, and on the microclimate, e.g. rainfall and its effects and the position of a structural element in relation to the fluctuating water level.

Most of the time-related deterioration processes for concrete are covered by guidance in general codes and publications. 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. 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.

The more important factors affecting the durability of concrete and reinforced concrete in seawater are:

- the pore structure of the concrete, as determined by the cement type and the water/cement ratio;
- the influence of the moisture state of the concrete on the various transport mechanisms by which water and dissolved deleterious salts and gases are transported within the pore structure of the concrete;
- the influence of the macroclimate and microclimate on the moisture state;
- the chemistry of the cementing system;
- the resistance of the reinforcing system to corrosion.

In 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. However, the presence of chlorides affects only the loss of passivity of the steel. The corrosion process needs oxygen to be available for the cathodic reaction. Saturated concrete stifles the flow of the oxygen and so greatly reduces the rate of corrosion. The moisture state of concrete depends on the macroclimate and the microclimate of a particular element of the structure. In structures subject to tidal action, the microclimate depends on the relationship of each member to the fluctuating seawater level and, in particular, the amount of time it remains dry after inundation by seawater or spray.

Concrete that is continually submerged remains saturated and, in cold and temperate climates and even in hotter climates, regularly wetted and surface-dried concrete within the tidal range remains saturated and is less at risk from chloride-induced corrosion. 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:

- locations subject to annual changes in mean sea level and tidal range due to seasonal, barometric or other reasons;
- locations such as dry docks, locks, slipways;
- areas adjacent to bollards, mooring winches and salt-water hydrants;
- areas at and just above high water level, which are subject to splash and irregular inundation;
- concrete exposed to seawater conditions in bridge piers, and underground structures and tunnels;

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

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 B.1, which includes the assignment of XS exposure classes to enable durability design.

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. 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 B.1, other, more damaging, processes can occur. The zones most at risk, as itemized above, correspond with the latter situation.

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

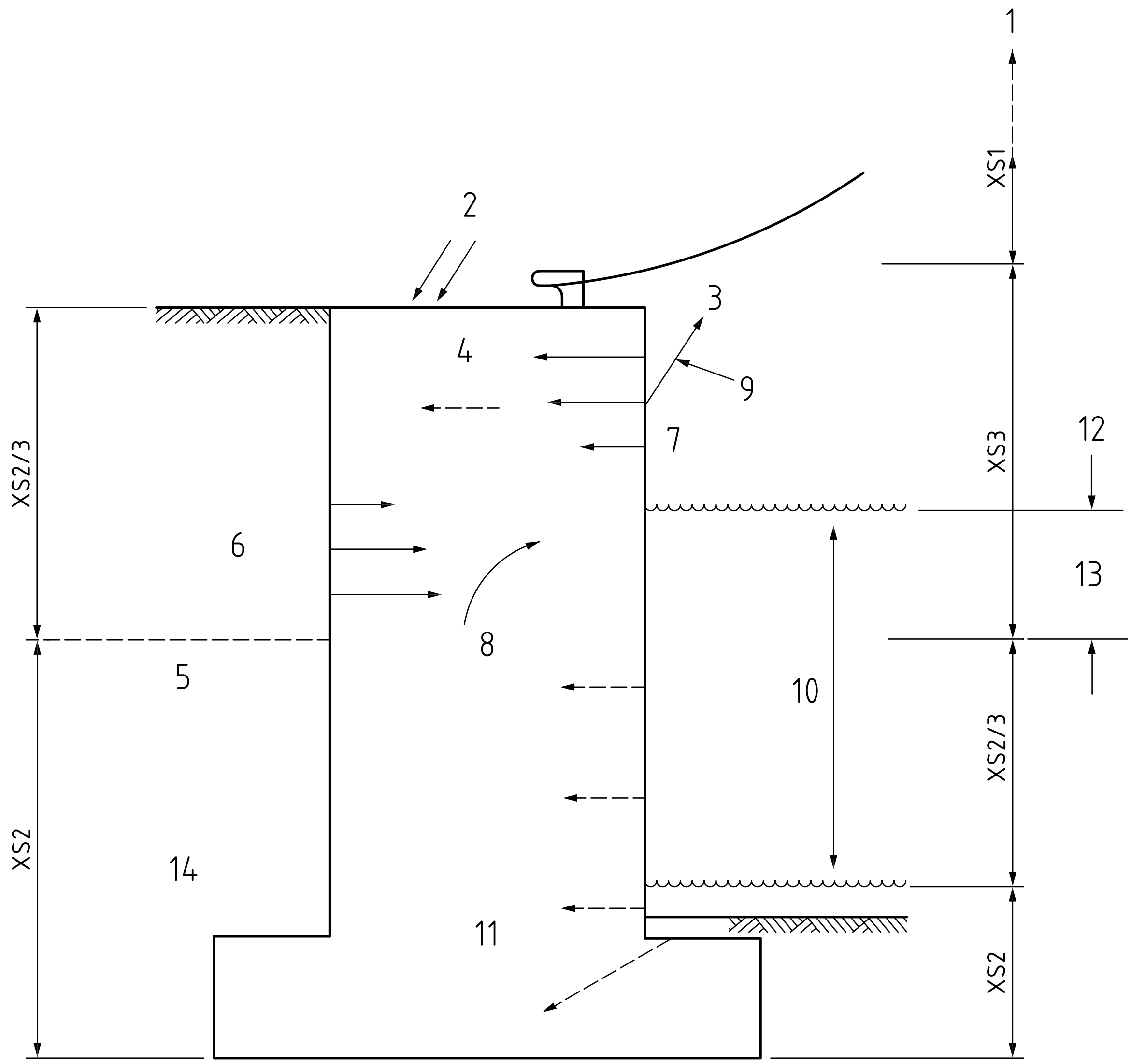
For more information on severity ratings and the assessment for site- and climate-specific environmental conditions, refer to *The design of coastal structures* [17].

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.

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.

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



Key

1 Airborne chlorides only (aerosol/mist – less than direct spray)

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

11 Diffusion of salt from seawater

12 Mean high water springs (MHWS)

13 Approximately one quarter of tidal range below MHWS

14 Permanently submerged

NOTE XS1 exposure class applies to elements not directly in a wetted zone, including superstructures and buildings adjacent to the coast.

Annex C (informative) Uses of bituminous materials

C.1 General

The choice of the various materials available for different maritime protection works is summarized in Table C.1.

Table C.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 sea-bed	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	—	Revetment and capping Grouting up stone	Moderately 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	—
Prefabricated 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 prefabricated 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

C.2 Revetments for dykes, closure dams, dunes and sea walls

These structures are listed in order of decreasing water-retaining function and increasing protective function against wave attack and scour. Asphaltic concrete and sand mastic grouted stones are extensively used for these structures; 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.

C.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.

C.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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