

BS 6349-1-4:2013

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Together with BS 6349-1-1, BS 6349-1-2 and BS 6349-1-3, this part of BS 6349 supersedes BS 6349-1:2000, which will be withdrawn when all four of the new subparts have been published.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

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.

- 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*

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.

- 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.

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 SO₃ 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, II/B 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	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA
0.50 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB
											IIB-V+SR (25% to 35% fly ash) ^{G)}
											IVB-V
											IIB-V with 21% to 24% fly ash ^{G)}
											CEM I
											CEM II/A-L(LL), II/A, II/B-S
XS2 – Submerged environment – permanently submerged											
C32/40	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 56% to 65% ggbs
0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB
											IIB-V+SR (25% to 35% fly ash) ^{G)}
C35/45	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 46% to 55% ggbs
0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IVB-V
C40/50	C35/45	C32/40	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 36% to 45% ggbs
0.40 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIB-V with 21% to 24% fly ash ^{G)}
											CEM I
											CEM II/A-L(LL), II/A, II/B-S
XS2/3 – Frequently wetted lower tidal, backfilled											
C40/50	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 46% to 65% ggbs
0.35 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB
											IIB-V+SR (25% to 35% fly ash) ^{G)}
											IVB-V
											IIIA with 36% to 45% ggbs
											IIB-V with 21% to 24% fly ash ^{G)}
											CEM I
											CEM II/A-L(LL), II/A, II/B-S

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/m ³) ^{D)}												Permissible cement and combination designations with additional restrictions (where appropriate)
Nominal cover, in millimetres ^{E)} , ^{F)}												
80 + 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	C32/40	C28/35	C28/35	C25/30	C25/30	C25/30	C20/25	C20/25	C20/25	IIIA with 56% to 65% ggbs	
	0.40 360	0.45 360	0.50 360	0.55 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB IIB-V+SR (25% to 35% fly ash) ^{G)}	
—	C40/50	C35/45	C32/40	C28/35	C25/30	C25/30	C25/30	C20/25	C20/25	C20/25	IIIA with 46% to 55% ggbs	
	0.35 360	0.40 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IVB-V	
—	—	C40/50	C35/45	C32/40	C28/35	C25/30	C25/30	C20/25	C20/25	C20/25	IIIA with 36% to 45% ggbs	
	—	0.35 360	0.40 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIB-V with 21% to 24% fly ash ^{G)}	
—	—	—	—	—	—	C40/50	C35/45	C35/45	C35/45	C32/40	CEM I	
	—	—	—	—	—	0.35 360	0.35 360	0.40 360	0.45 360	0.45 360	CEM II/A-L(LL), II/A, II/B-S	
Characteristic strength class: cylinder/cube (MPa). Lightweight aggregate concrete should conform to the equivalent strength classes.												
^{A)} Maximum free water/cement ratio in accordance with BS EN 206-1:2000.												
^{B)} 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.												
^{C)} Minimum cement content depends on maximum aggregate size (see Notes on Table 1, Table 2 and Table 3).												
^{D)} 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.												
^{E)} A dash (—) signifies that greater cover is recommended.												
^{F)} 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.												

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/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											
C35/45	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 36% to 65% ggbs
0.40 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB IIB-V+SR (25% to 35% fly ash) ^{G)} IVB-V
C40/50	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	IIB-V with 21% to 24% fly ash ^{G)}
0.35 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	CEM I
—	—	—	C40/50	C35/45	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	CEM II/A-L(LL), II/A, II/B-S
—	—	—	0.35 360	0.40 360	0.45 360	0.50 360	0.55 340	0.55 340	0.55 340	0.55 340	
XS2 – Submerged environment – permanently submerged											
—	C40/50	C35/45	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 46% to 65% ggbs
0.35 360	0.45 360	0.50 360	0.55 360	0.55 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB IIB-V+SR (25% to 35% fly ash) ^{G)} IVB-V
—	—	C35/45	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	C20/25	IIIA with 36% to 45% ggbs
0.40 360	0.45 360	0.50 360	0.55 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIB-V with 21% to 24% fly ash ^{G)}
—	—	—	—	—	—	C40/50	C35/45	C32/40	C32/40	C28/35	CEM I
—	—	—	—	—	0.35 360	0.40 360	0.45 360	0.40 360	0.45 360	0.50 360	CEM II/A-L(LL), II/A, II/B-S
XS2/3 – Frequently wetted lower tidal, backfilled											
—	—	C40/50	C35/45	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	C20/25	IIIA with 46% to 65% ggbs
0.35 360	0.40 360	0.45 360	0.50 360	0.55 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIIB IIB-V+SR (25% to 35% fly ash) ^{G)}
—	—	—	C40/50	C35/45	C32/40	C28/35	C25/30	C20/25	C20/25	C20/25	IIIA with 36% to 45% ggbs
0.35 360	0.40 360	0.45 360	0.50 360	0.55 360	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	0.55 340	IIB-V with 21% to 24% fly ash ^{G)}
—	—	—	—	—	—	—	—	C40/50	C35/45	C35/45	CEM I
—	—	—	—	—	—	—	—	0.35 360	0.40 360	0.40 360	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/m ³) ^{D)}											Permissible cement and combination designations with additional restrictions (where appropriate)
Nominal cover, in millimetres ^{E)} , ^{F)}											
80 + 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	II/A with 46% to 65% ggbs II/B with >66% ggbs II/B-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	II/A with 36% to 45% ggbs II/B-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	
Characteristic strength class: cylinder/cube (MPa). Lightweight aggregate concrete should conform to the equivalent strength classes.											
Maximum free water/cement ratio in accordance with BS EN 206-1:2000.											
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 II/B-V is deemed to contain 21% to 24% fly ash for the purposes of this table. The designation of II/B-V+SR contains 25% to 35% fly ash and is thus equivalent to a CEM II/B-V containing 25% to 35% fly ash as specified in BS EN 197-1.											

^{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.