How to design concrete structures using Eurocode 2

BS 8500 for building and civil structures

Introduction

BS 8500-1: Concrete – Complementary British Standard to BS EN 206[1] is the method of specifying concrete in the UK. It was first published in 2003 to align the specification, production and conformity of fresh concrete with BS EN 206[2]. This guide has been revised to coincide with the latest amendment of BS 8500, published in 2023. The most recent amendments are predominately concerned with increasing the range of cementitious materials, in particular the use of multi-component cements which have increased the range of lower carbon concretes now available.

Recommendations given in BS 8500-1 are deemed to satisfy the requirements for durability of concrete structures by using limiting values. These values are characteristic strength, minimum cement content and maximum free water/cement ratio and are based on the selected cover and exposure conditions.

This guide is intended to enable the designers of all types of building and civil structures to specify concrete effectively, efficiently and with confidence. It sets out the main requirements of BS 8500, however this guide is not a comprehensive method of specification and reference must be made to the full standard. Some clients and authorities may specify more onerous requirements for your project than those in BS 8500, and these should be followed accordingly.

Concrete design information

BS 8500 sets out five standard ways of specifying concrete. These are detailed within Table 1, providing a description of their applications.

Table 1: Standard methods for specifying concretes within BS 8500

Type of concrete specification	Description
Designated concrete	Designated concretes are types of designed concretes that allow the scope to be achieved using a range of predetermined mixes, where for a range of applications, the specifier only calls up the required designations e.g., FND2 is a concrete suitable for use in ground assessed as 'DC-2', Design Chemical Class 2. Similarly, RC28/35 is a designated concrete of C28/35 strength class suitable for example, for use in an internal suspended floor. Designated concretes can only be supplied by ready-mixed concrete producers who have third-party product conformity certification. A QSRMC or BSI Kitemark logo on the delivery ticket provides this confirmation. Designated concretes are not applicable for concrete which needs to resist the risk of corrosion of reinforcement by the ingress of chlorides, in such a situation, a designed concrete should be specified. The exception to this is PAV2 designated concrete which can be used for reinforced concrete paving applications subjected to deicing salts. Designated concretes are split into four main categories, as detailed below: ■ FND - Foundation applications ■ GEN - Concretes used for housing and non-structural building applications ■ PAV - Paving applications ■ RC - Reinforced concrete Whilst these concretes do not cover all building applications, they do offer a wide range of quality assured concretes that can be used in a vast array of scenarios.
Designed concrete	Designed concretes are for the informed specifier, where the designer considers all the requirements for the hardened concrete such as strength and durability to derive the necessary strength class and other properties such as cement type, minimum cement content and maximum water/cement ratio. Normally the designer will assess the exposure conditions and consider the recommendations set out in BS 8500-1 to determine the concrete properties and minimum cover to the reinforcement required to achieve the structural performance and service life. The flexibility of designed concretes makes them suitable for specifying concrete based on sustainability criteria, using lower carbon cements alongside other considerations such as the use of recycled or secondary aggregates. Once the designer has completed their sections of the specification, it is passed onto the contractor who then adds the requirements of the fresh concrete, such as consistence. The producer is then responsible for meeting the requirements of the specification through provision of the mix design.

Table 1: Standard methods for specifying concretes within BS 8500 continued

Type of concrete specification	Description
Prescribed concrete	Prescribed concretes allow the informed designer to specify concrete by prescribing the composition. This method is rarely used but is useful where a particular ratio of constituents is required, for example exposed aggregate concrete finishes. The term 'concrete mix' is sometimes used to refer to a prescribed concrete, but otherwise it should always be a 'concrete' that is specified.
Standardised prescribed concrete	Standardised prescribed concretes are intended for small building sites where concrete is either mixed by hand or in a small, less than 150 litres, concrete mixer. They are denoted ST, and have no requirement for strength demonstration, but BS 8500-1 provides some indicative values for the strength class that may be assumed for structural design. To ensure the ST concrete is safe for the indeterminate range of materials and site supervision, the prescribed cement content is very high. This results in ST concretes having a much higher embodied carbon value compared to designated concretes. Therefore, the use of ST concretes should be avoided where a ready-mixed concrete, either designated or designed, can be used.
Proprietary concrete	Proprietary concretes are developed by the producer and marketed based on their enhanced fresh or hardened properties. The producer will normally guarantee the performance of these products and provide test certificates. They may be covered by third party product conformity certification and are often used for high performance applications where the sustainability benefit is in the reduction in the total material volume used rather than the value per volume.

Exposure classification

The relevant exposure conditions should be identified early in the design process. In BS 8500-1, exposure classification is related to the deterioration processes of corrosion of reinforcement though carbonation (XC) or ingress of chlorides (XD or XS), chemical attack from aggressive ground (DC-class), cyclic freeze-thaw (XF) and chemical attack from sea water (XAS), see Table 2. These deterioration processes are sub-divided to represent different exposure conditions with examples given in the standard. The DC-class and XF exposure conditions can occur in combination with XD, XS and XC exposure classes. XD and XS exposure conditions normally occur in combination with XC exposure conditions.

Table 2: Exposure classes

Class	Class description	Informative example applicable to the United Kingdom
No risk of corrosion or attack (X0 class)		
X0	For concrete without carbon reinforcing steel or embedded metal: all exposures except where there is freeze-thaw, abrasion or chemical attack For concrete with carbon reinforcing steel or embedded metal: very dry	Unreinforced concrete surfaces inside structures. Unreinforced concrete completely buried in soil classed as AC-1 and with a hydraulic gradient not greater than 5. Unreinforced concrete permanently submerged in non aggressive water. Unreinforced concrete surfaces in cyclic wet and dry conditions not subject to abrasion, freezing or chemical attack. Concrete surfaces exposed to very dry conditions containing carbon steel reinforcement. Please note that the "very dry" exposure condition is unlikely to be found in the United Kingdom and so XC1 is the minimum recommended exposure class for carbon steel reinforced concrete.
Corrosion induced by carbonation (XC Classes)[A]) (where concrete containing carbon reinforcing steel or other embedded metal is exposed to air and moisture)		
XC1	Dry or permanently wet	Reinforced and prestressed concrete surfaces inside buildings with low air humidity. Reinforced and prestressed concrete surfaces inside enclosed civil engineering structures with low air humidity except voided superstructures. Reinforced and prestressed concrete surfaces permanently submerged in non aggressive water. Please note that leaching could occur due to long-term contact with water or other liquids and so consideration should be given as to whether the XC2 exposure class could be appropriate for permanently submerged elements.
XC2	Wet, rarely dry	Reinforced and prestressed concrete surfaces permanently in contact with soil not containing chlorides (i.e. not greater than 275 mg/l). For other situations see 'Aggressive Ground' section.
XC3 & XC4	Moderate humidity or cyclic wet and dry	External reinforced and prestressed concrete surfaces sheltered from, or exposed to, direct rain. Reinforced and prestressed concrete surfaces subject to high humidity (e.g. poorly ventilated bathrooms, kitchens). Reinforced and prestressed concrete surfaces exposed to alternate wetting and drying. Interior concrete surfaces of pedestrian subways not subject to de-icing salts, civil engineering voided superstructures or cellular abutments. Reinforced or prestressed concrete surfaces protected by waterproofing. Where the integrity of the waterproofing over the intended working life of the concrete surface it protects cannot be guaranteed or maintained then it may be prudent to assume XD1 or XS1 exposure class as appropriate.
Corrosion induced by chlorides other than from sea water (XD classes)[a]) (where concrete containing carbon reinforcing steel or other embedded metal liable to corrode is subject to contact with water containing chlorides, including de-icing salts, from sources other than from seawater)		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides. Reinforced and prestressed concrete supports more than 10 m but less than 12 m horizontally from a carriageway. Bridge deck soffits more than 5 m vertically above the carriageway. Parts of structures exposed to occasional or slight chloride conditions.

Table 2: Exposure classes continued

Class	Class description	Informative example applicable to the United Kingdom
XD2	Wet, rarely dry	Reinforced and prestressed concrete surfaces totally immersed in water containing chlorides[b)] Buried highway structures more than 1 m below adjacent carriageway[c)]
XD3	Cyclic wet and dry	Reinforced and prestressed concrete supports within 10 m horizontally of a carriageway. Bridge parapet edge beams and bridge parapets. Parts of bridge deck soffits 5 m or less above the carriageway. Other parts of bridge superstructures directly exposed to water containing chlorides. Buried highway structures less than 1 m below carriageway level. Reinforced pavements and car park slabs. Most external pavements and hardstandings are subject to XF4 exposure. See sections A.4.3 & A.4.4 of BS 8500 for further details.
Corrosion induced by chlorides from sea water (XS classes)[a)d)] (where concrete containing carbon reinforcing steel or other embedded metal liable to corrode is subject to contact with sea water or airborne salt originating from sea water)		
XS1	Exposed to airborne salt but not in direct contact with sea water	External reinforced and prestressed concrete surfaces in coastal areas closer than 100 m to the sea. An exposed structure further from the coast might also need to be considered as XS1 exposure.
XS2	Permanently submerged	Reinforced and prestressed concrete surfaces completely submerged or remaining saturated, e.g. concrete below mid tide level.[b)]
XS3[e)]	Tidal, splash and spray zones	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash and spray zones[f)], including exposed soffits above sea water.
Freeze-thaw attack (XF classes) (where concrete is exposed to significant attack from freeze-thaw cycles whilst wet)		
XF1	Moderate water saturation without de-icing agent	Vertical concrete surfaces such as façades and columns exposed to rain and freezing. Non vertical concrete surfaces not highly saturated, but exposed to freezing and to rain or water.
XF2	Moderate water saturation with de-icing	Concrete surfaces such as parts of bridges, which would otherwise be classified as XF1, but which are exposed to de-icing salts either directly or as spray or run off.
XF3	High water saturation without de-icing agent	Horizontal or near horizontal concrete surfaces, which are exposed to freezing whilst wet, such as parts of buildings where water accumulates and are exposed to freezing.
XF4[e)]	High water saturation with de-icing agent or sea water	Concrete surfaces subjected to frequent splashing with water and exposed to freezing. Horizontal concrete surfaces, such as roads and pavements, exposed to freezing and to de-icing salts either directly or as spray or run off. Concrete surfaces subjected to frequent splashing with water containing de-icing agents and exposed to freezing.
Chemical attack (XA classes) (where concrete is exposed to chemical attack)		
XA1	Slightly aggressive chemical environment	Concrete exposed to natural soil and ground water according to BS EN 206. These European exposure classes are not used in the UK where Table A.2 in BS 8500-1 shall be used to determine the ACEC class. See BRE Special Digest 1[4] for guidance on site investigation.
XA2	Moderately aggressive chemical environment	
XA3	Highly aggressive chemical environment	
Chemical attack from seawater (XAS classes) (where concrete is exposed to chemical attack from seawater)		
XAS[e)]	Exposed to seawater	Concrete surfaces in contact with seawater.

NOTES

a) The moisture condition relates to that in the concrete cover to reinforcement or other embedded metal but, in many cases, conditions in the concrete cover can be taken as being that of the surrounding environment. This might not be the case if there is a barrier between the concrete and its environment (see section on Cover to reinforcement or section A.3 in BS 8500-1).

b) Reinforced and prestressed concrete elements where one surface is immersed in water containing chlorides and another is exposed to air are potentially in a more severe exposure condition, especially where the dry side is at a high ambient temperature. Specialist advice should be sought where appropriate, to develop a specification that is appropriate to the actual conditions likely to be encountered

c) In deeply buried or fully submerged conditions, the availability of oxygen might not be sufficient to cause damage due to corrosion of reinforcement and so the depth at which this occurs can be assessed on a case-by-case basis.

d) The rate of ingress of chloride into the concrete depends on the concentration at its surface: brackish groundwater (chloride content less than 18 g/l) is less severe than exposure to sea water.

e) It is not normally necessary to classify the XF4 exposure classes to those parts of structures located in the United Kingdom which are in frequent contact with the sea.

f) Exposure XS3 covers a range of conditions. The most extreme conditions are in the spray zone. The least extreme is in the tidal zone where conditions can be similar to those in XS2. The recommendations given in this table take into account the most extreme conditions within this class.

Selecting concrete strength and cover

Having identified the relevant exposure condition(s), a recommended strength class and cover should be chosen. Table 6 (pages 6 and 7) indicates the nominal cover and limiting values required to meet common exposure conditions for intended working lives of at least 50 or 100 years; further explanation is given over the following pages. The recommended limiting values shown in Table 6 are to meet both of the assumed exposure conditions. For concrete exposed to more than one exposure condition, the most onerous of the limiting values are selected for the specification. The table does not cover all concrete exposure situations and reference should be made to BS 8500 for those cases not included. The cover may not be solely reliant on environmental conditions, for example fire or bond may be the governing factor.

Compressive strength

BS 8500 uses "compressive strength class" to define concrete strengths; the notation used gives the cylinder strength as well as the cube strength (see Figure 1). It is important to quote the compressive strength class in full to avoid confusion.

Figure 1: Explanation of the compressive strength class notation

Explanation of the compressive strength class notation			
C 'C' for normal weight concrete[a] 'LC' for lightweight concrete	40/ Cylinder strength[b]	50 Cube strength[c]	**a** Includes heavyweight concrete **b** Minimum characteristic cylinder (150 mm diameter by 300 mm) strength, MPa **c** Minimum characteristic cube (150 mm by 150 mm) strength, MPa

Cement and equivalent combinations explained

Portland cement is a factory produced material made from ground Portland cement clinker and is a main constituent of concrete. A cement producer my also combine Portland cement with other cementitious materials, such as GGBS or fly ash, to make different cement types such as Blast furnace cement or Portland fly ash cement.

Concrete producers may also combine 'additions' to Portland cement in the concrete mixer at the point of concrete production to make cements equivalent to those supplied from a cement works.

The production of Portland cement

There are four key stages in the production of cement:

1. Extraction and crushing/grinding of raw materials – the raw materials (e.g. limestone, chalk, clay and shale) are extracted by quarrying and are then crushed and ground to the required finess.
2. Blending of materials – the proportions of raw materials used are selected based on their mineral composition to ensure the resulting cement has the desired properties. These materials are blended and stored prior to the heating stage.
3. Heating the prepared raw materials in the kiln – The blended raw materials are heated to the point of liquefaction at about 1400°C – 1500°C in a rotary kiln, as this cools, a material called clinker is formed. It is a nodular in appearance, normally 3 mm - 25 mm in diameter and dark grey in colour.
4. Grinding the clinker and mixing with gypsum and other additions – the clinker is ground to a very fine powder with up to 5% gypsum to produce Portland cement. The gypsum is added to prevent flash setting of the cement when mixed with water to make concrete or mortar. Other additions such as fly ash or limestone fines may also be added to produce other cement types.

The term 'additions' refers to inorganic constituent material used in combination with cement to modify or improve concrete properties. Other terms are used to describe 'additions' such as 'supplementary cementitious materials' or 'cement replacements', however the term 'addition' is used within BS EN 206 and BS 8500. Examples of additions would be ground granulated blast-furnace slag (GGBS), fly ash or pigments used to alter the concrete's final colour.

BS EN 197[3], which is in a number of parts, is the UK implementation of the European standard for cement, and within the standard it covers six cement types designated with roman numerals I to VI, these are listed in Table 3. Except for CEM I and sulfate resisting cements CEM I-SR-0 to -SR 3, each has a range of allowable proportions and types of additions that define the cement type. The notes in Table 3 provide the nomenclature used for the different types of additions.

Table 3: Cement designations

Common cements	Type	Proportion of additions	Allowable additions
Portland cement	CEM I	-	
Portland-slag cement Portland-silica fume cement Portland-pozzolana cement Portland-fly ash cement Portland-burnt shale cement Portland-limestone cement Portland-composite cement	CEM II	A or B A or B A or B A or B A or B A or B A or B or C	S D P or Q V or W T L (or LL) M
Blast furnace cement	CEM III	A, B or C	S
Pozzolanic cement	CEM IV	A or B	P, Q or V
Composite cement (EN 197-1)	CEM V	A or B	S with P, Q or V[a)]
Composite cement (EN 197-5)	CEM VI	-	M

NOTE

The letters within the additions column in Table 3 reference the addition type which are; S – GGBS, D – silica fume, P – natural pozzolana, Q – natural calcined pozzolana, V – silicious fly ash, W – calcareous fly ash, T – burnt shale, L or LL – limestone fines and M – multicomponent cement consisting of clinker and two of the above additions.
a) CEM V is not listed as a general-purpose cement in BS 8500-2:2023, Table 1, but is included here for completeness.

The range of allowable proportions A, B and C differs by cement type as shown in Table 4.

Table 4: Proportions of additions

Proportion	CEM II	CEM III	CEM IV	CEM V[a)]
A	6 - 20	36 - 65	11 - 35	36 - 60
B	21 - 35	66 - 80	36 - 55	62 - 80
C	36 - 50	81 - 95		

a) CEM V is not listed as a general-purpose cement in BS 8500-2:2023, Table 1, but is included here for completeness.

Cements are produced at a factory and delivered to the producer whereas a combination is made by the concrete producer by combining cements and additions in the concrete mixer. These are denoted "C" instead of "CEM" but follow the same nomenclature as the cements. See Table 5 for examples of cement type and equivalent combination.

Table 5: Cement and equivalent combination nomenclature examples

CEMENT					COMBINATION			
CEM	III	/A		=	C	III	A	
CEM	II	/B	-V	=	C	II	B	-V
'CEM' for cement	Cement or combination type	Proportion of addition	Addition type		'C' for combination	Cement or combination type	Proportion of addition	Addition type

Cements that have sulfate resistance have additional notation "SR" and so, for example, a CEM III/A that meets the requirements for sulfate resistance is denoted CEM III/A + SR.

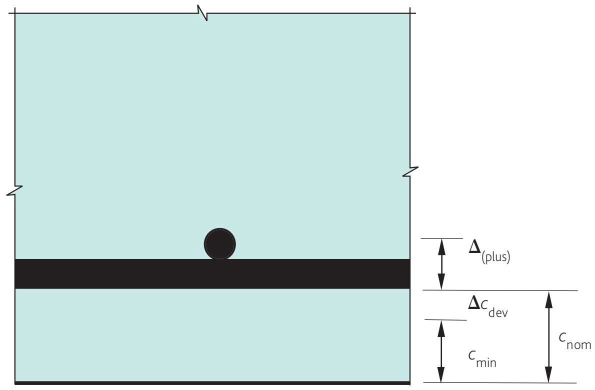
Cover to reinforcement

The durability guidance given in BS 8500-1 assumes that the minimum cover for durability is achieved. An allowance should be made in the design for deviations from the minimum cover (Δc_{dev}). This should be added to the minimum cover to obtain the nominal cover.

BS 8500 indicates that Δc_{dev} will typically be in the range of 5 to 15 mm; however, Eurocode 2[5] recommends that Δc_{dev} is taken as 10 mm, unless the fabrication is subjected to an agreed quality assurance system where it is permitted to reduce Δc_{dev} to 5 mm, or 0 mm if the element can be rejected if it is out of tolerance (e.g. precast elements).

The nominal cover, c_{nom}, should be used to determine the position of the reinforcement for structural design. It is also the cover that should be specified on the drawings for the position of the reinforcement. The specification for the project should advise the permissible construction tolerances. The permitted deviation of the reinforcing bar towards the surface of the concrete should not exceed Δc_{dev} and in civil engineering structures permitted deviation away from the surface of the concrete ($\Delta_{(plus)}$) should also be specified. There is no guidance given in either Eurocode 2 or BS 8500, but Figure 2 provides the recommendations based on BS EN 13670: Execution of concrete structures.

Figure 2: Permitted deviations



Notes

c_{min}	=	Minimum cover
Δc_{dev}	=	Allowance made in design for deviation (towards face of concrete)
c_{nom}	=	$c_{min} + \Delta c_{dev}$ = nominal cover
$\Delta_{(plus)}$	=	Permitted deviation (away from face of concrete) – see below
h	=	Height of cross-section

Cross-section dimension (mm)	$\Delta_{(plus)}$ (mm)
h ≤ 150	10
150 < h < 2500	15
h ≥ 2500	20

The minimum allowance for deviation, Δc_{dev}, should be 50 mm for concrete cast directly against the earth and 15 mm for concrete cast against blinding. For concrete initially cast against formwork before coming into contract with the ground this allowance is typically 5 mm to 15 mm. Where the ground contains chlorides, the nominal cover should comprise the recommended minimum cover for the associated XD or XS class plus an allowance for deviation Δc_{dev}, and the more onerous limiting values for the concrete should be selected.

Service life

Tables A.4 and A.5 in BS 8500 give recommended limiting values for durability of concrete containing carbon reinforcing steel or prestressed elements with an intended working life of 50-years or 100-years. However, for many buildings it is common for project specifications to adopt a 60-year life span. Whilst this is outside the scope of BS 8500, there are some scenarios, for example internal concrete structures, which can meet a 60-year working life with little or no additional design or resource requirements. This is because the mix design and cover recommendations for concrete containing carbon reinforcing steel or prestressed structural elements in an internal environment of a building are mostly the same for a predicted durability of both 50- and 100-year working lives. For extended or more specific working life requirements in other exposure conditions specialist durability modelling can be undertaken.

Some major infrastructure clients have their own technical standards covering the use of concrete. These standards may provide recommendations on use of concrete with working lives outside the scope of BS 8500.

Table 6: Selected recommendations for normal weight reinforced concrete quality for combined exposure classes and cover to reinforcement for either at least a 50-year or 100-year intended working life and 20 mm aggregate size.

Exposure conditions			Combined performance category	Minimum strength class, minimum cement or combination, maximum w/c ratio										
Typical example	Primary	Secondary		At least 50-year working life										
				Nominal cover to reinforcement[d]										
				15 +Δc_{dev}	20 +Δc_{dev}	25 +Δc_{dev}	30 +Δc_{dev}	35 +Δc_{dev}	40 +Δc_{dev}	45 +Δc_{dev}	50 +Δc_{dev}	55 +Δc_{dev}	60 +Δc_{dev}	65 +Δc_{dev}
Internal elements or permanently wet elements	XC1	-	All	C20/25, 200	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Buried concrete in DC–1 ground conditionse	XC2	DC-1	All	-	-	C25/30, 200	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Vertical surface protected from direct rainfall	XC3/4	-	All	-	C50/60, 200	C45/55, 200	C40/50, 200	C35/45, 200	<<<	C32/40, 200	C30/37, 200	C28/35, 200	<<<	C25/30, 200
Vertical surface exposed to rain and freezing		XF1	All	-	-	-	C40/50, 280, 0.6	C35/45, 280, 0.6	<<<	C32/40, 280, 0.6	C30/37, 280, 0.6	C28/35, 280, 0.6	<<<	<<<
Exposed horizontal surfaces		XF3	All except E4	-	-	-	C40/50, 340, 0.45	<<<	<<<	<<<	<<<	<<<	<<<	<<<
		XF3 (air entrained)	All except E4	-	-	-	C40/50, 280, 0.6	C35/45, 280, 0.6	<<<	C32/40, 280, 0.6	C30/37, 280, 0.6	C28/35, 280, 0.6	<<<	<<<
Elements subject to airborne chlorides protected from direct rainfall	XD1[f]	XF1	All	-	-	C45/55, 360, 0.45	C40/50, 320, 0.55	C35/45, 300, 0.6	<<<	C32/40, 300, 0.6	C30/37, 300, 0.6	C28/35, 300, 0.6	<<<	<<<
Exposed vertical surfaces near coast	XS1[f]	XF1	A1, B1, C1, D1, G1	-	-	-	-	-	-	C32/40, 380, 0.35	C30/37, 380, 0.4	C28/35, 360, 0.45	C28/35, 340, 0.5	<<<
			A2, D2	-	-	-	C40/50, 380, 0.35	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320,0.55	C30/37, 320, 0.55	C25/35, 320, 0.55	<<<	<<<
			A3, A4, D3, E4, F4	-	-	-	C40/50, 380, 0.4	C35/45, 340, 0.5	C35/45, 320, 0.55	C32/40, 320, 0.55	C30/37, 320, 0.55	C25/35, 320, 0.55	<<<	<<<
Exposed horizontal surfaces near coast		XF3	A1, B1, C1, D1, G1	-	-	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<
			A2, D2	-	-	-	C40/50, 380, 0.35	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<	<<<	<<<
			A3, A4, D3, E4, F4	-	-	-	C40/50, 380, 0.4	C40/50, 340, 0.45	<<<	<<<	<<<	<<<	<<<	<<<
		XF3 (air entrained)	A1, B1, C1, D1, G1	-	-	-	-	-	-	C32/40, 380, 0.35	C30/37, 380, 0.4	C28/35, 360, 0.45	C28/35, 340, 0.5	C25/30, 320, 0.55
			A2, D2	-	-	-	C40/50, 380, 0.35	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320, 0.55	C30/37, 320, 0.55	C25/35, 320, 0.55	<<<	C25/30, 320, 0.55
			A3, A4, D3, E4, F4	-	-	-	C40/50, 380, 0.4	C35/45, 340, 0.5	C35/45, 320, 0.55	C32/40, 320, 0.55	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	C25/30, 320, 0.55
Buried highways more than 1 m below adjacent carriageway	XD2[f]	-	All	-	-	-	C40/50, 380, 0.4	C35/45, 340, 0.5	C35/45, 320, 0.55	C32/40, 320, 0.55	C30/37, 320, 0.55	C25/35, 320, 0.55	<<<	C25/30, 320, 0.55
Elements permanently submerged, e.g. below mid-tide level	XS2[f]	-	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	-	-	C28/35, 380, 0.35	C25/30, 380, 0.4
		-	A2, D2	-	-	-	-	-	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 340, 0.5	C28/35, 320, 0.55	<<<	C25/30, 320, 0.55
		-	A3, A4, D3, E4, F4	-	-	-	-	C35/45, 380, 0.35	C35/45, 360, 0.45	C32/40, 340, 0.5	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	C25/30, 320, 0.55
Elements subject to moderate water saturation de-icing agent and freezing	XD3[f]	XF2	A1, B1, C1, D1, G1	-	-	-	-	-	C35/45, 380, 0.35	C32/40, 380, 0.4	C30/37, 360, 0.45	C28/35, 360, 0.45	<<<	<<<
			A2, A3, D2, D3	-	-	-	-	-	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	<<<
			A4, E4, F4	-	-	-	-	-	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	<<<
Elements subject to water saturation with de-icing agent and freezing		XF4	A1, B1, C1, D1, G1	-	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C40/50, 360, 0.45	<<<	<<<	<<<
			A2, A3, D2, D3	-	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<
			A4, E4, F4	-	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<
		XF4 (air entrained)	A1, B1, C1, D1, G1	-	-	-	-	-	C35/45, 380, 0.35	C32/40, 380, 0.4	C30/37, 360, 0.45	C28/35, 360, 0.45	<<<	<<<
			A2, A3, D2, D3	-	-	-	-	-	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	<<<
			A4, E4, F4	-	-	-	-	-	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 320, 0.55	C28/35, 320, 0.55	<<<	<<<
Elements in tidal, splash and spray zones	XS3	-	A2, D2	-	-	-	-	-	-	-	C30/37, 380, 0.35	C28/35, 380, 0.4	C28/35, 360, 0.45	C25/30, 340, 0.5
			A3, A4, D3, E4, F4	-	-	-	-	-	-	C32/40, 380, 0.35	C30/37, 360, 0.45	C28/35, 340, 0.5	C28/35, 320, 0.55	C25/30, 320, 0.55

Exposure conditions			Combined performance category	Minimum strength class, minimum cement or combination, maximum w/c ratio											
Typical example	Primary	Secondary		At least 100-year working life											
				Nominal cover to reinforcement[d]											
				$20 + \Delta c_{dev}$	$25 + \Delta c_{dev}$	$30 + \Delta c_{dev}$	$35 + \Delta c_{dev}$	$40 + \Delta c_{dev}$	$45 + \Delta c_{dev}$	$50 + \Delta c_{dev}$	$55 + \Delta c_{dev}$	$60 + \Delta c_{dev}$	$65 + \Delta c_{dev}$	$70 + \Delta c_{dev}$	$75 + \Delta c_{dev}$
Internal elements or permanently wet elements	XC1	-	All	C20/25, 200	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Buried concrete in DC–1 ground conditions[e]	XC2	DC-1	All	C28/35, 200	<<<	C25/30, 200	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Vertical surface protected from direct rainfall	XC3/4	-	All	-	C50/60, 200	C45/55, 200	<<<	C40/50, 200	<<<	C35/45, 200	<<<	C32/40, 200	C30/37, 200	<<<	C28/35, 200
Vertical surface exposed to rain and freezing		XF1	All	-	C50/60, 280, 0.6	C45/55, 280, 0.6	<<<	C40/50, 280, 0.6	<<<	C35/45, 280, 0.6	<<<	C32/40, 280, 0.6	C30/37, 280, 0.6	<<<	C28/35, 200
Exposed horizontal surfaces		XF3	All except E4	-	C50/60, 340, 0.45	C45/55, 340, 0.45	<<<	C40/50, 340, 0.45	<<<	<<<	<<<	<<<	<<<	<<<	<<<
		XF3 (air entrained)	All except E4	-	C50/60, 280, 0.6	C45/55, 280, 0.6	<<<	C40/50, 280, 0.6	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Elements subject to airborne chlorides protected from direct rainfall	XD1[f]	XF1	All	-	-	C45/55, 380, 0.4	C45/55, 360, 0.45	C40/50, 340, 0.5	C40/50, 320, 0.55	C35/45, 300, 0.6	<<<	<<<	<<<	<<<	<<<
Exposed vertical surfaces near coast	XS1[f]	XF1	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	-	-	C30/37, 380, 0.35	C30/37, 380, 0.4	C28/35, 380, 0.45
			A2, D2	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
			A3, A4, D3, E4, F4	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C35/45, 340, 0.5	C35/45, 320, 0.55	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
Exposed horizontal surfaces near coast		XF3	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C40/50, 380, 0.45
			A2, D2	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<	<<<
			A3, A4, D3, E4, F4	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<	<<<	<<<
		XF3 (air entrained)	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	-	-	C30/37, 380, 0.35	C30/37, 380, 0.4	C28/35, 380, 0.45
			A2, D2	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
			A3, A4, D3, E4, F4	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C35/45, 340, 0.5	C35/45, 320, 0.55	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
Buried highways more than 1 m below adjacent carriageway	XD2[f]	-	All	-	-	-	-	C40/50, 360, 0.45	C40/50, 340, 0.5	C35/45, 320, 0.55	<<<	C32/40, 320, 0.55	<<<	C30/37, 320, 0.55	C28/35, 320, 0.55
Elements permanently submerged, e.g. below mid-tide level	XS2[f]	-	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	-	-	-	-	-
		-	A2, D2	-	-	-	-	-	C40/50, 380, 0.35	C35/45, 380, 0.35	C35/45, 380, 0.4	C32/40, 360, 0.45	C30/37, 340, 0.5	<<<	C28/35 , 340, 0.5
		-	A3, A4, D3, E4, F4	-	-	-	-	-	C40/50, 380, 0.35	C35/45, 380, 0.4	C35/45, 360, 0.45	C32/40, 340, 0.5	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
Elements subject to moderate water saturation de-icing agent and freezing	XD3[f]	XF2	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	C435/45, 380, 0.35	C32/40, 380, 0.4	<<<	C30/37, 360, 0.45	C28/35, 360, 0.45
			A2, A3, D2, D3	-	-	-	-	-	C40/50, 380, 0.35	C35/45, 380, 0.4	C35/45, 360, 0.45	C32/40, 340, 0.5	C30/37, 340, 0.5	C30/37, 320, 0.55	C28/35, 360, 0.45
			A4, E4, F4	-	-	-	-	-	C40/50, 380, 0.4	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.55
Elements subject to water saturation with de-icing agent and freezing		XF4	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	C40/50, 380, 0.35	C340/50, 380, 0.4	<<<	C40/50, 360, 0.45	<<<
			A2, A3, D2, D3	-	-	-	-	-	C40/50, 380, 0.35	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<
			A4, E4, F4	-	-	-	-	-	C40/50, 380, 0.4	C40/50, 360, 0.45	C40/50, 340, 0.45	<<<	<<<	<<<	<<<
		XF4 (air entrained)	A1, B1, C1, D1, G1	-	-	-	-	-	-	-	C35/45, 380, 0.35	C32/40, 380, 0.4	C30/37, 380, 0.4	C30/37, 360, 0.45	C28/35, 360, 0.45
			A2, A3, D2, D3	-	-	-	-	-	C40/50, 380, 0.35	C35/45, 380, 0.4	C35/45, 360, 0.45	C32/40, 340, 0.5	C30/37, 340, 0.5	C30/37, 320, 0.55	C28/35, 320, 0.55
			A4, E4, F4	-	-	-	-	-	C40/50, 380, 0.4	C35/45, 360, 0.45	C35/45, 340, 0.5	C32/40, 320, 0.55	C30/37, 320, 0.55	<<<	C28/35, 320, 0.56
Elements in tidal, splash and spray zones	XS3	-	A2, D2	-	-	-	-	-	-	-	-	-	C30/37, 380, 0.35	C30/37, 380, 0.4	C28/35, 360, 0.45
			A3, A4, D3, E4, F4	-	-	-	-	-	-	-	-	C32/40, 380, 0.35	C30/37, 380, 0.4	C30/37, 360, 0.45	C28/35, 320, 0.55

Note: for XC classes for resistance to corrosion due to carbonation, the characteristic strength limiting value is at 28 days. For strength specification at greater than 28-days, such as at 56-days, the characteristic strength that this concrete will achieve at 28 days should be used as the value to assess cover. **Further Notes on Table 6 appear overleaf.**

TABLE 6 NOTES

a) This Table comprises a selection of common exposure class combinations. Requirements for other sets of exposure classes, e.g. XD2, XS2 and XS3 should be derived from BS 8500-1:2023, Annex A.

b) See Table 7.

c) For prestressed concrete the minimum strength class should be C28/35.

d) Δc_{dev} is an allowance for deviations.

e) For sections less than 140 mm thick, refer to BS 8500.

f) Freeze-thaw resisting aggregates should be specified.

g) Air-entrained concrete is required.

h) Option may not be suitable for areas subject to severe abrasion.

j) In some parts of the UK it is not possible to produce a practical concrete with a maximum w/c of 0.35.

k) Within BS 8500:2023 tables A.4a & A.5a, XC (corrosion induced by carbonation) classes only use strength as a limiting value. The minimum cement or combination content for any XC class should not be less than 200kg/m³. In the 2023 revision for BS 8500, some of the nominal cover requirements associated with a corresponding minimum strength class in a XC exposure class are different from the previous version. Therefore those designing the structure should use the updated values in BS 8500:2023.

l) Within BS 8500:2023 tables A.4b, A.4c, A.5b & A.5c, XD (corrosion induced by chlorides other than from sea water) & XS (corrosion induced by chlorides from sea water) classes only use maximum w/c ratio and minimum cement or combination content as the limiting values. The recommended minimum compressive strength class of normal and heavy-weight concrete containing embedded steel is C20/25 or C20/22 for lightweight concrete.

Cement types and minimum cement content

Table 7 may be used to understand the cement/combination designations. It should be noted from Table 6 that the limiting values may vary depending on the cement type used. BS 8500-1 uses combined performance categories to group cements/combinations based on their performance. Table 7 is to be read in conjunction with Table 6 to understand which cements/combinations are suitable based on the defined exposure conditions. Cements/combinations can include Portland cement, ground granulated blast-furnace slag (ggbs), fly ash, pozzolana, limestone or a combination of components.

Specifiers should avoid specifying particular cements/combinations, and where possible, use the combined performance category, as most concrete plants will not stock all cementitious materials. Also, not restricting cement types will also allow suppliers to provide the lowest carbon option. As clinker is the principle constituent material controlling the embodied carbon emissions of concrete, it is key that close consideration should be given to the Portland cement content, whilst also considering the functional design, construction practice requirements and ultimate fitness for purpose. Understanding the options available during the design process will help ensure the concrete meets the technical requirements whilst achieving the lowest embodied carbon concrete. It is also worth noting that when using a designated concrete, it is not necessary to specify the types of cement/combinations.

Table 7: Cement and combination type by combined performance

Combined Performance Category	Cement or equivalent combination	BS EN 197-1 or BS EN 197-5 cement notation	Equivalent combination notation	Additional requirement for composition
A1	Portland Cement	CEM I	-	
	Portland-slag cement	CEMII/A-S	CIIA-S	
		CEM II/B-S	CIIB-S	
A2	Portland fly ash cement	CEM II/B-V	CIIB-V	
	Blast furnace cement	CEM III/A	CIIIA	
A3	Blast furnace cement	CEM III/A	CIIIA	S≥46%
A4	Blast furnace cement	CEM III/B	CIIIB	
B1	Portland limestone cement, >42.5	CEM II/A-L	CIIA-L	
	Portland composite cement, >42.5	CEM II/A-M (S-L)[a]	CIIA-SL	
B2	Portland composite cement, >42.5	CEM II/B-M (S-L)[a]	CIIB-SL	S≥25%
C1	Portland limestone cement, 32.5	CEM II/A-L	CIIA-L	
D1	Composite cement to BS EN 197-5	CEM VI (S-L)[a]+SR[b]	CVI-SL+SR	S≥36%
D2	Portland fly ash cement	CEM II/B-V+SR	CIIB-V+SR	V≥25%
	Portland composite cement to BS EN 197-5	CEM II/C-M (S-L)[a]+SR[b]	CIIC-SL+SR	S≥36%
	Blast furnace cement	CEM III/A+SR[b]	CIIIA+SR	
D3	Blast furnace cement	CEM III/A+SR[b]	CIIIA+SR	S≥46%
	Composite cement to BS EN 197-5	CEM VI (S-L)[a]+SR[a)b)]	CVI-SL+SR	S≥46%
F4	Blast furnace cement	CEM III/B+SR[b]	CIIIB+SR	

NOTE

a) When more than one addition is listed e.g. CEM II/A-M (S-L) or CIIA-SL, the addition listed first has the higher proportion included.

b) Where the alumina content of the slag exceeds 14%, the tricalcium aluminate content of the Portland cement fraction or the Portland limestone cement fraction shall not exceed 10%.

Freeze-thaw resistance

Freeze-thaw can be achieved by air entrainment or by specifying a higher strength concrete. Where air entrainment is required for exposure classes XF3 and XF4 the minimum air content by volume of 4.0%, 4.5%, 5.5% or 6.5% should be specified for 40 mm, 20 mm, 14 mm and 10 mm maximum aggregate size respectively.

For exposure conditions XF3 and XF4 freeze-thaw resisting aggregates should be specified. The producer is then obliged to conform to the requirements given in BS 8500–2, Cl.4.3.

Aggressive ground

Where plain or reinforced concrete is in contact with the ground further checks are required to ensure durability. An aggressive chemical environment for concrete class (ACEC class) should be assessed for the site. BRE Special Digest 1[4] gives guidance on the assessment of the ACEC class, and this is normally carried out as part of the interpretive reporting for a ground investigation. Knowing the ACEC class, a design chemical class (DC class) can be obtained from Table 8. In general, fully buried concrete in the UK need not be designed to be freeze-thaw resisting.

For designated concretes, an appropriate foundation concrete (FND designation) can be selected using Table 9; the cover should be determined from Table 6 for the applicable exposure classes. A FND concrete has the strength class of C25/30, therefore, where a higher strength is required either for its strength or where the foundation is classified as XD2 or XD3, a designed concrete should be specified. For designed concretes, the concrete producer should be advised of the DC-class, not the ACEC class, as this does not provide sufficient information for the producer to design the correct concrete.

Table 8: Selection of the DC–class and the number of additional protection measures (APMs) where the hydrostatic head of groundwater is not more than five times the section width[a]

ACEC-class (aggressive chemical environment for concrete class)	DC–class		
	Intended working life		Combined Performance Category[a]
	At least 50 years	At least 100 years	
AC-1s, AC-1	DC-1 (RC25/30 if reinforced)	DC-1 (RC25/30 if reinforced)	All
AC-2s, AC-2	DC-2 (FND2)	DC-2 (FND2)	A1, A2, A3, A4, B1, C1, D1, D2, D3, E4, F4
AC-2z	DC-2z (FND2Z)	DC-2z (FND2Z)	All
AC-3s	DC-3 (FND3)	DC-3 (FND3)	D1, D2, D3, E4, F4, G1
AC-3z	DC-3z (FND3Z)	DC-3z (FND3Z)	All
AC-3	DC-3 (FND3)	DC-3 + one APM of choice FND3 + one APM of choice DC-4 or FND4	D1, D2, D3, E4, F4, G1
AC-4s	DC-4 (FND4)	DC-4 (FND4)	D1, D2, D3, E4, F4, G1
AC-4z	DC-4z (FND4Z)	DC-4z (FND4Z)	All
AC-4	DC-4 (FND4)	DC-4 + one APM from APM 2 to APM5 FND4 + one APM from APM2 to APM5	D1, D2, D3, E4, F4, G1
AC-4ms	DC-4m (FND4M)	DC-4m (FND4M)	F4
AC-4m	DC-4m (FND4M)	DC-4m + one APM from APM 2 to APM5 FND4M + one APM from APM2 to APM5	F4
AC-5z	DC-4z (FND4Z) + APM3	DC-4z (FND4Z) + APM3	All
AC-5	DC-4 (FND4) + APM3	DC-4 (FND4) + APM3	D1, D2, D3, E4, F4, G1
AC-m	DC-4m (FND4M) + APM3	DC-4m (FND4M) + APM3	F4

NOTE

a) When specifying concrete for DC-class conditions, refer to table A.12 in BS 8500-1 for the combined performance category available in relation to the provided limiting values.

b) APM is additional protective measure. Refer to BS 8500-1:2023 Table A.11 for the different APMs available.

Table 9: Guidance on selecting designated concrete for reinforced concrete foundations

DC-Class	Appropriate designated concrete
DC–1	RC25/30
DC–2	FND2
DC–2z	FND2z
DC–3	FND3
DC–3z	FND3z
DC–4	FND4
DC–4z	FND4z
DC–4 m	FND4 m
Note Strength class for all FND concrete is C25/30.	

Water resisting concrete

If control of shrinkage is of importance, this should be discussed with the concrete supplier to optimise the mix design to minimise shrinkage.

Fire design

Having selected concrete cover and strength to meet the durability recommendations of BS 8500, the nominal cover should be checked in accordance with Eurocode 2, for the minimum axis distance required for fire resistance.

Abrasion

BS 8500 does not contain abrasion classes; Table 10 identifies the criteria set out in EN 1992-1-1:2023 Table 6.1 which holds exposure class XM pertaining to mechanical attack of concrete by abrasion. Table 11 summarises the factors which affect the abrasion resistance of floors, but for further information reference can be made to BS8204-2[6] and Concrete Society Technical Report 34[8].

Table 10: Additional cover requirements for floors subject to abrasion as per EN 1992-1-1:2022

Exposure Class	Description of the environment	Informative example for the United Kingdom	UK requirement for additional cover $\Delta c_{dur,abr}$
XM1	Moderate Abrasion	Industrial sites frequented by vehicles with pneumatic tires	+5 mm
XM2	Heavy Abrasion	Industrial sites frequented by forklifts with pneumatic or soli rubber tires	+10 mm
XM3	Extreme Abrasion	Industrial sites frequented by forklifts with elastomer or steel tyres or track vehicles	+15 mm

Table 11: Factors affecting the abrasion resistance of concrete floors

Factor	Effect
Power floating	Power finishing and, in particular, repeated power trowelling is a significant factor in creating abrasion resistance, however, excessive repetitions of the process do not necessarily further enhance performance.
Curing	Prompt and efficient curing is essential in order to retain sufficient water in the surface zone to complete hydration and the development of concrete strength at and close to the surface.
Cement content	Cement content should not be less than 325 kg/m^3. Cement contents above 360 kg/m^3 are unlikely to enhance abrasion resistance and excessive cement content can impair the power finishing process.
Water/ cement ratio	Water/cement ratio is of great importance. It should not exceed 0.55. Reducing to 0.50 is likely to increase abrasion resistance but lowering further is unlikely to give further enhancement.
Aggregates	Coarse aggregate usually has no direct effect on abrasion resistance, except in floors in very aggressive environments where the surface is expected to be worn away. Coarse and fine aggregates should not contain soft or friable materials.
Dry shake finishes	Dry shake finishes can be used to enhance the surface properties in high abrasion locations.

Abrasion due to the action of the sea on the concrete sea defences is outside the scope of this guide.

Recycled aggregates

BS 8500 permits the use of coarse Recycled Aggregate (RA) and coarse Crushed Concrete Aggregate (CCA) in concrete, providing certain quality and performance criteria are met. RA is aggregate resulting from the reprocessing of inorganic material previously used in construction, while CCA principally comprises crushed concrete. Due to the uncertainty around the use of coarse RA based on the wide potential composition of the aggregates, BS 8500 highlights that the requirements for specified in BS 8500-2 are insufficient to form an adequate specification. Therefore, these requirements should be assessed on a case-by-case basis considering the specific composition of the RA. BS 8500-1:2023 Clause A.7.10.1 provides further details on this.

Clauses 4.3.7 and 4.3.8 of BS 8500-2:2023 and clause A.7.10 of BS 8500-1:2023 provide guidance on coarse RA and coarse CCA use in designated concrete, as shown in Table 12.

Table 12: Designated concrete - allowable percentage of coarse CCA and RA

Designated Concrete	Allowable CCA and RA as a percentage of coarse aggregate
GEN0 to GEN3	100%
RC20/25 to RC40/50	20%*
RC40/50XF	0%
PAV1 & PAV2	0%
FND2 to FND4	0%

*Except where the specification allows higher proportions to be used.

Note: On larger contracts an increased % coarse CCA can achieve the concrete specification, this is usually demonstrated based on proving trials or the experience of the specifier.

Since the amount of recycled content permissible in a mix varies between different designations it follows that the opportunity for including recycled aggregates varies between concrete uses. For example, 100% is allowable in GEN1, used for many reinforced foundations.

Coarse CCA and coarse RA is also permitted in designed concrete, although no direct guidance is given on limiting proportions. BS 8500-2 does however provide guidance on limiting concrete strength and exposure classes for coarse CCA and coarse RA use, as shown in Table 13.

Table 13: Permitted use of coarse CCA in designed concretes

Exposure	Use of coarse CCA and coarse RA permitted
X0	Yes
XC1, XC2 & XC3/4	Yes
XD1	Yes
XD2 & XD3	Possibly*
XS1, XS2 & XS3	Possibly*
XF1	Yes
XF2, XF3 & XF4	Possibly*
DC-1	Yes
DC-2, DC-3 & DC-4	Possibly*

*Coarse CCA and coarse RA may be used if it can be demonstrated that it is suitable for the exposure condition. This is carried out via testing to prove the resistance to freezing and thawing (and possibly to chloride ingress) or a proven history of use (10 years+) with no issues.

Note: The maximum strength class should be C40/50, unless the material is coarse CCA that has come from previously unused concrete of known composition, for example from a precast factory.

Provisions for the use of fine CCA and fine RA are not given in BS 8500, but this does not preclude their use when it is demonstrated that, due to the source of material, or verified via testing, significant quantities of deleterious materials are not present, and their use has been agreed.

Constraining factors for the use of CCA and RA include consistency of supply and the original source. Due to their inherent variability, testing regimes for quality control of the RA or CCA aggregates may need to be more rigorous than for natural/primary aggregates.

Specification

Method of specifying

There are various methods of specifying concrete to BS 8500 (see Table 1). The most popular are designated and designed. BS 8500 also includes ‘proprietary concrete’.

There are examples below showing schedules for the specification of designated and designed concretes as shown in the NSCS[9] (for buildings) and Appendix 17/1 from the manual of contract documents for highway works.

The specifier

In EN 206 the ‘specifier’ is defined as the person or body responsible for establishing the specification for fresh and hardened concrete properties. The specification is final compilation of the documented technical requirements of all parties which is then given to the producer.

As the specifier will normally be the purchaser of the concrete, the designer of the structure will need to ensure their requirements are incorporated into the specification. This will normally be through their own specification for the works (e.g. with the NSCS/Manual of contract documents for Highway Works). The specifier may include the designer’s specification into the technical requirements or extract the required information before giving to the producer. Figures 5, 6 and 7 have been annotated to indicate which information is typically provided by the designer and contractor. The designer should require that they be informed of any reported non-conformities to allow assessment.

Consistence

The term ‘workability’ to describe the slump or flow of concrete was replaced by the term ‘consistence’ and a series of consistence classes (ranges) were introduced. Table 14 demonstrates these consistence classes.

The consistence class should be determined by the constructor based on the method of placing the concrete. Normally the consistence class S3 is used, due to its suitability for most applications.

Table 14: Consistence classes (S – slump, F – Flow)

Consistence Class	Consistence range (mm)	
	For composite samples taken in accordance with BS EN 12350-1	For spot samples taken from initial discharge
S1	0 - 50	0 - 60
S2	40 - 100	30 - 110
S3	90 - 160	80 - 170
S4	150 - 220	140 - 230
F2	340 - 420	330 - 430
F3	410 - 490	400 - 500
F4	480 - 560	470 - 570
F5	550 - 630	540 - 640

Table 14 provides consistence based on two methods of testing. 'S' refers to slump testing and 'F' refers to flow testing. Slump tests should be measured in accordance with BS EN 12350-2[11] and flow tests in accordance with BS EN 12350-5[12].

Chloride class

Concrete that is to be prestressed, pre-tensioned or heat cured should normally be specified as chloride class Cl 0,10. Non heat-cured concrete containing reinforcement or other embedded metal produced with CEM I-SR 0 or CEM I-SR 3 cements are to be specified as Cl 0,20.

Reinforced concrete should be specified as class C l0,40 except where the concrete is in XS or XD exposure classes when class Cl 0,30 should be specified. Post-tensioned elements subject to XC1 exposure conditions e.g. internal post-tensioned office construction, can be specified as Cl 0,40. No further guidance is given in BS 8500 for post-tensioned concrete in other exposure classes, or for unbound pre-stressed concrete. The appropriate class will depend on the particular exposure, type of structure and construction method. Unreinforced concrete containing no embedded metal other than corrosion-resistant lifting devices can be specified as Cl 1,00.

Figure 5: Example specification of Designated Concrete

	Requirement	Project	Project	Project	Project	Designer / Contractor
1	Concrete designation	*GEN1*	*FND2*	*RC25/30*	*RC40/50*	D
2	Maximum aggregate size (mm) Enter 10, 14, 20 or 40	*20*	*20*	*20*	*10*	D
3	Consistence class. S1, S2, S3, S4 or other value	*S3*	*S3*	*S4*	*S3*	C
4	Special restrictions on cement types enter reference if required (e.g, combined performance category as per table A.6 BS8500-1:2023 or cement/ combination reference)	*All in A.6 except IIIB and IIIB+SR*	*D1, D2, D3, E4, F4*	*All in A.6 except IIIB and IIIB+SR*	*All in A.6 except IIIB and IIIB+SR*	D
5	Special requirements for aggregates, enter reference if required	---	---	---	---	D
6	Use of coarse crushed concrete aggregate (CCA) permitted? Enter a maximum mass fraction of total coarse aggregate, where permitted. Ref. BS 8500-1: 2023, CL A.7.10.1	*20%*	*No*	*20%*	*20%*	D
7	Requirements for accelerated or retarded set	---	---	---	---	C
8	Special colour requirements	---	---	---	---	D
9	Type and dosage of fibres	---	---	---	---	D
10	Chloride class Cl 1,0 for GEN series, Cl 0,20 for CEM I-SR 0 or 3, Cl 0,40 for all other concretes or enter special requirements	*Cl 1,0*	*Cl 0,40*	*Cl 0,40*	*Cl 0,40*	D
11	Minimum air content	---	---	---	---	D
12	Method of placing concrete	*Skip*	*Skip*	*Pump*	*Skip*	C
13	Requirement for finishing concrete	*Tamped*	*Tamped*	*Float*	*Tamped*	C
14	Identity testing for consistence or other properties required in accordance with BS EN 206:2013 Annex B and BS 8500-1:2023 Annex B. If YES, then details to be added	---	---	*Consistence*	*Consistence*	C
15	Digital monitoring and measurement required?	---	---	*Consistence records*	*Consistence records*	C
16[a)]	LCCG Benchmark (or equivalent – reference to be made to benchmark)	*C*	*B*	*C*	*C*	D/C

NOTE: This table is an example of a concrete frame construction specification. Reference should be made to template specifications within project specific details.

Key:

D Designer specifies concrete designation, maximum aggregate size and any additional requirements

C Contractor specifies consistence, any additional requirements and completes exchange of information

a) The reference to benchmarking should be project specific. It is recommended that suppliers are consulted early in a project to determine what the likely available concretes will be. This will then provide guidance on the achievable embodied carbon. See Annex A: Market benchmarking which provides further details on how to use industry benchmarks.

Red Text: Example specification

Figure 6: Example specification of Designed Concrete

	Requirement	Project	Project	Project	Designer / Contractor
1	Concrete reference	*Pads*	*Slab*	*External Columns*	D
2	Strength class	*C28/35*	*C25/30*	*C32/40*	D
3	Applicable exposure classes (except DC-classes)	*XC2*	*XC1*	*XD1, XC3/4, XF1*	D
4	DC – class where appropriate	*DC-2*	---	---	D
5	Maximum water/cement ratio, where appropriate (see BS 8500:2023 tables A.4 & A.5)	*a*	---	*0.6*	D
6	Minimum cement content kg/m3 , where appropriate (see BS 8500:2023 tables A.4 & A.5)	*a*	*200*	*300*	D
7	Permitted combined performance category/cement types – see BS8500-1:2023	*a*	*All*	*All*	D
8	Maximum aggregate size (mm) - enter 10, 14, 20 or 40	*20*	*20*	*20*	D
9	Concrete Chloride – a value MUST be entered unless Cl 0,40 is acceptable	*Cl 0,40*	*Cl 0,40*	*Cl 0,30*	D
10	Target density/density class – for lightweight and heavyweight concrete	---	---	---	D
11	Consistence class S1-S5, F1-F6 (see section on Consistence)	*S2*	*S3*	*S2*	C
12	Method of placing concrete	*Skip*	*Pump*	*Skip*	C
13	Requirement for finishing concrete	*Tamped*	*Float*	*Tamped*	D
14	Special requirements for aggregates	---	---	---	D
15	Use of coarse crushed concrete aggregate (CCA) permitted? Maximum mass fraction of total coarse aggregate. Enter a higher mass fraction of total coarse CCA aggregate, where permitted.Ref. BS 8500-1: 2023, CL A.7.10.1 and BS EN 1992-1-1:2023 Annex N	*20%*	*No*	*No*	D
16	Type and dosage of fibres	---	---	---	D
17	Minimum air content, or other requirements to resist freeze-thaw attack	---	---	---	D
18	Special requirements for temperature of fresh concrete	---	---	---	D/C
19	Special requirements for strength development	---	---	---	C
20	Special requirements for heat development during hydration	---	---	---	D/C
21	Special requirements for consistence retention time	---	---	---	C
22	Special requirements for resistance to water penetration	---	---	---	D
23	Special requirements for resistance to abrasion	---	---	---	D
24	Requirements for tensile splitting strength	---	---	---	D
25	Additional technical requirements – see BS 8500-1:2023 Cl 4.3.3 (n) & (o)	---	---	---	D
26	Strength identity testing required? If yes, in accordance with BS EN 206:2013 Annex B	---	---	*Yes*	C
27	Consistence identity testing required? If yes, in accordance with BS EN 20:2013 Annex B	---	---	*Yes*	C
28	Other properties identity testing required? If yes, in accordance with BS EN 206:2013 Annex B	---	---	---	C
29	Digital monitoring and measurement required?	*Consistence records*	---	*Consistence records*	C
30[b)]	LCCG Benchmark (or equivalent – reference to be made to benchmark)	*C*	*C*	*C*	D/C

NOTE: This Table is an example of a concrete frame construction specification. Reference should be made to template specifications within project specific details.

Key:

D Designer specifies concrete designation, maximum aggregate size and any additional requirements

C Contractor specifies consistence, any additional requirements and completes exchange of information

a) The producer will determine these requirements based on the DC-class.

b) The reference to benchmarking should be project specific. It is recommended that suppliers are consulted early in a project to determine what the likely available concretes will be. This will then provide guidance on the achievable embodied carbon. See Annex A: Market benchmarking which provides further details on how to use industry benchmarks.

Red Text: Example specification

Figure 7: Example specification for designed concrete (Appendix 17/1 of MCHW[7])

Requirement	Schedule		
	Pads	Pier	Slab
Intended working life of structure[a]	*100+*	*100+*	*100+*
Nominal cover to reinforcement[a]			
Applicable exposure classes (excluding DC–class)[a]			
DC–class (where appropriate)[b]	*DC-2z*		
Compressive strength class of concrete[b]	*C28/35*	*C40/50*	*C28/35*
Minimum cement content[b]	*320*	*380*	*360*
Maximum free water/cement ratio[b]	*0.55*	*0.40*	*0.45*
Required group or type of and class of cement or combinations (where a DC–class not specified)[b]	*All*	*A2, A3, D2, D3*	*A1, B1, C1, D1, G1*
Maximum aggregate size[b]	*20*		
Chloride content class[b]	*Cl0,40*	*Cl0,40*	*Cl0,40*
For lightweight concrete, the density class or target density[b]			
Consistence class[c]	*S2*	*S2*	*S3*
Special type or class of cement or combination			
Required source/special type of aggregate			*Freeze-thaw resisting*
Maximum cement content (kg/m^3)			
Required admixture			
Air entrainment required [Yes/No]	*No*	*No*	*Yes*
Minimum or maximum temperature of fresh concrete ºC			
Sampling and testing			
Other requirements			*4.5% air content*

Key

a Intended working life, nominal cover to reinforcement and applicable exposure classes (other than DC–class) do not form part of the specification to the contractor or concrete producer but may be listed here because the concrete requirements are dependent on these parameters. Intended working life of 100 years is generally acceptable for category 5 structures (e.g. highway and rail bridges and civil engineering structures).

b Denotes basic requirements for designed concrete.

c It is normally the responsibility of the contractor to make the selection of consistence and inform the specifier of the requirements. The specifier should add this requirement to the specification.

Red Text: Example specification

Conformity

Under BS 8500, the concrete producer is required to follow a formal procedure called 'conformity' to verify that the concrete is in accordance with the specification. It is, therefore, recommended that the concrete supplier should have third-party certification. Where this is not adopted, the specifier is advised to provide for adequate identity testing to ensure the concrete is as specified.

Identity testing is not normally required where the producer has third-party certification. If identity testing is required, the specifier is responsible for organising the testing, which can include strength, consistence and air content. Identity testing may be carried out:

- In cases of doubt
- For critical elements, e.g. high strength columns
- For spot checks on the producer

Digital monitoring and measurement

There are several digital monitoring and measurements systems available for both ready-mixed and site mixed concrete. These systems have the capability to provide information on the concrete at the time of delivery to the specifier, such as the consistence of the concrete. Suppliers may use different systems; however, these systems should be able to provide other factory production control records such as batching and dispatch records with signatures to provide almost instantaneous evidence that the concrete has been produced as ordered. This should reduce the need for product control testing, conformity assessment testing and spot sampling (identity testing) to assess consistence and strength.

Any digital surveillance should be specified with details of the production record requirements such as time of mixing, consistence at delivery etc.

Exchange of information

To enable the concrete producer to design and produce a suitable concrete, certain information must be provided in addition to the specification e.g. where the concrete needs to be pumped or a high-quality finish is required.

Summary

The inclusion of a wider range of multi-component cements and combinations in BS 8500:2023 provides greater flexibility when specifying and producing concrete with the lowest embodied carbon. These ternary combinations that include low carbon limestone fines have proportions equivalent to the binary cements commonly used in the UK market and have been categorised and tabulated for ease of specification. This 'How to guide' provides specifiers with the necessary information to understand the changes to the standard whilst touching on some key considerations when designing both building and civil engineering structures to achieve the lowest embodied carbon possible for that project. Concrete suppliers and precast concrete manufacturers are best placed to understand the cements and concretes available to meet the requirements of both construction and long-term durability. Early engagement with their technical teams is key in delivering the best solutions for your project.

If you need any further advice on your project, please contact The Concrete Centre helpline via **www.concretecentre.com/helpline**

Annex A – Market benchmarking of embodied carbon

The Low Carbon Concrete Group (LCCG) Market Benchmark summarises the distribution of cradle-to-grave carbon emissions of normal weight concrete recently produced in the UK. The benchmark covers LCA stages A1 to A3 ("cradle to batching plant gate", or "cradle to precast mould"). This benchmark will be updated periodically to reflect developments in the UK market. The 2023 update of the benchmark has been primarily based on embodied carbon data for normal weight ready-mixed concrete produced in the UK by MPA members in 2022.

It is fundamental when using benchmarks on projects, to understand that, whilst the LCCG market benchmark is a tool to assess embodied carbon of concrete, it must be used in the context of reducing overall project and global greenhouse gas (GHG) emissions. Sometimes concrete with a higher embodied carbon used more efficiently may result in a lower project and/or global GHG emissions.

It is also key to ensure that timely conversations happen between project teams and concrete suppliers to understand the available concretes for individual schemes. This will allow specifiers to better assess benchmarks for specific concrete mixes and end use.

Users should understand the following when referencing the LCCG Market Benchmark, or equivalent benchmarking schemes:

- When assessing a particular concrete, users should state the version of the benchmark which has been used (e.g. "LCCG Market Benchmark 2023")
- If a benchmark rating is included in a project specification it may reference the latest edition of the benchmark or a benchmark published in a previous year. Therefore, it may be sensible to reference the version that will be used to assess the placed concrete within the concrete procurement contract.

There are both static and dynamic benchmarking schemes in the UK market and more being developed globally, therefore when reference to a scheme is specified it is essential to understand the background and principles of the benchmarking scheme to ensure the concrete produced is assessed correctly.

Further information on the LCCG Market Benchmark can be found here: **www.concretecentre.com/marketbenchmark**

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