Guide to the selection of concrete quality and cover to reinforcement for normal concrete structures

Published July 2002
Reprinted October 2004

The new standards for concrete, BS EN 206–1 and BS 8500 will co-exist and have equal status to the existing BS 5328 until its withdrawal in December 2003. However, BSI recommends that BS 5328 is used for specifications until the end of 2003 and BS EN 206–1/BS 8500 is used from 2004.

One of a series of publications produced in conjunction with the following organizations, and part-funded by DTI (formerly DETR).

Association of Concrete Industrial Flooring Contractors
Association of Lightweight Aggregate Manufacturers
British Cement Association
British Standards Institution
Building Research Establishment
Cement Admixtures Association Cementitious Slag Makers Association
Concrete Industry Alliance
Concrete Society
Glanville Consultants
Institute of Concrete Technology
Ove Arup & Partners
Quarry Products Association
Ready-mixed Concrete Bureau
RMC Readymix Ltd
L M Scofield Ltd
United Kingdom Quality Ash Association

A full list of the publications in this series is given on the back page.

INTRODUCTION

This guide summarizes the recommendations in BS 8500 for the selection of concrete quality and cover to reinforcement for normal building structures with an intended working life of at least 50 years, the life recommended in BS EN 1990: *Basis of design*.

Some of the concepts in BS 8500 and Eurocode 2: *Design of concrete structures* will be new to UK designers. In particular, the exposure classification relates to the form of deterioration, e.g. corrosion due to carbonation, and a particular element can be exposed simultaneously to several of these forms of deterioration. Therefore the first stage of the process is to identify all the relevant exposure classes using the simplified classifications given in Tables 1, 3 and 4 or the detailed classification given in BS 8500–1: 2002, Table A.1. For each of the identified exposure classes and the selected cover to reinforcement, the recommended concrete qualities are noted and, with one exception (see Note 3 to Table 3), the most onerous requirements are selected and specified.

Another new concept is the way in which the nominal cover to reinforcement, i.e. the cover shown on the contract drawings, is determined as a minimum cover plus a margin for the fixing tolerance (typically in the range 5 to 15 mm). EC2 relates this margin to the level of quality control achieved on site, but the consequences of low cover should also be taken into account. For example the reinforcement in an internal suspended office slab is unlikely to corrode significantly when the concrete is carbonated and there is no significant durability risk. A margin of 5 mm may therefore be appropriate even though the level of workmanship on site is normal.

The recommendations are summarised in tables, each accompanied by comments that may be helpful when first applying these tables.

RESISTING CORROSION OF REINFORCEMENT

Table 1. Recommendations for normal-weight concrete quality for selected exposure classes and cover to reinforcement for a 50 year intended working life and 20 mm maximum aggregate size

	Exposure conditions		Cement/ combina -tion types[1]	Strength class, maximum w/c ratio, minimum cement or combination content (kg/m^3) Equivalent designated concrete Nominal cover to reinforcement[2]							
				15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc
No risk	**X0**	Completely dry	All	Recommended that this exposure is not applicable to reinforced concrete							
Carbonat- ion induced corrosion	**XC1**	Dry or permanently wet	All	C20/25, 0.70, 240 or RC25	<<<<<	<<<<<	<<<<<	<<<<	<<<<	<<<<	<<<<
	XC2	Wet, rarely dry	All	—	—	C25/30, 0.65, 260 or RC30	<<<<	<<<<	<<<<	<<<<	<<<<
	XC3	Moderate humidity	All except IVB	—	C40/50, 0.45, 340 or RC50	C32/40, 0.55, 300 or RC40	C28/35, 0.60, 280 or RC35	C25/30, 0.65, 260 or RC30	<<<<	<<<<	<<<<
	XC4	Cyclic wet and dry									
Chloride induced corrosion excluding chlorides from seawater	**XD1**	Moderate humidity	All	—	—	C40/50, 0.45, 360	C32/40, 0.55, 320	C28/35, 0.60, 300	<<<<	<<<<	<<<<
	XD2	Wet, rarely dry	I, IIA, IIB-S, SRPC	—	—	—	—	—	C28/35, 0.55, 320	<<<<	<<<<
			IIB-V, IIIA	—	—	—	—	—	C25/30, 0.55, 320	<<<<	<<<<
			IIIB, IVB	—	—	—	—	—	C20/25, 0.55, 320	<<<<	<<<<
	XD3	Cyclic wet and dry	I, IIA, IIB-S, SRPC	—	—	—	—	—	C45/55, 0.35, 380	C40/50, 0.40, 380	C35/45, 0.45, 360
			IIB-V, IIIA	—	—	—	—	—	C35/45, 0.40, 380	C32/40, 0.45, 360	C28/35, 0.50, 340
			IIIB, IVB	—	—	—	—	—	C32/40, 0.40, 380	C28/35, 0.45, 360	C25/30, 0.50, 340
Seawater induced corrosion	**XS1**	Airborne salts but no direct contact	I, IIA, IIB-S, SRPC	—	—	—	—	—	C35/45, 0.50, 340	<<<<	<<<<
			IIB-V, IIIA	—	—	—	—	—	C32/40, 0.50, 340	<<<<	<<<<
			IIIB, IVB	—	—	—	—	—	C25/30, 0.55, 320	<<<<	<<<<
	XS2	Wet, rarely dry	I, IIA, IIB-S, SRPC	—	—	—	—	—	C28/35, 0.55, 320	<<<<	<<<<
			IIB-V, IIIA	—	—	—	—	—	C25/30, 0.55, 320	<<<<	<<<<
			IIIB, IVB	—	—	—	—	—	C20/25, 0.55, 320	<<<<	<<<<
	XS3	Tidal, splash and spray zones	I, IIA, IIB-S, SRPC	—	—	—	—	—	—	C45/55, 0.35, 380	C40/50, 0.40, 380
			IIB-V, IIIA	—	—	—	—	—	C35/45, 0.40, 380	C32/40, 0.45, 360	C28/35, 0.50, 340
			IIIB, IVB	—	—	—	—	—	C32/40, 0.40, 380	C28/35, 0.45, 360	C25/30, 0.50, 340

NOTES
1 See Table 2 and for full details, see BS 8500–2: 2002, Table 1. 2 Also applies to prestressing reinforcement.

BSI took the view that, with all exposures, there should be a minimum quality of concrete and further increases in cover should not be accompanied by a reduction in this concrete quality. The '<<<<' signs in the table indicate that the concrete quality given in the cell to the left should not be reduced. Provided the extra cover is not required for structural or fire reasons, there is nothing to be gained by having extra cover.

Whenever an XD or XS exposure class is identified, there will also be an XC exposure class. Generally the recommendations for concrete quality are less severe for the XC exposure; the XD or XS recommendations are likely to control the specification.

Seawater can lead to reinforcement corrosion due to chlorides, but it is not always appreciated that it is also chemically aggressive to concrete. Consequently even unreinforced concrete is contact with seawater needs the concrete quality recommended in Table 3.

For XC exposures the alternative of a designated concrete is provided and recommended. There is no simple way of specifying designated concrete for the XD and XS exposures.

CEMENT/COMBINATION TYPES

BS 5328 used the word 'cement' to encompass combinations. A combination is where the Portland cement and ggbs/pfa/silica fume/metakaolin/ground limestone are combined in the concrete mixer instead of being supplied to the concrete producer pre-blended. In BS 8500, the two words are used to indicate the way in which the cement was formed, i.e. 'cement' when combined as dry powders or 'combination' when combined in the concrete mixer. However both BS 5328 and BS 8500 regard cements and combinations as being equivalent and consequently such semantics have no significance for specifications. The cement/combination notations used in Tables 1, 3 and 4 permit the producer to use either a cement or an equivalent combination.

Table 2. Summary of cement and combination types

Description	Notation
Portland cement	I
Sulfate-resisting Portland cement	SRPC
Cement/combination comprising Portland cement with 6 to 20% of a second main constituent, e.g. pfa, ggbs	IIA
Cement/combination comprising Portland cement with 21 to 35% of pfa	IIB-V or IIB-V+SR[1]
Cement/combination comprising Portland cement with 21 to 35% of ggbs	IIB-S
Cement/combination comprising Portland cement with 36 to 65% of ggbs	IIIA
Cement/combination comprising Portland cement with 66 to 80% of ggbs	IIIB or IIIB+SR[1]
Cement/combination comprising Portland cement with 36 to 55% of pfa	IVB or IVB+SR[1]
NOTE 1 Where the proportions and properties for a sulfate-resisting cement/combination are required.	

RESISTING ATTACK ON THE CONCRETE ITSELF

In the UK, it is not normally necessary to classify concrete that is fully buried, e.g. strip foundations, or fully immersed in seawater under the XF classification. In the more extreme freeze/thaw conditions, a choice of an air-entrained concrete or a non-air entrained concrete is provided. Where the concrete is horizontal and likely to be highly saturated, e.g. pavements, the air-entrained option is recommended

Table 3. Recommendations for normal-weight concrete quality with 20 mm maximum aggregate size in exposure classes where the concrete itself is at risk of attack

	Exposure conditions		Cement/ combination types[1]	Designated concrete options	Designed concrete options	Comments and other requirements[2, 3]
Freeze/ thaw action	**XF 1**	Moderate saturation without de-icers	All	RC35	C28/35, 0.60, 280	None
	XF 2	Moderate saturation with de-icers	All	RC40		Restricted to non-reinforced concrete only.
					C32/40, 0.55, 300	None
				PAV1		Restricted to non-reinforced concrete only.
					25/30, 0.60, 280	Minimum air content of 3.5%.
	XF 3	High saturation without de-icers	All except IVB	PAV1		None
					C25/30, 0.60, 280	Use freeze/thaw resisting aggregates[4] and a minimum air content of 3.5%.
				RC50XF		None
					C40/50, 0.45, 340	Use freeze/thaw-resisting aggregates[4].
	XF 4	High saturation with de-icers	All except IVB	PAV2		Restricted to non-reinforced concrete only.
					C28/35, 0.55, 300	Use freeze/thaw resisting aggregates and a minimum air content of 3.5%.
				RC50XF		Restricted to non-reinforced concrete only.
					C40/50, 0.45, 340	Use freeze/thaw-resisting aggregates[4].
Contact with seawater		Unreinforced concrete in contact with UK seawater[5]	I, IIA, IIB-S, SRPC		C28/35, 0.55, 300	None
			IIB-V, IIIA		C25/30, 0.55, 300	None
			IIIB, IVB		C20/25, 0.55, 300	None

NOTES

1 See Table 2 and for full details, see BS 8500–2: 2002, Table 1.

2 When the recommendations for an XF exposure class are combined with one or more from the XC, XD and XS exposure classes, the cover to reinforcement is that obtained from the XC, XD or XS exposure, i.e. there is no recommendation to increase the cover when these exposures are combined with an XF exposure.

3 Where exposure class XF2, XF3 or XF4 is identified in combination with one or more other exposure classes with a higher minimum strength class than recommended for the XF exposure, the higher minimum strength class may be reduced by one class for air-entrained concrete provided that all other limiting values are maintained.

4 Specify: The aggregates shall be freeze/thaw resisting as defined in BS 8500-2: 2002, clause **4.3**.

5 As all seawaters do not have the same level of aggressivity; follow local guidance.

Table 4. Recommendations for designated concretes to resist aggressive chemicals in natural ground with mobile water where the least dimension of the section is in the range 150 mm - 450 mm, the structural performance level is normal, e.g. building structures, and where the hydrostatic head is not more than five times the section width

NOTE. Where one or more of these conditions are not fulfilled, use the procedure in BS 8500–1 as less or more onerous requirements apply. Where the least section dimension is more than 450 mm and/or the groundwater is static, this table is safe, but more economic designs may be achieved if the procedure in BS 8500–1 is followed.

Design sulfate class	pH	Designated concrete options	Limiting values for the designated concrete[1]				
			Strength class	Cement/combination types[2]	Maximum w/c ratio	Minimum cement/ combination content kg/m^3	Aggregate carbonate range[4]
DS-1	> 5.5	GEN1 for unreinforced foundations	C8/10	All	—	180	Any
		RC30 for fully buried reinforced foundations with cover (25 + Δc)	C25/30	All	0.65	260[3]	Any
	≤ 5.5	FND2Z with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4)	C28/35	All except II-L or LL	0.55	300	Any
DS-2	> 5.5	FND2 with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4)	C28/35	I, IIA except II-L or LL, IIB-S, IIB-V, IIIA	0.50	340	Any
			C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.55	300	Any
	≤ 5.5	FND3Z with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4)	C28/35	All except II-L or LL	0.50	340	Any
DS-3	> 5.5	FND4* with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4); **OR**	C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.40	400	B
		FND3** with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4); **OR**	C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.45	380	C
		FND4 plus one additional protective measure[5] with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4); **OR**	C28/35	IIB-V+SR, IVB+SR	0.35	400	A
			C28/35	IIIB+SR, SRPC	0.40	400	A
			C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.45	380	B or C
		FND3 plus two additional protective measure[5] with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4)	C28/35	IIB-V+SR, IVB+SR	0.40	400	A
			C28/35	IIIB+SR, SRPC	0.45	380	A
			C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.50	340	B or C
	≤ 5.5	FND4** with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4); **OR**	C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.40	400	C

Continued on page 6

		FND4* plus one additional protective measure[5] with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4); **OR**	C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.40	400	B
		FND4 plus two additional protective measure[5] with a cover of (25 + Δc) for fully buried foundations (XC2) and (30 + Δc) for partially buried foundations (XC3 and XC4)	C28/35	IIB-V+SR, IVB+SR	0.35	400	A
			C28/35	IIIB+SR, SRPC	0.40	400	A
			C28/35	IIB-V+SR, IVB+SR, IIIB+SR, SRPC	0.45	380	B or C
DS-4, DS-4m, DS-5, DS-5m and brownfield sites		Follow guidance in BS 8500–1					

NOTES

1 Use these values to check that the recommendations for any other identified exposure classes are satisfied. If they are, specify the designated concrete; if they are not, select a different designated concrete or specify a designed concrete that satisfies all the recommendations.

2 See Table 2 and for full details, see BS 8500–2: 2002, Table 1.

3 For 20 mm maximum aggregate size.

4 See BS 882 for the details of the classification, but broadly A are high carbonate content aggregates, B are medium carbonate content aggregates and C are low carbonate content aggregates.

5 Select the additional protective measures from: use of controlled permeability formwork (APM2), provide surface protection (APM3), provide sacrificial layer (APM4) or address site drainage (APM5). Add these to the contract drawings/documentation.

The guidance provided in Table 4 is limited to the natural ground conditions found in most sites. The table does not apply to "brownfield" sites as defined in BS 8500–1. These are sites that contain chemical wastes remaining from previous industrial use or from imported waste. Many sites that have had previous use will therefore not fall within this classification. With a brownfield site, the possibility of it containing a cocktail of aggressive chemicals has to be taken into account and the full procedure in BRE Special Digest 1: *Concrete in aggressive ground* should be followed.

The recommendations to resist aggressive chemicals are likely to control the concrete specification. Use the values in Table 4 to check that the recommendations for any other identified exposure classes are satisfied. If they are, specify the designated concrete: if they are not, select a different designated concrete or specify a designed concrete that satisfies all the recommendations.

With many concretes the minimum cement/combination content depends on the maximum aggregate size. However, with the GEN and FND series of designated concretes, the minimum cement/combination content does not depend on the maximum aggregate size.

FURTHER READING

The other publications from this series will be helpful. Visit www.cementindustry.co.uk and click 'information'/'library'/'BCA publications' to check availability and for free download.

Standards for fresh concrete – a composite of BS EN 206-1 and BS 8500

Specifying concrete to BS EN 206–1/BS 8500:
- *Concrete for normal uses*
- *Concrete resistant to chemical attack*
- *Guide to the selection of concrete quality and cover for reinforcement for normal concrete structures*
- *Examples of the specification of designated concrete*
- *Examples of the specification of designed concrete*
- *Guidance on additional requirements for designed concrete*
- *Lightweight concrete*
- *Visual concrete*
- *Coloured concrete*
- *Concrete for industrial floors*

Specifying constituent materials for concrete to BS EN 206-1/BS 8500:
- *Cements*
- *Additions*

Admixtures

European replacements for British Standards: Concrete and its constituent materials

Specifying concrete to BS EN 206–1/BS 8500: Guide to the selection of concrete quality and cover to reinforcement for normal concrete structures

45.312
First published 2002
ISBN 0 7210 1589 1
Price group A

Published by the British Cement Association on behalf of the supporting organizations.

British Cement Association
Riverside House, 4 The Meadows Business Park
Station Approach, Blackwater
Camberley, Surrey GU17 9AB
Telephone 01276 608700
Facsimile 01276 608701
www.cementindustry.co.uk