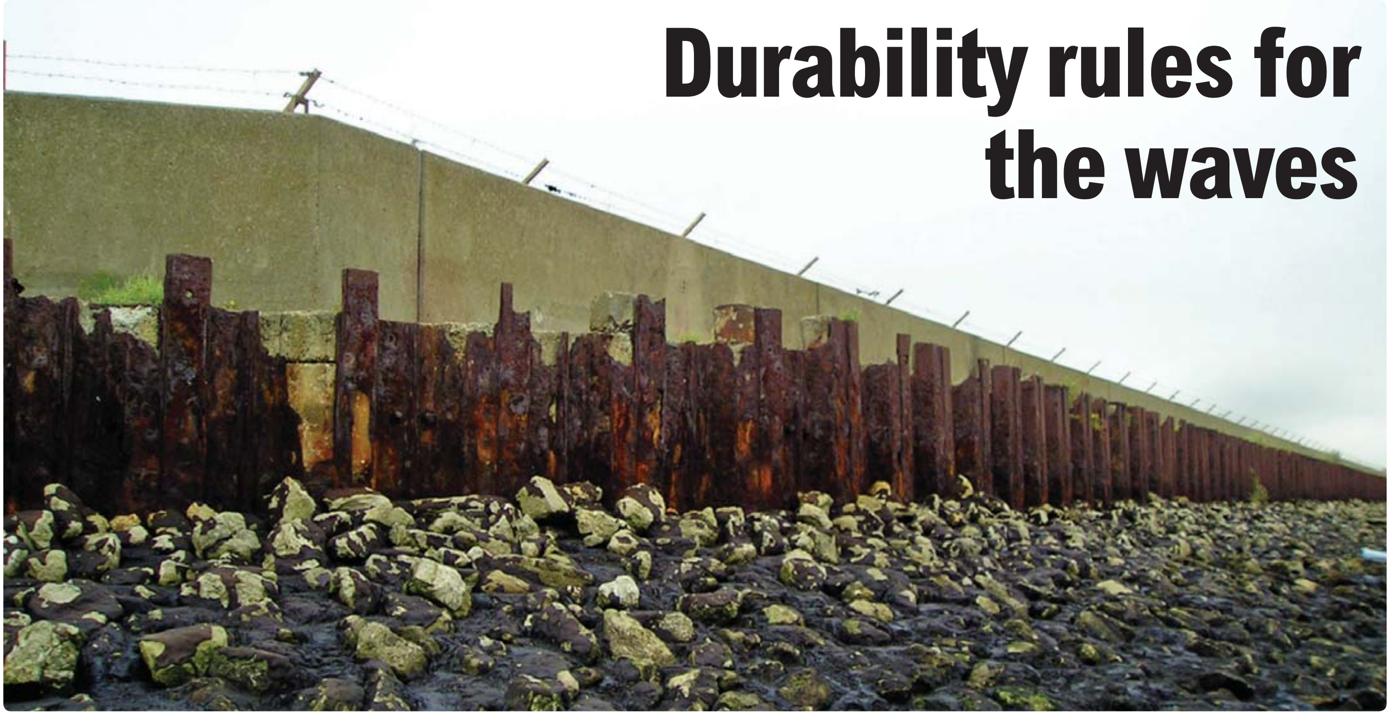

Durability rules for the waves

Chris Clear of the British Ready-Mixed Concrete Association and chairperson of the British Standards Institution technical committee Concrete, production and testing (B/517/1) discusses BS 6349-1-4 and BS 8500-1 guidance for reinforced concrete exposed to seawater.

A designer wishing to derive a specification for concrete exposed to seawater in accordance with European and British Standards should start by classifying the exposure classes as defined in EN 206[1] and may use additional guidance from BS 6349-1-4[2] or BS 8500-1[3]. It is evident that having two British Standards that recommend different requirements for seawater exposure is confusing. For this reason the forthcoming revision of BS 8500 will go for public comment incorporating the BS 6349-1-4 recommendations for seawater exposure and, subject to the comments made and consideration by the BSI technical committee, it is hoped to produce unified guidance.

It is a good time to propose such rationalisation as there have been a number of significant developments concerning durability to seawater exposure. These include:

- a considerable amount of research into seawater exposure, including field observations[4]
- the development and European standardisation of a test method to determine the unidirectional chloride diffusivity of concrete[5]
- a new system to specify durability – a proposal to introduce 'exposure resistance classes'[6] in EN 206 and Eurocode 2[7].

Figure 1: Concrete sea wall as photographed August 2005, constructed 1978. Remains of the original 1960s steel sheet wall shown in foreground.

Seawater exposure classes

Table 1 is a summary of the EN 206 exposure classes together with its informative examples and the informative guidance from BS 6349-1-4 and BS 8500-1.

From Table 2 it is evident that the classification of the environment is subject to interpretation where EN 206, BS 6349-1-4 and BS 8500-1 use different descriptions for each class of seawater exposure. With this difficulty in defining the exposure conditions it should be no surprise that there are also differences in the recommended quality of concrete required to protect embedded reinforcement and all three Standards give different recommendations. This type of discrepancy is not restricted to the UK and a European Standards Joint Working Group

Table 1 – Exposure classes for corrosion induced by chlorides from seawater

Class	EN 206 description of the environment	EN 206 examples	BS 6349-1-4 examples	BS 8500-1 Annex A examples and notes[A]
XS1	Exposed to airborne salt but not in direct contact with seawater	Structures near to or on the coast	Airborne salt environment – exposed to airborne salt but not in contact with seawater or splash	External reinforced or prestressed concrete surfaces in coastal areas
XS2	Permanently submerged	Parts of marine structures	Submerged environment – permanently submerged	Reinforced and prestressed concrete surfaces completely submerged and remaining saturated, eg, concrete below mid-tide level[B]
XS2/3			Frequently wetted lower tidal, backfilled	
XS3	Tidal, splash and spray zones	Parts of marine structures	Infrequently wetted upper tidal, 'dry' internal faces of submerged structures	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash spray zones[C]

A The rate of ingress of chloride into the concrete will depend on the concentration at its surface: brackish groundwater (chloride content less than 18g/l) will be less severe than exposure to seawater.
B Reinforced and prestressed concrete elements where one surface is immersed in water containing chlorides and another is exposed to air are potentially a more severe condition, especially where the dry side is at a high ambient temperature.
C 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.

Table 2 – Proposed binder content, water:cement ratio and cover for a design working life of 100 years' exposure to XS2

Binder type, cement or combination of cement and an addition	Minimum binder content (kg/m^3)	Maximum water:cement ratio	Minimum cover for 100 years design working life (mm)
CEM I	N/A	N/A	N/A
CEM II/A, eg, 6–20% fly ash or GGBS	280	0.40	55
CEM II/B, eg, 21–35% fly ash or GGBS	280	0.40	55
CEM III/A, 36–65% GGBS	*	*	*
CEM III/B, 66–80% GGBS	280	0.38	55

N/A Not applicable
** Proposals to be developed*

(JWG) has been considering this together with other issues concerning the durability of concrete.

A European view

The JWG is comprised of representatives of the European Standards Technical Committees dealing with the Design of concrete structures (CEN/TC 250/SC2) and Concrete – Specification, performance, production and conformity (CEN/TC 104/SC1). For the next revision of Eurocode 2, the JWG is proposing 'exposure resistances classes' where each class is performance based. The definition of the resistance class is to be related to the appropriate exposure class corresponding to realistic requirements, while not necessarily being the final requirements. For 'chloride resistance classes' the performance level is to be based on XS2 exposure as this is stable with time and can be simulated in long-term laboratory tests.

From the JWG proposals, the most chloride-resistant concrete class is to be designated RSD45, defined as a concrete where on 50-year exposure to XS2 there is a 10% probability of the chloride concentration exceeding 0.5% (by mass of cement) at a depth of 45mm. In the JWG model, it is when the concrete around the reinforcement reaches a 0.5% chloride concentration – the critical chloride level – that corrosion is deemed to be initiated and this point is taken as the end of service life. In reality there is considerable variation in the reported values of critical chloride level; a report from 2007[8] indicated values from as low as 0.02% to over 3%.

Expressed as a performance requirement, the RSD45 class concrete has an effective 50-year chloride diffusivity of around 0.2×10^{-12} m^2/s, where the effective 50-year chloride diffusivity value is determined from testing and estimates of an ageing factor that is largely dependent on cement type. Alternatively, the JWG suggests some preliminary deemed-to-satisfy values for concretes with various binder combinations and these are summarised in Table 2 for a 100-year design working life.

For any practical level of workability and available materials, the binder content to achieve the stated minimum water:cement ratio (w/c) is likely to be higher than the 280kg/m^3 indicated in Table 2. It is the w/c ratio that is the most important factor affecting the durability of concrete.

Current UK requirements

For structural design, the engineer finds an indication of strength class indispensable and the specification of a minimum cement content is also considered useful for quality control as cement content can be readily verified by inspection of weigh-batch records. As a consequence, the limiting properties for composition, and properties of concrete for durability, are expressed in the UK as compressive strength class, maximum w/c ratio and minimum cement or combination content.

Table 3 is a summary of the current limiting values for composition and properties of concrete according to BS 6349-1-4 and BS 8500-1, for design working lives of 100 years. The table is for XS2 exposure, 55mm minimum cover and for the range of cements or combinations available in the UK. XS2 exposure is selected as the basis for comparison as 'permanently submerged' should be an environment least susceptible to variations of interpretation.

For 100 years' exposure, inspection of Table 3 demonstrates that adopting the BS 6349-1-4 requirements for XS2 exposure will reduce the maximum w/c ratio from 0.55 to 0.40 or 0.45, and increase the total cementitious content from 320 to 360kg/m^3. This is a significant change but aligns with the JWG proposals as shown in Table 2 and as both sets of guidance were based in part on the Bamforth[9] model then similarities are to be expected. For a working life of 50 years there is not a large difference between the BS 6349-1-4 and BS 8500-1 recommendations,

Table 3 – Limiting values for composition and properties of concrete for a design working life of 100 years (XS2 exposure at 55mm minimum cover)

Cement or combination type	Standard composition	Additional restriction on composition	Compressive strength class, maximum water:cement ratio and minimum cement or combination content (kg/m^3)					
			BS 6349-1-4 Table 3			BS 8500-1 Annex A Table A.5		
CEM I CEM II/A-V CEM II/A-S CEM II/B-S	 6–20% fly ash 6–20% GGBS 21–35% GGBS	–	–	–	–	C28/35	0.55	320
CEM II/B-V	21–35% fly ash	–	C35/45	0.40	360A)	C25/30	0.55	320
		25–35% fly ash	C32/40	0.45	360	C25/30	0.55	320
CEM III/A	36–65% GGBS	–	C35/45	0.40	360A)	C25/30	0.55	320
		46–65% GGBS	C32/40	0.45	360	C25/30	0.55	320
CEM III/B	66–68% GGBS	–	C32/40B)	0.45	360	C20/25	0.55	320
CEM IV/B-V	36–55% fly ash	–	C32/40B)	0.45	360	C20/25	0.55	320

A) If the BS 8500 strength and cement type relationship with w/c ratio is adopted, this value would be 380kg/m^3.
B) If the BS 8500 strength and cement type relationship with w/c ratio is adopted, this value would be C28/35.

other than that BS 6349-1-4 requires more than 55mm cover if a CEM I or low GGBS or fly ash content cement is used.

Historic UK requirements

Many engineers value experience and on the basis that many successful reinforced concrete maritime structures have been constructed over the past 100 years then the recommendations derived from this experience are worth consideration. From 1972 to 1997 there were no British Standard recommendations for the equivalent of 'XS2 totally submerged' but only reference to concrete exposed to seawater. It is also important to note that during this period the design working life was not defined. Under these conditions the maximum w/c ratio recommended was in the range 0.42–0.50, with a minimum cement content from 330 to 400kg/m^3 and a cube strength from 40 to 50MPa.

During the late 1970s and early 1980s, a significant proportion of the Thames Tidal Defences that run from the Thames Barrier at Woolwich to Southend-on-Sea were constructed with a concrete containing 350kg/m^3 of what would now be designated CEM I-SR3. The specified nominal cover was 50mm. As shown in Figure 1, the concrete wall was showing no signs of distress after nearly 30 years. As an aside, it is noticeable that the original defences, a painted steel trench sheet wall as shown in the foreground, have almost completely disappeared due to corrosion.

From 2000, BS 6349 introduced sets of requirements for 50 and 100 years, and from 2002 BS 8500 included durability tables for XS exposure classes for a working life of at least 50 years. It is only with the introduction of this classification for exposure classes and setting the design working life that it is possible to start to develop recommendations based on modelling.

The recommendations in the 2013 edition of BS 6349-1-4 were derived using chloride ingress modelling[10]. This type of modelling was also used to derive the 50-year table of BS 8500 but using a recommendation in Eurocode 2 the 100-year table of BS 8500 was largely based on just adding 10mm cover to the 50-year values. So, perhaps it should not be a surprise that there is some disparity between the recommendations of BS 6349-1-4 and BS 8500 for a design working life of 100 years.

Concluding remarks

A record of satisfactory long-term performance in actual structures should be considered as suitable evidence to justify concrete quality requirements in Standards but sufficient details of the concrete used and its performance need to be presented. At the current time there is not a sufficient amount of such field data to favour either the BS 6349-1-4 or BS 8500-1 recommendations but it is acknowledged that to have two different sets of requirements for nominally the same exposure conditions is unsatisfactory.

BSI has recently published a draft for a public comment version of BS 8500, where the requirements of BS 6439-1-4 in terms of maximum w/c ratio will be incorporated. This will represent a significant change for the 100-year durability recommendations and it is hoped that designers will consider the changes in some detail and comment accordingly. The intention is to ensure that the designer is presented with a single set of recommendations based on the widest possible consultation.

The Draft for Public Comment of BS 8500 is on the BSI Draft Review System (*http://drafts.bsigroup.com*) late in 2014. Comments can be sent directly to Chris Clear at: chris.clear@mineralproducts.org, with a copy to Mussa Awaleh: mussa.awaleh@bsigroup.com ●

● **Acknowledgement**

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