DISCUSSION

Concrete mixes for durable marine structures by M G Alexander and J R Mackechnie, in *Journal of the South African Institution of Civil Engineering, 45(2) 2003*

Comments received from Dr R Amtsbüchler PrEng, Manager: Product Assistance Department, Lafarge South Africa

The authors have presented an interesting concept to achieve durable marine structures. Reference is made to a chloride prediction model that is based on early-age concrete properties and medium-term (three years) performance data from marine exposure stations. One key parameter is the chloride conductivity test for concrete undertaken at 28 days, which is one of the three durability index tests recently developed in South Africa.

While this test is described as simple and rapid, there are a number of open questions.

First, has this test been validated against other chloride conductivity methods or was only the prediction model validated?

Second, no agreement has yet been reached regarding single operator precision, operator repeatability and laboratory reproducibility, which is required for proficiency testing and inter laboratory comparisons.

Two recent durability index testing round robin exercises conducted by Industry and uiniversities have revealed the following:

Round 1: Chloride conductivity determined on split samples of concrete produced at one central laboratory showed >100 % differences in results between participating laboratories with very high variation coefficients of up to 28 %.

A detailed work instruction was subsequently compiled and distributed to participating laboratories in order to reduce test variation. Nevertheless, variation coefficients obtained from 'Round 2' stayed high (17 % to 28 %).

In terms of inter-laboratory comparisons a variation coefficient of <5 % is termed good, with <10 % just acceptable.

The consequence of these variations was that laboratory concrete of the same quality achieved again index values of up to 100 % difference. In other words, a specific concrete could fall into different durability ranges (as proposed) depending on which laboratory would be conducting the testing(!)

This raises the question about the validity of this test (at this point in time) being used as a key parameter for the chloride prediction model – even though this test is in essence an index test that does not measure an intrinsic property of concrete.

Another question are some of the preferred mix proportions for a 50-year service life under 'extreme' and 'very severe' exposure (as per table 2).

Can we from an engineering point of view accept the advised rather high water/binder ratios of 0,60 (extreme exposure) and 0,69 (very severe exposure) linked to total binder contents of only 300 kg/m^3 and 280 kg/m^3 respectively for mixes containing 50% CEM I and 50% (Corex) slag ?

Surely, a low chloride conductivity result for this binder combination cannot be the deciding parameter to prescribe durability mixes with 'high' water/cement ratios (and almost asking for an open pore structure and carbonation as in the case with w/b 0,69)?

Fulton's concrete technology (chapter 9, 'Durability of concrete' by Y Ballim and J Basson) gives detailed recommendations for concrete in aqueous environments. Table 9.3 shows in the column 'Chloride attack of steel' (= marine environment) much higher minimum cement contents and much lower minimum w/c ratios than the ones referred to above.

The type of binder in concrete has undoubtedly a major influence on durability, but the ration of water to cementitious material remains a primary determent of the permeability of concrete subsequently influencing quality and durability.

Could the authors please comment on the preferred PC–SL mixes with rather high w/b ratios (especially in view of the fact that Corex slag has been available only for a short time in South Africa, making long-term performance assessment of actual structures almost impossible at this point in time)?

In conclusion the writer agrees with both authors that the durability performance of reinforced concrete structures in the marine environment needs an improvement. A number of open questions have, however, to be answered before durability specifications based on the proposed durability index tests can be introduced with confidence.

Authors' response

The authors would like to thank Dr Amtsbüchler for his comments and queries on the above paper. In answer to the points he raised, we offer the following.

1 The chloride conductivity test has been compared with several other approaches and the results presented in a paper by the authors in May 2000.[1] The test was shown to be able to characterise a range of concrete mixes using different binder types, without being unduly affected by, for instance, initial pore solution conductivity of the concrete. While further issues continue to be studied, such as possible effects of microstructural damage during specimen preparation, the test has shown sufficient ruggedness during ASTM-type trials to give reasonable confidence in its use at this point.

As to the prediction model itself, this relied for its validation on medium-term data from exposure sites, as well as long-term data from actual structures in the Western Cape.

2 The issue of coefficients of variation continues to be investigated at present, mainly by way of a national series of round robin tests. However, work in our labs and by others indicates typical CVs for the full suite of index tests,[2] as reflected in the table below.

3 While it is true that the CVs from previous round robin tests have on occasions been high, this appears to be related more to the particular lab in question than indicating a universal problem. Procedures have been tightened and additional indicators of test proficiency introduced (eg weighing of samples to indicate proper saturation), and it is hoped this will improve the precision.

These values were obtained during sustained periods of testing in two different laboratories, and with at least three

Concrete source	Water sorptivity	Oxygen permeability	Chloride conductivity
Actual structures	13 %	3 %	**14 %**
Wet-cured, site mixed concrete	12 %	2 %	**7 %**
Wet-cured, ready mixed concrete	7 %	1 %	**5 %**
Laboratory	5 %	1 %	**4 %**
Streicher (1996) operator 1	8 %	2 %	**8 %**
Streicher (1996) operator 2	6 %	1 %	**6 %**

different operators. Thus it appears that it is possible to obtain reasonably low CV values with due care.

As to the comment that **'In terms of inter-laboratory comparisons a variation coefficient of <5 % is termed good, with <10 % just acceptable', this depends on the parameters being measured. For transport parameters such as permeability or conductivity, the variability is known to be much higher. This is related to the microstructure and pore structure of the concrete, with transport properties being far more sensitive to these properties than, say, strength. This inherent higher variability is not particularly problematical since it can be considered when applying test results to criteria for acceptability, by allowing a larger margin.**

4 Concerning the relatively high w/b ratios, the prediction model produces these values. However, the paper cautions that chloride resistance alone (as measured by chloride conductivity) does not dictate final binder selection (see pages 23 and 24 of the paper). What the model does show very convincingly, however, is the necessity of using blended binders such as fly ash or slag in chloride environments. Plain CEM I (OPC) mixes are entirely unsuitable for such applications, unless the structure is unreinforced.

5 Work on Corex slag in he Western Cape has recently been completed by Jaufeerally[3] and the results have been published in a monograph.[4] This material is a new entrant to the market, but results to date are very encouraging for its likely excellent durability performance.

The authors would like to stress that the work presented in the paper is not the final word on the subject, but represents the results of innovative and relevant local research into the problems of marine concrete durability. The paper reflects the present state and application of knowledge in this area in the South African context.

References

1 J R Mackechnie and M G Alexander 2000, Rapid chloride test comparisons, *Concrete International*, 22(5), May, pp 40–46.

2 S M Gouws, M G Alexander and G Maritz 2001, Use of durability index tests for the assessment and control of concrete quality on site, *Concrete Beton*, 98, April, pp 5–16.

3 H Jaufeerally 2002, Performance and properties of structural concrete made with Corex slag, MSc (Eng), University of Cape Town.

4 M G Alexander, H Jaufeerally and J R Mackechnie 2003, Structural and durability properties of concrete made with Corex slag, Research Monograph No 6, Department of Civil Engineering, University of Cape Town.

Errata: Technical paper 559, 'Wave revetments for inland lakes', *Journal* 45(4) 2003

by C F Watermeyer

- In the unreferenced table above figure 1 on page 12:
  Under F = 0,5 km, delete 1,77 km for Wf and insert 0,177 km:

F (km)	0,5	1	4	8	16
Wf	0,177	0,250	0,500	0,707	1,000

- In the example below table 5 on page 13, the second sentence should end with the words 'will comprise the materials and layer thicknesses as shown in table 5'

- In figure 2 on page 14, the hydrostatic pressure shown below point B, at the level of point A, should read ρw.Rd.g and not Pw.Rd.g

- In equation 28 for Mc, on page 14, delete the symbol X after the equal sign

$$Mc = \sqrt{G^2+1}\,.Rd\,.D_c\,.\rho c\,.g\,\frac{G.Rd}{2} = \frac{Dc.Rd^2.G.\sqrt{G^2+1}\,.\rho c.g}{2} \quad (28)$$

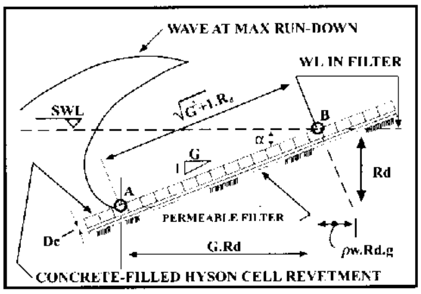

***Figure 2** Design parameters for concrete-filled Hyson Cell wave revetment*

- In equation 30 for Dc, on page 14, insert an equal sign after the first symbol Dc

$$\therefore D_c = \frac{2.\sqrt{G^2+1}}{3.G}\,.\,Rd\,.\,\frac{\rho_w}{\rho_c} = \frac{\sqrt{G^2+1}\,.\,Rd}{3.6\,.G}\ (m) \quad (30)$$

- Equation 13 on page 12 should equate to

$$Hs = \frac{16{,}154.Fw.\sqrt{Fe}}{1000}$$

Note by the author on the minimum thickness of an individual filter layer

Allowing for effective filter action to occur within the initial 50 mm thickness of an appropriately graded filter material from the interface with the protected material, then a 75 mm thickness of an individual filter layer is exceedingly thin. The minimum individual filter layer thickness for a wave revetment should be at least 100 mm and the filter layers should comprise consistent correctly graded material laid with a box spreader. In seismically active regions, the minimum individual filter layer thickness should be increased threefold to at least 300 mm for a wave revetment and to at least 1,50 m for an impermeable clay core.