SERVICE LIFE OF CONCRETE IN A MARINE ENVIRONMENT

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Ash Development Association

FLY ASH REFERENCE DATA SHEET

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1.0 GENERAL

The key to predicting service life of concrete structures is to evaluate the life of each component using a model or process appropriate to the micro-environment or concrete interaction. For a given structure, different models may be required for different components. The components with shortest predicted service lives will dictate the service life of the total structure, especially when the failure of the given component has serious consequences.

The aim is to provide the best possible estimate of the service life of concrete structures in the predicted environment for efficient asset management. In other words, 'exact' determination of service life is not possible but 'reasonable' answers should be the objectives.

In this section, a practical procedure for estimating the service life of reinforced concrete structures is proposed. This procedure is devised to assist the engineers in design for durability against marine attack. It will also be used to evaluate the influence of the beneficial characteristics of fly ash blended cement on service life of marine concrete structures discussed previously.

1. BASIC ASSUMPTIONS

Based on practical considerations, a reasonable definition of service life is the time taken from construction until visible damage to concrete is observed. In practice, it is highly unlikely that a maintenance and repair plan will be put in placed if there is no visible damage. Regular inspection is therefore an integral part of effective asset management.

In this section, it is assumed that the only deterioration mechanism of the concrete structure is that resulting from chloride ion penetration and subsequence corrosion of steel reinforcement. This is a simplistic view of the marine environment. It is aimed to provide a basis for comparison and a background for a more detailed evaluation of service life in a marine environment.

The important parameters required in predicting service life of reinforced structures are the prediction of the rate of chloride contamination at the steel surface and the chloride level at which steel corrosion progresses at an acceptable rate.

1.2 PREDICTION OF CHLORIDE PENETRATION INTO CONCRETE

1.2.1 EQUATION

Since the ingress of chloride ions into concrete always involves inward movement through its pore structure of water containing chloride ions, the prediction of chloride ion penetration into concrete is usually obtained using Fick's second law of diffusion. A solution for Fick's second law of diffusion is shown below:

$$C(x,t) = C_i + \left(C_s - C_i\right) erfc\left[\frac{x}{\sqrt{4Dt}}\right]$$

Where D is the chloride diffusion coefficient; C_i is the initial background chloride concentration of concrete and is usually negligible; C_S is the surface chloride content, x is depth in concrete, t is exposure time; $C(x,t)$ is the chloride concentration at depth x after time t and erfc is the complement of error function. Concrete's resistance to chloride penetration is characterised by D and C_S. The main interest is to predict the value of $C(x,t)$ where x = concrete cover at various times t relevant to required design life.

While using the above equation for predicting chloride penetration at the steel surface, relevant corrections for time-dependent characteristics of D and C_S needs to be made.

1.2.2 CORRECTIONS FOR *D* AND *Cs*

In practice, it has been observed that D decreases and C_S increases with time of exposure. This means that in using equation (1) for predicting chloride concentration at cover depth after time t, reasonable values of D and C_S should be used. If t is 40 years, then expected values of D and C_S at 40 years should be used rather than those observed during short termed testing.

(It should be noted that the variation of D and C_S vs t cannot be predicted by an increase in initial curing of a sample in short-term testing).

For example, the D value obtained from an aged sample subjected to short-term exposure is at least an order of magnitude higher than that obtained from short curing with long-term exposure[1].)

It has been noted that a straight line is often observed when D vs t is plotted on a log-log scale[2-5]. This can be exploited to obtain value of D at the required time based on the trend observed from short termed data. Typical variation of D with time t is shown in Figure 2. This means that with a reasonable number of data points obtained from short to medium-term testing, the long-term value of D can be estimated from the log-log plot.

As in most cases of extrapolation where long-term prediction is needed, a conservative approach is advisable, especially when using a log-log scale.

Available laboratory-based data suggest that a similar technique can be used in estimating long-term value of C_S. Field data however indicate that C_S tends to reach a “maximum” value. A conservative means of obtaining C_S for the purpose of predicting chloride contamination at the steel surface is by assuming the concrete porosity is filled with a solution equivalent to saturated sodium chloride (35% NaCl).

For concrete wet-cured for 7 days (to AS 3600 requirements) prior to exposure to a marine environment, the following values of C_S have been suggested, based on porosity measurements and saturated NaCl

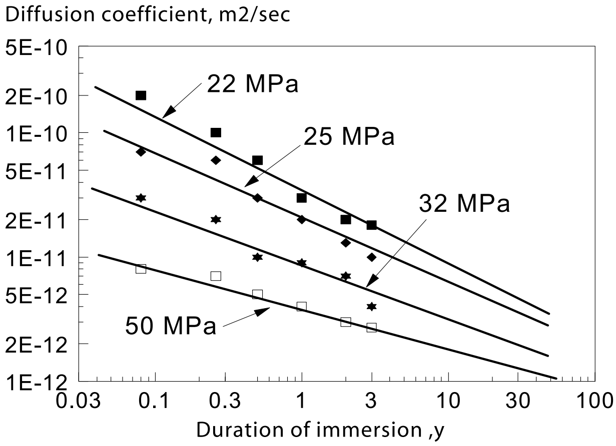

Figure 2: Observed variation of D for concretes of different grades after immersion in seawater.

Grade	Cl / concrete (w/w)
• 32 MPa Grade	C_S = 1.5%
• 40 MPa Grade	C_S = 1.2%;
• 50 MPa Grade	C_S = 1.0%
• 60 MPa Grade	C_S = 0.8%

Field data denote that these suggested values do not differ from those calculated from long-term chloride profiles in real structures.

1.3 ACCEPTABLE CHLORIDE LEVEL AT A STEEL SURFACE

Chloride is a well-known de-passivating agent. When chloride is present at the steel surface, corrosion of steel reinforcement is likely. Chloride ions can break down the passivating layer on the steel surface and promote active steel dissolution. The intermediate corrosion product $FeCl_2$ is acidic and can cause deterioration of the surrounding hardened concrete.

A chloride threshold level is commonly used to indicate the initiation of steel corrosion in concrete. However, published values of chloride threshold level vary from 0.1 to 1.0 percent by weight of cement (acid soluble chloride concentration) [6]. The lack of a universal chloride threshold level may be due to the fact that there is no unique threshold value of chloride concentration in concrete for the initiating of pitting [7] due to different experimental techniques and the undefined line between potential to corrode and actual progression of steel corrosion [8-14].

From an engineering point of view, the chloride level at which steel corrodes at an acceptably low rate is a practical criterion for use in service life prediction. It is suggested that 2(A.cm^{-2} is a reasonable value to be used as an acceptable corrosion rate. At this rate, published data indicate that it will take some time for concrete to crack and the damage to the behaviour of the reinforced concrete member is small [15-19].

Sea water testing

CSIRO data obtained from studies of steel corrosion rate versus chloride contamination at steel surfaces indicate that when the chloride level at the steel surface is less than 0.2% w/w concrete, the steel corrosion rate is "normally" less than 2 µA.cm^{-2} (Figure 3). This chloride level, indicating cracking of concrete is imminent, is used in the estimation of service life of reinforced concrete structures in a marine environment.

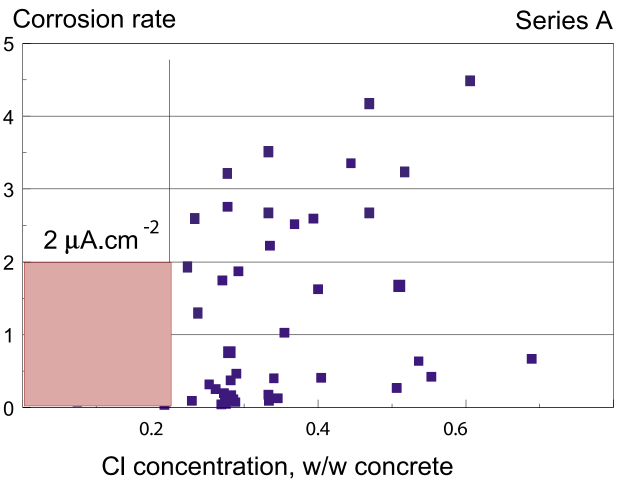

Figure 3: Corrosion rate of steel vs Cl concentration in different concretes and covers

1.4 SUGGESTED PROCEDURE FOR ESTIMATING SERVICE LIFE OF MARINE CONCRETE STRUCTURES

A simple procedure for making an initial estimation of service life of marine concrete structures consists of the followings:

- Determine the suitable chloride diffusion coefficient *D* based on short to medium-termed data of *D* by extrapolation on log-log scale to relevant time *t*;
- Select suitable value of C_S based on concrete grade (or by estimation from concrete porosity)
- Calculate chloride concentration at steel surface

after time t by using where x is the minimum concrete cover;

$$C(x,t) = C_i + (C_s - C_i)\,erfc\left[\frac{x}{\sqrt{4Dt}}\right]$$

- Repeat the calculation with different sets of *D* and *t* until *C(cover, t)* = 0.2% Cl w/w concrete;
- The time t at this point is the estimated service life of the concrete member.

It should be noted that experiments to obtain *D* are commonly performed in fully immersed condition (B2 exposure). Consistency of data is most likely in this condition. Attempts to simulate other marine exposure are not as successful in terms of duplicating real exposure. The following corrections are suggested for estimating D in different marine exposures (based on D of fully immersed condition):

- Atmospheric Zone ~ 0.25 D;
- Spray Zone ~ 0.7 D;
- Splash Zone ~ 2.5 D;
- Upper Tidal ~ 1.5 D;
- Mean Tidal/Lower Tidal ~ D

2. SUMMARY

A procedure for estimating the service life of reinforced, marine concrete structures is suggested in this guideline. With the data generated using fly ash concrete and portland cement concrete (See Fly Ash Reference Data Sheet No. 6.*), it can be demonstrated that for a given grade of concrete and cover thickness, fly ash concrete can provide longer service life under B2 and C exposures.

* Required cover thicknesses for different design lives are suggested for fly ash blended cement concretes in marine environments.

3. LIMITATIONS

The work presented in this report, particularly in aspects related to service life, is limited to normal cast in situ concrete wet cured for 7 days. The 'average' behaviours of portland and fine grade fly ash concretes were reported. The translation of the suggested requirements to specific concrete mixes with and without the use of a specific fly ash, under different curing regimes or made with different processes should NOT be done without relevant data.

It should be noted further that to ensure the achievement of service life of marine concrete structures, it might be necessary to consider the consequence of concrete damages by other physical/chemical/biological degradations relevant to the specific marine environment. The evaluation of risk of failure at different stages during the design service life is advisable. This is critical for marine structures where the risk of failure is linked to safety and/or substantial economic lost.

4. REFERENCES

The full text of CSIRO Research Report BRE 062, Guidelines for the Use of Fly Ash Concrete in Marine Environments, prepared by H.Trinh Cao and Liana Bucea is available on the Ash Development Association website www.adaa.asn.au

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Ash Development
Association of Australia
P.O. Box 1194, Wollongong
NSW 2500 Australia
Telephone: +61 2 4228 1389
Facsimile: +61 2 4258 0169
Email: adaa@adaa.asn.au
www.adaa.asn.au

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