oncrete Durability
nd Repair Technology

roceedings of the International Conference
eld at the University of Dundee, Scotland, UK
n 8-10 September 1999

dited by

Ravindra K. Dhir
irector, Concrete Technology Unit
niversity of Dundee

nd

Michael J. McCarthy
Lecturer, Concrete Technology Unit
University of Dundee

ThomasTelford

PREDICTION OF SERVICE LIFE AND CHOICE OF REPAIR STRATEGY

C Henriksen
C Michaux
In-Situ SA
Luxembourg

ABSTRACT. The increasing damage to concrete structures during the last few years has led to an increasing need for repair works and is not likely to change in the future, until all old concrete structures have been repaired or secured against repair through preventive maintenance. As the extent of repair works exceeds available funding there is a need to optimise spending of the available funds. Service life calculations have become a necessary part of this process. No established well documented service models are however available. The paper consider that there is an extensive need for the developing of more reliable models, but that it is possible to carry out reliable service life evaluations based on existing knowledge. Furthermore it is highlighted that the sampling of the data to be used in the models is far more important for reliability of repair assessment needs than the model itself. A simple model, therefore, is preferable and the paper sets up a guideline for such model and finally how to prepare realistic repair strategies.

Keywords: Deterioration, Corrosion, Frost, Alkali-aggregate reactions, Service life modelling, Economic calculations, Repair strategies.

Carsten Henriksen is Manager of In-Situ SA., Luxembourg. He specialises in testing of concrete structures, concrete durability, corrosion and evaluation of repair strategies for reinforced concrete structures.

Christophe Michaux is Fifield Engineer. He specialises in testing of concrete structures, concrete durability, corrosion and evaluation of repair strategies for reinforced concrete structures.

SERVICE LIFE MODELS - PROBLEMATICS

Service life modelling has become a necessary part of the evaluation of existing structures.

- Data sampled from the structure are put into a theoretical model and the time of initiation of damage and the remaining service life are calculated ref. Figure 1.

Most models available are based on the second law of Ficks[1,2,3]. It is wellknown that this diffusion model is not all time valid e. g:

- The model is based on the diffusion of the aggressive agents (CO_2 and chlorides primarily). Chloride ingress in not submerged structures however will take place through capillary suction as well. This process is a far more rapid process than that of diffusion.

- The model requires a permanent water filled pore system. The moisture content in not submerged structures however is varying with the surrounding climate. Saturation takes place in wet periods and drying out in dry periods. In most climates the concrete cover layer over years will tend to be in an equilibrium with 85-90 % RH (the annual moisture average the most places). The requirement to saturation rarely can be fulfilled in practise.

Another critical parameter is the threshold value for the chloride content. Chlorides are the main reason of the most durability problems to reinforced concrete structures [3]. Consequently the most modelling concerns chloride initiated corrosion. The initiation depends on the size of the threshold value. However we have no all-time valid threshold value for chloride.

On this bases it is hard to claim that reliable service life models are available. Better or theoretically more correct models are being developed but if they will improve the decision basis is difficult to know..

Most concrete durability problems are related to hidden execution faults[3]. Even the most advanced theoretical model can not foresee where execution faults are located. The quality of the sampling in practise (to detect where these faults are located) therefore is more decisive for the quality of the estimate than the model itself. A simple service life model therefore should be preferred despite the uncertainty.

Finally it must be stressed that the evaluation of the load carrying capacity is a crucial element in the service life calculation. This is often forgotten discussing durability and service life.

SAMPLING OF DATA

Based on the sampled data the times t1, t2, t3 and t4, ref. Figure 1, are estimated. The sampling of data itself is crucial for the estimation. To ensure the reliability of the sampled data a certain procedure has to be followed from time to time. In the following a test procedure is suggested. The procedure is valid in cases where durability problems are caused by chloride induced corrosion

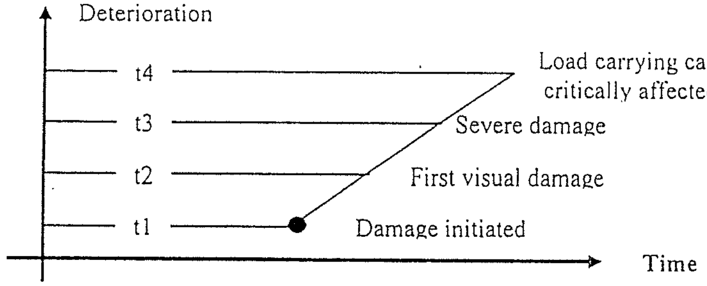

Figure 1 Service life curve for a concrete structure

The suggested procedure for the data sampling is:

Phase 1: The Overview

- structural evaluation by a structural engineer(detection of areas critical to the load carrying capacity, expected crack patterns etc.)
- visual inspection of the structure to detect cracks and other obvious visible concrete damage.
- hammer tapping and eventually Impact Echo testing or similar to detect areas with internal flaws.
- potential measurements to detect areas with corrosion(corrosion will not be initiated without effecting the electrochemical potential).

Phase 2: The Confirmation

- Based on the potential measurements the structure is preliminary divided into e.g. high risk, medium risk and low risk corrosion zones ref figure 2. This can be done automatically by equipment available on the market. Or following e.g. the ASTM-standards(even it is wellknown that they are not all time valid).
- chloride profile and carbonation measurements are carried out in each corrosion risk zone[4]. It is important that chloride profiles are sampled to a depth behind the reinforcement layer in relevant intervals e.g. 0-15mm, 15-30mm, 30-50mm and 50-70mm.
- covermeter measurements are carried out in each risk zone
- break-ups to visually inspect the actual state of corrosion in each corrosion risk zone. Even the rebars in the low risk zone have to be visually inspected.
- cores are cut for the purpose of detecting areas with delamination, evaluating the concrete quality or the risk of frost/alkali aggregate reactions[5]. The locations of the cores are chosen based on the results of the visual inspection, the hammer tapping and the Impact-Echo testing.

Phase 3: Re-evaluation

This phases is initiated if Phase 1 and 2 have revealed results not being logic or not fully confirmed.

Typically problem: No correlation between potential measurements and the visual inspection of the exposed rebars e.g.:

- *the measurements indicate corrosion and no corrosion can be visually observed.* Visual corrosion products develop over time. Not immediately after the initiation of the corrosion process. If the concrete is carbonated or chloride contaminated it is obvious to conclude that a corrosion process actually is developing. Repair/maintenance means will be needed. If the concrete is not carbonated or chloride contaminated other parameters than active corrosion are affecting the potentials(shall not be detailed in this paper). Consequently there are no need to initiate repair/maintenance means. A future survey might be preferable.
- *the measurements indicate no corrosion, the concrete however is chloride contaminated/carbonated and corrosion has developed.* The potential measurements and the ranking in low risk, medium risk and high risk zones has to be re-evaluated. The evaluation of the potential measurements carried out during Phase 1 is preliminary only. The correct correlation between the visual observations and the potential measurements has to be set-up during phase 3. This is done changing the potential limits preliminary used (e.g. the ASTM-standard) in a more positive direction (from e.g. -300 to -250mV, from -250 to -200mV etc) until the correlation is correct. More break-ups might be needed.

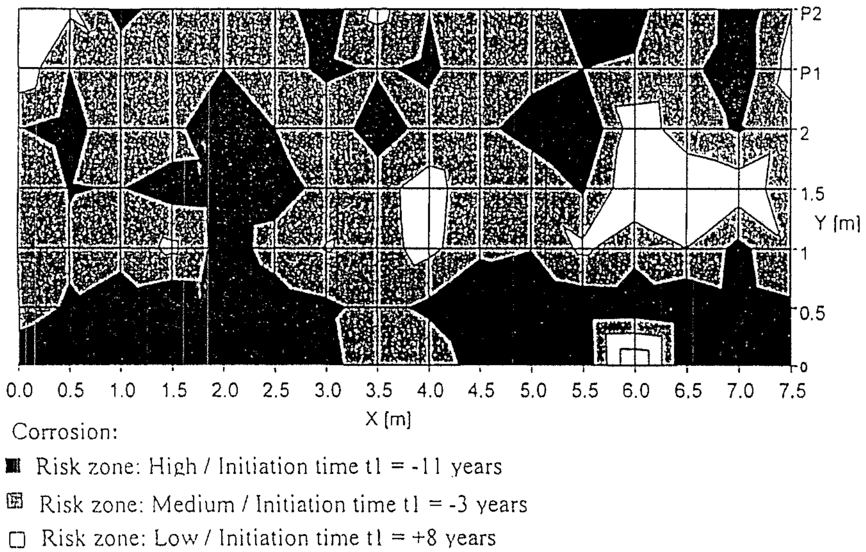

Figure 2 Results of the potential mapping of a concrete structure (a wall of a swimmingpool) and related estimates on the time of initiation, ref Figure 3

SERVICE LIFE CALCULATION

General

In the following a simple model of service life calculation is described. This model requires uncracked conditions. If the concrete is cracked the model is not valid.

In case of cracking conclusions have to be based on a structural evaluation/calculation.

If the concrete appears with delaminated or spallen areas the model can not be used neither. Such areas anyway have to be repaired. Which mean to be initiated has to be decided upon based on a structural evaluation/calculation. Finally it must be stressed that the definition of the service life is an individually choice. In this paper the time of initiation is defined as the service life. The time until the damage has affected the structure (t2, t3 or t4) however might be defined as the service life.

Calculation

In the following a calculation model based on a simplified version of Fick's 2. law is used[1,2]. The model requires that any transport takes place as diffusion and that the concrete is saturated.

The theoretical time of initiation is calculated according to the formula:

$X = K\sqrt{t}$ where
X = concrete cover layer thickness (mm)
K = constant
t = age (years)

Example 1: Calculation

The threshold chloride level (e.g. 0,05% mass of dry concrete) is located in the depth of 20 mm(X) in a 25 years (t) old structure ref. Figure 3.

The constant K then is:
$K = 20/\sqrt{25} = 4$

With K=4 the time(t1) until the chlorides penetrate the concrete cover layer (X1) can be calculated:

$t1 = (X1/K)^2 = (30/4)^2 = 56$ years

The structure is 25 years(t) old. The remaining service life until corrosion theoretically will be initiated is:

Remaining Service Life = t1-t = 56-25 = 31 years

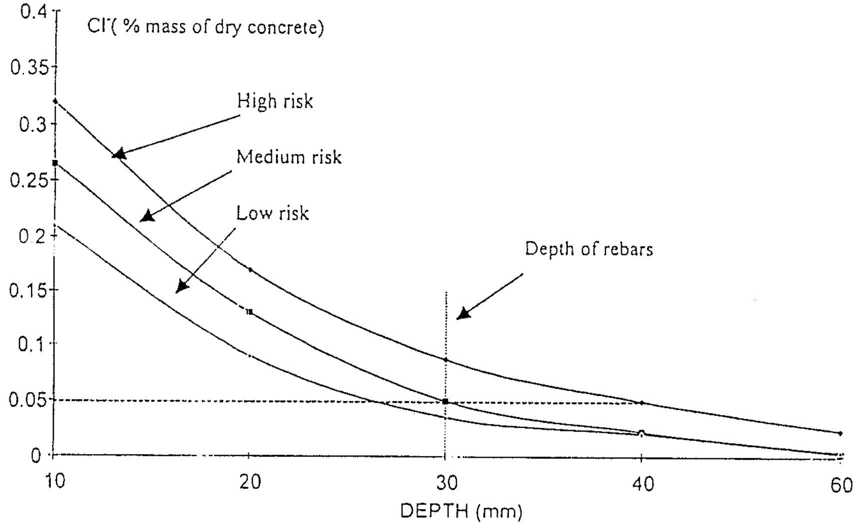

Figure 3 Chloride profiles measured in each of the corrosion risk zones ref Figure 2

Figure 3 illustrates 3 chloride profiles sampled in each of the 3 corrosion risk zones defined in Figure 2.

Based on the formula described in example 1 the time of initiation (defined as the remaining service life) of each risk zone can be calculated(threshold chloride value: 0.05% mass of dry concrete):

- High risk: -11 years
- Medium risk : -3 years
- Low risk: + 8 years

In the high risk zone corrosion already has been initiated and corrosion damage extensively developed. In the medium risk zone the corrosion too has been initiated but the reinforcement and the concrete normally still will be without extensive damage. In low risk zones the corrosion has not yet been initiated.

CHOICE OF REPAIR STRATEGY/ ECONOMIC CALCULATIONS

For each corrosion risk zone the remaining service life has been estimated ref. Figures 2 and 3. Based on the potential measurements the area (m²) of each zone can be estimated.

Normally the number of repair strategies available is limited. Furthermore each of them require that the structure has a certain remaining service life to prevent from early age repair damage, ref. Figure 4.For each risk zone the available strategies and costs are assessed based on Figure 4.

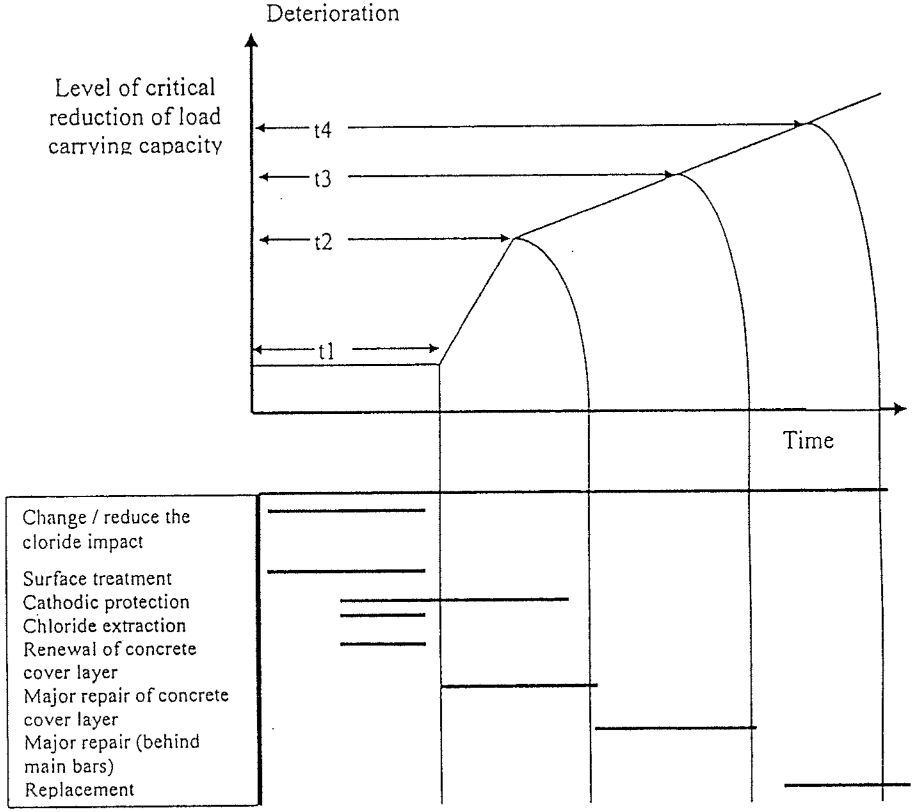

Figure 4 Relevant methods depending on the level of deterioration. The service life curve is calculated based on a special investigation

The final choice of relevant strategies has to be a mix suiting the best the actual situation. It is obvious that repairs initiated step by step to the different risk zones at different times are not realistic. An overall repair strategy has to be initiated for the entire structure. Either initiating immediate actions or choosing a different strategy to be executed later. In the following 3 different strategies for the wall are described.

Strategy 1:	Local major repair and surface treatment Major repair of all high and medium risk zones and finally surface coating of all areas to prevent from further damage. The work must be carried out immediately. The strategy includes regular repair of the coating every 10 years.
Strategy 2:	Overall major repair The load-carrying capacity will not be affected the first 10 years. The repair is postponed 10 years. There is extensive damage after 10 years. Major repairs have to be carried out to the entire structure(all high, medium and low risk zones). A surface treatment is included to prevent future damage(to be

Strategy 3: Local minor repair and cathodic protection
Only the most necessary minor repairs are carried out to high risk zones.
Further damage to medium and low risk zones is prevented using cathodic protection(to be repaired every 15 years).The strategy has to be initiated as soon as possible to limit the extent of concrete repairs.
Cost for the surveillance of the cathodic installation has to be included.

The financial requirements over a 20-year-period are shown in Table 1.

Table 1 Costs of 3 different strategies

YEAR	STRATEGY		
	1	2	3
0	175,000		145,000
5			10,000
10	40,000	475,000	10,000
15			50,000
20	40,000	40,000	10,000
Total costs	255,000	515,000	225,000
Net present value *	206,000	250,000	180,000

* Discount rate 7%

Choice of Strategy/risk Analyses

Strategy 1 and 3 are technically and economical equal, strategy 3 however having the lowest cost over time(20 years).

If money is available now, strategy 3 should be chosen. If no funds are available it is apparent that the technical and economic consequences will be extensive. If the repair works are postponed an extensive development of damage has to be foreseen and finally call for another repair strategy(strategy 2).

Strategy 2 is however not attractive in any respect and stress that a postponement- policy in most cases is not beneficial.

FINAL REMARKS

Service life modelling based on in-place testing will be a necessary tool when trying to optimise investments in concrete repairs and maintenance in the future. With today's knowledge, evaluation of service life is somewhat uncertain. But this is no obstacle to an evaluation as long as the technical and economic consequences are also evaluated. In most cases the effect of uncertainties is minor. Only in cases where long time predictions are made (> 20-25 years) care should be taken to confirm the predictions through regularl controls over the period.

The model described in this paper is of a very simple nature that does not pretend to be very accurate. However as a tool in the hands of an experienced engineer it will be of a sufficient accuracy to prepare repair strategies within the time perspective of 10-25 years. This time perspective normally covers the most cases.

The experienced engineer normally will know how to handled deterioration problems even without any model. The model in fact does only support his evaluation and helps him to detail the time of execution, helps him to evaluate if preventive measures are more beneficial than repair means and finally helps him to describe correctly the extent of areas in the need of repair to prevent early age repair damage.

Future developments however have to be implemented in order to improve our basis for decision-making. This benefits both the individual engineer and society in general.

REFERENCES

1. POULSEN, E. 13 betonsygdomme, Beton 4, SBI 1985. (E. Poulsen, " 13 Concrete Diseases " Concrete 4, SBI 1985)

2. POULSEN, E. Klorider og 100 ars levetid, DBF-Publikation nr 36, (E. Poulsen, " Chlorides and 100 years service life ", DBF Publication n° 36)

3. Chloride-induced Corrosion, The Danish Road Directorate, October 1991

4. GERMANN, C, PETERSEN, ANKER HANSEN, O G. Dansk Beton Nr 1 1991, RCT-Metoden, (Danish Concrete Nr 1, 1991, The RCT Method by C. Germann Petersen and Anker, Hansen)

5. HENRIKSEN, C. Consequences of alkali-aggregate reaction in Denmark, Presented at the 6th international DBMC, 1993, Japan)

6. HENRIKSEN, C. Service Life Prediction; Choice of Repair Strategy for RC Structures, Presented at the Materials Research Society Fall Meeting, December 1997 in Boston.