# DETERMINAREA DURATEI DE SERVICIU A STRUCTURILOR DIN BETON
# DETERMINATION OF SERVICE LIFE FOR CONCRETE STRUCTURES

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***Premature deterioration and failure of reinforced structures in last 4 -5 decades deviated focus of researchers from compressive strength to durability and service life of structures. Several structures constructed before invention of modern cement and other advanced building materials are in service condition, whereas new structures were deteriorating faster than those old structures. Therefore, determination of remaining service life of concrete structures is significant. This article presents a service life model suitable for semitropical regions of India, developed using MATLAB for estimating residual service life of deteriorating structures and for predicting corrosion initiation time for new structures.***

***Keywords:*** *concrete, carbonation, model, reinforcement, corrosion, deterioration, service life*

## 1. Introduction

Premature and faster deterioration of concrete structures during recent time highlighted need for effective methods for condition evaluation and maintenance. This resulted in development of several service life models worldwide. Service life models can play an important role in evaluating condition and planning maintenance or replacement of reinforced concrete (RC) structures. However, deterioration mechanisms, parameters influencing durability their effect with age depends precisely on climatic metrological conditions of the region. Therefore, a model has been developed using data from a field survey performed at Bhopal city, which is suitable for semitropical regions of India.

Several models have been developed worldwide using different tools. Goulet and Smith (2012) [1] proposed a model to understand and predict the behavior of structures and proposed approach is applied for monitoring of Langensand Bridge in Lucerne, Switzerland. A multispecies model has been developed by Yuan et al. (2011) [2] by using parameters such as porosity, density, chemical composition of pore solution, diffusion coefficient and chloride binding isotherm. Orcesi and Frangopol (2011) [3] utilized a model using lifetime functions to evaluate a probability of survival of bridge components. Huang (2010) [4] developed a model with MATLAB programs, based on data from previous maintenance and inspection, to determine the deterioration of RC bridges. An algorithm has been developed by Dao et al. (2010) [5] which utilize different steel corrosion models including a FEM based model for predicting the service life of bridges. A probability based model considering the effects of bio-deterioration in degradation of RC structures has been proposed by Bastidas-Arteaga et al. (2008) [6] to assess life time of RC structures. Song et al. (2007) [7] presented a micromechanics based corrosion model which divides service life in four parts - initiation period, propagation period, acceleration period, and deterioration period. Beek et al. (2003) [8] presented a Life Time Extending (LEM) model for predicting condition and service life of RC structures. Vu and Stewart (2002) [9] measured service life of structures exposed to aggressive environments by the probability of cracking and spalling of concrete cover.

## 2. Evaluating service life of RC structures

Model presented in this article is suitable for RC structures situated in semi tropic regions of India such as Bhopal city. Present model requires data from field such as concrete cover in mm (cc), carbonation depth in mm (cd), difference between concrete cover and carbonation depth (dccd), chloride content at rebar depth in percentage weight of concrete (cl) and age of structure in years for evaluating present condition and estimating remaining service life of RC structures. Present condition of structure is evaluated through a ten point (0-9) condition rating proposed by Verma et al. (2013) [10] in Table 1. Present condition of a RC structure can be evaluated using this table, based on parameters such as carbonation depth, difference between concrete cover and carbonation depth, chloride concentration and age of structure.

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## 3. Prediction of corrosion initiation time for deteriorating structures

After evaluating present condition from condition rating system, it is required to calculate corrosion initiation period. Corrosion initiation period can be defined as time required for carbonation front to reach the rebar level depth i.e. carbonation depth becomes equal to the concrete cover, or when chloride concentration of the concrete surrounding the rebar reaches to its threshold value (0.2% by the weight of concrete). Now, corrosion initiation time can be evaluated considering the following variables:

ti(cd) is time period for carbonation to reach rebar depth after construction, ti(cl) is time required for chloride content to reach the threshold value (0.2%) at rebar level. Hence, corrosion initiation time is the smaller time between ti(cd) and ti(cl).

Values of ti(cd) and ti(cl) have been calculated through carbonation and chloride ingress models. In the present research carbonation depth and chloride concentration are evaluated through well established Fick's laws. Value of ti(cl) has been evaluated through well known Fick's second law of diffusion presented in eqns. (1 to 3).

$$C(x,t) = Cs[1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)] \qquad \text{eqn. (1)}$$

Where erf is the error function

$$\mathrm{erf}\,(u) = \frac{2}{\sqrt{\pi}}\int_0^u e^{-t^2}\,dt \qquad \text{eqn. (2)}$$

Hence, ti(cl) can be evaluated using above model as

$$\mathrm{ti(c)} = \frac{C^2}{4D}[\mathrm{erf}^{-1}\left(1 - \frac{Cth}{Cs}\right)]^{-2} \qquad \text{eqn. (3)}$$

where Cs is surface chloride content, Cth is threshold chloride content and D is chloride diffusion coefficient. Values of D and Cs evaluated in a study performed by authors in their previous paper (verma et al., 2013) [11] shown in Table 2, have been utilized in present research. .

Model presented in eqn. (4) is applied as a carbonation model, which Fick's first law of diffusion

$$Cd = K\sqrt{t} \qquad \text{eqn. (4)}$$

value of K is considered as 5.73, calculated in authors previous paper, (Verma et al., 2015) [12], from this relation ti(cd) has been be calculated as $ti(cd) = (Cd/k)^2$.

## 4. Development of service life model

A service life model has been developed using MATLAB to predict remaining service life of deteriorated concrete structures, in which corrosion is initiated. This model also estimates corrosion

**Table 1**

Ten point Condition rating system for RC structures (Verma et al. 2013) [10]

| Condition Rating (CR) | Failure Extent | Description (In terms of cl and dccd) | Action required |
|---|---|---|---|
| 0 | safe | cl < 0.2 and dccd > 0 and age ≤ 10 | Excellent condition |
| 1 | good | cl < 0.2 and dccd > 0 and age > 10 | No maintenance required |
| 2 | Low risk but satisfactorily | cl <0.2 and dccd ≤ 0 or cl = 0.2 and dccd ≥ 0 | Corrosion initiated, required regular inspection |
| 3 | fair | 0.25 > cl > 0.2 and dccd > 0 | Required frequent inspections |
| 4 | Moderate risk | 0.25 > cl > 0.2 and dccd ≤ 0 | No immediate maintenance, it may be delayed |
| 5 | poor | 0.3 > cl ≥ 0.25 and dccd > 0 | Maintenance is required to increase the service life |
| 6 | High risk | 0.3 > cl ≥ 0.25 and dccd ≤ 0 | Maintenance is must for continuous use, likely to repair |
| 7 | serious | 0.4 > cl ≥ 0.3 and dccd > 0 | Structure must be closed for maintenance |
| 8 | critical | 0.4 > cl ≥ 0.3 and dccd ≤ 0 | Poor condition not likely to be repaired |
| 9 | failure | cl ≥ 0.4 | Replacement of structures |

**Table2**

Values of D and Cs for structures of different age (Verma et al., 2013)[11]

| S. No. | Age of structure (years) | Surface chloride content (Cs) (% wt. of concrete) | Diffusion coefficient $D \times 10^{-12} (m^2/sec)$ |
|---|---|---|---|
| 1 | 11 to 20 | 0.391 | 1.394 |
| 2 | 21 to 30 | 0.684 | 0.966 |
| 3 | 31 to 40 | 0.651 | 1.455 |
| 4 | 41 to 50 | 0.796 | 0.819 |
| 5 | 51 to 60 | 0.643 | 1.473 |

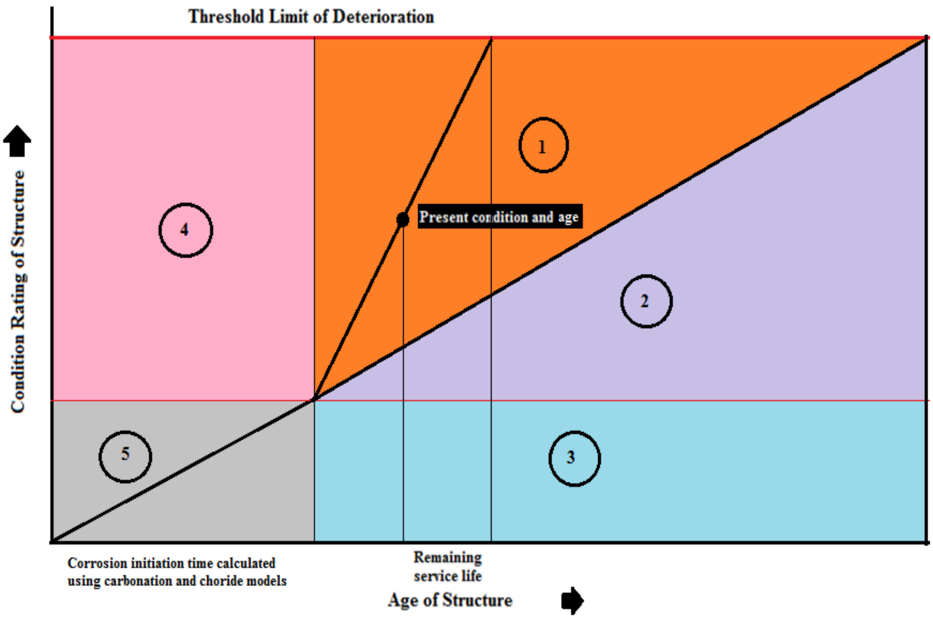


Fig. 1- Classification of structures.

initiation time for new or good condition structures. This developed model requires data from field to evaluate present condition of structure through a condition rating system shown in Table 1 and calculates corrosion initiation time through carbonation and chloride ingress models. Thereafter, from present condition and initiation period produced a graph indicating different phases of service life for a structure. Calculated corrosion initiation time depends over chloride and carbonation models, which may not represent real corrosion initiation time. Structures may get corroded at a rate slower or faster than calculated from models, this depends over the exposure conditions. Moreover, if maintenance is provided on time it improves the performance of structure and increases the service life of structures. Developed model considered all these aspects and classified structures in following five categories according to their present condition and performance, as presented in Figure 1.

### 4.1. *Classification of structures (type 1 to 5) on the basis of their present condition and performance*

1. Deteriorated concrete structures without any maintenance
2. Deteriorated concrete structures with required maintenance provided after initiation of corrosion
3. Present age is more than initiation time calculated using chloride and carbonation models, and it is deteriorating at a rate slower than estimated rate.
4. Corrosion initiated before the time calculate by using chloride and carbonation models, and it is deteriorating at a rate faster than estimated rate.
5. New structure with excellent condition and age below initiation period calculated using chloride and carbonation models.

This Model provides service life graph for RC structures, presented in Figures 2 to 10 for different categories of structures classified according to above classification (type 1 to type 5). Figure 2 presents the service life graph for type1 structures produced by developed model. This indicates calculated corrosion initiation time, present condition and estimated residual service life for a structure.

Figures 3 and 4 presents the service life of type 2 structures, to which required maintenance is provided at the time of corrosion initiation. The maintenance reduces deterioration rate and increases the service life.

Figures 5 and 6 presents the service life graph for type 3 structures, present age of these structures is more than initiation time calculated using chloride and carbonation models and corrosion is not yet initiated. Hence, it has been concluded that structures are deteriorating at a rate slower than estimated deterioration rate. As corrosion is not initiated, therefore, for type 3 structures this model can predict only corrosion initiation time.

Figures 7 and 8 presents the service life graph for type 4 structures, in which corrosion is initiated before the time calculate using chloride and carbonation models. Therefore, it has been found that these structures are deteriorating at a rate faster than estimated rate and remaining service life can be estimated as shown in Figure 8.

Service life graphs for type 5 structures have been presented in Figure 9 and 10. Type 5, are new structures with excellent condition and age below calculated initiation period. For these types of structures corrosion initiation can be estimated as shown in Figure 10.

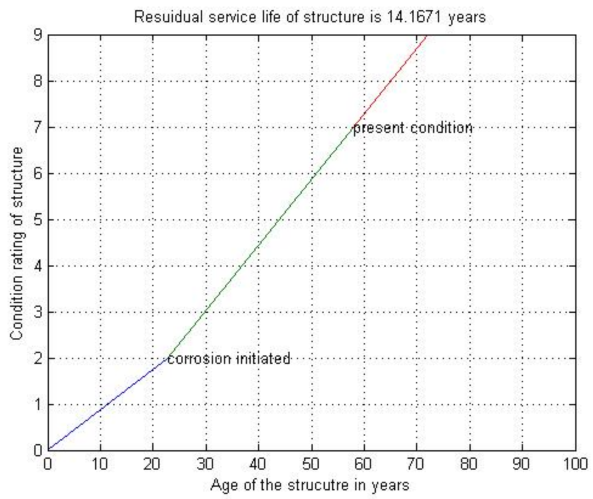


Fig.2 - Result of model for type 1 structures.

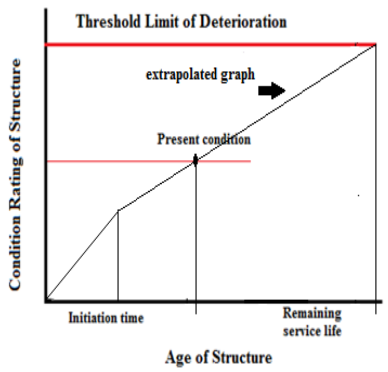


Fig. 3 - Pattern of Service life for type 2 structures.

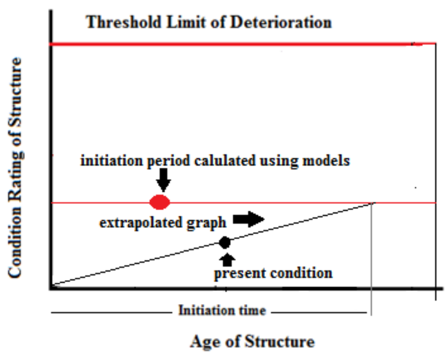


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Fig. 5 - Pattern of Service life for type 3 structures.

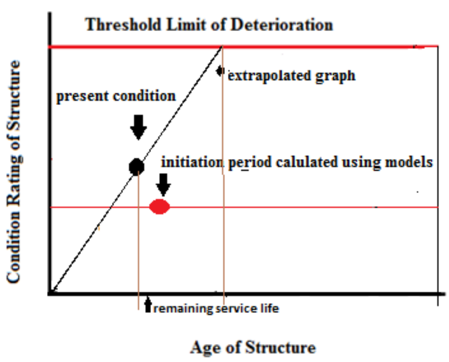


Fig. 7- Pattern of Service life for type 4 structures.

## 5. Discussion and Conclusions

It has been concluded that change in environmental conditions significantly influences the performance and deterioration of RC structures. Therefore, a service life model developed using MATLAB for existing RC structures, suitable for semitropical regions of India, has been presented here, this developed model is having following specifications-

1. It predicts residual service life of deteriorated concrete structures and estimates corrosion initiation time for new structures.

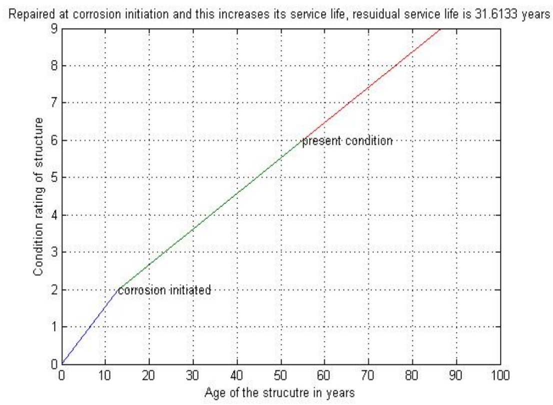


Fig.4- Result of model for type 2 structures.

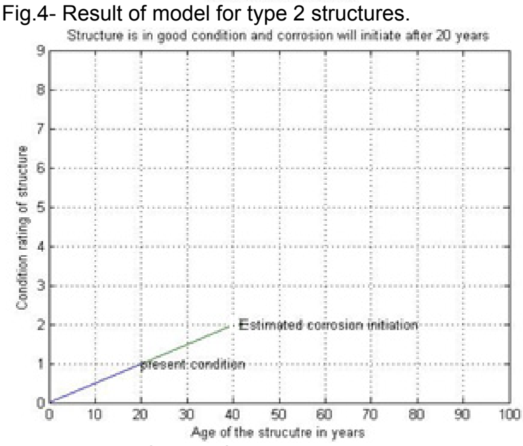


Fig.6 - Result of model for type 3structures.

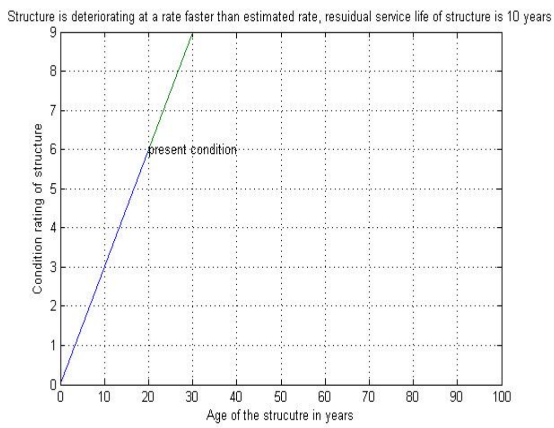


Fig.8 - Result of model for type 4 structures.

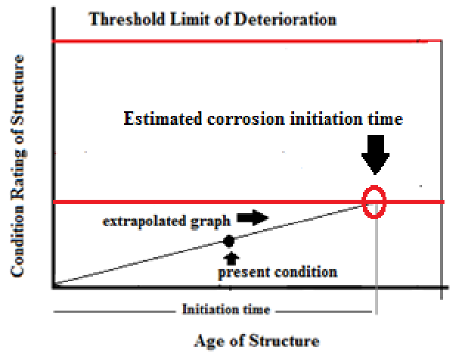


Fig. 9 - Pattern of Service life for type 5 structures.

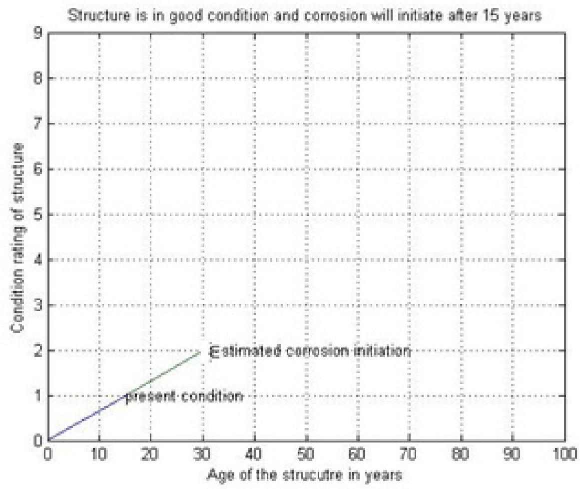


Fig.10 - Result of model for type 5 structures.

2. Above prediction is based on present condition of structures obtained from Table 1, through the values of chloride content, concrete cover, carbonation depth and age of structure.
3. It classified RC structures in five categories from type 1 to type 5, based on present condition and performance of structure.
4. Above classification depends on fact that real deterioration and performance of structures may differ from those values calculated using chloride and carbonation ingress models. This difference is due to exposure conditions and maintenance provided.
5. Figures 2 to 10 presents service life graph plotted by developed model for all the five type of structures.

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