Scientific Journal of Impact Factor (SJIF): 4.72

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 10, October -2017

SERVICE LIFE ASSESSMENT OF R.C.C. SLABS

Dr. Archana Bohra Gupta,

Associate Professor, Dept. of Stru. Engg., MBMEC, JNVU Jodhpur, India.

Abstract- *Reinforced cement concrete (RCC) structures in an aggressive or salt laden environment deteriorate with time due to chloride-induced corrosion of reinforcing bars. When the RCC slabs of structures are exposed to a very aggressive environment, higher deterioration rates can develop. For new and existing RC slabs, the concrete cover forms a necessary factor to prevent or delay the chloride-induced reinforcement corrosion causing the deterioration of structural performance. Also the water cement ratio forms another important parameter affective the service life of RCC elements. Several service life models are available for estimating the service life of reinforced concrete structures, viz Life-365^{TM}, DuraCrete, Stadium, ClinConc etc. All the models are not applicable for all conditions and all structures specifically when the environmental exposure conditions are complex. This paper proposes the application of service life model Life-365^{TM} for estimating the service life of RCC slabs exposed to chloride laden environment in service. The parameters that are critical for the estimation of service life are identified and their role in designing service life is evaluated. A parametric study with the help of Life-365^{TM} is taken up which provides a systematic methodology to determine the service life of RCC slabs which can help plan their maintenance schedules.*

Index terms- *Service life, reinforced concrete, corrosion, chloride diffusion, Life-365^{TM}*

I. INTRODUCTION

Reinforced cement concrete (R.C.C.) structures are supposedly designed to have a high service life. But in practice the structures perform for a very less period than intended owing to poor maintenance schedules, durability problems etc. Reinforced concrete slabs exposed to aggressive environments such as salt laden water are at high risk of penetration of chloride ions into concrete, which is a major cause of corrosion of reinforcement and subsequent deterioration of structure. The financial aspect of these structural elements requires the engineers to minimize the deteriorating effects and increase their service life. This requires an in-depth understanding of what service life is and what are the parameters affecting it.

As per Eurocode 1 [1], the service life for a structure can be defined as:

"A structure shall be designed and executed in such a way that it will, during its intended life with appropriate degrees of reliability and in an economic way:

- remain fit for the use which it is required; and
- sustain all actions and influences likely to occur during execution and use."

Weyers (1998) [2] gave that the end of service life is the time of the occurrence of first cracking.

Amey et. al. (1998) [3] said that when the percentage of reinforcement subjected to corrosion exceeds a certain threshold value, it shows the end of the service life.

B. Martín-Péreza, Z. Lounis (2003) [4] said that the service life is defined as the time until damage accumulation reaches an unacceptable level or 'limit state', i.e., it is the time when the failure probability reaches an unacceptable level (which depends on the type of structure and failure mode).

Z. Lounis, L. Amleh (2004) [5] said that service life can also be defined as the time at which any of the following limit states are reached: onset of corrosion, cracking, delamination, spalling, or accumulated damage reaching a specified limiting value. An appropriate definition of failure, and consequently service life should consider the acceptable risk of failure, which depends on the risk of loss of life, structure type, failure mode etc.

H. W. Song et al. (2007) [6] defined the service life for their study as the time for the corrosion initiation, i.e., when a chloride concentration reaches the critical threshold value (1.2kg/m^3 of total chloride content) at surface of rebar. They also suggested that the time interval from the initiation of corrosion to corrosion cracking in concrete cover is the cracking time of structures.

In Life-365^{TM} [7], service life (t_s) of reinforced concrete is defined as the sum of the time to initiation of corrosion and the propogation time required for corroding steel to cause sufficient damage to require repair, hence also called time to first repair (t_r) (M.A. Ehlen, M.D.A. Thomas, E.C. Bentz (2009)) [8]. This is based on Tuutti's corrosion model (Tuutti 1982) [9].

Life-365 analysis can be classified into four sections:

- Predicting the time for the onset of corrosion of reinforcing steel, commonly called the *initiation period*, (t_i);
- Predicting the time for corrosion to reach an unacceptable level, commonly called the *propagation period*, (t_p);
- Determining the repair schedule after first repair; and
- Estimating life-cycle cost based on the initial concrete costs and future repair costs.

The first two steps are covered in this study to calculate the time for first repair $t_r = t_i + t_p$.

Life-365 uses a simplified approach based on Fickian diffusion that requires only simple inputs from the user. LIFE 365 predicts the initiation period assuming diffusion to be the dominant mechanism for chloride ingress.
Fick's second law is the governing differential equation:

$$\frac{dC}{dt} = D.\frac{d^2C}{dx^2} \qquad (1)$$

where, C = the chloride content, D = the apparent diffusion coefficient,
x = the depth from the exposed surface, and t = time.

The chloride diffusion coefficient is a function of both time and temperature, and Life-365 uses the following relationship to account for time and temperature dependent changes in diffusion:

$$D(t) = D_{ref}\left(\frac{t_{ref}}{t}\right)^m \qquad (2)$$

where, D(t) = diffusion coefficient at time t,
Dref = diffusion coefficient at time t_{ref} (= 28 days in Life-365), and
m = diffusion decay index, a constant.

In order to prevent the diffusion coefficient decreasing with time indefinitely, the relationship shown in Eq. 2 is assumed to be valid only up to 25 years, beyond which *D(t)* stays constant at the D(25 years) value.
Life-365 uses the following relationship to account for temperature-dependent changes in diffusion:

$$\mathrm{D}(\mathrm{T}) = D_{ref}.exp\left[\frac{U}{R}.\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \qquad (3)$$

where, D(T) = diffusion coefficient at time t and temperature T,
D_{ref} = diffusion coefficient at time t_{ref} and temperature T_{ref},
U = activation energy of the diffusion process (35000 J/mol),
R = gas constant, and T = absolute temperature.
These equations are available in combined form, as given by B. Martín-Péreza, Z. Lounis (2003) [4]

$$\mathrm{D}(\mathrm{t},\mathrm{T}) = D_{ref}.\left(\frac{t_{ref}}{t}\right)^m.exp\left[\frac{U}{R}.\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right]$$

In the model, t_{ref} = 28 days and T_{ref} = 293K (20°C).
The solution for time for initiation of corrosion is carried out using a finite difference implementation of Eq. 1 where the value of D is modified at every time step using Eq. 2 and Eq.3.

II. DETERMINATION OF SERVICE LIFE PARAMETERS

Corrosion propogation period t_p – Weyers et. al. (1998) [2] determined that time between corrosion initiation and cracking varied between 3-7 years for reinforced concrete bridge decks in United States. M. Li, R. Ranade, L. Kan, V. C. Li (2010) [10] used t_p = 6 years for R.C. bridge decks, based on study of Weyers et al. (1998) [2] and others, and t_p = 60 years for E.C.C. (engineered cementitious composites) bridge decks based on the damage model analysis results by Lepech (2006) [11] who considered the large tensile strain capacity of ECC to resist the radial fracture caused by rust expansion of rebar.

Reference diffusion coefficient D_{28}- Diffusion coefficient of R.C.C. is proportional to the square of the crack width and d for ECC varies linearly with number of cracks (crack width taken constant), (M. D. Lepech, V. C. Li. (2005)) [12]. The model determines the values of D_{28} and m based on concrete's mixture proportions. LIFE-365™ uses the following equation based on the results from Bulk Diffusion Test (NordTest NTBuild 443) performed at the University of Toronto and some other published data from the same type of test, to determine D_{28} for the mixtures that does not contain silica fume:

$$D_{28} = 10^{[-12.06+2.4(w/c)]}$$

M. Li, R. Ranade, L. Kan, V. C. Li (2010) [10] calculated the D28 from the number of cracks remaining after considering the self healing effect of E.C.C.

Aging factor m- E.A.B. Koenders et al. (2009) [13] used the value of aging factor from 0.3- 0.6 in their service life model. Mangat and Molloy (1994) [14] and Poulsen [15] (Hetek 1997) [16] have given formulae to calculate aging factor m or α. For ordinary concrete with $0.25 \leq w/c < 0.60$, can be calculated from Poulsen's (Hetek, 1997) [16] expression:

$$\alpha = m = e^{-\left[\frac{(w/c)^2}{0.19}\right]} + 0.1e^{-\left[\frac{0.1}{(w/c)}\right]^{2.5}}$$

The aging factor α used by Poulsen [15] is same as the aging factor m used by Life 365 model.

Critical chloride threshold C_t – In general, the chloride threshold is the point of metal depassivation and it is a function of the structures of the concrete and the metal (usually "black" steel), and of the environment. According to Schiessl & Lay (2005) [17], "The chloride threshold, C_t, is the mass of total chloride per unit volume of concrete that results in permanent depassivation of the steel (for a specific set of mixture proportions, history, and environmental factors)."

W. Chai, W. Li, H. Ba (2011) [18], considered the critical chloride ion concentration as the main factor governing the concrete service life. The value of 0.4 % of chloride ion by weight of the cement is considered by RILEM (1985) [19] as an appropriate threshold.

The value of C_t is selected by the software on the basis of the type and quantity of corrosion inhibitor, and the nature of the reinforcement or inputted. For the black steel, this value is 0.05 % by weight of cement. The same is taken for the present study.

III. PARAMETRIC STUDY

Two cases are taken of two cities having wide variation in design parameters related to location. The software model LIFE 365^{TM} is used for calculation of service life. The effect of variation of water cement ratio (w/c) on service life is studied. Then the effect of increasing the depth of slab on service life is presented for case II only.

Common parameters:
The exposure condition – Urban highway bridges
Cement used - Ordinary Portland Cement
Concrete hydration period – 25 years
Rebar steel type- Black steel
Member- Slab
Corrosion Propogation period – 6 years
Chloride profiles and temperature profiles for both places are directly taken from the software. Figures 2 and 4 show that the maximum surface chloride concentration for Case I is same as that for Case II.

CASE - I: Time to build maximum chloride concentration t= 200 years.
Maximum surface chloride concentration C_s = 0.68 %

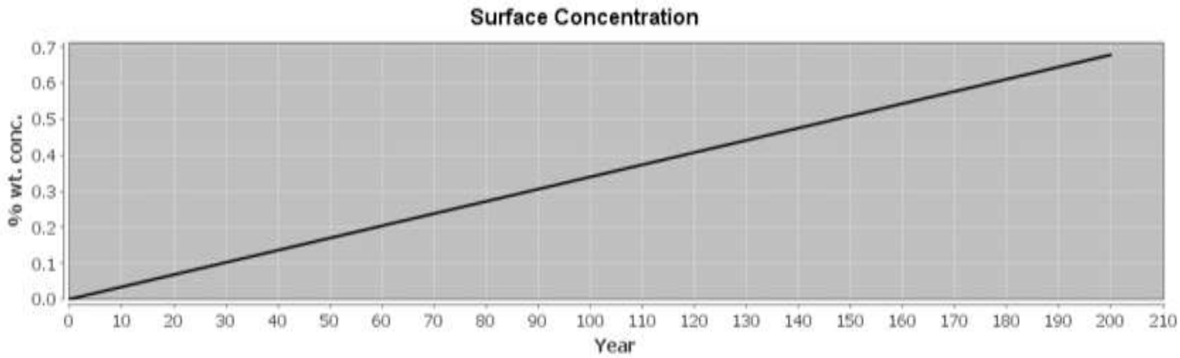

Figure 1: Chloride profile for location in Case I

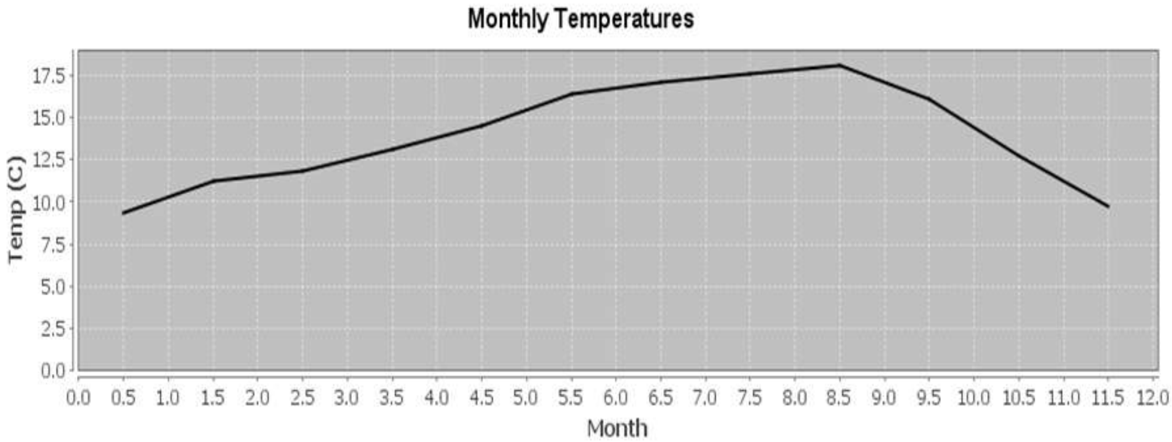

Figure 2: Temperature profile for location in case I

CASE - II: Time to build maximum chloride concentration t= 7.4 years.
Maximum surface chloride concentration C_s = 0.68 %

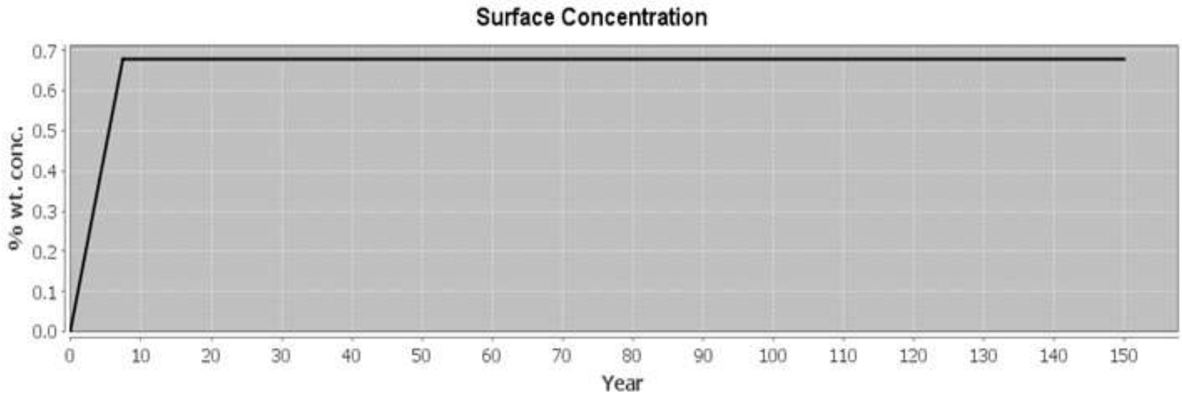

Figure 3: Chloride profile for location in Case II

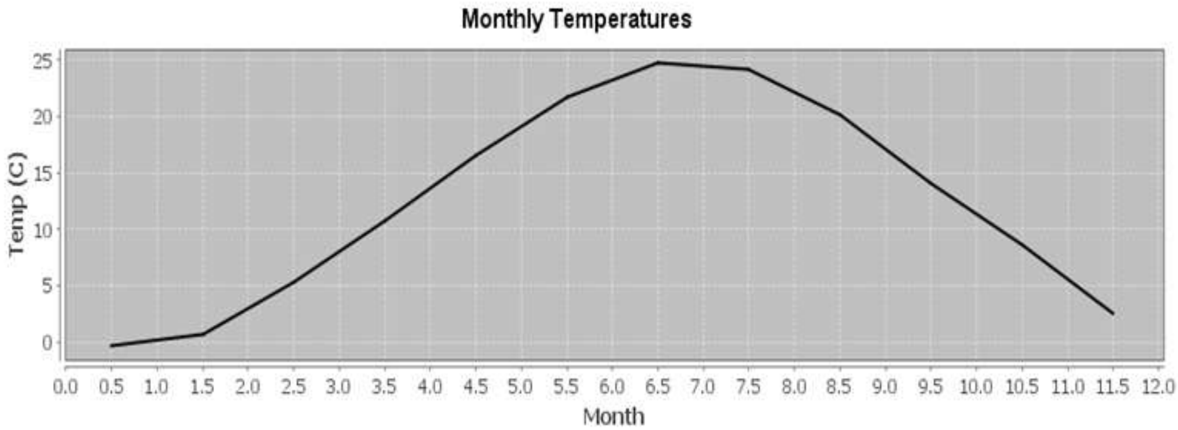

Figure 4: Temperature profile for location in case II

IV RESULTS

Calculation of service life t_s :

Service Life Parameters			Case I Without membrane & Cover 30 mm	Case II Without membrane & Cover 30 mm	Case II Without membrane & Cover 40 mm	Case II With membrane & Cover 30 mm	Case II With membrane & Cover 40 mm
w/c	D_{28}	m	t_s (years)				
0.5	1.38E-11	0.37	43.8	10.4	12.6	18.0	21.5
0.49	1.31E-11	0.38	45.3	10.6	12.8	18.6	22.1
0.48	1.24E-11	0.40	47.8	10.9	13.7	19.4	23.4
0.47	1.17E-11	0.41	49.6	11.4	14.4	19.8	24.4
0.46	1.11E-11	0.43	52.5	11.8	15.3	20.8	25.8
0.45	1.05E-11	0.44	54.7	12.3	16.0	21.6	27.1
0.44	9.91E-12	0.46	58.2	12.8	17.5	22.8	29.3
0.43	9.38E-12	0.48	62.2	13.7	19.0	24.3	31.8
0.42	8.87E-12	0.49	64.9	14.4	20.5	25.3	33.8
0.41	8.39E-12	0.51	69.7	15.5	22.8	27.0	37.5
0.4	7.94E-12	0.53	74.8	16.7	26.2	29.3	41.6
0.39	7.52E-12	0.55	80.7	18.3	30.4	31.8	46.5
0.38	7.11E-12	0.56	84.9	19.6	33.8	34.0	50.4

V. DISCUSSIONS

We find that the service life values obtained for Case I are 4.0 to 4.33 times the service life values for Case II. This is because the number of years for maximum surface chloride concentration to reach for Case I (200 years) is much higher than for Case II (7.4 years). For a location similar to that in Case II, the first repair time varies between 10-20 years with a cover of 30 mm for the various values of water cement ratios taken. But this time increases to between 12-about 34 years only by increasing the cover to 40 mm. The increase in w/c causes a reduction in the values of the initial chloride diffusion coefficient D_{28} and increase in the aging factor. For Case I, the service life increases by 93.8 % on reducing the water cement ratio from 0.5 to 0.38. For Case II, the service life increases by 88.5 % on reducing the water cement ratio from 0.5 to 0.38. The increase is approximately same (~90%) for both locations. For Case II, the service life increases from 73.1% for water cement ratio of 0.5 to 73.5% for water cement ratio of 0.38, on providing a membrane for clear cove 30 mm. For Case II, the service life increases from 70.6% for water cement ratio of 0.5 to 49.1% for water cement ratio of 0.38, on providing a membrane for clear cove 40 mm. the reduction in the percentage increase in service life shows that the effect of membrane reduces when the cover is more. Membranes only impact the rate of chloride build-up. Membranes start with an efficiency of 100%, which deteriorates over the lifetime of the membrane. The service life increases by 21.2% for water cement ratio of 0.5 to 72.4% for water cement ratio of 0.38 on increasing the clear cover from 30 mm to 40 mm. The service life increases by 106.7% for water cement ratio of 0.5 to 157.1% for water cement ratio of 0.38 on increasing the clear cover from 30 mm to 40 mm and also providing the membrane. This increase is increasing every time on reducing the water cement ratio.

VI. CONCLUSIONS

LIFE 365^{TM} is an effective tool for estimating service life. The service life reduces drastically with the decrease in number of years for maximum surface chloride concentration to build up and with increase in maximum surface chloride concentration. Service life can be increased substantially by varying the concrete design parameters. In the present study, the service life values have increased by 3-7% on reducing the water cement ratio by 0.01. The service life values can be increased by 2 to 14 years for the various water cement ratios taken by just increasing the cover by 10mm. The increase is more for lower water cement ratios. Service life values increase by 49- 73 % on providing membranes. The service life can be increased by 2 to 2.5 times by increasing the cover to reinforcement by 10 mm and providing membranes.

VII. REFERENCES

[1] EN 1991-1, Eurocode 1: Basis of design and actions on structures - Part 1: Basis of design, CEN (European Committee for Standardization), Brussels, 2002.
[2] R.E. Weyers, "Service life model for concrete structures in chloride laden environments." ACI Materials Journal, Volume 95, No.4, 1998, pp. 445-53.
[3] S.L. Amey, D.A. Johnson, M.A. Miltenberger, & H. Farzam, “Predicting the service life of concrete marine structures: An environmental methodology”, ACI Structural Journal, 95(1), 1998, pp. 27-36.
[4] B. Martín-Péreza, Z. Lounis, “Numerical Modelling of Service Life of Reinforced Concrete Structures”, Proceedings of 2nd International RILEM Workshop on Life Prediction and Aging Management of Concrete Structures, Paris, France, May 5-6, 2003, pp. 71-79.
[5] Z. Lounis, L. Amleh, “Reliability-Based Prediction of Chloride Ingress and Reinforcement Corrosion of Aging Concrete Bridge Decks”, Life Cycle Performance of Deteriorating Structures, ASCE, 2004, pp. 113-122.
[6] H. W. Song, H. J. Kim, V. V. Saraswathy, T. H. Kim, “A Micro-mechanics Based Corrosion Model for Predicting the Service Life of Reinforced Concrete Structures”, International Journal of Electrochemical Science, Volume 2, 2007, pp. 341 – 354.
[7] Life-365^{TM} Service life prediction model and computer program for predicting the service life and life-cycle cost of reinforced concrete exposed to chlorides, Version 2.0.1, Life-365 Consortium II, 2010.
[8] M.A. Ehlen, M.D.A. Thomas, E.C. Bentz, Concrete International, May 2009.
[9] K. Tuutti, “Corrosion of Steel in Concrete”, CBI, Research Report 4, 1982, Stockholm.
[10] M. Li, R. Ranade, L. Kan, V. C. Li, "On Improving the Infrastructure Service Life Using ECC to Mitigate Rebar Corrosion" Proceedings of 2nd International Symp. on Service Life Design for Infrastructure, Proc., 2nd Int'l Symp. on Service Life Design for Infrastructure, Delft, The Netherlands, RILEM PRO 70, Edited by K. van Breugel, G. Ye, and Y. Yuan, 2010, pp. 773-782.
[11] M. D. Lepech, "A Paradigm for Integrated Structures and Materials Design for Sustainable Transportation Infrastructure." Ph.D. University of Michigan Ann Arbor, 2006.
[12] M. D. Lepech, V. C. Li., "Water Permeability of Cracked Cementitious Composites", Compendium of Papers, ICF 11. Turin, Italy. (CD-ROM), 2005.
[13] E.A.B. Koenders , M. Ottelé, B. Obladen, “A spreadsheet model for service-life predictions”, Concrete Repair, Rehabilitation and Retrofitting II, edited by Alexander et al., Taylor & Francis Group, London, ISBN 978-0-415-46850-3, 2009.
[14] P.S. Mangat, B.T. Molloy, “Predicting of long term chloride concentration in concrete”, Materials and Structures, Vol. 27, 1994, pp. 338-346.

[15] E. Poulsen, "The chloride diffusion characteristics of concrete: approximate determination by linear regression analysis", Nordic Concrete Research No. 1, Nordic Concrete Federation, 1990.
[16] Hetek, "A system for Estimation of Chloride Ingress into Concrete" Theoretical Background Report no. 83, Road Directorate, Denmark, 1997.
[17] P. Schiessl, S. Lay, "Influence of concrete composition", Corrosion in reinforced concrete structures, H. Böhni (ed.), Cambridge, UK: Woodhead Publishing Limited, 2005.
[18] W. Chai, W. Li, H. Ba, "Experimental Study on Predicting Service Life of Concrete in the Marine Environment", The Open Civil Engineering Journal, 5, 2011, pp. 93-99.
[19] RILEM, Committee 60-CSG, Corrosion of Steel in Concrete, State of Art Report, Edited by P. Schiessl, Chapman and Hall, London, 1987.