Assessment of Ageing Factors: Case of Fly

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Abstract: In concrete, binding materials are used such as Ordinary Portland Cement. To enhance concrete properties additional cements such as Fly Ash is used. Fly Ash enhances chloride resistance of concrete. Bridge structures are built in land and sea environment. In both environments, when bridge structures exposed to de-icing slats experience chloride ingress. Continuous process of chloride diffusion causes corrosion of steel embedded in concrete. In such cases it is important to predict the corrosion start time. So, that it may be monitored properly. Also repair strategy may be applied timely. The process of diffusion is difficult to monitor over a long time. So, using ageing factors it is predicted for a time under study. The ageing factor if accurate can predict more accurately diffusion over time. A number of available ageing factors in literature raises question, that which ageing factor is more correct to be applied for prediction. For this purpose available ageing factors have been assessed. In present study, a chloride diffusion and ageing factor for bridge structures has been developed. So, it will be helpful to predict the corrosion start time of concrete used in bridges.

Keywords: Reinforced Concrete, Chloride Diffusion, Ageing Factor, Bridge Structures, Service Life Models

1. Introduction

Highway bridge reinforced concrete structures (R.C.C) exposed to chloride environment build up chloride content. This chloride content causes reinforcement corrosion. Bridge structures are mainly exposed to de-icing salts. These de-icing salts cause corrosion of steel. So, prediction of corrosion start time becomes important o correctly estimate the service time of bridges. Service life estimation needs knowledge about diffusion co-efficient (D), and ageing factor. So, that prediction of chloride diffusion over time may be performed. In literature a number of diffusion models and ageing factors are available. So, a question arises, which model is more accurate and which ageing factor is more accurate.

2. Diffusion in concrete

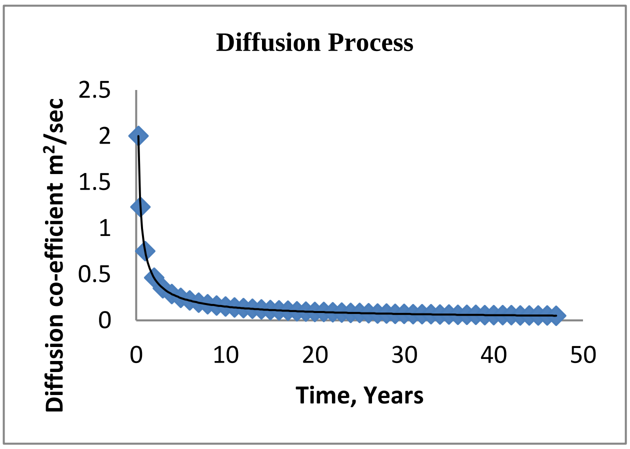
Concrete exposed to chloride ions gets chloride content by diffusion process. So, chloride ions if in a more quantity on surface of concrete causes a speedy diffusion process. In this situation, only resistance to chloride ion diffusion is offered by concrete itself. This resistance is mainly offered by the low water content in concrete. So, a high water cement ratio causes the high diffusion of chloride ions. Fick's aw of diffusion is used to determine chloride content in structural concrete.

$$C(x,t) = Cs\left[1 - erf\left(\frac{x}{2\sqrt{D(t).t}}\right)\right] \quad \text{Equation-01}$$

This equation calculates chloride content at a depth after specified time.
In equation-01, chloride diffusion co-efficient (D), is used by calculating value of D over D. This equation was used by Goltermann P. This equation (equation-02), finds chloride diffusion co-efficient for time period from initial chloride diffusion co-efficient, initial time time where valu of Dt is need (t) in seconds and ageing co-efficient (α).

$$Dt = Do\left(\frac{t_o}{t}\right)^{\alpha} \quad \text{Equation-02}$$

Furthermore, diffusion phenomena can be seen in figure-01.



Grpah-01 Diffusion Process

3. Methodology

A number of diffusion models are available in literature and also a number of ageing factors are available in literature. So, their correct selection is a problem. To solve this problem, literature is surveyed and the top selected models have been tested with available ageing factors.

4. Available models

1. Diffusion models available in literature

From the available models following models have been selected for the present study.

3.1 *Mangat and Molloy*

They developed a model using ageing factor. Their model calculates effective chloride diffusion co-efficient (Dc) from initial effective chloride diffusion co-efficient (Di), ageing factor (m). They also given equation to find ageing factor from water cement ratio, which is, $m = 2.5\ (w/c) - 0.6$

$$Dc = Dit^{-m} \qquad \textbf{Equation-03}$$

3.2 *S.W. Pack's Model*

This model is based on the concept of ageing of concrete as described by m. Additionally, this model includes 1 / (1-m) factor, as can be seen in equation-04.

$$Dm\ (t) = \frac{D_r}{1-m}\left(\frac{t_R}{t}\right)^m \qquad \textbf{Equation-04}$$

3.3 S.W. Pack's Model based on water cement ratio

This model is based on water cement ratio and first year chloride ingress.

$$Dc = at^n \qquad \text{Equation-05A}$$

$$n = -1 + 1.1\ (w/c) \qquad \text{Equation-05B}$$

3.4 Diffusion Model used by Goltermann P.

They developed his model, which calculates diffusion at time (Dt) using ageing factor (α).

$$Dt = Do\left(\frac{t_o}{t}\right)^{\alpha} \qquad \textbf{Equation-06}$$

3.5 Tang Luping

Their model includes exposure period. This model is a modified form of a famous decay model.

$$D_a = \frac{D_o}{1-n}\left(\frac{t'_o}{t}\right)^n \cdot \left[\left(1+\frac{t'_o}{t}\right)^{1-n} - \left(\frac{t'_{ex}}{t}\right)^{1-n}\right] \qquad \textbf{Equation-07}$$

3.6 P. Bamforth

Their model calculates value of n from first year values. They used ageing values to find diffusion. Their equation calculates ageing factor as $n = -1 + 1.1\ (w/c)$.

$$Dc = at^n \qquad \textbf{Equation-}$$

4.Ageing factor values available

In Equation-02 ageing value is used. In literature a number of values are given which are as,

01. Mangat and Molloy n = 0.47, m = 0.45
02. Per Goltermann α = 0.93
03. P. Bamforth n = -0.699
04. M.D.A Thomas n = 0.52* n = 0.52*
05. Odd E. Gjorv μ=0.6, σ=0.12
06. Zahir n = -0.774

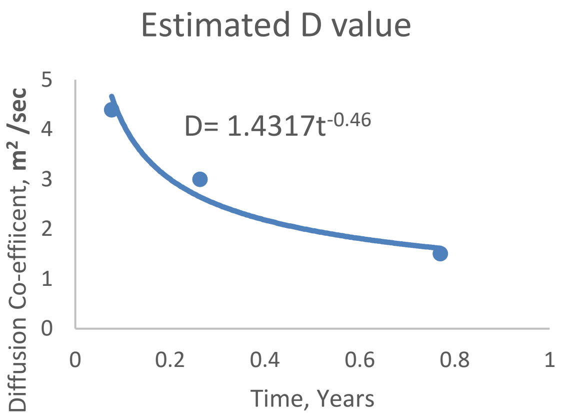
Note: values with * are recalculated

5. Available Data in the Literature

Data about highway bridges is very limited in literature. So, extensively literature was surveyed to find the long term data and laboratory data. Long term data was collected for highway bridges and for same concrete mixes laboratory data was collected. Ferhat Akgul has given $D = 0.265\ E\ {-12}\ m^2$/sec for 12 years old concrete with mix details of *31.03 MPa, w/c =0.44*. Williamson has given $D = 13\ E\ {-12}\ m^2/sec$ for 1.21 years old concrete, $D = 15\ E\ {-12}\ m^2/sec$ for 15 years old concrete, $D = 1.03\ E\ {-12}\ m^2/sec$ for 16 years old concrete, $D = 0.512\ E\ {-12}\ m^2/sec$ for 17 years old concrete with mix details of Fly Ash / Slag. Ferhat Akgul given $D = 1.097\ E\ {-12}\ m^2/sec$ for 42.85 years old concrete with mix details of compressive strength of $20.68\ N/mm^2$, $w/c = 0.50$ and Fly Ash / Slag. Similarly, for laboratory concrete literature was surveyed and data was collected. M.D.A Thomas has given $D = 4.4\ E\ {-12}\ m^2/sec$ 0.0767 years old concrete with mix details of compressive strength of $20.68\ N/mm^2$, $w/c = 0.26\text{-}0.35$ and 25 %Fly Ash. DuaINT Project has given $D = 3.0\ E\ {-12}\ m^2/sec$ 0.263 years old concrete .Zahir has given $D = 17.4\ E\ {-12}\ m^2/sec$ 0.38 years old concrete with mix details of compressive strength of $40\ N/mm^2$, *w/c = 0.45 and 30%*Fly Ash. Paraic C Ryan has given $D = 1.51\ E\ {-12}\ m^2/sec$ 0.77 years old concrete with mix details of 30%Fly Ash. Zahir has given $D = 7\ E\ {-12}\ m^2/sec$ 0.96 years old concrete with mix details of w/c = 0.45 and 30%Fly Ash and compressive strength of 40 N/mm^2. M.A. Issa has given $D = 2.4\ E\ {-12}\ m^2/sec$ for 1.03 years old concrete and $D = 2.56\ E\ {-12}\ m^2/sec$ for 1.97 years old concrete with mix details of 20%Fly Ash and w/c = 0.21

6. Estimation of the Chloride Diffusion Co-efficient (D)

Initially, for a period of one year, chloride diffusion co-efficient is calculated using laboratory values of D. In this way value of D for 28 days has been found. Later this value has been used in various models. In this way, chloride diffusion co-efficient (D) for 28-days is found as $4.66\ E\ {-12}\ m^2/sec$ and for first year it is 1.43 E -12 m^2 /sec

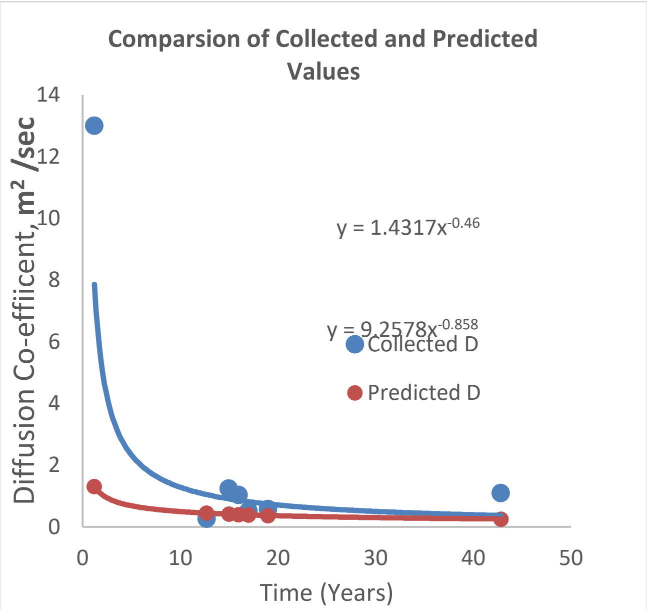


Grpah-02 Estimated D value, m^2 /sec

7.Assessment of the Selected Ageing Factors with Diffusion Models

7.1 Mangat and Molloy's Model,

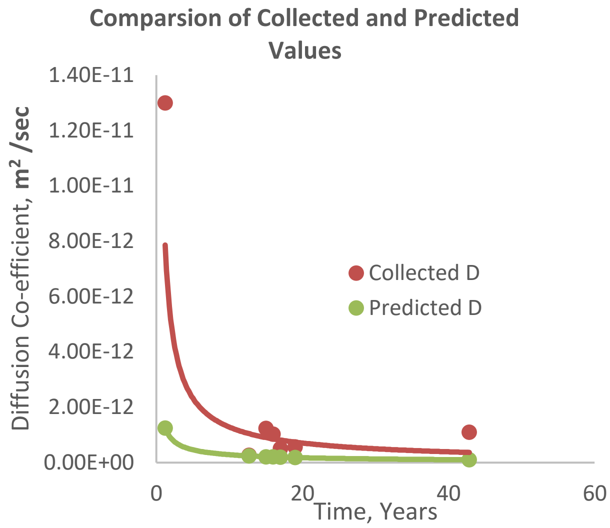
To assess Mangat and Molloy's Model**,** values such as D = 1.43 E -12, and n and w/c as 0.525 and 0.45 respectively were used. Ageing factor as m = 0.52 was used. Graph 03, shows, comparison of actual D values to the predicted.



Graph 03- Assessment of Mangat and Molloy's Model

7.2 P.Bamforth's Model

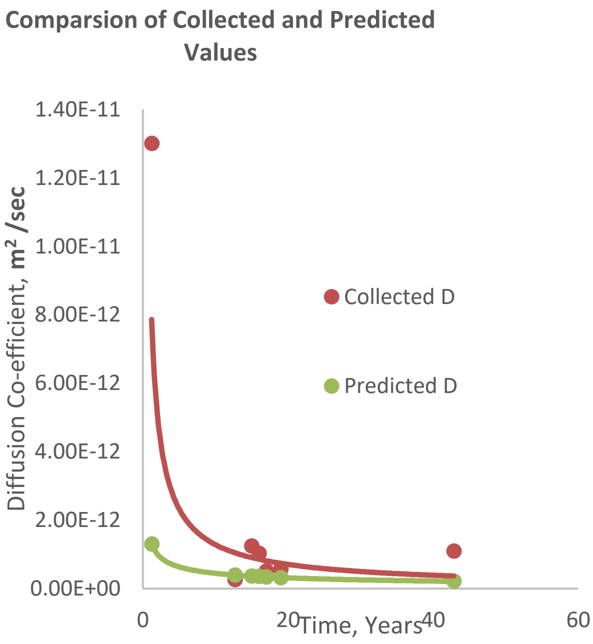
To assess this Model, values such as D = 4.73 E-12 m^2/sec for first year chloride diffusion and n =-0.699 were used.Values obatined are shown in graph-04 see very close predicted and caculated values.



Graph 04- Assessment of P. Bamforth's Model

7.3 P. Bamforth's Model based on w/c ratio

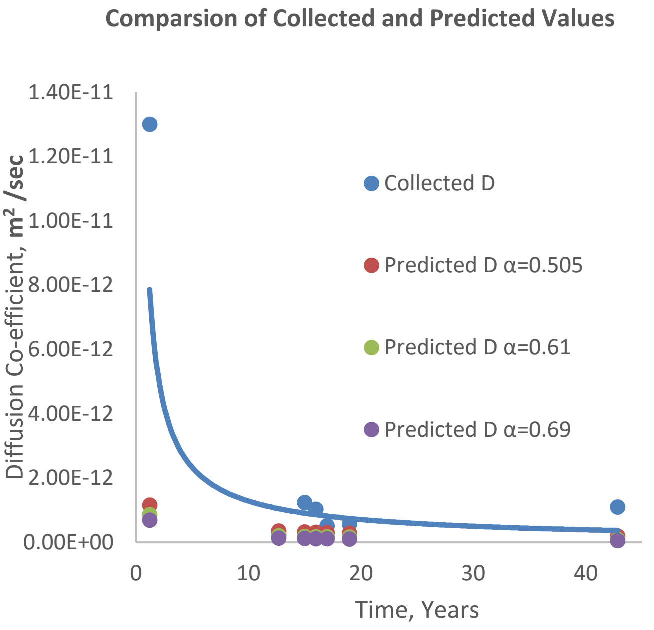
This Model was assessed using values **as** for D = 4.73 E -12 m2 /sec, t = 1 Year, n = -0.699. In graph-05 it can be seen that predicted diffusion curve are higher as compared to actual.



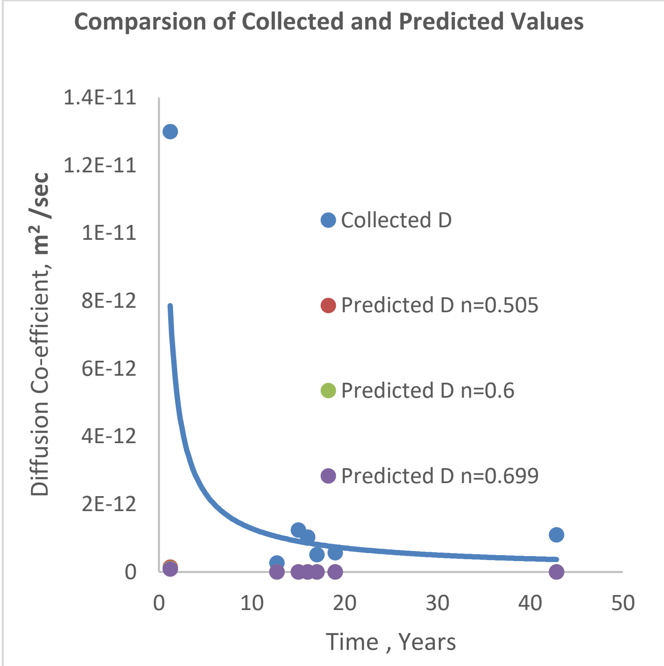
Graph 05- Assessment of P. Bamforth's Model based on w/c

7.4 Diffusion Model used by Goltermann P.

Goltermann P. was assessed using values such as as 4.73 E-12 m^2 /sec. Graph-06 shows curve developed with n=0.505 is more near to the collected values.



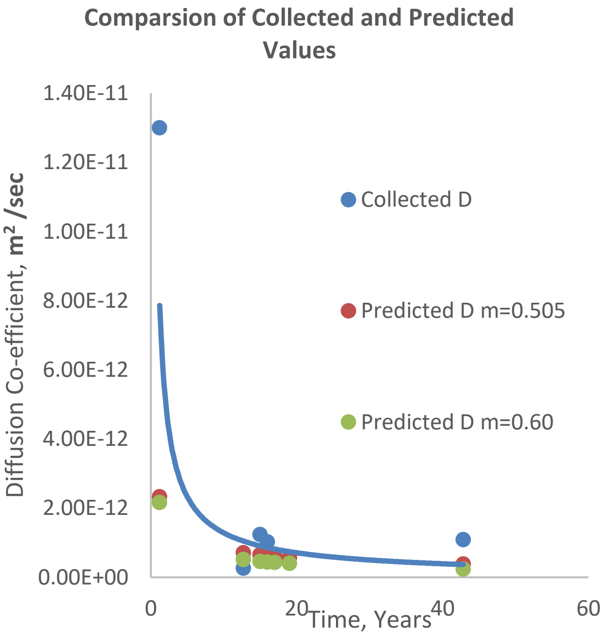
Graph 06- Assessment of Golterman P. Model



Graph 08- Assessment of Tang Luping's Model

7.5 S. W. Pack's Model

S. W. Pack's Model was assessed using values such as D =4.66 E -12 m^2/sec. It cab seen in graph-07 that predicted diffusion values are lower as compared to the actual values.



Graph 07- Assessment of S.W. Pack's Model

7.6 Tang Luping's Model

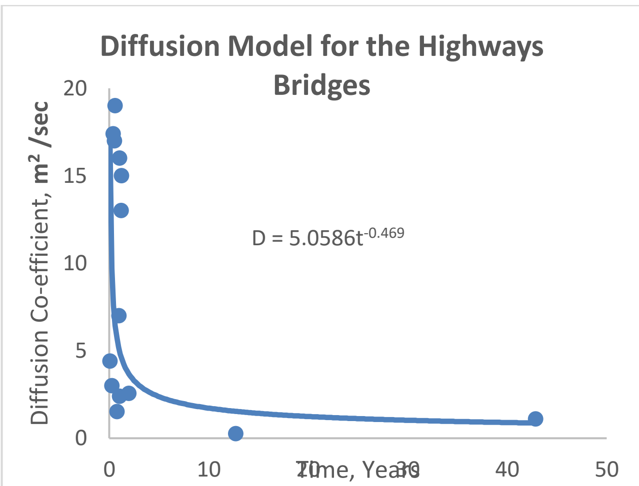
This Model was assessed for values D =4.73 E -12m^2/sec. It can be seen that Graph-08 shows that using n=0.699, predicted values are more close to actual values.

8. Development of the Diffusion Model for the Highways Bridges

In present study, a model is developed which calculates chloride diffusion co-efficient for target time as shown in equation-09. This model has been developed for the concrete with w/c ratio of 0.45 fo fly ash as 30% replacement.

$$D = 5.0586\, t^{-0.469} \qquad \text{Equation-08}$$

Using the data from literature the equation-08 has been developed. As well ageing factor is proposed as n =0.416 and may be used as n = 0.42 based on experience. This value of ageing factor (n), is used in equation-02. Graph-09 shows the predicted diffusion curve using equation-08 and n= 0.416 for 30% replacement with fly ash and water cement ratio as 0.45.



Graph 09- Diffusion Model for the Highways Bridges

9. Discussion

Generally ageing factors have been derived from values obtained from laboratory tests. To study the ageing factors in depth, data about concrete exposed in natural environment was collected. For environment exposure purpose data from structures with focus on chloride bridges was collected. While collecting data, it was found that data about such structures is very much limited and very few researchers have provided details for mixes used in bridges. Akgul reported details about strength and water cement ration and diffusion co-efficient (D) and Gregory Williamson has given details for water cement ratio for diffusion co-efficient (D) values for fly ash concrete. Values of D for bridge structures are generally for long time. So, for the fly ash concrete laboratory values were also collected. To be specific, concrete with fly ash as 30% and water cement ratio =0.45 was selected .

Conclusion

It was found that predicted values using Mangat and et al model were very close to actual values. Predicted values using P. Bamforth's model were found little higher than actual values.. Predicted values using Tang and et al model were found lower values than actual values. $D = 5.0586\ t^{-0.469}$ was calculated for highway bridges using the data collected during present study. Ageing factor was calculated as n = 0.42 for highway bridges. It was found that a lot of variability in data is present, so it is proposed that mean and standard value of D may be used.

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