Service Life Prediction of Concrete Structure Using Life-365 Software

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Abstract: The performances of repaired concrete structures continue to be a major global concern. This is the improvement in repairing materials and method, several repaired concrete structures still fail, leading to costly and time-consuming. This study was conducted to assess the effect of long-term chloride penetration as well as the effect of fly ash, water-cement ratio, and inhibitor on concrete structures to predict its Service life to obtained high strength durable concrete. The water-cement ratio played a vital role, as the water-cement ratio is reducing to get more service life of the concrete and at the value of 0.5, it seems that the peak value of service life of the concrete structure. In this paper, it is generally finding the service life of a concrete structure by reviewing the previous researches and by using Software Life-365.

Keyword: Service Life Prediction, Fly Ash, Water Cement Ratio.

1. Introduction

Concrete is the regularly used construction material in the world, mainly because of its adaptability and substantially low cost. Concrete structures have been examined to be usable with long life. Combine ideas and construction methods can form the early decay of structures, so a continuous view of field structures is expected to decide the state of the structure. It is cost-effective and can be built into endless forms, despite the demands that it is not a ‘green’ material, has a particularly low carbon footprint [1], concrete structures can decay ahead of time, providing growth to lower strength performance [2]. When the RC Structures are created and revealed to a climate, and they experience a method of degeneration. The rate of decay depends on the aggression of the conditions to which a structure is exposed [3], service life is the stage during which a structure surpasses the least demands fixed for it. The parameters restricting the service life can be professional, practical, or economical [4], service life has been altered into three steps 1) Initiation 2) Propagation time and 3) Time to strength reduction[5]. The method of chloride penetration within the concrete is, consequently, one of the various important parameters for managing the service life of the structure; which can be theoretically formulated by mathematical modeling of a chloride transportation mechanism [6], It permits a time-dependent apparent diffusion coefficient, with no clear idea of binding and effect of the ingressing chloride ions [7], it is important to develop an analytic model of steel-corrosion for the prediction of corrosion initiation as well as corrosion-induced cracking. Most of the research has been affected with modeling the diffusion of chloride ions through un-cracked concrete based on Fick’s second law [8]. Amongst these factors, chloride-induced corrosion is aggressive for structures in marine or deicing salt conditions [9], the diffusion equating based on the Fick’s second law of diffusion is a common suitable mathematical model to explain the non-steady diffusion methods of chloride ingress in a concrete structure [10], the corrosion of the steel leads to concrete fracture, which shows in the kind of steel cross-section reduction, lack of bond between concrete and steel, cracking, and degeneration of concrete cover [11], the service life investigation of concrete structures by adopting an excellent spatial variability strategy, which executes the stochastic spatial variation of characteristic variations beyond the structure [12], the service life of RC structures has been separated into different aspect by researchers and designers. The first is the initiation and the second is propagation [13], it is general practice nowadays in concrete design against corrosion of reinforcing steel to use low-permeability concrete [14]. Life-365 Service Life Prediction ModelTM is developed by Thomas and E. C. Bentz and was released in 2001. As then Life-365 software has been applied to estimate concrete mixture balances and corrosion protection plans that extend service life and decrease life-cycle costs. [15].

2. Literature Review

Ch. Hema Durga Rajeswari et al [16] stated that the usage of fine materials like ground granulated blast furnace slag (GGBS) and silica fume in the concrete leads to low permeability and penetration of chloride ion into the concrete. If penetration of chloride ions is less, then the corrosion of steel present in the concrete will also below. And it will take more time to get corroded. From the results, one can understand the amount of chloride ion penetration in relation to both time and depth.
Desire Ndahirwa et al [17] stated that the degeneration of reinforced concrete due to analytic attack, there is a major variation in strength properties and hence the strength of exposed concrete structures. The decay mechanism depends on material elements and exposure requirements.

E Possan et al [18] stated that service life investigations are brought out in a deterministic or probabilistic way. This selection is associated with the aspired effect and, if the interest is determining the structure service life reflecting the degeneration, the deterministic way is recommended.

S. Mahima et al [19] stated that the exact service life prediction expects an exact calculation and proper analysis of the chloride threshold value. The chloride threshold value is used as a part of the type of steel rebar in most of the service-life prediction models. Several parameters are determined to change the chloride threshold value, such as the measurement methods used, supplementary cementations material used, and several different physical properties of the concrete and surface conditions.

Mark G Alexander [20] stated that the idea for service life in reinforced concrete structures, linked to continuous challenges in concrete strength. Service life plan indicates the strength to do service life prediction and modeling; still, at this stage, it is way off comprehensive models that are defined and precise. The difficulty is increased by the type of exposure conditions for concrete structures that are tough to measure.

Li Ying [21] stated that the outcome of spatial change on decay and optimizing the improvement strategy for concrete structures. This paper is mainly based upon the use of probability-based reliability and corrosion model methods. The spatial variability of the concrete properties is being taken into account that it has a vital impact on the maintenance and design determinations for structure.

Kat Vu & MG Stewart [22] stated that the development of random models for crack initiation and propagation took from stimulated corrosion testing of RC slabs. The modern study later introduced the modeling of the decay process, and the consequent probability of breaking or spalling for RC structures regarding concrete cover, w/c ratio, and surface chloride Conc as a computative variable.

Brad Violetta [23] stated that Life-365 enables the author to investigate different individual corrosion protection methods. A creative feature of Life-365 is that it additionally provides the user to examine various combinations of corrosion protection methods. For example, the mixture of fly ash, silica fume, a corrosion inhibitor, and black steel could be correlated to a less water-cement ratio (w/c) supplementary concrete cover.

3. Methodology

The following Figure 1 shows the flow chart of work done for following research work sequence.

![Flow Chart](image)

**Figure 1.** Methodology of work done

All of the software tabs that perform certain steps are explained below.
The Project tab enables the user to input the name, classification, structure type systems of measure, and economic conditions, especially, to identify the project and set the type and dimension of unique structure, the economic outline parameters, and the numbers and titles of the alternative project as displayed in Figure 2 below.

This section (Identify Project) sets the Project Name, Classification, Analyst, and Date, most of which are done to simply document the project, yet also are part of the description.

Under Define Economic Parameters, four parameters are applied to fix the time and interest rates above which life-cycle cost is calculated. The Base year is fixed to be the present year or a different primary year that is related to the study. The Study period is fixed to be the period time above which life-cycle cost should be determined. 75 years is a normal period and Life-365 enables the user to decide up to 200 years and here it is set as 150 years.

The inflation rate (1.8 %) is the yearly rate at which the value of equipment and services will increase over time. The Real interest rate (2 %) is the yearly rate at which future costs are discounted to base-year dollars, net of the rate of inflation.

In Define, Alternatives is done to fix the number, title, and classifications of alternatives to be examined and compared such as Base case and Alternative1. Use the Add a new alternative and delete currently selected alt buttons to make and remove alternatives, respectively.

3.1. Exposure Tab

This Exposure tab (Figure 3) is used to fix the exposure of the concrete to surface chlorides and to fix the monthly temperatures to which the concrete is displayed.

![Figure 2. Project Tab](image)

![Figure 3. Exposure Tab](image)
In Select Location when the Use default box is checked, the user can choose a location, Sub-location, and Exposure that closely meets the requirements of the project, and Life-365 will utilize its database of places to determine the Max surface concentration of chlorides and in this project, the max concentration is 0.560% wt. and Time to build to max in the upper panel (i.e., 7.4 years) and the Temperature History in the below panel (i.e., 25°C). In Define Chloride Exposure the time of build-up and maximum level of surface chloride concentration change the rate of chloride entrance and eventually the concrete service life.

3.2. Concrete Mixture Tab

In the concrete Mixture tab in figure 4, it is adopted to define the concrete mixtures of various project alternatives described in this project tab.

In Define Concrete Mixtures enables the user to input the concrete mixtures and corrosion protection strategies of various alternatives. Because the estimation of concrete service life is computationally fast, the user needs to check the Calculate service life key after presenting the inputs of the mixtures and plans to make the estimates. check the Compute uncertainty box if the user wants Life-365 to compute the uncertainty of service life for a various concrete mixture.

In Selected Mixture, this section lists the characteristics of the concrete is selected in the top, Define Concrete Mixtures, panel, and enables us to alter these characteristics. To see the characteristics of any one of the concrete mixtures, simply check the row of the mixture in the top panel.

Mixture group - This section is used to fix the water-cement ratio (w/cm) of the concrete mixture, and to what level it can be used of Supplementary Cementitious Materials (SCMs). Enter the SCMs values in % substitution, in this case, the SCM amount is 15 % of fly ash for both Base case and Alternative case and w/c ratio as 0.42 for a Base case and 0.50 for Alternative case.

Rebar and Inhibitors groups – this section selects the type of steel used in the structure i.e., Black steel, which affects the initiation period and the propagation period of the concrete service life. The Rebar percent volume of the concrete area is used to input the % of the concrete that is steel, this is done to estimate the cost of steel in the concrete structure, where the costs of the steel are fixed in the Individual Costs tab, below the Default Concrete and Repair Costs tab, and the Default Settings and Parameters tab at the bottom of the Life-365 window. Use the Inhibitor drop-down to add in the mixture any corrosion inhibitors that will be used. The units of certain inhibitors are either l/cub. m. (liters per cubic meter) or gal/cub. yd (gallons per cubic yard), depending on the Base unit selected in the Project tab, and in this project, Rebar is used as a Black Steel for both the case (i.e., the Base case and the Alternative case) and Inhibitor (Ca Nitrite – l/cub. m.) for alternative case only.

Barriers group – this section includes the use of a membrane or sealant application on the concrete.

In Custom Mixture Properties in enhancement to provide the inputs of the constituting material concrete mix and other corrosion protection plans, Life-365 enables the user to input directly the model characteristics used to estimate service life.
The Service Life tab (Figure 5) displayed the service life of various alternative concrete mixture alternatives, in terms of the component initiation period and propagation period.

![Service Life Tab](image1)

**Figure 5. Service Life Tab**

The Initiation tab (Figure 6) displayed two graphs: the concentration of chlorides at the point of beginning, by the bottom of the structure (the left graph, Concentration Vs. Depth); and the concentration of chlorides at the rebar depth, at this point, up to beginning (the right graph, Concentration Vs. Depth). The left graph comprises a vertical line indicating the depth of steel, and the right graph line showing the year.

![Concrete Initiation Graphs](image2)

**Figure 6. Concrete Initiation Graphs**

The right graph displays that the base case mixture knocks initiation in 20 years at a rebar chloride Conc of about 0.05 % wt of concrete, while the Alternative case mixture knocks initiation in 40 years with a rebar Conc of 0.075 % wt of concrete.

The Concrete Characteristics tab in figure 7 shows two new diagrams that help explain the representation of the concrete mixtures. The left side graphs, (Diffusivity Vs. Time), show how the estimated concrete chloride diffusivity variations over the initiation periods, by the mixture. The right side diagram, (Surface Conc Vs. Time), explains how the concrete surface conditions vary over the same time. The right-hand side graph shows that both the base and the alternative case have the same surface concentrations.
In the Initiation period tab when the compute uncertainty box is checked and then when the Initiation Time Figure 7. Uncertainty panel in the tab is begun, the Service life is recalculated and calculated for every concrete mixture placed in the concrete mixtures tab.

Graph from the left-hand side, the Base case (red line) is from the first mixture with no additives such as fly ash. The alternative case (blue line) has added inhibitor (Ca Nitrite-5 l/cub m.) in the project window, the first case has an estimated initiation period of 20 yrs and the second case has an estimated initiation period of 40 yrs with a service life of 26 and 47 yrs, each. Some important points can be made with this graph: first, it's difficult if not unlikely to understand anything about the probabilistic service lives of each case (26 and 47 yrs, each) from this graph: the most important point on a particular line is the most likely initiation period but typically not too the common initiation period. Next, the top of the first case (red line) is larger than the peak of the second case (blue line) and peaks earlier in years. The total probability density capacity from the right side of the graph simply adds per year's expectation to achieve cumulative probabilities. The service life result section includes an Initiation Variation Graph (Figure 9). The graph is shown alternative the level of uncertainty in various initiation periods and the elements of this uncertainty. In the figure, it shows that the alternative case has much larger uncertainty than the base case and the uncertainty is essentially due to replaced by uncertainties in cover depth and D28.
3.3. Individual Costs Tab

The Individual Costs tab (Figure 10) enables the user to edit the separate component value and value parameters, and observe the result they have on the component costs that advance up the life-cycle cost.

| Component | Start Year | End Year | Interval | Amount | Units | $/sq m | Total |
|-----------|------------|----------|----------|--------|-------|--------|-------|
| Construction cost | 0 | 0 | 0 | 10,000 | sq m | $20.00 | $200,000 |
| Repair cost | 40 | 140 | 10 | 1,000 | sq m | $30.00 | $30,000 |

In Concrete Costs in the upper-left corner of the screen, the Concrete Costs tab enables the user to set particular values for the concrete mixture costs. Originally, this table presents the default concrete cost that is listed in the Concrete & Steel section of the Default Settings and Parameters tab, this default cost should represent the cost of concrete alone, with no SCMs value. If, however, a particular mixture uses, for example, Supplementary Cementitious Materials or different materials that affect concrete costs to be different from the default cost, enter that price in this table. Default Concrete and Repair Costs this section (Figure 11) lists the costs compared with three categories of project costs: Concrete & Steel, Barriers & Inhibitors, and Repairs. When the user first starts the project, this software uses the default values of these prices listed in the Default Settings and Parameters tab are converted, when required, from the systems of measure listed in this tab to the systems used in this project. If the user keeps the project and obtains it later, it will show again the project values of cost.

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Costs for various Mix Design based on these values, the Project Costs part list up to 3 costs: Construction cost, or cost of processing the concrete, Fence cost, or the cost of utilizing a layer of sealer, and Repair cost, or the cost of fixing the concrete above the study duration.

In Cost, Timeline this segment displays a time-line of the project values. The graph (Figure 10) displays, in particular, the primary construction cost transpiring between year 0 and year 1, and then the repair costs beginning after construction (as indicated by the red arrow) and continuing every 10 yrs (as shown by the vertical grey lines within the white box) till year 75.

3.4. Life-Cycle Cost Tab

Once the group tab and the individual costs data have been listed, the resulting life-cycle cost of the different blends are estimated then, related in the Life-cycle cost tab in the figure below.

![Life-Cycle Cost, by Alternative](image)

The Timelines tab in Figure 13 displays the element costs over time. This tab displays all four graphs collectively. The upper two panels show the individual-year and collective constant-dollar costs, i.e., costs that have been improved to account for the effects of progress in the prices of supplies and labor and time-value of money, and that is summed to measure life-cycle cost.

![Constant Costs](image)

The below two panels display the individual-year and collective current-dollar costs, which are fixed only for reflation. For these differences, the upper-right Collective Present Value gives a good demonstration of why case 1 (the blue line in the graph) has a below life-cycle cost, while it does have a slightly higher cost at the primary construction and same repair costs, it has several repairs due to the long service life.

![Cumulative Present Value](image)
3.5. Service Life and Life-Cycle Cost Reports Tabs

Finally, Life-365 provides two pre-defined reports of this project: a Service Life Report (Figure 14) and a Life-Cycle Cost Report (Figure 15). Those two reports list the largest but not all the parameters used in this study. The report can be imprinted by pressing the printer icon in the upper-left corner of the window. If the user wants to save the report as a PDF file, click on the disk-drive icon in the upper-left corner, then select the file type as pdf, then enter the file name and save.

Ultimately, the user can renew and patch the result from Life-365 to their Word- or PowerPoint-based reports.

4. Conclusion

This study was conducted to assess the effect of long-term chloride penetration as well as the effect of fly ash, water-cement ratio, and inhibitor on concrete structures to predict its Service life to get high strength durable concrete. Here different percentages of fly ash are used but it shows peak value at 15% of fly ash by this it can get high performance concrete structure. Black steel is introduced in the concrete and the service
life of the structure gets enhanced and a very good strength is achieved. The water-cement ratio played a vital role, as the water-cement ratio is reducing to get more service life of the concrete and at the value of 0.5, it has been obtained the peak value of service life of the concrete structure. The inhibitor (Ca Nitrate-5 L/m³) is used in the second case which positively affects the concrete structure and hence the service life is more than in the first case. From all the parameters and inputs it can conclude that the service life of the alternative case is much higher than the base case as the service life for the base case is 26 years and alternative case is 47 years hence the alternative case is preferable to use. This model can be used by Engineers to evaluate the service life and performance of concrete structures for planning, maintenance and replacement of structures.

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