Estimating Life Cycle Cost of Concrete

Using Life-365

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The following article is an overview of Life-365, a service life prediction and life cycle cost model for reinforced concrete. An in-depth article, including equations and assumptions, is available on the STRUCTURE website, www.structuremag.org.

Introduction

Steel reinforcement corrodes in concrete if chloride from deicing salts or seawater penetrates to the level of the steel. Expansion stresses due to formation of voluminous hydrated iron oxides cause delamination and spalling, which interfere with trafficability and may even progress to the point of structural failure if not addressed. This form of premature concrete deterioration costs billions of dollars a year worldwide in repair and replacement costs. Many strategies exist for increasing the service life of reinforced structures in the presence of chloride salts.

Each strategy offers different benefits and has its own cost. An optimum strategy will take into account the specific exposure and construction conditions of the structure, and the needs of the owner. Some protection methods may reduce repair costs and/or repair frequency. Even though using a protection strategy may increase initial costs, it should always reduce life cycle cost. Life cycle cost analysis is a calculation that includes both initial construction costs and predicted repair costs over the life of the structure.

In November 1998, a workshop was sponsored by the National Institute of Standards and Technology (NIST), the American Concrete Institute (ACI), and the American Society for Testing and Materials (ASTM) to develop a "standard model" that would eventually be placed under the jurisdiction of the existing ACI Committee 365 "Service Life Prediction" after following the ACI consensus procedures. The new model was released as Life-365 (version 1.1) in December 2001. This represented the first phase of the long-term goal of developing a comprehensive service life prediction and life cycle cost model for reinforced concrete.

Description of Life-365

Life-365 makes three separate calculations based on the input parameters:

- It calculates chloride concentrations at rebar depth for increasing exposure times in a selected geographic location and predicts the time to the onset of corrosion, commonly called the initiation period, t_i, which is when the chloride concentration at the rebar depth, x_d, reaches the threshold concentration for corrosion, C_t.
- The propagation period, t_p, is set at 6 years for black steel and 20 years for epoxy-coated steel. The model calculates the time to first repair, t_r, as the sum of the initiation and propagation periods, i.e., $t_r = t_i + t_p$. The total of the two is the time for corrosion damage to first reach an unacceptable level. The repair schedule after the first repair depends on the propagation period.
- It estimates life cycle costs based on the initial concrete parameters and future repair costs out to a specified ("design") age.

Predicting the Initiation Period

The initiation period, t_i, is the time it takes for chloride ions to penetrate the concrete cover and initiate corrosion at the depth of the embedded steel. This is the time required for the critical threshold concentration, C_t, to reach the rebar depth, x_d, from chloride on the surface. The model determines a maximum surface chloride concentration, C_s, and the time taken to reach that maximum, t_{max}, based on the type of structure, and expected salt and weather exposure on an annual basis for the geographic location selected by the user. Alternatively, these parameters, including the rate of buildup and the maximum value can be defined and input by the user. The temperature and age of the structure also affect the diffusion coefficient, and are taken into account.

The base case assumed by the model is plain Portland cement concrete with no special corrosion protection applied.

Effect of Corrosion Inhibitors

The model allows input for two chemical corrosion inhibitors with documented performance; these are calcium nitrite inhibitor (CNI) and Rheocrete 222+ (a proprietary product from Master Builders). More inhibitors will be included when appropriate documentation of their performance becomes available. However, data from other corrosion inhibitors can be directly entered into the model for comparison purposes.

Effect of Epoxy-Coated Steel

The presence of epoxy-coated steel clearly does not affect the rate of chloride ingress in concrete, nor would it be expected to impact the chloride threshold of the steel at areas where the steel is unprotected. Consequently, the use of epoxy-coated steel does not influence the initiation period, t_i. However, it is assumed in the model that the rate of damage buildup is lower when epoxy-coated steel is present, and these effects are dealt with by setting the propagation period, t_p, to 20 years.

Effect of Stainless Steel

In the current version of Life-365 it is assumed that grade 316 stainless steel has a corrosion threshold of C_t = 0.50% (i.e. ten times black steel).

Calculation Procedure

Life-365 is based on a 1-dimensional and 2-dimensional finite difference calculations using Fick's Second Law. The time steps used in the temporal derivatives are increased during the analysis to decrease analysis times.

Repair Schedule

The propagation period, t_p, is set at 6 years for black steel and 20 years for epoxy-coated steel. The time to the first repair, t_i, is predicted by Life-365 from a consideration of the properties of the concrete, the nature of any corrosion protection strategy and details of the environmental exposure. The cost and extent of this first repair, i.e., percentage of area to be repaired; and the cost, extent and schedule of future repairs are decided by the user.

Estimating Life Cycle Costs

Price Information

The user is responsible for providing the cost information on the cost of concrete mixes, repairs and discount rate (i). Life-365 assumes default costs for various rebar protection strategies. The user can change the costs of all materials.

Present Worth Value

The total life cycle costs are calculated as the sum of the initial construction costs and the discounted future repair costs over the life of the structure. Future repair costs are calculated on a "present worth" basis using the discount rate, i, provided by the user.

All the predicted future repair costs over the entire design life of the structure are calculated in this manner and added to the initial construction costs to give the total life cycle costs.

Cash Flow Diagram

Cash flow diagrams are available in Life 365 and show the estimated cash flow over the design life of the structure. Note that these costs are not discounted to present worth, but are corrected (increased) for inflation.

Availability and Future Versions

A second consortium was formed in 2002 to upgrade Life-365. The current version produces only a single deterministic time to first corrosion. The next version will do probabilistic modeling. Concrete construction by its very nature is quite variable in terms of quality from one project to another. Life-365 will predict a range of expected times to first corrosion to better manage the risk associated with construction. Also, the life cycle costing functionality will be improved. These will make the economic analysis easier to use and understand. The addition will include the use of current and constant dollars, net savings, and probabilistic measures.

Summary

The solutions provided by Life-365 are intended to be helpful comparing different designs for reinforced concrete structures exposed to chlorides. However, the calculated service life and life cycle cost information produced by the model should not be taken as absolute values. Many assumptions have been made to simplify the model, such that the solution only approximates actual conditions.

The user is encouraged to run various scenarios with minor adjustments to the values selected by Life-365. This will aid in developing an understanding of the roles of these parameters and the sensitivity of the solution to their values. Life-365 is very much a "work in progress." It will continue to evolve as further information becomes available. It is expected that Version 2.0 will be available early in 2004.■

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Life 365 Version 1.1 is available today to download from **www.corrosioninhibitors.org** and other Internet sites.

Thomas, M. D. A. and Bentz, E. C., manual "Computer Program for Predicting the Service Life and Life Cycle Costs of Reinforced Concrete Exposed to Chlorides," October, 2000, is available with the program at **www.corrosioninhibitors.org**.