Transportation Consortium of South-Central States (Tran-SET)

A Comprehensive Reliability-Based Framework for Corrosion Damage Monitoring and Repair Design of Reinforced Concrete Structures

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Developing a framework for assessing the corrosion-induced deterioration of reinforced concrete structures and predicting their remaining service life

The purpose of this study is to develop a reliability model framework for corrosion-induced degradation of reinforced concrete systems. Several parameters have been tested and characterized in the model to explore the correlation between concrete material properties and degradation processes of cylindrical samples for 5 years. Based on the current observations, two different approaches are proposed and validated for the long-term samples: the initial approach is the evidence-based modified corrosion model based on the classical Fick's expression of chloride transport and accumulation within the concrete structures; the second approach is innovatively derived based on electrochemical concepts considering different measured parameters. Both models have integrated the uncertainties within the parameters and models to provide the reliable prediction. The theoretical framework will incorporate the results obtained for different geometry samples exposed to long and short-term conditions. The model prediction will consider the impact of concrete material properties and environmental conditions on the corrosion process.

Problem Statement

The durability and reliability of civil infrastructure are largely affected by the corrosion-induced deterioration of reinforced concrete (RC). A recent cost-of-corrosion study by the Federal Highway Administration has estimated the annual cost of corrosion to US bridges to be approximately 30 billion, not including indirect costs incurred by the traveling public due to infrastructural closures.

In addition to increasing traffic demands, natural environmental conditions set degradation due to corrosion damage as a critical barrier to durable and reliable infrastructures. By considering reinforced concrete as the critical element of the entire macrostructure, this study aims to develop a comprehensive framework to manage structural integrity and to address the corrosion deterioration problem.

Figure 1. Reinforced concrete bridge affected by salt-water corrosion.

Summary

This work aims to analyze, through deterministic modeling, the electrochemical behavior at the initiation stage of small specimens exposed in different locations along the Gulf of Mexico coast. Understanding the initial corrosion stage and its relation to the aggressive environments will provide a general view to proposing corrosion control actions. The long-term exposed reinforced concrete samples designed, cast included typical aggregate (fine and coarse) and ordinary Portland cement. One parameter critical for the corrosion activity is the mixes water/cement ratios, the samples considered: 0.46, 0.50, 0.53, 0.70 and 0.76. Another concrete fabrication property is the curing time; we have results for 1, 3, and 7 days. In this project, the samples are under no load conditions, the theoretical framework includes coastal environments influence the corrosion process due to the combination of factors activating the passivated rebar and depredating the composite asset. While the chloride content can be an indirect measure for corrosion, there are some parameters affecting the dissolution process that can be used as parameters to build a reliability model.

Findings

Different reinforced concrete cylinders (7.5 cm x 15.0 cm) with a reinforcing steel bar (9.5 mm nominal diameter and 20.0 cm long) placed in the center of the cylinder were tested using electrochemical equipment (Figures 2 and 3). The impacts of material and exposure conditions to the material durability are quantified for RC structures subject to marine atmospheric environment. Figures 2 and 3 present the corrosion current density (icorr) evolution for the long-term exposure of samples with different water to cement (w/c) ratios, measured after 1 and 7 days of curing, respectively. For samples cured for 1 day, all samples show an increase in corrosion current density with increasing time, indicating an increase in corrosion rate. This shows that the samples with a high w/c ratio tend to have higher corrosion current density during the first 50 months of exposure. Following the 50 months, there is a higher variability for the same magnitude. The corrosion current density values of high w/c ratio samples become lower after 50 months. In contrast, in this period (after 50 months), the samples with the low w/c ratio become more active as indicated by higher icorr. For the initial 10 months, all samples are in the passive condition (icorr < 0.1 μA/cm2), and then corrosion activity becomes more active as indicated by an increase in icorr after 10 months (except for the sample with the lowest w/c ratio which shows passivity extension until 20 months). Similarly, all these behaviors are also observed for samples cured for 7 days.

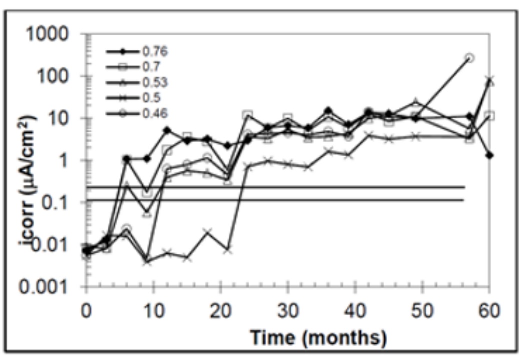

Figure 2. Corrosion current density evolution of samples with various w/c ratios after 1 day of curing measured for sixty months.

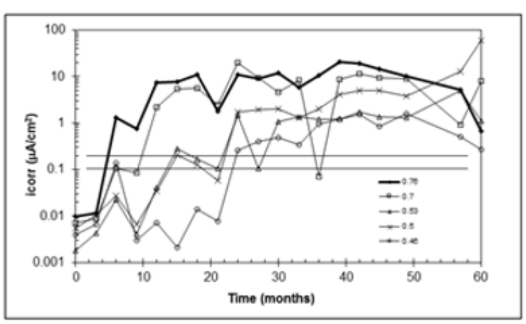

Figure 3. Corrosion current density evolution of samples with various w/c ratio after 7 days of curing measured for sixty months.

The results may indicate that the impacts of the w/c ratio on the corrosion process are more significant compared to those of the concrete curing time. Probabilistic modeling will be used to improve the understanding of the parameter sensitivities and to identify the significant parameters. Long-term samples will be used to calibrate the two different approaches to corrosion-based reliability model. Short-term samples will be used to increase the robustness of the model and an increase of the number of parameters that can be used for reliability and integrity modeling. The project includes the structural aspects of the RC components by using load data from the literature, and will also establish monitoring techniques to obtain real-time data for components of reinforced concrete bridges.

Impacts

The proposed research will develop an efficient management system for corrosion-damaged reinforced concrete elements so that the current bridge inspection and management system can be improved to work better. In addition, an important class of physical assets; reinforced concrete bridges, can be preserved by mitigating corrosion induced damages. The proposed research will provide a necessary asset management system for managing corrosioninduced deterioration of reinforced concrete structures. The proposed research will provide methods for scientific assessment of remaining service life and design for repair and strengthening of critical reinforced concrete structures exposed to corrosion environments.

Tran-SET

Tran-SET is Region 6’s University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 “to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes”.

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