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Numerical Validation of Concrete Corrosion Initiation Model Considering Crack Effect Model and Aging Effect

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Abstract

Conducted research is focused on the validation of numerical results of in-house finite element analysis of chloride ion concentration at reinforced concrete bridge deck with cracks and epoxy-coating reinforcement protection. The steel reinforcement corrosion is caused by penetration of chloride ions. The chloride ingress analysis is conducted with a special description of the effect of cracks in the directly exposed bridge deck. The diffusion coefficient of concrete in the crack is changed in order to simulate faster penetration of aggressive agents through cracks. The model focuses on the estimation of chloride ion concentration and corrosion initiation in particular locations of the embedded reinforcing steel bars or damaged areas of epoxy-coated bars. The paper deals with evaluation of the chloride concentration with respect to the time to corrosion initiation. The results obtained by in house model are compared with the analytical formula as well as with the commercial software ANSYS.

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Keywords: Concrete; finite element analysis; durability assessment; corrosion; reinforcement; initiation, propagation; chlorides.

1. Introduction

Many structures constructed from reinforced concrete require premature repairs and reconstructions as a result of defects caused by the effect of environment or the long term actions of loads including chemical actions. In case of public infrastructure, repairs and shorter lifespan lead to higher demand on public budgets. Thus, it is desirable to focus on design and construction of more durable construction systems in order to build cost-effective and manageable

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infrastructure. It is generally accepted that more durable structures can be designed with more in-depth understanding of the nature and background of the degradation processes. Here physical and/or numerical models help in order to simulate the behavior of real structures. If the numerical simulation is discussed, the development of models for corrosion of steel reinforcement caused by chloride ingress to concrete is carried out by many research teams around the world (see e.g. [1, 2, 3, 4, 5, 6, 7, 8 and 9]).

Since concrete is prone to cracking, thus considering the crack effect on the chloride ion penetration is desirable. The effect of crack width on the penetration of chlorides into concrete is discussed in ACI 222 [10]. There are works supporting the relationship between cracks and the capability of concrete to facilitate the passage of chlorides which leads to a more rapid propagation of corrosion, including [11, 12].

In-house model [13] based on the commercial ANSYS Finite Element Analysis (FEA) tool extends the work [7] by the consideration of 2D bridge deck cracking effect and evaluation of epoxy-coated reinforcement protection strategy. Comparison of 2D experiments and numerical analysis was conducted by Marsavina in [14] and Bentz in [15]. Marsavina [14] and Konečný [7] applied boundary conditions of a concentration of chlorides directly in crack. On the other hade, Bentz [15] and Konečný [8] model the effects of cracks in the form of changes in the material parameters in the area of the crack.

Authors in [15] used constant diffusion coefficient in time and very refined mesh in the area of crack effect. The mesh size selected in [8] was rather coarse even though the model has the capability of capturing the aging effect. The initial optimization of 2D element shape effect and the time step effect of the model [8] was studied in [16], however, the quality of the model was verified with 1D analytical formula and simple 2D problem only.

The chloride attack was simulated on rectangular area with boundary conditions on two adjacent edges. The article brought promising results due to comparison of the 1D model with the analytical formulas. Moreover, the 2D simulation capability on the shape affected elements was analyzed with the help of the effect of symmetry. The actual effect of crack was not compared yet.

2. Significance

The aim of the paper is to compare the quality of 2D chloride ingress model of the in-house code with the available commercial FEA system. Special attention is given to the numerical validation of corrosion initiation considering crack effect model and concrete aging.

Results from in-house model are compared with results from commercial software ANSYS. The 1D results are cross validated with analytical formula based on Mangat a Molloy [17]. The study is enhanced by the comparison of models of reinforced concrete bridge deck from ordinary Portland cement concrete mixture (OPC) and high performance concrete (HPC) with steel reinforcement protected by the epoxide coating. The main objective is to compare the results prepared by [8] with the model prepared in commercial software that was prepared based on original model [7].

3. Numerical modeling

The models focus on the transport of chloride ions through a reinforced concrete bridge deck with a transverse crack. There are three locations on the steel reinforcement embedded in concrete studied: the location under the crack, the location at a certain distance from the crack, and the location at the edge of the concrete slab where the effect of crack is none.

The 2D FEA models serve to calculate chloride ion concentration at the selected locations using the computer tool compatible with the MatLab [8] and commercial software ANSYS [7]. Both models allow the inclusion of cracks in the concrete and also concrete aging effect. Finite element models are also compared with analytic solution [14] at the edge of the concrete slab. This case allows comparison the FEA results with another independent approach.