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A comprehensive probabilistic model of chloride ingress in unsaturated concrete

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ABSTRACT

Corrosion induced by chloride ions has become a critical issue for many reinforced concrete structures. The chloride ingress into concrete has been usually simplified as a diffusion problem where the chloride concentration throughout concrete is estimated analytically. However, this simplified approach has several limitations. For instance, it does not consider chloride ingress by convection which is essential to model chloride penetration in unsaturated conditions as spray and tidal areas. This paper presents a comprehensive model of chloride penetration where the governing equations are solved by coupling finite element and finite difference methods. The uncertainties related to the problem are also considered by using random variables to represent the model's parameters and the materials' properties, and stochastic processes to model environmental actions. Furthermore, this approach accounts for: (1) chloride binding capacity; (2) time-variant nature of temperature, humidity and surface chloride concentration; (3) concrete aging; and (4) chloride flow in unsaturated conditions. The proposed approach is illustrated by a numerical example where the factors controlling chloride ingress and the effect of weather conditions were studied. The results stress the importance of including the influence of the random nature of environmental actions, chloride binding, convection and two-dimensional chloride ingress for a comprehensive lifetime assessment.

1. Introduction

Corrosion of steel reinforcement has become a critical issue for many reinforced concrete (RC) structures, in particular, when they are located in chloride-contaminated environments and/or exposed to carbon dioxide. Given the high alkalinity of concrete at the end of construction, a thin passive layer of corrosion products protects steel bars against corrosion, and therefore, the structure is insusceptible to corrosion attack. However, chloride-induced corrosion begins when the concentration of chloride at the steel bars reaches a threshold value destroying the protective layer. The mechanisms by which corrosion affects the load carrying capacity of RC structures are: loss of reinforcement section, loss of steel–concrete bond, concrete cracking and delamination. Therefore, design or retrofitting of structures susceptible to corrosion should ensure optimum levels of serviceability and safety during their lifecycle.

Since chloride penetration into a concrete matrix is paramount to corrosion initiation, several studies have been focused on understanding and modeling the phenomenon. Chloride ingress implies a complex interaction between physical and chemical processes. However, under various assumptions, this phenomenon can be simplified to a diffusion problem [1]. The analytical solution of the diffusion equations based on the error function is valid only when RC structures are saturated and subjected to a constant concentration of chlorides on their exposed surfaces. Nevertheless, these conditions are only valid for submerged zones where the low concentration of dissolved oxygen reduces considerably corrosion risks in comparison to unsaturated zones. There are other analytical solutions to the Fick's second law based on the Mejlbro function [2]. This approach, called the Mejlbro–Poulsen or HETEK model, solves the most part of the shortcomings of the solutions based on the error functions. For instance, it considers the time-dependence of the apparent diffusion coefficient as well as the chloride concentration of the exposed surface. Besides, the HETEK model also provides the model's parameters for a wide range of concrete compositions and environmental conditions obtained from experimental tests. This model also proposes a numerical solution to account for chloride ingress by convection and the effect of chloride binding. However, the interaction between chloride penetration and temperature and chloride ingress in two dimensions are not considered by the HETEK model. Besides, the analytical approach does not consider chloride binding and concrete aging. Other researches have directed their efforts to enhance

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