Investtigation on the corrosion initiation time of reinforced concrete structures in different distances from the Sea

Amirhossein Jafary[1], Mohsenali Shayanfar[2*], Mohammad Ghanoonibagha[3]

[1]School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[2]The Centre of Excellence for Fundamental Studies in Structural Engineering, Iran University of Science and Technology, Tehran, Iran
[3]Department of Civil Engineering, East Tehran Branch, Islamic Azad University, Tehran, Iran

ABSTRACT

Corrosion is one of the crucial damages that may occur to reinforced concrete structures. It also may affect the expected performance of the structure during the possible earthquakes. Onshore reinforced structures, bridges exposed to deicing salts in winter and also the pillars of marine structures under tidal waves, all of which are examples of corrosion damages. Corrosion mostly occurs due to two main reasons: chloride and carbonation which cause pitting corrosion and uniform corrosion, respectively. Corrosion starts with reaching of those two ions to the bar surface, passing by the physical and chemical passive covers. Corrosion also affects the mechanical properties of the steel and the concrete and reduces the seismic performance of the structure. One of the most important parameters in studying the corrosion and its effects on the seismic performance and life cycle of the structure is the corrosion initiation time. According to Fick's law, the initiation time is a function of surface and critical chloride, chloride diffusion coefficient and concrete cover on armatures. In the present study, the chloride-based corrosion is considered. Besides, corrosion initiation time is determined by deterministic and probabilistic Monte-Carlo methods considering the uncertainties in the effective parameters. In the end, by comparing these two methods, the effect of uncertainties in the possibility of corrosion initiation time is presented. Furthermore, parameters like the distance from the sea and the water to cement ratio are discussed in a parametric study.

KEYWORDS

Concrete structures, Corrosion, Corrosion initiation, Monte-Carlo Simulation, Uncertainties

* Corresponding Author: Email: shayanfar@iust.ac.ir

1. Introduction

Buildings and bridges have been damaged prematurely by reinforcement corrosion in recent decades, and reinforcement corrosion occurs due to chloride ions in reinforced concrete structures[1, 2]. Rebar in concrete is protected by two physical and chemical factors. One of the factors is the coating on the reinforcement, while the other is the highly alkaline environment in concrete (PH > 13.5). In order to optimize the cost of repairing damaged concrete, designing new structures, and evaluating the stability of new cement materials, it is necessary to be able to predict the start time of corrosion[3]. The penetration of chloride ions and the onset of corrosion of reinforced concrete structures have been examined in several studies. In a study conducted by Shayanfar et al., ultra-exploratory methods were used to calculate the likelihood of corrosion of rebars under conditions of chloride penetration and carbonation of reinforced concrete members[4]. Ghanooni-Bagha studied the variations of reinforcement tensile strength due to the stress concentration of pitting corrosion analyzed. The stress concentration consequence of corrosion on the reinforcement tensile capacity was studied by utilizing tension tests and creating different ABAQUS software models. According to the modeling in various corrosion depths, strength reduction was less than 5% in corrosion with pit radius to reinforcement diameter ratio up to 0.3, and for corrosion higher than 0.4, the measure of capacity reduction was increased to 30%[5]. In order to predict corrosion initiation time, Chateauneuf et al. considered uncertainties in the parameters affecting corrosion onset. Based on the results, the proposed method can be very useful for determining the corrosion initiation time of reinforced concrete structures, especially those that have just been built[6].

This research predicts the corrosion start time by using probabilistic and non-probabilistic methods. The corrosion initiation time has been investigated using Monte Carlo simulations in a probabilistic manner. Also, the effect of surface chloride concentration and the effect of water-cement ratio have been investigated. Calculations and results have been compared for corrosion start times based on different distances from the coast, water-cement ratios, and failure probabilities. In addition, uncertainties in corrosion initiation have also been examined.

2. Chloride release in concrete and corrosion time

In order to calculate the rate at which chlorides penetrate concrete and to reach the critical chloride concentration for corrosion, Fick's second law must be applied. The second rule of Fick is as follows:

$$C(x,t) = C_S \left[1 - erf\left(\frac{x}{2\sqrt{Dt}}\right) \right]$$

Which C represents the concentration of chloride in moles per cubic meter, D represents the diffusion coefficient in square meters per second, and x represents the desired depth from the surface of the reinforced concrete member in meters (m), as well as surface chloride levels at corrosion. In accordance with relation (1), corrosion start time is calculated as follows:

$$t_{Corr} = \frac{Cover^2}{4D} \left[erf^{-1}\left(1 - \frac{C_r}{C_S}\right) \right]^{-2} \quad (1)$$

In the same way as with structures, the following relationship can be used to estimate when corrosion will start by determining how high the chloride concentration is on the surface of the rebar (D) and the amount of critical chloride (R).

$$g(X,t) = R(X,t) - D(X,t)$$
$$= C_{Cr} - C_S \left[1 - erf\left(\frac{x}{2D_C t}\right) \right] \quad (2)$$

3. Results and discussion

Extended For the determined case, the corrosion start time has nearly quadrupled with a 25% reduction in the water/cement ratio for critical chloride concentrations of 0.6, 0.9 and 1.2 kg/m3 at 100 meters from the coast. For a critical chloride concentration of 9 kg/m3 at 350 meters from the coast, corrosion time has doubled. In the case of a distance of less than 100 meters from the coast, where corrosion initiation takes less time than at other distances, by reducing the water-cement ratio to less than 0.4, corrosion initiation times become longer than the useful life of the structure. Moreover, when the critical chloride concentration changes, significant changes in the results are observed, which makes it impossible to make accurate decisions about preventing future damage and reducing financial and life damage. Hence, it is recommended that low water-to-cement ratios are considered in coastal areas, such as the Persian Gulf, and environmental conditions that contribute to corrosion initiation. The probability of corrosion onset in 50 years with a critical chloride concentration of 0.9 kg/m3 and a distance of 100 meters from the coast, as well as a 25% reduction of water to cement with COV[1], is 13%, and COV[2] is 34%. At 350 meters of distance from the coast, COV[1] has a 57% probability of corrosion start time, while COV[2] has a 37% probability. The probability of corrosion occurring at a distance of 1000 meters from the coast is very low. With COV[1] at 100 m from the coast, a critical chloride concentration of 1.2 kg/m3 is 46% reduced, COV[2] 36% reduced, and COV[1] with a critical chloride concentration of 0.6 kg/m3 is 36% reduced. COV[2] has a reduction of 4% while COV[1] has a reduction of 32% while COV[2] has a reduction of 37%. With increasing water-cement ratios (increasing concrete permeability) and decreasing distance from the coast, as in the non-probability case, corrosion initiation times decrease. In addition, if the corrosion initiation is investigated in a probabilistic manner with the probability of different failures, the corrosion initiation time is reduced as compared to a non-probabilistic condition. This issue illustrates the importance of considering uncertainties on the effective parameters at the time of corrosion initiation in order to make the best prediction and prevent corrosion damage. There were many differences in the results of the ratio of water to different cements due to different coefficients of change and failure probabilities. Considering the existing conditions of a project under review, it is necessary to select the coefficients of changes and effective parameters at the time of corrosion. Moreover, in order to determine which of these parameters has a greater influence on the probability of structural failure, different uncertainties have been considered for each parameter. By considering a 10% probability of corrosion initiation, a shorter corrosion initiation time is obtained. It is also important to consider different uncertainties for concrete coatings when predicting corrosion up to 50%, as these uncertainties have a significant impact on the results and lead to uneconomic designs being presented during the design process. In addition, corrosion start times will probably be estimated longer in high probability situations, which results in a lower degree of safety during design and implementation. This issue also illustrates the importance of choosing the coefficients of change carefully in order to provide a design that is both economical and safe, especially for the concrete cover.

4. Conclusion

First, the results from the non-probabilistic state are presented in this paper, then the results from the probabilistic state for three distances less than 100 meters, 350 meters, and 1000 meters from the coast are presented, as well as corrosion start times for structures situated less than 100 meters from the coast. In order to analyze the quality of construction and the effect of concrete permeability, different probabilities of failures are presented for different surface chloride concentrations, critical chloride concentrations, and water-to-cement ratios. A comparison of two sets of coefficients of variation for the influencing parameters on corrosion initiation was conducted in order to evaluate the importance of accuracy in determining the uncertainties appropriate for the existing conditions of the project. The corrosion start time for a non-probability case with 0.6, 0.9, and 1.2 kg/m3 critical chloride concentrations and a distance of 100 meters from the coast has increased almost four times. For a critical chloride concentration of 9 kg/m3 at a distance of 350 meters from the coast, the corrosion time has doubled. As for probability mode, with a 10% probability of corrosion initiation, as was observed, with a 25% decrease in the water/cement ratio, corrosion initiation time increases three to four times. Also, in the 10% probability for the start of corrosion, taking into account more uncertainties for the effective parameters, especially for the concrete coating, this will result in a lower corrosion start time than in the previous cases, and finally, an uneconomic plan will be presented. A comparison of the results shows how surface chloride concentration, critical chloride concentration, and water-cement ratio play an important role. As we approach the coast, surface chloride concentration increases and the water-cement ratio becomes more important. The longer the distance from the coast, the longer it will take for corrosion to start because water to cement ratios are reduced. The ratio of cement to water in structures near the coast should be low during design and especially during implementation to reduce damage during the structure's useful life and to improve earthquake resistance.

5. Refrences

[1] E.A. Dizaj, R. Madandoust, M.M. Kashani, Probabilistic seismic vulnerability analysis of corroded reinforced concrete frames including spatial variability of pitting corrosion, Soil Dynamics and Earthquake Engineering, 114 (2018) 97-112.
[2] S. Ahmad, Reinforcement corrosion in concrete structures, its monitoring and service life prediction—a review, Cement and concrete composites, 25(4-5) (2003) 459-471.
[3] J. Wu, P.N. Faye, W. Zhang, B. Diao, Chloride diffusivity and service life prediction of RC columns with sustained load under chloride environment, Construction and Building Materials, 158 (2018) 97-107.
[4] M.A. Shayanfar, M.A. Barkhordari, M. Ghanooni-Bagha, Estimation of corrosion occurrence in RC structure using reliability based PSO optimization, Periodica Polytechnica Civil Engineering, 59(4) (2015) 531-542.
[5] M. Ghanooni-Bagha, Influence of chloride corrosion on tension capacity of rebars, Journal of Central South University, 28(10) (2021) 3018-3028.
[6] A. Chateauneuf, A. Messabhia, A. Ababneh, Reliability analysis of corrosion initiation in reinforced concrete structures subjected to chlorides in presence of epistemic uncertainties, Structural Safety, 86 (2020) 101976.