

Advances in predicting reinforcement corrosion damage on concrete structures

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Abstract. Steel corrosion-induced damage in reinforced concrete (RC) structures is a pervasive problem that affects minor and major infrastructural developments alike. In the recent past, focus has shifted from prediction of corrosion rate which is affected by several inter-related factors, to the prediction and management of corrosion-induced damage in the propagation phase. Much focus has also been placed on the prediction of the residual life of these structures. These developments have been facilitated by a number of developments in the field including advancements in materials technology, impact of climate change, improved laboratory testing / simulations, real-time in-situ remote monitoring, and capacity / people development. This paper discusses the main drivers that have shaped and provided impetus for the advances in the management of steel corrosion damage in RC structures.

1 Introduction

Steel corrosion-induced damage in reinforced concrete (RC) structures, especially in the marine environment [1], is a pervasive problem that has persisted for decades despite the numerous studies in this field. The damage takes different forms that stretch across both the serviceability and ultimate limit states of the affected RC structures, and include cover cracking (initiation and propagation), delamination and spalling, increased deflection, and loss of steel cross-sectional area. Even with relatively good durability design, specification and in-situ quality control, steel corrosion is inherently difficult to completely eliminate, and most approaches resort to the management of the risk thereof.

It is unavoidable to talk of steel corrosion damage without referring to corrosion propagation. This is because steel corrosion-induced damage is directly associated with the corrosion propagation phase in the service life of a corrosion-affected RC structure. More than a decade ago, Otieno *et al.* [2] stated that “the impetus to include corrosion propagation in the design service life of RC structures can be attributed to a number of reasons including, among others, (i) the rapid increase in the number of deteriorated RC structures due to steel corrosion, (ii) the need to safely utilize the residual serviceability and strength of the RC structure with or without remedial measures [3], and (iii) the propagation phase may in some instances be sufficiently long to merit consideration and quantification. These statements are still valid today!

2 Prediction of corrosion damage

Prediction of steel corrosion damage in RC structures is intrinsically linked to the prediction of the progress of steel corrosion in the propagation phase i.e. corrosion rate. The latter, in addition to the lack of a unified method for its quantification, is not easy to predict even though several models have been proposed to date [4]. Furthermore, corrosion rate is affected by a number of inter-related factors including cover depth and condition (cracked or uncracked), concrete quality (including binder type), temperature, concrete resistivity, relative humidity and specimen design [1, 5]. These pose challenges to the prediction of corrosion rate.

It is however clear that to date, due to the aforementioned challenges, there has been no consensus on the universal applicability of the various corrosion rate prediction models, and focus seems to have shifted to the prediction and management of corrosion-induced damage in the propagation phase. Much focus has also been placed on the prediction of the residual life of these structures.

The prediction of steel corrosion damage in RC concrete structures is hinged on adopting limit states for corrosion-induced damage. A limit state refers to a state beyond which a structure or part of it no longer satisfies the desired performance criteria [6]. In order to depict the different stages of corrosion-induced damage in the propagation phase, the propagation phase is usually sub-divided into sub-phases, the boundaries of which are denoted by different limit states [4, 7].

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3 Focus areas – drivers for advancements

The advancements in the management of corrosion damage have been realized due various reasons. Salient ones are briefly discussed in the following sections.

3.1 Developments in materials technology

Advances in the field of materials used to manage and repair corrosion damage such as surface coatings, corrosion inhibitors and sacrificial anodes [8] cannot be ignored. These need to be further exploited to minimize corrosion damage and maximize the total service life of these structures.

3.2 Impact of climate change

The impact of climate change on the deterioration of RC structures cannot be overlooked. The increasingly harsher exposure environments due to, e.g., global warming [9], require a corresponding response from engineers not only in terms of reducing the carbon footprint of concrete structures and focusing on the need for net zero energy infrastructure but also in mitigating the short- and medium-term needs. There is need for further work on climate adaptation of corrosion-affected RC structures.

3.3 Improved laboratory testing / simulations

Empirical laboratory tests are invaluable in the development of steel corrosion deterioration prediction models. We therefore need to be acutely careful in the experimental designs to simulate exposure environments, and be even more careful in generalizing the applicability of the results and models thereof.

3.4 Real-time in-situ remote monitoring

The technological advancements such as artificial intelligence and data analytics should be exploited in the monitoring of in-service corrosion-affected RC structures, and more importantly, the associated damage. This is critical for some critical ageing RC structures such as nuclear power plants. This will help immensely in the validation and calibration of existing models and forecasting of the performance of RC structures in the long-term.

3.5 Forecasting corrosion-induced damage

Advancements in time-dependent reliability analyses have made it possible to predict and forecast cumulative corrosion damage in RC structures.

3.6 Capacity / People development

It is incumbent upon researchers to capacitate engineers – especially novice ones – with the advancements in knowledge relating to steel corrosion damage in RC structures.

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References

1. M. Otieno, M. Thomas, Ch. 7: Marine Exp. Envmts. & Expsr. Sites, *Marine Concrete Structures: design, durability and performance*, ISBN: 978-0-08-100905-5, 171-196 (2016)
2. M. Otieno, H. Beushausen, M. Alexander, Pro. Int. Symp. on Serv. life Des. Infra. 4th-6th Oct., Delft, The Netherlands, *Significance of the corrosion propagation phase in service life prediction of cracked RC structures*, 533-560 (2010)
3. W. Y. Jung, Y. S. Yoon, Y. M. Sohn, Cem. & Conc. Res., *Predicting the remaining service life of land concrete by steel corrosion*, **33(5)**, 663-677 (2003)
4. M. Otieno, H. Beushausen, M. Alexander, Cem. & Conc. Comps., *Modelling corrosion propagation in reinforced concrete structures - a critical review*, **33**, 240-245 (2011)
5. M. Otieno, M. Alexander, H Beushausen, Magz. Conc. Res., *Corrosion in cracked and uncracked concrete - influence of crack width, concrete quality and crack re-opening*, **62(6)**, 393-404 (2010)
6. ISO-2394, General principles on reliability for structures. *International Organization for Standardization, Geneva* (1998)
7. C. Q. Li, ASCE J. Struct. Eng., *Reliability based service life prediction of corr. affected concrete structures*, **130(10)**, 1570-1577 (2004)
8. F. Bolzoni, A. Brenna, M. Ormellese, Cem. & Conc. Res., *Recent advances in the use of inhibitors to prevent chloride-induced corrosion in reinforced concrete*, **154** (2022)
9. P. de-Wilde, D. Coley, Bldg. & Envmt., *The implications of a changing climate for buildings*, **55**, 1-7 (2012)