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Need for further development in service life modelling of concrete structures in chloride environment

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Abstract

Designing concrete structures for a very long service life may have considerable economic and societal benefits including minimized material consumption over the long term, thus contribute to more sustainable solutions. However, such long service lives require determination and extrapolation of environmental loadings and material durability performance over a long period, as well as reliable and operational models for service life predictions. Codes and standards give deem-to-satisfied recommendations for intended working (service) life up to about 100 years. However, if higher working lives of 200 and 300 years are specified, as for monumental buildings, bridges and other important infrastructures, more in-depth service life predictions are required. This paper focuses on durability and service life predictions for reinforced concrete structures for working (service) life requirements above 100 years.

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Keywords: concrete structures; service life; chloride ingress; chloride threshold; probability.

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1. Introduction

Despite the fact that almost all current concrete structural design codes and standards make no allowance for the effects of deterioration during the life of the structure, premature deterioration of concrete buildings and infrastructure due to corrosion of reinforcement is still a severe challenge, both technically and economically. Moreover, repair-work on the public transportation infrastructure are causing significant inconveniences and delays for both the industry and the general public, and are now recognized as a substantial cost for the society.

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The provisions within codes of practice for concrete structural design and the associated materials standards are typical given in tabulated form relating the provision of resistance (e.g. cement type and quality, maximum water/binder ratio, depth of cover, concrete grade, minimum air content, type of curing, control of early cracking, crack width limitation) to the aggressivity of the environment and the length of the design service life.

In general, Eurocode 2 for concrete structures, an a priori assumption is made that 50-year service life will be achieved for structures designed in accordance with the given requirements and provisions. Other national codes and regulations may adopt higher service lives, like in the Norwegian annex to Eurocode 2 [1]; specifying minimum concrete covers for design lives of both 50 and 100 years.

For some important long-life infrastructures and monumental buildings, target service life of 200 and 300 years, or even more, may be specified. Service life modelling, or chloride ingress modelling, based on Fick's second law of diffusion is becoming the common tool for performance-based specifications of such concrete structures.

An interesting long-life infrastructure in this respect is the design and construction of the Second Gateway Bridge in Australia with a service life requirement of 300 years [2]. Chloride induces corrosion was of particular concern for the durability of the main pier pile caps. These elements were designed with a concrete cover to the ordinary black steel of 150 mm. To control surface cracking of such large cover depth, a mat of LDX 2101 stainless steel reinforcement was specified and places at a distance of 75 mm from the exposed concrete surface. A ternary blend concrete consisting of 30 % fly ash (FA) and 21 % blast furnace slag (BFS) with a water/binder ratio of 0.32 was used in these elements in order to improve concrete durability properties substantially.

Other examples of long service life requirements are the design and construction of concrete foundations for some major residential areas located at the sea front in Norway. In one of those construction projects, the client has specified a target service life (design service life) of 200 years. To meet this design life requirement, a cover of 100 mm to ordinary black steel was specified together with a ternary blend concrete with 6 – 20% FA and 4 % silica fume (SF).

In the above construction projects, the concrete cover specifications were verified through probabilistic service life calculations based on Fick's second law of diffusion. Based on the cover specifications, a conclusion could have been drawn that a cover depth of 100 mm is needed for 200 year design life, whereas 150 mm cover is needed for achieving 300 years. However, this is not the case. This paper discusses the uncertainties associated with the service life model and how the output of the probabilistic model is applied for the prediction and specification of cover depths in the two construction projects

It is worth mentioning that in both projects the service life design included an addition safety margin as electrical continuity was specified for reinforcement in the most aggressive environment, to enable future cathodic protection to be installed.

2. Chloride induced corrosion - Service life modelling

Service life of reinforced concrete is often divided into two distinct time periods – the initiation period and the propagation period, respectively. The initiation period is the time when chlorides penetrate through the concrete towards the reinforcement, with negligible concrete deterioration. The propagation period is the time after corrosion initiation of the reinforcement, including concrete cracking, delamination and reduced reinforcement area.

In the design of new structures, the end of service life is often defined at the time when the chloride content at the surface of the reinforcement has exceeded a critical level resulting in depassivation and corrosion initiation of the reinforcement. This critical chloride content, or chloride threshold level, becomes therefore a key parameter in the prediction of the design service life.

For estimation of residual service life and capacity, the corrosion process of the reinforcement (i.e. the propagation period) is important. However, to the authors' knowledge, such operational service life models are lacking.