Concrete in Marine Tidal Environment – Modelling for Service Life Prediction with respect to Chloride Ingress

Abstract

Corrosion of steel in reinforced and prestressed concrete members exposed to the marine tidal zone is a severe durability problem. It results in frequent maintenance and repair work leading to high life cycle costs and even premature failure of structural members if left unattended. Thus the design of elements exposed to marine tidal zone for prolonged maintenance-free service life assumes paramount importance. Service life design in exposure environments, including aggressive or extreme ones, can best be done through mathematical modelling of transport processes of aggressive external agents involved in the deterioration of structural elements. All the material degradation processes leading to element deterioration and resulting serviceability failure occur in the solution phase often in the presence of moisture as a necessary condition. The other agents that play a dominant role in the de-passivation of reinforcing or pre-stressing steel are water-soluble chloride salts. Seawater attack on concrete also involves sulfate attack, but the high solubility of calcium sulfates in seawater diminishes their expansive actions and resultant cracking. Hence it is imperative that estimation of service life and design for desired service life demand modelling of moisture and chloride ingress in concrete elements. While numerous physical/empirical mathematical models were developed for the prediction of deterioration of concrete members in the marine environment, modelling the boundary conditions and characterization of moisture and chloride profiles in the tidal zone remains relatively unexplored.

The main aim of this project is to estimate the severity of chloride attack in the tidal zone so as to enable one to estimate the service life with reference to chloride ingress for given concrete material characteristics and section parameters. The above procedure of estimation in turn would enable one to determine the appropriate material characteristics and section parameters as decision variables for desired service life design. This estimation is facilitated by using several penetration indices already reported in the existing literature. To achieve this, finite element (FE) models are developed to solve for the moisture and chloride profiles exposed to alternate wetting and drying

encountered in the tidal environment. The developed models are validated with published experimental results from existing literature. The validated FE models are then used to evaluate the moisture and chloride profiles for several wet-dry regimes prevalent in the tidal zones. A superimposed tide model having closer proximity to real tides is proposed as a novel alternative to the conventionally used diurnal tide model for simulating the wet-dry regimes in the tidal zone. The simulated moisture and chloride profiles are characterized using well-defined penetration indices, which are used as metrics for comparing the severity of chloride attacks along the tidal zone. Also, the proposed methodology was implemented for the case of six Indian coastal stations to estimate the safe cover depth for steel reinforcement across tidal zones.

The key findings from the study are: 1) The proposed methodology for evaluating the penetration indices along the tidal zone facilitates locating the critical zone of chloride attack, the attributes of which can be used for the durability design of the rest of the tidal zone. 2) The study presents a systematic methodology for using real-time tidal environmental data in calculating the environmental loads affecting the durability of concrete elements exposed to tidal zone. This methodology helped in estimating the environmental loads and the corresponding responses from concrete elements at different geographical locations. 3) The proposed superimposed tide model is a closer approximation of the real tides compared to the conventionally used diurnal tides. It gives conservative predictions compared to the diurnal tide models, which underestimate the severity of chloride penetration in the tidal zone. 4) The estimated values of safe cover depth to reinforcing steel across 6 Indian coastal stations were found to differ by 20-25 mm, which is significant and indicates a need for classifying the coastline into different severity zones. This zoning would be a significant improvement over the current practice, wherein a distinction is not made between the severities of tidal zones of different coastal stations. 5) The comprehensive sensitivity analysis helped in identifying the parameters that cause significant variations in the penetration indices. This preliminary analysis is useful in shortlisting relevant design variables for the development of surrogate/metamodels.