CRITICAL PARAMETERS FOR CORROSION INDUCED DETERIORATION OF MARINE BRIDGE SUBSTRUCTURES IN FLORIDA

PROBLEM STATEMENT

Corrosion-induced deterioration of reinforced concrete bridge structures in Florida, particularly those located along the coastline and exposed to sea or brackish waters, is a pervasive economic, societal, and technical problem. This damage occurs because sea salts (esp. chlorides) progressively diffuse into the concrete, and, upon achieving a critical concentration at the reinforcement depth, cause corrosion and concrete cracking and spalling. Left unaddressed, such damage will eventually compromise the bridge's structural integrity.

Life-cycle models for predicting deterioration of reinforced concrete structures and for projecting repair and rehabilitation requirements are now available. Critical parameters in such models are the threshold chloride concentration that initiates corrosion of the embedded reinforcement, c_{th}, and the coefficient for diffusional chloride transport. Presently, there is variability in the literature as to the magnitude of the former parameter with reported values differing by more than a factor of ten. Chloride thresholds for concrete fabricated using local Florida materials tend to be relatively high compared to those reported in the rest of the United States. Failure to take this fact into account in life-cycle modeling could result in an underestimation of structure life and, in turn, unnecessary overdesign.

OBJECTIVE

The purpose of this research was to investigate the dependence of the chloride threshold upon the mix design variables listed above and possible other factors, including differences in temperatures and relative humidity. Particular tasks included the following:

- continued monitoring and analysis of existing specimens and new experiments that extended the existing tests to include temperature and humidity
- defining and quantifying how the onset of corrosion might be affected by statistical aspects of microstructural features associated with the reinforcement-concrete interface by including among the test specimens some larger than the standard G109

FINDINGS AND CONCLUSIONS

Researchers assessed time-to-corrosion based upon the exposure of a series of (1) G109 specimens to wet-dry NaCl solution ponding and (2) simulated piling specimens to continuous partial immergence and potential and macro-cell current measurements.

The results indicated that time-to-corrosion for 0.50 water-cement ratio (w/c) G109 specimens fabricated using cement of equivalent alkalinity (Na_2O_e) 1.078 (designated HA) exceeded by a factor of six the time-to-corrosion of specimens with Na_2O_e=0.317 (designated LA). Corrosion has not initiated for w/c 0.37 HA specimens, so comparisons cannot be made in the case of this lower w/c. Time-to-corrosion for w/c 0.37 LA G109 specimens that have become active exceeded by a factor of about 20 time-to-corrosion for specimens with w/c 0.50 LA.

The chloride threshold, which was projected from the concentration of this species along the top of the G109 upper bar trace upon specimen autopsy, increases in proportion to time-to-corrosion. The mean chloride concentration threshold for corrosion initiation for the w/c 0.50. LA G109 specimens was in the range 5.5-9.2 kg/m^3 (9.3-15.6 pcy) on a concrete weight basis. This value exceeds by a factor of 7-12 the commonly referenced value in the North American concrete literature (0.77 kg/m^3 (1.3 pcy)). FDOT experience has indicated a threshold of 2.3-4.4 kg/m^3 (2-6 pcy). These ranges are in general accord with the Florida experience threshold range listed above. Variations in concrete or steel (or both) composition and microstructure at the bar surface from one specimen to the next are thought to cause time-to-corrosion, and, hence, the Cl threshold to be a distributed parameter.

G109 specimens that were cyclically ponded at 40^{o}C had relative short times-to-corrosion initiation compared to exposures (a) at 80 percent relative humidity and ambient laboratory temperature, (b) outdoors, and (c) at ambient laboratory relative humidity and temperature, with the latter exhibiting the longest times-to-corrosion. Chloride threshold for the 40^{o}C and outdoor condition exposures exceeded by a factor of two the threshold for the ambient laboratory and outdoor exposures.

An analysis of material features along the top of the upper rebar trace indicated that corrosion initiated preferentially at larger air voids (maximum void diameter was 5 mm). This effect was more pronounced for the HA compared to LA specimens, because the former exhibited a higher density and larger size of voids.

Time-to-corrosion for w/c 0.50 HA piling specimens exceeded by a factor of approximately 2.5 time-to-corrosion for w/c 0.50 LA specimens. For comparable w/c 0.37 specimens, the difference was a factor of two. Time-to-corrosion for piling type specimens exposed to a cyclic water level that simulated tidal action was less than when the specimens were exposed to a constant water level.

The effective diffusion coefficient, D_{eff}, for specimens periodically sprayed with a NaCl solution while exposed to constant relative humidity, RH (RH = 35, 55, 75, and 95 percent), increased with increasing RH. Also, D_{eff} for a specimen that was cycled between RH 35 and RH 95 was approximately the same as for the average of these two values (RH = 65 percent). Thus, variations in RH, as invariably occur in outdoor exposures, apparently did not affect Cl^- diffusion rate.

The effective diffusion coefficient of specimens that were continuously ponding with a NaCl solution while exposed at ambient temperature (~23^{o}C) and in constant temperature chambers at 0, 20, and 40^{o}C increased with increasing temperature. Also, D_{eff} was greater for a specimen that was cycled between 20 and 40^{o}C than for one constantly exposed at 40^{o}C. This observation indicates that laboratory experiments performed at constant temperature may underestimate Cl^- intrusion rates in actual service.

BENEFITS

Using high alkalinity cement in coastal Florida bridges and developing more corrosion resistant micro-structures that reduce the size and number of air voids (i.e., self-compacting concretes) would lengthen the life of a structure prior to the point at which reinforcing steel corrosion initiates. High alkalinity cements cost no more than the normal alkalinity cements presently used; therefore, cost savings could be obtained through reduced maintenance and without any increase in initial materials or construction costs.

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