Summary of Final Report, WPI# 0510756
August 2001

CORROSION RESISTANCE AND SERVICE LIFE OF DRAINAGE CULVERTS

PROBLEM STATEMENT

Highway drainage culverts are basic components of the Florida's transportation infrastructure. The durability of culverts is an important cost issue because of the large number of units involved and because replacement of in-service culverts can require expensive demolition and reconstruction of associated roadwork. Consequently, the design service life requirement for highway culverts commonly approaches 100 years. This requirement makes materials selection and performance prediction difficult, particularly when considering the attractive choices of materials, such as aluminum or aluminum clad steel, that in the last few years have been introduced for this application. More traditional materials, such as reinforced concrete, are subject to technological advancements and, thus, require consequent reevaluation. Galvanized steel has the longest service record and represents an important design alternative when considering a compromise between conservative design and overall cost.

The FDOT recognizes four classes of drainage culvert materials for which corrosion is likely: galvanized steel, aluminized steel, clad aluminum alloy, and reinforced concrete. The estimated durability of reinforced concrete exceeds that of the other materials in many service conditions. However, the accuracy of the estimates, in general, is uncertain, especially for reinforced concrete.

Reinforced concrete deteriorates because of chemical degradation of the concrete (due to the presence of acidity and sulfates in the soil), but more commonly because of corrosion of the reinforcement, which occurs in stages. The first stage is an initiation period during which chloride ions or other aggressive species penetrate the concrete cover and depassify the steel surface. A propagation stage follows, in which the steel corrodes until the concrete cover is cracked (Tuuti, 1982). Determining the value and variability of the capacity to resist chloride ion penetration of present-day concrete formulations used in culverts is critical.

Further, the extent of chloride buildup at the surface of the concrete was assumed, but little was known about the actual values encountered in the field. These parameters are needed to develop design criteria more closely based on quantitative information than are the present estimates. Several recent investigations on the progression of corrosion in reinforced concrete have resulted in improved methods for estimating durability. These investigations include the massive research thrust of the recently completed Strategic Highway Research Program (SHRP), the contributions of several European agencies, and work sponsored by the FDOT that (1) investigated the durability of Florida bridges and (2) more recently, investigated in the laboratory Florida reinforced concrete culverts.

OBJECTIVES

These recent developments can be applied to validate and, if necessary, update guidelines for the use of reinforced concrete in Florida highway drainage applications. Thus, the primary objectives of this study were (1) to obtain experimental and field information on the parameters, especially with regard to chloride exposure, that determine the durability of reinforced concrete culverts in Florida highway drainage applications, and (2) to revise as required guidelines for predicting the durability of reinforced concrete drainage culverts.

FINDINGS AND CONCLUSIONS

Laboratory and yard tests of corrosion initiation and propagation were conducted over a period of several years with regular production culvert pipes from two different manufacturers. The pipes were designated as 0 (concrete made with unblended Type II cement) and F (concrete made with cement blended with fly ash). Laboratory exposure to cyclic saltwater ponding for 4.4 years resulted in the initiation of sustained corrosion in all of the F but in none of the 0 specimens. Laboratory exposure to continuous simulated seawater ponding for 3.4 years resulted in sustained corrosion initiation in only one of the F and in none of the 0 specimens. The difference in corrosion behavior between 0 and F does not necessarily reflect any special corrosion resistance particular to 0 pipe materials since the 0 specimens tested had significantly thicker average rebar concrete cover than those of the F specimen group.

Corrosion rates in the laboratory specimens that showed sustained initiation were modest, on average. Corrosion appeared to be localized. No external manifestations of corrosion (rust stains, cracks) were detected in the laboratory specimens. Chloride penetration from cyclic ponding was substantial in both types of materials. The results suggested that chloride binding was stronger in F specimens. Apparent chloride diffusivity for both concretes (especially 0) was higher than that commonly encountered in low permeability concrete, even though in both cases the water to cementitious ratio was very low. This behavior may be due in part to the modest cementitious content reported for both materials, and it suggests that performance may be improved by the use of higher cementitious content concrete containing fly ash. Tentative estimates of critical chloride concentration in the specimens that underwent corrosion initiation yielded values somewhat larger than those normally reported for steel in concrete.

A yard exposure facility with full-size samples of 0 and F culverts was implemented and operated with saltwater for over 2 years. To date, results suggest that the steel has reached a condition of sustained active corrosion. No external manifestations of corrosion (rust stains, cracks) have yet been detected in any of the yard-exposed culverts.

The culvert field survey sampled sites ranging from benign conditions to extremely aggressive service. As expected, culverts exposed in locations with low chloride, sulfate, and moderate pH showed no indications of corrosion distress. Culverts exposed to coastal seawater for estimated periods ranging from 27 to 43 years showed conditions ranging from some rust staining at the exposed end of the culvert to extensive corrosion-related staining and severe cracking, although all culverts appeared to be fully functional. Concrete cores extracted from culverts in the saltwater locations showed extensive chloride penetration.

Laboratory and yard experiments have shown that corrosion initiation is possible in regular production culverts of at least one source after relatively short times in aggressive chloride environments. These observations agree with the substantial chloride penetration encountered after relatively short times in the laboratory and with the extensive penetration recorded for the concrete of culverts in the field after several decades of exposure to salt water. The concrete used for typical production culverts does not appear to provide any exceptional protection against chloride penetration or initiation of corrosion. Thus, the length of the corrosion initiation stage should be projected as is commonly done for other reinforced concrete systems with similar concrete cover and average concrete quality. The laboratory results underscored the importance of evaporative concentration of chlorides in creating a highly aggressive environment.

FDOT has in place guidelines for estimating service regimes of marine substructures where evaporative concentration is important. A similar approach should be applied to culvert pipes: pipes in saltwater having above 2,000 ppm chloride and having portions immediately above high tide should be treated for service life estimation as though they were exposed to seawater service. Further, the actual environmental chloride content should be used (current practice) for calculating the service life of pipes experiencing continuing or full immersion, or environmental water chloride contents of less than 2,000 ppm.

This research project was conducted by Alberto Sagues, Ph.D., P.E., at the University of South Florida. For more information, contact Rick Kessler at (352) 337-3205, richard.kessler@dot.state.fl.us