Summary of Final Report, BC380
October 2002

A UNIFIED APPROACH TO CONCRETE MIX DESIGN OPTIMIZATION FOR DURABILITY ENHANCEMENT AND LIFE-CYCLE COST OPTIMIZATION

PROBLEM STATEMENT

Concrete bridges in coastal locations, as are common in Florida, are susceptible to chloride induced reinforcing steel corrosion and to resultant concrete cracking and spalling. Design approaches adapted in the past decade by the Florida Department of Transportation (FDOT) to provide enhanced corrosion resistance include (1) use of high performance concretes—that is, ones with low water-to-cement ratio and pozzolanic and corrosion inhibiting admixtures, (2) 76 mm (3.0 in) and 102 mm (4.0 in) of cover over reinforcement for prestressed and cast-in place concretes, respectively, and (3) elevation of substructure components above four meters (12 feet), where feasible. At the same time, Florida concretes, for the most part, are formulated using native aggregates, the coarse type of which is a relatively porous limestone, although a more dense Alabama limestone may be employed in the panhandle region of the State. As such, basic principles suggest that the structure and properties of Florida coarse aggregates act against the overall objective of achieving (1) relatively impermeable concretes and (2) the requisite longevity for coastal bridges, which is now 75 years.

The present study was based upon prior micro-compositional analyses of cores taken from the upper splash zone region of the Long Key Bridge which showed that chlorides were located in the paste only and not in the coarse aggregate. Such a finding infers that the ingress path for this species (chlorides) circumvented coarse aggregate particles such that these aggregates were beneficial to rather than detrimental to durability enhancement. Accordingly, the possibility exists that mix designs could be formulated where, by optimized grading and blending of coarse and perhaps fine aggregates, enhanced diffusional path tortuosity and a reduced chloride ingress rate could be affected.

OBJECTIVES

The objective of the present study was to more comprehensively investigate the influence of native Florida limestone coarse aggregates in concrete upon chloride diffusion and, based upon the results, propose mix designs that focus specific attention upon aggregate properties such that corrosion-related durability is enhanced.

FINDINGS AND CONCLUSIONS

A series of mortar and concrete specimens was fabricated and, subsequent to curing, exposed to cyclic ponding with a ten w/o NaCl solution. After approximately one year, the exposures were terminated and chloride concentration was measured as a function of depth below the exposed surface by a wet chemistry method. From the result, the effective diffusion coefficient was calculated. Mix design variables for the mortar specimens included (1) water-to-cement ratio (0.38, 0.45, and 0.55), (2) type of silica sand (two different fineness moduli), and (3) sand-cement ratio. For the concrete specimens, all of which utilized silica sand of the higher fineness modulus, the variables were (1) water-to-cement ratio (0.38, 0.45, and 0.52), 2) coarse aggregate type (porous Florida limestone (Southdown), dense Alabama limestone (Vulcan), and Ohio quartz (Sidley)), (3) coarse aggregate-fine aggregate-cement ratio, and (4) coarse aggregate grading [as-received, which did not conform to AASHTO M-43 (alternatively, ASTM C33) versus rescreened material that was regraded to within specification]. The results from these exposures were intended to allow for, first, comparison of the native coarse aggregate with other products, including one has been reported to be particularly dense and impermeably (the Ohio quartz) and, second, determination of the affect of mix design upon chloride intrusion rate.

The results showed that the effective chloride diffusion coefficient, D_{eff}, and the surface chloride concentration, c_s, are both important parameters with regard to the intrusion rate. Also, D_{eff} for concrete specimens fabricated using the porous Florida coarse aggregate was only 16 percent higher than with the Alabama limestone and 26 percent higher than with the Ohio quartz. Thus, the porous Florida limestone performed comparably with dense, impermeable aggregates from other regions of the country with regard to the chloride ingress rate and corrosion related durability. Also, concrete specimens prepared using the coarse aggregate that was rescreened and regraded to within AASHTO M-43 (ASTM C33) specification had a lower D_{eff} than did those prepared using the as-received aggregate, although the difference may not be of practical significance. With further mix design refinements, it may be possible to affect additional D_{eff} reductions based upon aggregate grading modification alone.

BENEFITS

In the Department's continuing efforts to find ways to improve concrete durability, this research has shown that by altering mix design variables, chloride permeability can be improved. The research also shows that local materials can be used to make durable concrete. There was no special advantage in importing materials perceived to be of higher quality. This finding will help control the cost of building durable structures.

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