South Carolina
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SUMMARY REPORT

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Permeability of Portland Cement Concrete (PCC) Structures in South Carolina – Volume I

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Over the past two decades, the alarming rate of deterioration of the nation's bridges and other civil infrastructure has become apparent. Concrete bridge decks in particular are failing to complete their typical service lives without repairs. This is commonly due to the corrosion of the reinforcing steel inside the deck. Corrosion leads to cracking and spalling of the concrete cover and is commonly caused by the presence of chloride ions in the concrete at the level of steel reinforcement. There are several solutions to this problem, including increasing the concrete cover, applying concrete surface sealers or overlays, adding corrosion inhibitor to concrete mix, using epoxy-coated reinforcing steel, and others. These methods of protection are being implemented with varying degrees of success, but each introduces some possible problems to the deck such as increased maintenance requirements or longer steel development length requirements. Another solution is to use less permeable, more durable concrete to resist harmful chemical contamination without compromising the integrity of the structure.

This better-quality concrete is commonly referred to as high-performance concrete, or HPC. HPC was originally described as concrete with a high compressive strength, typically higher than 41.4 MPa (6000 psi). The definition of HPC has evolved, and it currently involves high strength and enhanced durability. One of the characteristics included in the durability criterion for HPC is chloride permeability. Because of corrosion, having low chloride permeability becomes more important than having high strength for reinforced concrete bridge decks. The effects of the concrete constituents and construction practices on the chloride permeability become very important in the design of high-durability concrete. Standard chloride permeability measurement should be included as a means of acceptance and quality control.

The objective of this research is to measure the chloride permeability of HPC mixes used in South Carolina using the Rapid Chloride Permeability Test, ASTM C 1202. An experimental program was developed to compare the mix designs used by the South Carolina Department of Transportation (SCDOT) and to observe the change in chloride permeability and percent air voids over a period of time. The results of this program will assist the SCDOT in improving the current mix design for high performance concrete bridge decks and in establishing a standard procedure for chloride permeability testing.

The Rapid Chloride Permeability and Ponding Tests (RCPT) was performed on several concrete mix designs used by the South Carolina Department of Transportation (SCDOT) for the construction of bridge decks. The conclusions drawn from the research described in this report are as follows

The chloride permeability of concrete core and cylinder specimens was successfully determined using RCPT. Four sets of core samples of varying age and mix design were provided by the SCDOT. The following conclusions are drawn from this portion of the research:

1. Chloride permeability varies greatly with concrete age. Therefore, the permeability of concrete of different ages cannot reasonably be compared.

2. The chloride permeability of concrete without supplementary cementitious materials will have a higher ultimate permeability than those with supplementary cementitious materials.

Five versions of Class E concrete, the original mix and four modified versions, were tested at 28 and 56 days to determine their chloride permeability, compressive strength, and modulus of elasticity. The following conclusions are made from the experimental results obtained from the batch comparison study:

3. The batch comparison showed the most current version of the Class E mix design, Class E"-current (Batch 3), to have an average chloride permeability of 5048 and 3012 Coulombs at 28 and 56 days, respectively. At 56 days, Batch 3 also had a compressive strength of 45.8 MPa (6640 psi) and a modulus of elasticity of 20.9 GPa (3031 ksi).
4. Of all the five concretes evaluated, the Class E"-current concrete with no corrosion inhibitor (Batch 5) performed the best, having the lowest chloride permeability values and highest compressive strengths at both 28 and 56 days. Batch 4, Class E" with calcium nitrite corrosion inhibitor, had the highest chloride permeability at both test dates.

Testing was completed to compare the RCPT to the 90-day ponding test method. The following conclusions were drawn from this study:

5. Both the RCPT and 90-day ponding test indicate a much higher permeability for Class D concrete as compared to Class E concrete.
6. When the testing methods are compared to the original comparison proposed by Whiting (1981) discussed in Chapter 2, the values obtained from both tests do not correspond.
7. The chloride values obtained for both Class E and Class D concrete are lower than common threshold values at the minimum concrete cover depth for concrete deck slabs in mild climates according to AASHTO Standard Specifications for Highway Bridges.

A class comparison study was conducted to evaluate the differences between the Class D and Class E concrete with respect to compressive strength, modulus of elasticity and rapid chloride permeability for 28, 56 and 100 day testing. The Class E and Class D concrete mixtures exhibited very similar compressive strength and modulus of elasticity values. The main difference between the two is their chloride permeability values:

8. The Class E concrete consistently had a lower permeability and it was about 41% of the Class D chloride permeability at 28 days. The differences increased with time with the difference at 100 days being 65%. In all cases chloride permeability decreased with time.

A time study was conducted on each concrete batch tested. The time study consisted of compressive strength, air voids, and rapid chloride permeability testing over time. The following are the conclusions drawn from this section of the research:

9. The chloride permeability decreases with time although the decrease does begin to level off after about 100 days. The chloride permeability for all Class E concrete batches followed the same pattern. The Class D concrete chloride permeability values were much higher for each case.
10. A comparison between chloride permeability and compressive strength indicates that the chloride permeability decreases as the compressive strength increases. All Class E concrete batches exhibited a similar behavior with the same rate of chloride permeability reduction with respect to compressive strength increase. Class D batch exhibited a similar rate of reduction with much higher, however, chloride permeability values.
11. The percent of air voids decreased between 3 and 4 % with time. At 70 days, the percent or air voids was between 11.1 and 11.5 %. As the percent of air voids increases the chloride permeability increases.

The following recommendations are made to the SCDOT from the experience gained in this research:

1. Specify 56-day chloride permeability values as a means of acceptance and quality control for high performance mix designs. Regional acceptable permeability values ranging between 1000 and 3000 Coulombs need to be specified.
2. Specify stringent curing procedures for concrete bridge decks to reduce the permeability of concrete and reduce problems with early cracking.
3. Concrete including silica fume (Class E) should be used for bridge deck concrete due to its decreased permeability compared to Class D concrete.

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