MISSOURI S&T

CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY

BEHAVIOR OF HIGH-PERFORMANCE CONCRETE IN STRUCTURAL APPLICATIONS

by

Jared Brewe

A National University Transportation Center at Missouri University of Science & Technology

Disclaimer

Technical Report Documentation Page

1. Report No. NUTC R203	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle BEHAVIOR OF HIGH-PERFORMANCE CONCRETE IN STRUCTURAL APPLICATIONS		5. Report Date October 2007
		6. Performing Organization Code
7. Author/s Jared Brewe		8. Performing Organization Report No. 00016751
9. Performing Organization Name and Address Center for Transportation Infrastructure and Safety/NUTC program Missouri University of Science & Technology 223 Engineering Research Lab Rolla, MO 65409		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTRT06-G-0014
12. Sponsoring Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration 400 7th Street, SW Washington, DC 20590-0001		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code
15. Supplementary Notes		
16. Abstract This project is aimed at graduate research training of students interested in pursuing careers in transportation areas. Financial support will be provided to recruit eight new graduate students interested in pursuing their doctoral degrees in transportation areas each year. These students can pursue their doctoral studies in any department at MST. In departments where a master's degree is the highest degree awarded, students pursuing their master's degree with thesis option will be considered. Areas as stated in the goals, interests and objectives of State Departments of Transportation and Missouri Department of Transportation in particular will be considered for support in this project.		
17. Key Words Design, economic development, education, finance, Future Transportation Professionals, management, materials, operations, safety, security, policy	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classification (of this report) unclassified	20. Security Classification (of this page) unclassified	21. No. Of Pages 3 / 22. Price

Form DOT F 1700.7 (8-72)

BEHAVIOR OF HIGH-PERFORMANCE CONCRETE IN STRUCTURAL APPLICATIONS

Jared Brewe
Advisor: Dr. John Myers

This research project is comprised of several phases of work, with each phase including several opportunities for contribution to civil engineering. The first phase involved concrete mixture optimization for high-strength concrete; followed by phase two looking into important material characteristics of high-strength concrete such as creep and shrinkage which would include structural testing of specimens produced using mixtures developed, and the final phase would lead to development of empirical predictors or models of structural behavior.

There are numerous methods for concrete mix design, with some methods developed from experience and the art of mixture proportioning, while others are more scientifically based. For this project a more scientific based approach was used, which focused on particle packing or particle size optimization. The concept of particle size optimization involves trying to pack the maximum number of particles (aggregate, cement, etc.) into a unit volume. This packing will provide the maximum density, minimum porosity, optimum mix of materials and thus highest strength. This method is commonplace in ceramic engineering in their development of refractory materials for high temperature and high stress applications. The development of a computer program to determine the optimal mix of materials using EXCEL, and experimental testing of the optimal mix designs from the program were performed. A secondary aspect of this mix design allowed production of high-strength concrete with a lower cement ratio, thus a more economical and environmentally friendly mix. High strength concretes typically have above 25 weight percent cement content, but using this method comparative strength can be produced with 10-15 weight percent cement. The following paper was accepted and presented at the 2005 Prestressed Concrete Institute National Bridge Conference:

PARTICLE SIZE OPTIMIZATION FOR REDUCED CEMENT HIGH PERFORMANCE CONCRETE

ABSTRACT

High Performance Concrete (HPC) with improved properties has been developed by obtaining the maximum density of the matrix. Mathematical models developed by J.E. Funk and D.R. Dinger, are used to determine the particle size distribution to achieve the densest packing of particles in the matrix. Once the particle size distribution of each material is established, these models can be applied to determine the optimal mix. By using these models, mixes with packing densities above 90% can be obtained. These mixes will generally contain a lower amount of cement, but will have enhanced mechanical properties like higher compressive strength, improved durability, etc. In addition, using supplementary cementitious materials, i.e. fly ash or ground-granulated blast-furnace slag, to replace portions of the cement will further reduce the amount of cement. Therefore, it is possible to produce a self-consolidating HPC mix with 15 weight % cement and compressive strengths above 17 ksi. This paper discusses the impact of particle size optimization on HPC mixes.

Further research into concrete mix design developed from the increased usage of Self – Consolidating Concrete (SCC), which was first developed in Japan in the 1990's with applications observed in bridge, building, and tunnel structures [Ouchi et al. (2003)]. Over the past few years, SCC has gained increased use and acceptance in the US due to the reduced potential for segregation, voids and surface defects. SCC also eliminates the need for vibration, due to the availability of new admixtures, and therefore reduces fabrication time and labor costs. Due to these advantages, SCC is becoming the material of choice for the precast industry as numerous research studies in recent years have studied the material and mechanical properties of SCC for use in precast members. The studies have shown variations in mechanical property behavior of SCC compared to conventional high-strength concrete (HSC) mixtures in the 8-12 ksi range. Specifically, research results have indicated lower modulus of elasticity (MOE) values for SCC when compared to conventional HSC's [Schindler et al. (2006)]. This lower MOE is attributed to the fact that lower coarse aggregate contents are often specified and used to obtain the required plastic characteristics of the mix. HSC mixes, as opposed to SCC mixes, often utilize significantly higher course aggregate contents to obtain higher MOE levels for serviceability requirements. This implies that the use of SCC for longer spanning members may require higher levels of pretensioning force to address serviceability related issues for a given mix design with lower MOE values.

In prestressed concrete design several stress checks are performed to avoid over-stressing the concrete, which could lead to serviceability problems. The first stress check is performed immediately after transfer of prestress, with checks performed for both the compression fibers and tension fibers. Currently, *AASHTO LRFD Bridge Design Specifications* and *ACI 318 Building Code Requirements for Structural Concrete* limit the extreme fiber stress in compression of concrete immediately after prestress transfer to $0.60f'_c$, with a note stating that these permissible stresses may be exceeded if testing and/or analysis demonstrate no loss in performance of the member. Also, the PCI Standard Design Practice recognizes this limit but states that "*Initial compression is frequently permitted to go higher in order to avoid debonding or depressing of strands. No problems have been reported by allowing compression as high as* $0.70f'_c$." Limits also exist for the extreme fiber stress in tension, which combined with the compression stress limits address serviceability of the concrete members and helps to avoid excessive cracking of concrete. One problem associated with calculating fiber stresses is accurate determination of the prestressing force. The initial prestress force is reduced due to prestress losses, primarily occurring from: elastic shortening of concrete, creep of concrete, shrinkage of concrete and relaxation of steel. Of these four losses, only elastic shortening of concrete is not time dependant. Numerous methods are used in prestress loss prediction, with the newest method outlined in the *National Cooperative Highway Research Program (NCHRP) Report 496: Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders*. As the title suggests, the method was developed for HSC and its applicability to SCC has not been verified. Following this report a research project looked into calibration of the shrinkage prediction models for mixtures subjected to accelerated curing. It' a common belief that heat and steam cured specimens will exhibit less shrinkage due to the improved strength gain and microstructure development. The following paper has been accepted and will be presented at the 2008 Concrete Bridge Conference:

CALIBRATION OF SHRINKAGE BEHAVIOR OF HIGH-STRENGTH CONCRETE (HSC) SUBJECTED TO ACCELERATED CURING AT EARLY AGE

ABSTRACT

A research study was undertaken to determine the effect of early-age accelerated or steam curing on the shrinkage behavior of High-Strength Concrete (HSC). Typically, accelerated or steam cured specimens will exhibit less shrinkage than conventionally cured specimens due to reduced drying shrinkage. In this study, 252 shrinkage specimens were subjected to various accelerated curing temperatures, laboratory and moist curing conditions. Mix designs were produced with commercially available materials found locally in Missouri and approved for highway structures. The variables included were: two water-cementitious materials (w/cm) ratios typically utilized for HSC, fly ash replacement levels of 35 and 50% of cement by weight, and surface sealant was applied to half of the specimens to retain moisture. Quality control specimens were also produced to test at prestress release (1-day) and service (56-day) to determine compressive strength and modulus of elasticity, and to verify the mix designs were HSC. Results from this study were compared to the current NCHRP 496 shrinkage prediction model for HSC used in the determination of prestress losses. Correction factors are presented to account for reduced shrinkage in accelerated or steam cured specimens.

An additional issue that is ignored in the computations of long-term prestress losses is the variation of stresses along the section length and height. It is current practice in the estimation of creep losses to consider only the maximum obtained compression stresses at the centroid of the prestressing steel. The prediction of creep in concrete is correlated to tests performed according to *ASTM C 512: Standard Test Method for Creep of Concrete in Compression*, which outlines the methodology for performing creep testing on concrete, specifically cylinders under uniform uniaxial load at a value of 40% of the concrete compressive strength. However, prestressed members have a stress distribution which may lead to increased or decreased amounts of creep in concrete. These conditions are often ignored in the design of prestressed concrete girders, which if accounted for may lead to significant decreases in the long-term prestressing losses and subsequently increase the prestressing force. Combining the increased use of SCC, the desire to increase the prestressing force and thus the fiber stresses in precast members, and the need for accurate determination of prestress losses, unpredictable camber and serviceability problems have developed. Further studies into the effect of utilizing SCC and increased prestressing forces, as well as its effect on accurate prestress loss prediction are needed.

Finally, an analytical investigation along with the development of empirical predictors or models of structural behavior would be performed. The analytical investigation will examine the appropriateness of the latest NCHRP Report 496 shrinkage and creep prediction models developed for HSC for application to SCC. Variation in the creep effects that are monitored in the experimental phase due to increased release stresses will be taken into account. The analytical study will also focus on developing prediction models that address the variation of camber experienced in SCC girders. Technology transfer will occur through reports submitted to sponsoring organizations, journal articles and conference proceedings, and class lectures.