BRIDGE SPECIFICATIONS FOR HIGH PERFORMANCE CONCRETE

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ABSTRACT

A review of the American Association of State Highway and Transportation Officials (AASHTO) specifications for materials, test methods, bridge design, and bridge construction was made to identify provisions that affect the use of high performance concrete (HPC). Based on this review, a series of proposed changes to the AASHTO specifications were developed to make the specifications more suitable for use with HPC and to remove existing barriers that prevent the efficient and economical use of HPC. Topics include classes of concrete; cementitious materials; temperature monitoring; making, curing, and testing test specimens; concrete curing; aggregate specifications; self-consolidating concrete; modulus of elasticity; modulus of rupture; shrinkage; creep; and prestress losses.

Keywords: Bridges, Cast-in-place concrete, High-strength concrete, High performance concrete, Precast concrete, Prestressed concrete, Specifications.

INTRODUCTION

In 1993, the Federal Highway Administration (FHWA) initiated a national program to implement the use of high performance concrete (HPC) in bridges. The program included the construction of 18 demonstration bridges in 13 states. In addition, other States have implemented the use of HPC in various bridge elements. Construction of these bridges has provided a large amount of data about the use of HPC[1]. In addition, the need to update bridge specifications for use with HPC has been identified.

In 1999, the FHWA funded a project to collect and compile information from each of the joint State-FHWA HPC bridge projects, to review the American Association of State Highway and Transportation Officials (AASHTO) specifications for provisions that affect the use of HPC, and to develop recommended revisions to the specifications where sufficient research results were available to justify the changes. Where insufficient research results existed, specific recommendations for needed research were developed. This paper summarizes the proposed revisions that were developed as part of the project.

SCOPE

The scope of the project included the following documents:

AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1—Specifications and Part 2—Tests

AASHTO Standard Specifications for Highway Bridges, Division I—Design and Division II—Construction

AASHTO LRFD Bridge Design Specifications

AASHTO LRFD Bridge Construction Specifications

HIGH PERFORMANCE CONCRETE

For this project, HPC was based on the FHWA definition[2]. As such, it included the durability characteristics of freeze-thaw resistance, scaling resistance, abrasion resistance, and permeability and the strength characteristics of compressive strength, modulus of elasticity, shrinkage, and creep. In addition, the characteristics of alkali-silica reactivity, sulfate resistance, and flowability were included.

METHODOLOGY

A detailed review of the AASHTO specifications was made to identify provisions that impact the use of HPC. For those sections of the specifications that relate to structural design, the biggest impact comes from the use of high strength concrete. For those sections that relate to materials, the impact is from the use of HPC as a durable concrete, a high-strength concrete, or a combination of both. Details of the review are included in the project final report[3].

Based on the review and available information from the demonstration bridges and other sources, proposed revisions to the AASHTO specifications were developed. The proposed revisions will be submitted to the appropriate AASHTO committees for their consideration.

During the project, it was recognized that several National Cooperative Highway Research Program (NCHRP) projects were underway or in the process of development and will address the use of high-strength concrete in specific articles of the specifications. The NCHRP projects will address the articles related to shear, transfer length, development length, splice length, and design for flexural and axial forces. Consequently, proposed revisions to these articles were not developed as part of this project.

PROPOSED REVISIONS

Based on the work performed in this project, proposed revisions as summarized in the following sections of this report are recommended. Specific word changes that are required to implement these revisions are included in the project final report together with the reasons for the revisions[3].

AASHTO MATERIAL SPECIFICATIONS

1. Revise several individual specifications so that they are more consistent with current concrete technology and terminology. Specific recommendations include:

    - Change Portland Cement Concrete to Hydraulic Cement Concrete wherever appropriate.
    - Include AASHTO M 302 Ground Granulated Blast-Furnace Slag, AASHTO M 307 Microsilica, and ASTM C 1157 Hydraulic Cement in lists of materials for use in concrete.
    - Add data for 56 days to tables that list properties at different ages.
    - Change the name of microsilica to silica fume.
    - Revise water-cement ratio to water-cementitious materials ratio wherever appropriate.
    - Revise cement content to cementitious materials content.
    - Eliminate the term "bags of cement."

2. Revise the alkali-silica reaction provisions of M 6 Fine Aggregate and M 80 Coarse Aggregate to allow either a performance type approach or a prescriptive approach.

3. In M 157, add the concept of performance-based specifications since a performance-based specification is often more appropriate for HPC. In this concept, the engineer specifies the hardened and sometimes the fresh concrete properties. The contractor then demonstrates that the concrete has these properties through trial mixtures.

4. Revise M 182 Burlap Cloth Made From Jute or Kenaf to include cotton mats since they provide an effective way to cure HPC bridge decks.

5. In M 205 Molds for Forming Concrete Test Cylinders Vertically, eliminate the use of paper molds. For specified concrete strengths greater than 6000 psi (40 MPa), require that sheet metal or plastic molds be provided with tightly fitting domed metal or plastic caps to maintain the circular shape at the top of the cylinder while providing clearance above the finished surface.

6. In M 241 Concrete Made by Volumetric Batching and Continuous Mixing, allow the use of three 4x8-in. (100x200-mm) cylinders as an alternative to two 6x12-in. (150x300-mm) cylinders. For specified compressive strengths greater than 5000 psi (35 MPa), require a minimum of three cylinders irrespective of the cylinder size. For specified compressive strengths greater than 5000 psi (35 MPa), revise the specifications so that the required average strengths are consistent with ACI 318[4].

7. Adopt a new specification for combined aggregates since the combined grading of aggregates is important for HPC. The proposed specification includes the following four approaches to combined grading:

   - Fineness modulus
   - Coarseness factor
   - Power chart
   - Percent retained on each sieve

AASHTO TEST METHODS

1. Revise several individual test methods to be consistent with the proposed revisions to the Material Specifications. Specific recommendations include the following:

   - Revise Portland Cement to Hydraulic Cement.
   - Add data for 56 days to tables that list properties at different ages.
   - Revise cement to cementitious materials.
   - Eliminate the term "bags of cement."
   - Clarify that self-consolidating concrete should not be consolidated by rodding or vibrating.

2. Revise the following test methods to make the AASHTO method consistent with the corresponding ASTM method:

    - T 23 Making and Curing Concrete Test Specimens in the Field (ASTM C 31)
    - T 24 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (ASTM C 42)
    - T 231 Capping Cylindrical Concrete Specimens (ASTM C 617)

3. Revise the following test methods to ensure that all materials intended for use in an application are included in the concretes tested:

    - T 132 Tensile Strength of Hydraulic Cement Mortars
    - T 157 Air-Entraining Admixtures for Concrete
    - T 188 Evaluation by Freezing and Thawing of Air-Entraining Additions to Portland Cement

4. In T 161 Resistance of Concrete to Rapid Freezing and Thawing, add a note that for HPC, the test should be discontinued when the relative dynamic modulus decreases to 80 percent.

5 In T 259 Resistance of Concrete to Chloride Ion Penetration, add a note that low permeability concretes need a longer ponding period than 90 days to discern differences.

6. In T 277 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, require that the specimens be moist cured for 56 days prior to the start of specimen preparation or use accelerated curing and test at 28 days.

7. Adopt a new test procedure for slump flow.

AASHTO STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES

Revisions to 30 articles of the Standard Specifications for Highway Bridges were developed as part of the project. Many of the revisions are similar to those proposed for the LRFD Bridge Design Specifications and the LRFD Bridge Construction Specifications. Since it is unlikely that revisions to the Standard Specifications will be implemented, they are not included in this paper.

AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS

1. In Table 3.5.1-1 and 5.4.2.4, revise the unit weight of concrete so that it increases as concrete strength increases above 5.0 ksi.

2. In 5.1 and 5.4.2.1, allow the use of concrete compressive strengths greater than 10.0 ksi in design when specific articles permit their use.

3. In 5.3, revise the definition of concrete compressive strength so that the default age of 28 days is not included. The engineer should specify the age based on the anticipated strength development of the concrete and the intended application.

4. In Table C5.4.2.1-1, add two new classes of concrete known as Class P(HPC) and Class A(HPC). Class P(HPC) is intended for use in prestressed concrete members with a specified compressive strength greater than 6.0 ksi (41 MPa). Class A(HPC) is intended for use in cast-in-place construction where performance criteria in addition to concrete compressive strengths are specified.

5. In 5.4.2.1, allow a cementitious materials content up to 1000 lb/yd^3 (593 kg/m^3) of concrete for Class P(HPC) concrete.

6. In 5.4.2.3, adopt the recommendations of NCHRP Project No. 18-07 for creep and shrinkage for specified concrete strengths up to 15.0 KSI (100 MPa).

7. In 5.4.2.4, add a factor in the equation for modulus of elasticity for different types of aggregates and local materials. The factor shall be taken as 1.0 unless determined by physical tests. Allow the equation to be used for specified concrete strengths up to 15.0 KSI (100 MPa).

8. In 5.4.2.6, revise the value of modulus of rupture for normal weight concrete to include lower and upper bound values for specified concrete strengths up to 15.0 KSI (100 MPa). The lower bound value applies when considering service load stresses, serviceability, or deflections. The upper bound value is more appropriate for determining minimum amounts of reinforcement.

9. In 5.7.1, calculate the modular ratio from actual values for all concrete strength levels.

10. In 5.8.2.8, allow the use of design yield strengths of 75.0 KSI (517 MPa) for shear reinforcement in prestressed concrete beams.

11. In 5.9.4.1 and 5.9.4.2, allow the use of strength design at release for prestressed concrete members as an alternative to the current stress limits.

12. In 5.9.5, adopt the recommendations of NCHRP Project No. 18-07 for prestress losses for specified concrete strengths up to 15.0 KSI (100 MPa).

AASHTO LRFD BRIDGE CONSTRUCTION SPECIFICATIONS

1. In Table 8.2.2-1, add two new classes of concrete known as Class P(HPC) and Class A(HPC).

2. In 8.3.1, require trial batches for Class P(HPC) and Class A(HPC) concrete.

3. Add 8.3.5 to permit the use of combined aggregate gradings.

4. In 8.3.7, include AASHTO M 295 Fly Ash Pozzolans and Calcined Natural Pozzolans, AASHTO M 302 Ground Granulated Blast-Furnace Slag, and AASHTO M 307 Silica Fume as mineral admixtures.

5. In 8.4.3, allow a cementitious materials content up to 593 kg/m^3 (1000 lb/yd^3) of concrete for Class P(HPC) concrete.

6. In 8.4.4, allow the following maximum percentages of cementitious materials for HPC:

    - Fly ash – 25 percent
    - Ground granulated blast-furnace slag – 50 percent
    - Silica fume – 10 percent
    - Any combination – 50 percent

7. In 8.5.7.1, allow the use of three 100x200-mm (4x8-in.) cylinders as an alternative to two 150x300-mm (6x12-in.) cylinders. For specified compressive strengths greater than 35 MPa (5000 psi), require a minimum of three cylinders irrespective of the cylinder size.

8. In 8.5.7.5, allow the use of cylinders made in match-cured chambers for all specified concrete strengths of accelerated cured members. Require the use of match-cured cylinders for specified strengths greater than 41 MPa (6000 psi).

9. In 8.6.6 and 8.6.7, require the use of Class A(HPC) concrete in structures exposed to salt water and sulfate soils.

10. In 8.11.3.5, require that concrete temperatures be monitored instead of enclosure temperatures in accelerated cured members.

11. In 8.11.4, require 7-day water curing immediately after finishing for Class A(HPC) concrete in bridge decks.

CONCLUSIONS

Based on the work summarized in this paper, a large number of the AASHTO specifications need to be revised for their use with HPC. Proposed revisions have been developed. However, additional research is still needed to address all the provisions of the specifications that are affected by HPC.

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REFERENCES

1. High Performance Concrete, Compact Disc, Federal Highway Administration, Version 3.0, February 2003.
2. Goodspeed, C. H., Vanikar, S., and Cook, R., "High Performance Concrete Defined for Highway Structures," *Concrete International,* V. 18, No. 2, February 1996, pp. 62-67.
3. Russell, H. G., Miller, R. A., Ozyildirim, H. C., and Tadros, M. K., "Compilation and Evaluation of Results from High Performance Concrete Bridge Projects—Final Report," FHWA, U.S. Department of Transportation, February 2003, 461 pp.
4. ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02), American Concrete Institute, Farmington Hills, MI, 2002, 443 pp.

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