COMPILATION AND EVALUATION OF RESULTS FROM HIGH PERFORMANCE CONCRETE BRIDGE PROJECTS

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ABSTRACT

In 1999, the Federal Highway Administration initiated a project to collect and compile information from 19 high performance concrete bridges in 14 states. The compiled information included data on the benefits of HPC, costs, structural design, specified concrete properties, concrete mix proportions, measured properties, associated research projects, sources of data, and specifications.

The compiled information was then compared with the AASHTO material specifications, test methods, bridge design specifications, and bridge construction specifications for provisions that directly impact the use of high performance concrete. Over 90 proposed revisions were developed to facilitate the use of high performance concrete. Twenty-two revisions have already been approved by AASHTO for publication in 2004. Others are still under review.

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 demonstration bridges in each of the FHWA regions and the dissemination of the technology and results at showcase workshops. In addition, other States have implemented the use of HPC in various bridge elements.

The bridges were located in different climatic regions of the United States and used different types of superstructures. The bridges demonstrated practical applications of high performance concretes. In addition, construction of these bridges provided opportunities to learn more about the placement and actual behavior of HPC in bridges. Consequently, many of the bridges were instrumented to monitor their short- and long-term performance. Additionally, concrete material properties were measured for most of the bridges. In 1999, FHWA initiated a project to collect and compile information on these bridges and to compare the information with the AASHTO specifications. This paper contains a summary of the project.

HIGH PERFORMANCE CONCRETE DEFINITION

For this project, HPC was based on the FHWA definition[1]. 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.

COMPILATION OF INFORMATION AND SPECIFICATIONS FROM HPC BRIDGES

The first objective of the project was to collect and compile information on concrete mixtures, concrete properties, research projects, girder fabrication, bridge construction, live load tests, and specifications from each of the joint State-FHWA High Performance Concrete bridge projects and other HPC bridge projects. This included all information related to material properties and structural performance.

Information from a total of 19 bridges located in 14 states was collected. The States, abbreviated bridge names, and bridge locations are listed in table 1.

Table 1. HPC Bridges Included in the Compilation.

State	Bridge Name	Location
Alabama	Highway 199	Highway 199 over Uphapee Creek, Macon County
Colorado	Yale Avenue	Interstate 25 over Yale Avenue, Denver
Georgia	SR 920	SR 920 (Jonesboro Rd) Over I 75
Louisiana	Charenton Canal Bridge	LA 87 over Charenton Canal in St. Mary Parish
Nebraska	120th Street	120th Street and Giles Road Bridge, Sarpy County
New Hampshire	Route 104, Bristol	Route 104 over Newfound River, Bristol
New Hampshire	Route 3A, Bristol	Route 3A over Newfound River, Bristol
New Mexico	Rio Puerco	Old Route 66 over the Rio Puerco
North Carolina	U.S. 401	Northbound U.S. 401 Over Neuse River, Wake County
Ohio	U.S. Route 22 Near Cambridge	U.S. Route 22 over Crooked Creek at Mile Post 6.57 Near Cambridge in Guernsey County
South Dakota	I 29 Northbound	I 29 Northbound over Railroad in Minnehana County, Structure No. 50-181-155
South Dakota	I 29 Southbound	I 29 Southbound over Railroad in Minnehana County, Structure No. 50-180-155
Tennessee	Porter Road	Porter Road over State Route 840, Dickson County
Tennessee	Hickman Road	Hickman Road over State Route 840, Dickson County
Texas	Louetta Road	Louetta Road Overpass, SH 249, Houston
Texas	San Angelo	U.S. Route 67 over North Concho River, U.S. Route 87, And South Orient Railroad, San Angelo
Virginia	Route 40, Brookneal	Route 40 Over Falling River, Brookneal In Lynchburg District
Virginia	Virginia Avenue, Richlands	Virginia Avenue over Clinch River, Richlands
Washington	State Route 18	Eastbound Lanes of State Route 18 over State Route 516 in King County

CD COMPILATION

The compiled information was placed on a CD for easy retrieval and viewing[2]. On the CD, the information is presented in two formats. The first format consists of an individual compilation for each bridge.

The compilation for each bridge is divided into the following sections:

Description. This section contains a summary of the overall bridge features.

Benefits of HPC and Costs. Highlights why HPC was used in the bridge and provides total cost, cost per sq ft, cost per ft, or any other information that was obtained.

Structural Design. Lists essential features about the structural design of the bridge.

Specified Items. This section includes relevant items that were required by the HPC special provisions.

Concrete Materials. This section lists information obtained before actual construction of the bridges. It represents the information that would normally be submitted for approval of concrete mix proportions plus additional data that were available because of the research component.

Concrete Material Properties. This section contains information obtained during the actual construction. It is separated into sections on material properties from quality control (QC) tests and material properties from research tests. Separate sections are provided for each HPC element used in the bridge such as girders and deck.

Other Research Data. This section contains research data specifically related to the construction of the showcase bridge. The information varies considerably between compilations depending on the approach and interests of the researchers.

Other Related Research. This section contains other research information that was usually obtained prior to construction of the bridge.

Sources of Data. References of documents used for the compilation are listed. Some of the data were obtained directly from the States and do not appear in the published data. The names of individuals who supplied the data are listed.

Drawings. This section contains miscellaneous details to clarify the written information.

HPC Specifications. When available, the special provisions for HPC in the bridge are included.

The second format on the CD compilation consists of ten summary tables that can be used to compare data from different states and different bridges. The information contained in the summary tables is not as detailed as the information in the individual bridge compilations. The ten summary tables reflect the primary information contained in the individual bridge compilations. Table 2 is an example of the information in the summary tables.

On the CD, information on a specific topic can be obtained by using the search option.

Table 2. Major features of the HPC Bridges.

STATE	AL	CO	GA	LA	NE	NH	NH	NM	NC	OH
BRIDGE NAME	AL 199	Yale Av.	SR 920	Charenton	120th St.	Route 104	Route 3A	Rio Puerco	U.S. 401	U.S. 22
Girder Type	BT-54	BOX	II, IV	III	NU1100	III	NE 1000	BT1600	IV, III	B42-48
Girder Depth, in.	54	30	36, 54	45	43.3	45	39.4	63	54, 45	42
Max. Span, ft	114	112	127.1	72	75	65	60	101.1	91.9	115.5
Max. Spacing, ft	8.75	Adjacent	7.6	10	12.4	12.5	11.5	12.6	10.2	Adjacent
Max. No. of Strands	50	64	56	34	30	40	26	42	30	30
Dia. of Strands, in.	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.5	0.6	0.6
Girder Concrete Strengths										
Specified at Release, psi	8000	6500	8000	7000	5500	6500	5500	7000	7000	6000
Actual at Release, psi	8040-9810	5600-10,900	10,464	7618-9852	8471	6700	6800	7325	7700-10,500	6670-9210
Age at Release, hours	19-45	—	24	21-40	—	14-17	—	72	27	18
Specified Design, psi	10,000	10,000	10,000	10,000	12,000	8000	8000	10,000	10,000	10,000
Actual at Design Age, psi	8440-11,060	7800-14,000	13,300	10,502-12,023	13,944	7755	11,200	10,151	11,800-15,000	9570-12,920
Design Age, days	28	56	56	56	56	28	28	56	28	56
Deck										
Total Deck Thickness, in.	7	11.5	8	8	7.5	9	9	8.7	8.5	5.5(1)
Curing Type (2)	Wet	Wet (3)	Wet	Wet	Wet	Wet	Wet	Wet	Moist	—
Curing Duration, days	7	5	7	7	8	4	7	14	7	—
Deck Permeability										
Specified, coulombs	—	—	2000	2000	1800	1000	1000	—	—	—
Actual, coulombs	2870	5597	3963	1390	589	753	1060	—	—	—
Age, days	56	—	56	56	56	56	56	—	—	—
Deck Concrete Strengths										
Specified, psi	6000	5076	7250	4200	8000	6000	6000	6000	6000	—
Actual, psi	7370	5310	7740	5493	10,433	9020	9004	6160	7150	—
Age, days	28	28	56	28	56	28	28	28	28	—

(1) Ohio bridge used of 5.5-in. thick top flange of box beam and 3-in. thick asphalt.
(2) The terminology is that used by the states. In general, wet and moist curing represent the same procedures.
(3) May – September only. For November – March, membrane curing with insulated blankets was specified. For April and October, either method was allowed.

Table 2. Major features of the HPC Bridges (continued).

STATE	SD	SD	TN	TN	TX (Louetta) (1)		TX (San Angelo) (1)		VA	VA	WA
BRIDGE NAME	I 29 NB	I 29 SB	Porter	Hickman	NB	SB	EB (2)	WB	Route 40	VA Av.	SR 18
Girder Type	II	II	BT-72	BT-72	U 54	U 54	IV	IV	IV	III	W74G
Girder Depth, in.	36	36	72	72	54	54	54	54	54	45	73.5
Max. Span, ft	61	61	159	151.33	136.5	134.0	157	140.3	80	74	137
Max. Spacing, ft	11.4	11.4	8.33	8.33	12.94	16.62	11	8.26	10	9.25	8
Max. No. of Strands	32	32	54	50	87	87	c	64	54	34	40
Dia. of Strands, in.	0.5	0.5	0.6 sp	9/16	0.6	0.6	0.6	0.5	0.5	0.6	0.6
Girder Concrete Strengths											
Specified at Release, psi	8520	8520	8000	8000	8800	8800	8100	6600	6000	6800	7400
Actual at Release, psi	—	—	8635	8719	9190	9680	11,630	8560	7340 s 7820 m	8840	8150
Age at Release, hours	—	—	24-72	24-72	21	21	46	—	18 s, 72 m	18	18-60
Specified Design, psi	9900	9900	10,000	10,000	13,100	13,100	14,000	8900	8000	10,000	10,000
Actual at Design Age, psi	15,900	13,250	9651	10,529	14,440	14,550	15,240	10,130	9060 s 11,490 m	11,200	12,220
Design Age, days	28	28	28	28	28(3)	28(3)	28 (3)	28	28	28	56
Deck											
Total Deck Thickness, in.	9	9	8.25	8.25	7.25	7.25	7.5	7.5	8.5	8.5	7.5
Curing Type (4)	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Moist	Moist	Wet
Curing Duration, days	7	7	7	7	10	10	10	10	7	7	14
Deck Permeability											
Specified, coulombs	—	—	1500	1500	—	—	—	—	2500	2500	—
Actual, coulombs	461	1058	—	—	1730	900	—	—	778	1457	2645
Age, days	90	—	28 (5)	28 (5)	56	56	—	—	28 (5)	28 (5)	> 210
Deck Concrete Strengths											
Specified, psi	4500	4500	5000	5000	4000	8000	6000	4000	4000	5000	4000
Actual, psi	7070	6170	8265	6460	5700	9100	7345	6120	6600	5400	5490
Age, days	28	28	28	28	28	28	28	28	28	28	28

(1) For the Texas bridges, different concrete strengths were specified for different girder span lengths. Listed strengths are largest values.
(2) Values are for modified design.
(3) Specified at 56 days, generally tested at 28 days.
(4) The terminology is that used by the states. In general, wet and moist curing represent the same procedures.
(5) Includes 21 days at 100 ^{o}F.
c = combination of pretensioning and post-tensioning was used, m = moist curing, s = steam curing, sp = special.

REVIEW OF THE SPECIFICATIONS OF THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

The second objective of the project involved a detailed review of the AASHTO specifications to identify provisions that impact the use of HPC. The review included all material specifications and test methods related to aggregates, concrete, curing materials, admixtures, and hydraulic cement of the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Twenty First Edition[3]; Sections 3, 8, 9, and 17 of Division I and Section 8 of Division II of the *Standard Specifications for Highway Bridges*, 16th Edition[4] and Interim Revisions through 2000; Sections 5 and 9 of the *AASHTO LRFD Bridge Design Specifications,* Second Edition[5] and Interim Revisions through 2001; and Section 8 of the *AASHTO LRFD Bridge Construction Specifications,* First Edition[6] and Interim Revisions through 2001.

BACKGROUND

The *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing* consists of specifications and test methods for materials commonly used in the construction of highway facilities[3]. Part I contains specifications for materials. Part II contains the test methods. The relevant specifications for concrete are indexed under the three general subject areas of aggregates; concrete, curing materials, and admixtures; and hydraulic cement. Many of the specifications are similar to the equivalent specification published by the American Society for Testing and Materials (ASTM). However, equivalent documents are frequently not identical. When the AASHTO document does not contain a particular specification, bridge owners reference the ASTM specification.

The *AASHTO Standard Specifications*, like the ASTM Specifications are generally based on conventional concrete and have proved to be reliable over the years. However, with the rapidly changing pace of technology, it is difficult for consensus standards to maintain pace with the technology and new information. This is particularly true with the many aspects of high performance concrete. HPC has unique characteristics such as high strength, improved workability, and low permeability. These require closer attention to quality control and quality assurance. High performance concrete is not as forgiving as conventional concrete. It is engineered concrete and must be produced with great care and attention. Performance specifications are highly desirable for HPC. Yet, many specifications still remain prescriptive in their approach and need to be revised to make them more appropriate for use with high performance concretes.

The latest edition of the *Standard Specifications for Highway Bridges* was published in 2002. Article 9.15 states that the design of precast, prestressed members ordinarily shall be based on the compressive strength of 5000 psi (34 MPa). "An increase to 6000 psi is permissible where, in the Engineer's judgment, it is reasonable to expect that this strength will be obtained consistently. Still higher concrete strengths may be considered on an individual area basis. In such cases, the Engineer shall satisfy himself that the controls over materials and fabrication procedures will provide the required strengths." Article 9.15, which affects all precast, prestressed concrete members appears to be out of date in light of the consistently higher strengths being achieved in practice. As such, it does not preclude the use of higher strength concrete but does little to encourage its use.

The design philosophy of the *Standard Specifications* is being slowly replaced by the newer design philosophy of load and resistance factor design (LRFD) as published in the *LRFD Bridge Design Specifications*[5]. The LRFD specifications introduced the design philosophy of load and resistance factor design for all materials. In this approach, variability in the behavior of structural elements is taken into account in an explicit manner. The *LRFD Specifications* rely on the use of statistical methods but set forth the results in a readily usable manner. Design of concrete structures in the *LRFD Specifications* is addressed in one section that contains all provisions for design of reinforced, prestressed, and partially prestressed concrete. This is in contrast to the *AASHTO Standard Specifications,* which has reinforced concrete and prestressed concrete in separate sections.

Article 5.4.2.1 of the *LRFD Specifications* limits the applicability of the specifications to a maximum concrete compressive strength of 10,000 psi (69 MPa) unless the physical tests are made to establish the relationship between concrete strength and other properties. Hence, the *LRFD Specifications* have extended the implied limit from 6,000 psi (41 MPa) in the *Standard Specifications* to 10,000 psi (69 MPa). With the greater usage of higher strength concrete and its economical and technical advantages, consideration needs to be given to raising the limit above 10,000 psi (69 MPa).

The first edition of the *AASHTO LRFD Bridge Construction Specifications* was published in 1998[6]. Section 8 of the specifications deals with concrete structures and is essentially the same as the *Standard Specifications for Highway Bridges*, Division II, Section 8, Concrete Structures. Therefore, the same limitations on the use of HPC appear in both documents.

REVIEW SUMMARY

For those sections of the specifications that relate to structural design, the biggest impact came from the use of high-strength concrete. For those sections that relate to materials, the impact was 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[7].

PROPOSED REVISIONS TO THE AASHTO SPECIFICATIONS

The third objective of the project was to develop proposed revisions to the AASHTO specifications based on the detailed review and available information from the demonstration bridges and other sources. The proposed revisions have been submitted to the appropriate AASHTO technical 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.

The proposed revisions are summarized in the following sections of this paper. Specific word changes that are required to implement these revisions are included in the project final report together with the reasons for the revisions[7].

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[8].

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:

    - Change Portland Cement to Hydraulic Cement wherever appropriate.
    - 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 almost certain that revisions to the Standard Specifications will not 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 compressive 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 compressive 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 compressive 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 compressive 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 required 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 compressive 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 a new section 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 concrete compressive 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.

ACCOMPLISHMENTS

The proposed revisions have been submitted to either the AASHTO Subcommittee on Materials or the AASHTO Subcommittee on Bridges and Structures for their consideration. At its June 2003 Annual Meeting, the AASHTO Subcommittee on Bridges and Structures approved 22 revisions to the *AASHTO LRFD Bridge Design Specifications* and the *AASHTO LRFD Bridge Construction Specifications* for the 2004 Editions to facilitate the implementation of high performance concrete. The following is a summary of the approved revisions. The revisions **do not** become the official specification articles until they are published by AASHTO. Once codified, these revisions will have the following impact:

AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS

- Recognize that concrete unit weight increases as concrete compressive strength increases (Table 3.5.1-1).

- Extend some provisions to concrete compressive strengths greater than 10.0 ksi (Articles 5.1 and 5.4.2.1).

- Facilitate concrete compressive strength being specified at ages other than 28 days (Article 5.3).
- Allow the use of ground granulated blast-furnace slag (Article C5.4.1).
- Allow higher cementitious materials content for high-strength concrete (Article 5.4.2.1).

AASHTO LRFD CONSTRUCTION SPECIFICATIONS

- Introduce two new classes of high performance concrete (Articles 8.2, 8.3.1, 8.4.1, 8.4.4, 8.6.6, 8.6.7, and 8.11.1).
- Allow the use of ASTM 1157 Blended Hydraulic Cement (Article 8.3.1).
- Allow a combined aggregate grading (Article 8.3.5 and a new Appendix).
- Allow the use of ground granulated blast-furnace slag (Articles 8.3.7, 8.4.4, and 8.6.4.1).
- Allow higher cementitious materials content for high-strength concrete (Article 8.4.3).
- Recognize the use of 4x8-in. cylinders (Article 8.5.7.1).
- Facilitate concrete compressive strengths being specified at ages other than 28 days (Articles 8.5.7.3 and 8.5.7.5).
- Require the use of match-cured cylinders for high-strength precast concrete (Article 8.5.7.5).
- Ensure proper curing of high performance concrete (Articles 8.6.4.1, 8.11.1, 8.11.3.5, 8.11.4, and 8.13.4).

Other proposed revisions are still under review by the two AASHTO Subcommittees at the time of this publication.

RESEARCH NEEDS

The fourth objective of the project was to identify research needs. Where sufficient research results did not exist to support needed changes in the specifications, research problem statements were developed to obtain the required information. The following six research problem statements and objectives related to concrete materials and four research problem statements related to structural design were prepared.

MATERIALS RESEARCH

Performance Requirements for High Performance Concrete
Objective: To develop performance criteria for HPC

Use of Wash Water in High Performance Concrete
Objective: To develop guidelines and specifications for the use of wash water in concrete

Air-Void Requirements and Freeze-Thaw Testing Requirements for Durability of High Performance Concrete
Objective: To establish the required air-void system for HPC and to develop revised test procedures if appropriate

Penetrability Criteria for High Performance Concrete
Objective: To improve existing test procedures and to establish acceptable ranges for the penetrability of HPC

Curing of High Performance Concrete
Objective: To establish effective curing methods for HPC

Procedures for Measuring Compressive and Flexural Strengths of High-Strength Concrete
Objective: To refine existing methods and procedures for measuring compressive and flexural strengths for concrete with compressive strengths up to 20,000 psi (140 MPa)

STRUCTURAL RESEARCH

Application of Bridge Design Specifications to High-Strength Concrete Structural Members: Material Properties
Objective: To develop recommended revisions to the AASHTO specifications to extend their applicability to compressive strengths of normal weight concrete greater than 10,000 psi (70 MPa)

Application of Bridge Design Specifications to High-Strength Concrete Structural Members: Shear Provisions Except Prestressed Concrete Beams
Objective: To develop recommended revisions to the AASHTO specifications to extend the applicability of the shear design provisions to compressive strengths of normal weight concrete greater than 10,000 psi (70 MPa)

Verification of Stress Limits and Resistance Factors for High Performance Concrete
Objective: To collect data and evaluate the resistance factors and stress limits used in the AASHTO specifications

Confinement of High-Strength Concrete Columns for Seismic and Non-Seismic Regions
Objective: To determine the requirements for transverse reinforcement to ensure strength and ductility in high-strength concrete columns.

A full description of each research problem statement is included in the final report[7].

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