High Performance Concrete Showcase Bridges

Prepared by

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* This report was developed primarily by Henry G. Russell.
This report describes twelve bridges that were built as part of the Federal Highway Administration's national program to implement and showcase the use of high performance concrete in bridges. High strength concrete was used in the precast, prestressed concrete girders to permit longer span lengths, wider girder spacings, or shallower sections. High performance concrete was used in the bridge decks to provide more durable concrete and to extend the service life of bridges. For each bridge, information on the structural characteristics, concrete mix proportions, concrete properties, and planned instrumentation is reported. Preliminary results indicate that increased structural efficiency, durability, and economy can be achieved in precast, prestressed concrete bridges by using high performance concrete.
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.

The bridges are located in different climatic regions of the United States and use different types of superstructures. The bridges demonstrate 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.

Definition of HPC

As part of its implementation program, the FHWA developed and published a definition of HPC that includes eight performance characteristics and categorizes these characteristics into performance grades. The performance characteristics are freeze-thaw durability, scaling resistance, abrasion resistance, chloride penetration, compressive strength, modulus of elasticity, shrinkage, and creep. The maximum number of performance grades is four, although four grades are not used for every characteristic. The performance characteristics provided the basis for criteria to be used in the HPC specification for the demonstration bridges.

Benefits of HPC

The use of high strength concrete in precast, prestressed concrete girders allows for longer span lengths, wider girder spacings, or shallower sections. Longer span lengths result in fewer spans in a multi-span bridge. This, in turn, means fewer substructures. Wider girder spacings result in fewer girder lines for a given bridge width with savings in girder costs. Shallower sections mean less material for approach embankments or less material to be removed for underpasses. For replacement bridges, new girders with higher load capacity can replace existing girders with the same depth. All of these factors indicate a potential for cost savings through the use of HPC in bridge girders.

High performance concrete in bridge decks provides a concrete that has greater resistance to chloride penetration, freeze-thaw deterioration, deicer scaling, and abrasion damage. The primary thrust in the showcase bridges has been to provide a concrete with low permeability, and not necessarily a high strength concrete. The use of a low permeability concrete is expected to increase the service life of bridge decks.

Chapter 1 of this report contains a description of twelve bridges. Details of the structural features are given in Chapter 2. Chapter 3 lists the concrete mix proportions for the girders and corresponding concrete properties. A summary of the planned instrumentation for each bridge is given in Chapter 4.

CHAPTER 1 — HPC BRIDGES

This chapter contains a brief description of each bridge and the rationale for using HPC. Further details of many of the bridges are given in References 2 through 4. Photographs of selected bridges are shown in Figs. 1.1 through 1.10.

Alabama: Highway 199 Over Uphapee Creek, Macon County

The HPC bridge in Alabama is a replacement for an original bridge that suffered damage from scour and stream bed degradation. The bridge is located on AL 199 approximately 1 mile (1.6 km) north of I-85 in Macon County near Tuskegee, Alabama. It is 40 ft (12.2 m) wide and carries a high volume of gravel and log truck traffic. The HPC bridge consists of seven spans of 114 ft (34.7 m) and uses five lines of BT-54 girders.

The original design for the bridge was made using conventional strength concrete and resulted in eight spans of 100 ft (30.5 m) using six lines of BT-54 girders. The use of HPC resulted in the elimination of 810 ft (247 m) of BT-54 girders for an estimated cost savings of $100,000. Additionally, the use of HPC resulted in one less pier at an estimated savings of $100,000. Consequently, total savings were approximately $200,000 less the added cost of the HPC. Bid analysis results did not indicate any significant price increase for furnishing HPC.

The anticipated benefits with the use of HPC were twofold. One was a saving on initial construction costs from the use of one less girder line and one less pier. The second was the anticipation of a more durable concrete structure resulting in lower maintenance costs and a longer service life.

Colorado: Interstate 25 Over Yale Avenue, Denver

Colorado’s HPC bridge replaced a previous structure that carried I-25 over Yale Avenue (see Fig. 1.1). The previous structure consisted of a four-span, cast-in-place T-girder bridge with piers located in the median of Yale Avenue and at each side of the roadway. The HPC bridge consists of a two-span structure using adjacent box beams made continuous over the center support. The box beams are 67 in. (1700 mm) wide and 30 in. (762 mm) deep with span lengths of 112 ft (34.1 m) and 97 ft 7 in. (29.7 m). Specified concrete compressive strength for the box beams was 10,000 psi (69 MPa) at 56 days. The 6.9 in. (175 mm) thick cast-in-place concrete bridge deck had a specified compressive strength of 5000 psi (34 MPa) at 28 days.

The use of HPC in combination with box beams met the requirements for long spans with a shallow superstructure.
depth. To provide additional room for a turning lane under the bridge, the HPC bridge used two spans in place of the original four spans. At the same time, it was desirable to improve the vertical clearance over Yale Avenue without significantly changing the existing vertical alignments of I-25 and Yale Avenue.

This optimum solution was adjacent precast box beams. To obtain the prestressing force, 0.6 in. (15.2 mm) diameter strands at 2 in. (51 mm) spacings were necessary. The new bridge is 138 ft (42 m) wide and has one pier with four columns. The previous bridge was 110 ft (33.5 m) wide and had three piers and a total of 45 columns. As a result, the new bridge has improved aesthetics and sight distances.

Nebraska: 120th Street and Giles Road Bridge, Sarpy County

The Nebraska HPC bridge is located in Sarpy County at 120th Street and Giles Road (see Fig. 1.2). The superstructure utilizes seven lines of the NU1100 pretensioned concrete girders with three spans of 75 ft (22.9 m). The 84 ft (25.6 m) width carries two lanes of traffic in each direction. The site was selected for two reasons.

First, a conventional concrete bridge with identical geometry was to be constructed less than a half-mile from the HPC bridge. This is used as a control structure to help evaluate the service life of the HPC bridge.

Second, the bridge had already been designed using conventional concrete. This allowed a comparison of design and construction costs with relative ease.

The strategy for the project was to eliminate or reduce the fear of producing, placing, and curing HPC, not necessarily to optimize the design. The project specifications required a 56-day concrete girder strength of 12,000 psi (83 MPa), which is about twice the normal design strength in Nebraska. This was the only performance characteristic identified for the concrete girders. The bridge deck concrete, however, required two performance characteristics — strength and chloride permeability. A 56-day concrete deck strength of 8000 psi (55 MPa) was required — again, about twice the normal design strength. The acceptance criteria also included a rapid chloride permeability of less than 1800 coulombs at 56 days.

The success of this project centered on the partnership that was formed at the outset. The input from people in industry, academia, local, state, and federal governments was invaluable when determining the project strategy. Because of this partnership, a scheme that was realistic, achievable, and cost effective was developed.

An important outcome of this project was the development of a High Performance Concrete Strategic Plan for the future by the Nebraska Department of Roads Bridge Division, in conjunction with Material & Test Division. The plan contains incremental steps that are realistic, achievable, and cost effective.

New Hampshire: Route 104 Over Newfound River, Bristol

The first New Hampshire HPC bridge was constructed in Bristol on NH Route 104 over the Newfound River (see Fig. 1.3). The bridge is a 65 ft (19.8 m) long single-span struc-
ture with a total width of 57.5 ft (17.5 m) and was designed to accommodate three lanes of traffic and a sidewalk. The superstructure consists of a cast-in-place concrete deck composite with five AASHTO Type III prestressed girders. The girders are spaced at 12.5 ft (3.8 m) on center. Approach slabs were constructed at finish grade. Both the deck and approach slabs utilize concrete as the final riding surface.

As with all New Hampshire bridges, this bridge was designed for the standard AASHTO MS22 (HS-25) truck loading. The girder 28-day concrete compressive strength was specified to be 8000 psi (55 MPa) with a release strength of 6500 psi (45 MPa). Low-relaxation strands with a 1/2 in. (12.7 mm) diameter and spaced at 2 in. (51 mm) centers were used.

The required 28-day concrete strength for the deck was 6000 psi (41 MPa), and the reinforcing steel was epoxy coated. The approach slabs also required 6000 psi (41 MPa) concrete. However, for comparison purposes, uncoated reinforcement was used. The superstructure cost was $59 per sq ft ($635/m²) of deck area compared to an average cost of $48 per sq ft ($517/m²) for conventional bridges.

As part of its program to construct high quality bridges cost effectively, the New Hampshire Department of Transportation decided to investigate the feasibility of constructing an HPC bridge structure. Three important characteristics were determined to be critical for the success of HPC in the state:

The first characteristic was to select a bridge site that provided a good representation of the majority of bridges built in New Hampshire — single-span structures less than 100 ft (30 m) long.

The second characteristic was to choose practical materials, which are readily available in the region and, with those materials, specify concrete that would have easily attainable strength and durability levels.

The third characteristic was to test and evaluate the performance of the HPC materials and the in-situ performance of the bridge itself.
With success, additional HPC bridges could be constructed with the potential of providing higher quality, more durable, and more economical structures. Further details of the bridge are given in References 2, 3, and 5.

**New Hampshire: Route 3A Over Newfound River, Bristol**

The second New Hampshire HPC bridge was also constructed over the Newfound River in Bristol (see Fig. 1.4). The bridge utilized New England bulb-tee girders with stay-in-place precast, prestressed concrete deck panels that became composite with the cast-in-place deck. The girder 28-day concrete compressive strength was specified to be 8000 psi (55 MPa) with a specified strength of 5500 psi (40 MPa) at release of the strands.

The specified concrete compressive strengths for the precast panels were 4000 psi (28 MPa) at release of the strands and 6000 psi (41 MPa) at 28 days. The specified concrete compressive strength for the deck was 6000 psi (41 MPa) at 28 days. The specified maximum chloride permeabilities per AASHTO T 277 were 1500 coulombs at 56 days for the precast girders and deck panels and 1000 coulombs at 56 days for the cast-in-place deck.

The use of HPC in the recently developed New England bulb-tee girders allowed the designers to achieve wider girder spacings and to use a shallower girder than if conventional strength concrete had been used. One line of girders was eliminated through the use of higher strength concrete in the girders. The use of precast panels aided the contractor in spanning across the wider girder spacing and minimized construction time. Greater durability with reduced long-term maintenance will be derived by using HPC in both the girders and the deck.

**North Carolina: U.S. 401 Over Neuse River, Wake County**

North Carolina’s HPC showcase bridges are dual structures over the Neuse River, 10 miles (16 km) north of Raleigh, North Carolina. This site was chosen both for its suitability for HPC and its proximity to the design office and North Carolina State University for monitoring. Each bridge is a four-span structure made up of two 92 ft (28 m) spans and two 58 ft (17.5 m) spans.

The superstructure consists of a five-girder system with an 8.5 in. (215 mm) thick HPC deck and supports a 39 ft (11.9 m) wide roadway and a 5 ft (1.5 m) wide sidewalk. The girders are AASHTO Type IV and Type III shapes with 10,000 psi (69 MPa) HPC and 0.6 in. (15.2 mm) diameter prestressing strands. The girders were detailed for continuity under live load.

There were several reasons why HPC was selected for use in these structures. The potential for initial cost savings was the most significant factor. By utilizing HPC, it was possible to use a five-girder system instead of the six-girder system that would have been required with a normal design.

In addition to the initial cost savings, it is expected that the effective life of the bridge deck will be improved, resulting in lower maintenance and life-cycle costs. North Carolina is especially interested in using HPC as a means to reduce the chloride permeability of its bridge decks.

To achieve this objective, the specifications require fly ash to be substituted for 20 percent of the portland cement in the concrete mix for the deck. The specifications for both the deck and the girders are performance based; the contractor is responsible for submitting a mix design that satisfies the specified performance parameters. It is anticipated that this approach will result in the lowest cost.

**Ohio: U.S. Route 22 Over Crooked River at Milepost 6.57 Near Cambridge in Guernsey County**

The project in Ohio is a single-span, noncomposite, adjacent box girder bridge located on U.S. Route 22 near Cambridge, just west of the intersection of I-70 and I-77 (see Fig. 1.5). This bridge is a replacement structure with a span of 115.5 ft (35.2 m). Originally, the bridge was designed with conventional strength concrete and 0.5 in. (12.7 mm)
diameter strands as a three-span, noncomposite, adjacent box girder system using 21 in. (530 mm) deep girders.

With HPC and 0.6 in. (15.2 mm) diameter strands, it was possible to significantly increase the span of the Ohio box girders to the point where the bridge could be built as a single span using 42 in. (1.07 m) deep by 48 in. (1.22 m) wide girders. The extra depth was considered a reasonable trade-off for the elimination of the piers. Twelve girders were used.

The HPC prestressed box girders were designed based on a 6000 psi (41 MPa) concrete release strength and a 10,000 psi (69 MPa) design strength at 56 days. For durability reasons, the concrete was specified to have a rapid chloride permeability using AASHTO T 277 of less than 1000 coulombs at 56 days. The abutment concrete was cast-in-place HPC.

Since durability was a prime concern, the cast-in-place concrete was required to have a 56-day rapid chloride permeability of less than 1000 coulombs. To achieve this durability, a pozzolanic mix was used. This mix had a 56-day design compressive strength of 8000 psi (63 MPa), but actual strengths exceeded 10,000 psi (69 MPa).

The beam girder mix used Type III cement, as this was the type of cement typically used by the precaster. A natural river sand was used for the fine aggregate and a partially crushed No. 8 river gravel (3/4 in. or 10 mm maximum) was used as the coarse aggregate. Microsilica was added to the mix but was not used as a cement replacement. The odd percentage of microsilica (11.8 percent) occurred because the microsilica was batched by adding 25 lb (11.3 kg) bags of the material into the mixer.

Texas: Louetta Road Overpass, SH 249, Houston

The Louetta Road Overpass is on State Highway 249 in Harris County just outside the northwest city limits of Houston (see Fig. 1.6). The overpass originally consisted of two adjacent three-span bridges with roadway widths that varied from 60 to 105 ft (18.3 to 32.0 m) to accommodate ramps. The overpass was subsequently widened to an overall width that varies from 150 to 190 ft (45.7 to 57.9 m), with a 1 in. (25 mm) longitudinal joint between bridges. The supports are skewed at 33 to 39 degrees due to the orientation of the roadway underneath. HPC was used in the decks, beams, and substructures of these bridges.

The simple-span 54 in. (1372 mm) deep U-beams sit on neoprene bearing pads and are supported by individual piers. Wide beam spacings, ranging from 11.5 to 16.6 ft (3.5 to 5.1 m), are possible because of the U-beam’s 8.0 ft (2.4 m) top width. The piers consist of hollow-core match-cast post-tensioned segments with capitals at the tops to support the U-beams.

The decks are continuous across the three spans with control joints formed at centerlines of the interior supports. The decks are composite, consisting of precast, prestressed concrete subdeck panels with cast-in-place toppings. Deck reinforcement is uncoated. The unit cost for the total structure was $24.09 per sq ft ($259.30/m²) of deck area for the two bridges compared to an average cost of $24.61 per sq ft.
($264.90/m²) of deck area for 12 conventional concrete U-beam bridges on the same project.

Texas: U.S. Route 67 Over North Concho River, U.S. Route 87, and South Orient Railroad, San Angelo

The North Concho River, U.S. Route 87, and South Orient Railroad Overpass in Tom Green County in the city of San Angelo consists of two adjacent multi-span bridges with 40 ft (12.2 m) roadway widths (see Fig. 1.7). HPC was used in the deck, beams, and substructure of the eight-span eastbound bridge, and in the deck of Spans 1 through 5 of the nine-span westbound bridge.

The simple-span 54 in. (1372 mm) deep AASHTO Type IV prestressed beams sit on neoprene bearing pads and are supported by the caps of single-column cast-in-place bents at the interior supports. The superstructures consist of one- and two-span units with sealed expansion joints between units. Spans 1 through 5 of the eastbound bridge range in length from 131 ft (39.9 m) with four beams at 11 ft (3.4 m) spacings to 157 ft (47.9 m) with six beams at 6.6 ft (2.0 m) spacings. Spans 6 through 8 of the eastbound bridge are short due to the underneath roadway and railroad constraints. The total length of the eastbound bridge is 950 ft (290 m).

The decks, which consist of precast, prestressed concrete subdeck panels with cast-in-place toppings, are continuous across the two-span units with control joints at interior supports. The deck reinforcement is epoxy coated in the eastbound bridge except for Span 1, and is uncoated in the eastbound bridge.

With a total inventory of over 48,000 bridges in Texas, the Texas Department of Transportation continues to look for ways to improve the long-term performance and extend the life of its bridges. High performance concrete is a means to help achieve this. In cooperation with The University of Texas at Austin and other state universities, concrete research and implementation continue.

The focus of the research is on improved performance while maintaining constructibility, using local materials and typical construction methods to the extent possible, and determining the most appropriate test methods to predict good long-term performance. Design and construction specifications are updated as additional results are obtained. Further details of the Texas bridges are given in references 2, 3, 6, 7, and 8.

Virginia: Route 40 Over Falling River, Brookneal in Lynchburg District

The Route 40 bridge in Virginia consists of four 80 ft (24.4 m) long spans (see Fig. 1.8). Each span has five AASHTO Type IV beams spaced at 10 ft (3.1 m) centers. The minimum 28-day compressive strength of the air-entrained concrete in the beams was 8000 psi (55 MPa). The bridge was designed to use five beams in each span compared to seven that would have been required with the 6000 psi (41 MPa) concrete. The girder spacing of 10 ft (3.1 m) necessitated a deck thickness of 8.5 in. (215 mm), an increase of 0.5 in. (13 mm) over the original design using seven girders. All concrete in the structure was required to meet VDOT’s new proposed low permeability concrete special provisions. These require a rapid chloride permeability of 1500 coulombs or less for the prestressed concrete, 2500 coulombs or less for the deck concrete, and 3500 coulombs or less for the substructure concrete.

The bridge deck and substructure concretes contained Type II cement and ground granulated blast-furnace slag for cementitious materials. The actual water-cementitious materials ratios were lower than the maximum values specified because of a penalty clause in the contract. For the bridge deck and superstructure concrete, the actual ratios were 0.40 and 0.44, compared to specified values of 0.45 and 0.49, respectively.

Results indicated that even the substructure concrete had a rapid chloride permeability of less than half that required for the bridge deck concrete. With more experience, it will be evident that a conventional concrete with Class F fly ash,
silica fume, or slag can meet the permeability requirements at conventional water-cementitious materials ratios. Thus, the fear factor that results in higher cost will be minimized.

The cost of the deck and the substructure concrete was more than the conventional concrete. This is attributed to the permeability requirements and the associated penalty clause. Even with the requirement for low permeability concretes, the bridge construction cost was $49 per sq ft ($527/m²), which is less than the 1994 average cost of $58 per sq ft ($624/m²) for 34 bridges in the Federal-aid highway system in Virginia. The initial savings were estimated to be $30,000, approximately 4 percent of the total bridge cost. Additional savings are expected over the life of the structure due to anticipated longevity and low maintenance of HPC.

Virginia: Virginia Avenue Over Clinch River, Richlands

The Virginia Avenue Bridge consists of two 74 ft (22.6 m) long spans, continuous for composite dead load and live load (see Fig. 1.9). Each span has five AASHTO Type III beams. With conventional strength prestressed concrete, seven beams would be required. For the first time, VDOT used air-entrained concrete with a minimum compressive strength of 10,000 psi (69 MPa) and 0.6 in. (15.2 mm) diameter strands at 2 in. (51 mm) spacings in the prestressed concrete beams.

All concretes were required to meet VDOT’s new proposed low permeability concrete special provisions. Concretes for the beams contained silica fume. The beams were steam-cured and the strands released the morning following casting. The bridge deck and substructure concrete con-
tained Type I cement and Class F fly ash as the cementitious materials. For both the deck and the substructure concrete, the permeability values were about one-fourth of that specified for the deck concrete.

The bridge construction cost was $61 per sq ft ($656/m²), which was less than the 1996 average cost of $69 per sq ft ($742/m²) for similar bridges.

**Washington: Eastbound Lanes of State Route 18 Over State Route 516 in King County**

The Washington State HPC bridge is located on state Route 516 eastbound about 5 miles (8 km) east of the City of Auburn in the western part of the state (see Fig. 1.10). It is a three-span continuous prestressed concrete I-girder bridge with a center span of 137 ft (41.8 m) and end spans of 80 ft (24.4 m). It has a 38 ft (11.6 m) wide roadway, carrying two 12 ft (3.7 m) wide lanes, and 4 and 10 ft (1.2 and 3.1 m) wide shoulders. The superstructure design was based on the AASHTO LRFD Bridge Design Specifications.

Five Washington State standard precast, prestressed concrete W74G girders spaced at 8 ft (2.4 m) on center are used with a 7.5 in. (190 mm) thick cast-in-place concrete slab. The design compressive strength was 10,000 psi (69 MPa) at 56 days for the prestressed girders and 4000 psi (28 MPa) at 28 days for the roadway slab.

High performance concrete was specified for the prestressed concrete girders to improve durability of the structure and to reduce the number of lines of girders from seven to five. This resulted in a savings of 594 ft (181 m) of girders on this project. The other purposes of HPC are to reduce the depth of the girders, to increase vertical clearance, or to extend the span length of the girders.

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**CHAPTER 2 — STRUCTURAL COMPARISONS**

A summary of the major structural characteristics for each of the bridges described in Chapter 1 is given in Table 2.1. Where span lengths, girder spacings, number of strands, and concrete strengths varied between spans of a particular bridge, only maximum values are given. Consequently, the maximum span and maximum girder spacing may not occur on the same span. A blank space in the table indicates that the information was not available to the committee. A dash in the table indicates that the information is not applicable or known to be not available.

Based on the information in Table 2.1, the following observations can be made:

- Span lengths range from 60 to 157 ft (18 to 48 m).
- With the exception of the U-beams used on the Louetta Road Overpass in Texas, the maximum girder spacing is 12.5 ft (3.8 m).
- The longer span bridges use 0.6 in. (15.2 mm) diameter strands in the girders.
- Specified strengths for the prestressed concrete girders at strand release range from 5500 to 8800 psi (38 to 61 MPa).
- Actual concrete compressive strengths at strand release are as high as 11,630 psi (80.2 MPa).
- Specified design strengths for the prestressed concrete girders range from 8000 to 14,000 psi (55 to 97 MPa), with the most common strength being 10,000 psi (69 MPa).
- Actual compressive strengths are as high as 15,240 psi (105.1 MPa).
- Design strengths for the prestressed concrete girders are specified at either 28 or 56 days.
- Specified rapid chloride permeabilities for the bridge decks range from 1000 to 2500 coulombs.
- Specified compressive strengths for the deck concrete range from 4000 to 8000 psi (28 to 55 MPa).
- For most bridge decks, concrete compressive strengths are specified at an age of 28 days.
- The specified durations of wet or moist curing for the bridge decks range from 5 to 14 days.
Summaries of the approved concrete mix proportions and corresponding concrete properties for the prestressed concrete girders of the twelve bridges are given in Tables 3.1 and 3.2, respectively. A blank space in the tables indicates that the information was not available to the committee. A dash in the tables indicates that the information is stressed concrete girders of the twelve bridges are given in

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Concrete strengths:
- Specified at release, psi: 8,000, 6,500, 5,500, 5,500, 7,000, 6,000, 8,800, 8,100, 6,000, 6,800, 7,400
- Actual at release, psi: 5,600, 5,600, 4,871, 6,700, 6,800, 7,700, 7,920
- Age at transfer, hours: 14-17
- Specified design, psi: 10,000, 10,000, 12,000, 8,000, 8,000, 10,000, 10,000, 13,100, 14,000, 8,000, 10,000
- Actual at design age, psi: 7,800, 14,000, 13,944, 7,755, 11,200, 11,800-15,000, 9,570, 12,290
- Design age, days: 28, 56, 56, 28, 28, 28, 28, 56, 28, 28, 28, 56

DECK
- Thickness, in.: 7, 11.5, 7.5, 9, 9, 8.5, N/A, 7.25, 7.5, 8.5, 8.5, 7.5
- Permeability:
  - Specified, coulombs: 1,800, 1,000, 1,000, 1,000, 1,000
  - Actual, coulombs: 5,597, 589, 753
  - Age, days: 56, 56, 56, 56, 56, 28, 28
- Concrete strengths:
  - Specified, psi: 6,000, 5,076, 8,000, 6,000, 6,000, 6,000, 8,000, 8,000, 8,000, 6,000, 4,000, 5,000, 4,000
  - Actual, psi: 5,310, 10,433, 9,020, 9,004, 7,150, 8,000, 6,500, 6,800, 5,000, 5,000, 5,000, 5,000
  - Age, days: 28, 28, 28, 28, 28, 28, 28
  - Curing method: 7 dw, 5 dm, 8 dw, 5.7 dw, 7 dw, 7 dw, 10 dw, 10 dw, 7 dw, 7 dw, 14 dw

Note: 1 in. = 25.4 mm; 1 ft = 0.3048 m; 1 psi = 6.895 kPa.
* For the Texas bridges, different concrete strengths were specified for different girder span lengths. Listed strengths are largest values for Louetta southbound and San Angelo eastbound bridges.
† Specified at 56 days, generally tested at 28 days.
‡ Includes 21 days at 100°F (38°C).
§ Ohio bridge did not have a separate cast-in-place, concrete deck — values are for the abutment.
c = combination of pretensioning and post-tensioning, dw = days wet, m = moist curing, ps = partial steam curing, sc = self curing.

CHAPTER 3 — MATERIAL COMPARISONS

Summaries of the approved concrete mix proportions and corresponding concrete properties for the precast, prestressed concrete girders of the twelve bridges are given in Tables 3.1 and 3.2, respectively. A blank space in the tables indicates that the information was not available to the committee. A dash in the tables indicates that the information is not applicable or not available. In Table 3.2, properties are based on either production concrete or trial batches as indicated at the top of each column.

Based on the information listed in Table 3.1, the following observations about concrete mix proportions are made:
- Both Type I and Type III cements are used.
- Cementitious materials include Type C fly ash, silica fume, and ground granulated blast-furnace slag (GGBFS) used separately or in combination.
- Total cementitious material contents range from 765 to 1000 lb per cu yd (4.54 to 593 kg/m³).
- Fly ash contents range from 133 to 315 lb per cu yd (79 to 187 kg/m³).
- Silica fume contents range from 35 to 100 lb per cu yd (21 to 59 kg/m³).
- Coarse aggregate contents range from 1671 to 2000 lb per cu yd (911 to 1187 kg/m³).
- For most projects, limestone is used as the coarse aggregate.
- The maximum size of coarse aggregate used most is either 3/4 or 1 1/2 in. (19 or 13 mm).
- Fine aggregate contents range from 670 to 9940 lb per cu yd (282 to 485 kg/m³).
- The water-cementitious materials ratios (w/cm) range from 0.24 to 0.33.
- All projects used a high-range water reducer.
- Half the projects used a retarding admixture.

Based on the data listed in Table 3.2, the following observations can be made:
- Slumps range from 2 to 11 in. (51 to 280 mm).
- Where air entrainment is used, air contents range from 4 to 7 percent.
- Actual concrete compressive strengths at release of the strands range from 6700 to 9940 psi (46.2 to 68.5 MPa).
- Concrete compressive strengths at 28 or 56 days range from 7755 to 14,510 psi (53.5 to 100.0 MPa).
- Rapid chloride permeabilities (RCP) range from 125 to 1590 coulombs.

PCI JOURNAL
Table 3.1. Concrete mix proportions for prestressed concrete girders.

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<thead>
<tr>
<th>STATE</th>
<th>BRIDGE NAME</th>
<th>AL 199</th>
<th>CO</th>
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<th>NH</th>
<th>NC</th>
<th>OH</th>
<th>TX</th>
<th>TX</th>
<th>VA</th>
<th>VA</th>
<th>WA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixtures</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Cement type</td>
<td>III</td>
<td>III</td>
<td>I</td>
<td>III</td>
<td>II</td>
<td>I/II</td>
<td>III</td>
<td>III</td>
<td>I</td>
<td>I</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cement quantity, lb/yd³</td>
<td>753</td>
<td>730</td>
<td>750</td>
<td>777</td>
<td>550</td>
<td>990</td>
<td>846</td>
<td>671</td>
<td>671</td>
<td>752</td>
<td>752</td>
<td>728</td>
</tr>
<tr>
<td></td>
<td>Fly ash type</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Fly ash quantity, lb/yd³</td>
<td>133</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
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</tr>
<tr>
<td></td>
<td>Silica fume, lb/yd³</td>
<td>35</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<td>50</td>
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<tr>
<td></td>
<td>GGBFS, lb/yd³</td>
<td>—</td>
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</tr>
<tr>
<td></td>
<td>Fine aggregate, lb/yd³</td>
<td>1,069</td>
<td>1,363</td>
<td>990</td>
<td>1,075</td>
<td>1,200</td>
<td>905</td>
<td>927</td>
<td>1,086</td>
<td>1,062</td>
<td>1,425</td>
<td>1,350</td>
<td>890</td>
</tr>
<tr>
<td></td>
<td>Coarse aggregate, lb/yd³</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<td>—</td>
</tr>
</tbody>
</table>

Table 3.2. Actual concrete properties for prestressed concrete girders.

<table>
<thead>
<tr>
<th>STATE</th>
<th>BRIDGE NAME</th>
<th>AL 199</th>
<th>CO</th>
<th>NE</th>
<th>NH</th>
<th>NH</th>
<th>NC</th>
<th>OH</th>
<th>TX</th>
<th>TX</th>
<th>VA</th>
<th>VA</th>
<th>WA</th>
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<tr>
<td></td>
<td>Fresh concrete properties</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slump, in.</td>
<td>4-9</td>
<td>2.11</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>4-8</td>
<td>4-9</td>
<td>5-7</td>
<td>6.6</td>
<td>3-6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air content, percent</td>
<td>0.1-6</td>
<td>2-5</td>
<td>6.6</td>
<td>3.5</td>
<td>4.8</td>
<td>5.8</td>
<td>2</td>
<td>2</td>
<td>2.9</td>
<td>4.4</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unit weight, lb/ft³</td>
<td>151</td>
<td>151</td>
<td>147.1</td>
<td>148.6</td>
<td>154</td>
<td>153</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>149.1</td>
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<td>Hardened properties</td>
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<td></td>
<td>Compressive strength</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Release, psi</td>
<td>7,500</td>
<td>6,700</td>
<td>6,800</td>
<td>7,800</td>
<td>8,935</td>
<td>8,740</td>
<td>9,740</td>
<td>9,940</td>
<td>7,340</td>
<td>8,840</td>
<td>8,150</td>
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<tr>
<td></td>
<td>3 day, psi</td>
<td>9,450</td>
<td>9,800</td>
<td>9,700</td>
<td>9,900</td>
<td>9,280</td>
<td>9,100</td>
<td>9,100</td>
<td>9,100</td>
<td>8,900</td>
<td>9,800</td>
<td>8,900</td>
<td>8,900</td>
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<tr>
<td></td>
<td>7 day, psi</td>
<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
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<td>9,600</td>
<td>9,600</td>
<td>9,600</td>
</tr>
<tr>
<td></td>
<td>28 day, psi</td>
<td>9,600</td>
<td>12,966</td>
<td>7,755</td>
<td>11,200</td>
<td>12,480</td>
<td>10,780</td>
<td>13,610</td>
<td>14,510</td>
<td>9,060</td>
<td>11,490</td>
<td>14,100</td>
<td>11,100</td>
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<tr>
<td></td>
<td>56 day, psi</td>
<td>9,900</td>
<td>13,962</td>
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<td>—</td>
<td>—</td>
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<td>—</td>
<td>—</td>
<td>9,857</td>
<td>—</td>
<td>12,220</td>
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<td>Modulus of rupture</td>
<td>28 day, psi</td>
<td>1,150</td>
<td>1,435</td>
<td>1,140</td>
<td>920</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<td></td>
<td>56 day, psi</td>
<td>1,156</td>
<td>1,608</td>
<td>1,250</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<td>Permeability</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>RCP, coulombs</td>
<td>335</td>
<td>1,590</td>
<td>1,100</td>
<td>350</td>
<td>≤ 1000</td>
<td>≤ 1000</td>
<td>272</td>
<td>≤ 1000</td>
<td>272</td>
<td>≤ 1000</td>
<td>272</td>
<td>1,010</td>
</tr>
<tr>
<td></td>
<td>Test age, days</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>28</td>
<td>28</td>
<td>56</td>
</tr>
</tbody>
</table>

Note: 1 in. = 25.4 mm; 1 lb/yd³ = 0.593 kg/m³; 1 fl oz/yd³ = 39 mL/m³; 1 gal/yd³ = 5 L/m³.
* Lumps measured to 1/2 in.
† Steam-cured girders only.

Note: 1 in. = 25.4 mm; 1 lb/yd³ = 0.593 kg/m³; 1 fl oz/yd³ = 39 mL/m³; 1 gal/yd³ = 5 L/m³.
* Measured on trial batches for approved concrete mix proportions.
† Measured on production concrete. For Texas bridges, different concrete strengths were specified for different girder span lengths. Listed numbers are average values for Louetta southbound and San Angelo eastbound bridges.
‡ Includes 21 days at 100°F (38°C).
= steam curing, m = moist curing.
CHAPTER 4 — INSTRUMENTATION

As part of FHWA’s Implementation Program, a set of Instrumentation Guidelines9 was developed. In general, these guidelines were followed by the states to monitor the performance of the HPC bridges. A summary of the types of measurements planned for each bridge is shown in Table 4.1.

Curing temperatures were measured to determine the heat of hydration of the prestressed concrete beams. With high strength concrete, concrete temperatures are often higher than the temperature in the enclosure surrounding the beam. In addition, temperatures are higher in thicker sections such as top and bottom flanges compared to temperatures in the thinner web. During initial curing, temperatures of matched cylinders and temperatures of quality control cylinders were also measured.

Prestress losses as a result of elastic shortening, creep, and shrinkage were measured using embedded strain gauges. Since the output from these gauge is affected by temperature changes, temperatures were also measured at the gauge locations.

Temperature gradients in the deck and girders resulting from daily and seasonal temperature changes were measured on several completed structures. This information can be used for comparison with design gradients and to determine the number of freeze-thaw cycles.

Deflections of girders relative to their ends were measured using surveying techniques or by measurements relative to a taut wire stretched between the ends of the girders. Both techniques provide a means of determining initial camber as well as long-term deflections.

Load tests were performed on some bridges using heavily loaded trucks positioned at various locations on the span. Measured deflections and strains can be compared with calculated values.

Other instrumentation was used to determine transfer lengths at the ends of the beams, strand slip at transfer, overall beam length change, initial prestressing force, beam natural frequency, beam end rotation, and load distribution.

<table>
<thead>
<tr>
<th>STATE</th>
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<th>Yale Av.</th>
<th>NE Route 120th St</th>
<th>NH Route 104</th>
<th>NH Route 3A</th>
<th>U.S. 401</th>
<th>S.R. 22</th>
<th>Louetta</th>
<th>San Angelo</th>
<th>VA Av.</th>
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<th>S.R. 18</th>
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<td>Prestress losses</td>
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<td>Other</td>
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<td>✓</td>
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</tr>
<tr>
<td>* Transfer length and strand slip.</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>† End rotation and prestressing force.</td>
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<td></td>
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</tr>
<tr>
<td>§ Transfer length, initial prestressing force, cracking load, natural frequency, strain distribution and load distribution factors.</td>
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</tr>
<tr>
<td>** Transfer length, strand slip and overall length change.</td>
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</tbody>
</table>

CHAPTER 5 — SUMMARY

This report describes twelve bridges that were built as part of the FHWA national program to implement the use of HPC in bridges. These projects serve to demonstrate that HPC can be used to increase span lengths of girders, increase girders spacing, or allow the use of shallower girders. For bridge decks, HPC can be used to produce a less permeable concrete with an anticipated longer service life.

The high strength concretes used in the precast, prestressed girders were produced using various combinations of cement, fly ash, silica fume, and ground granulated blast-furnace slag as the cementitious materials. Chemical admixtures always included a high-range water reducer and either a water reducer or a retarder. Concrete compressive strengths as high as 11,630 psi (80 MPa) at strand release and 15,240 psi (105 MPa) at 56 days have been achieved. In most projects, a design compressive strength of 10,000 psi (69 MPa) was used for the girders.

HPC RESOURCES

As part of the implementation program for HPC in bridges, a bi-monthly newsletter titled “HPC Bridge Views” is published by the FHWA and the National Concrete Bridge Council (NCBC). A free subscription is available by contacting the NCBC at 847-966-6200 (telephone) or ncbc@portcement.org (e-mail). Previous issues can be viewed and downloaded at www.portcement.org/br/newsletters.asp.

A compact disc containing a compilation of information from the demonstration bridges is available from the FHWA by contacting Terry D. Halkyard by phone: 202-366-6765, fax: 202-366-3077, or e-mail: terry.halkyard@fhwa.dot.gov.

Further information on HPC for bridges can also be obtained from the Federal Highway Administration web site at http://www.fhwa.dot.gov/bridge/hpc.htm.
REFERENCES


2. PCI/FHWA International Symposium on High Performance Concrete, Proceedings, October 20-22, 1997, New Orleans, LA, 721 pp. (Symposium Proceedings published by Precast/Prestressed Concrete Institute, Chicago, IL, 1997.)


4. PCI/FHWA/fib International Symposium on High Performance Concrete, Proceedings, September 25-25, 2000, Orlando, FL, 829 pp. (Symposium Proceedings published by Precast/Prestressed Concrete Institute, Chicago, IL, September 2000.)


ACKNOWLEDGMENTS

The PCI Committee on High Performance Concrete expresses its gratitude to the following individuals for their contributions to Chapter 1 and for verifying information in other chapters: FHWA, S. N. Lane; Alabama, W. F. Conway; Colorado, M. A. Leonard; Nebraska, M. W. Beacham; New Hampshire, C. Waszczuk, M. Whittemore; North Carolina, T. Rowntree; Ohio, R. A. Miller; Texas, M. L. Ralls; Virginia, H. C. Ozyildirim; Washington, M. M. Lwin. Some of the information contained in this report was collected under the FHWA Contract No. DTFH61-00-C-00009 titled “Compilation and Evaluation of Results from High Performance Concrete Bridge Projects.”

FHWA HPC BRIDGE COMPILATION

In 1993, the Federal Highway Administration initiated a national program to implement the greater use of high performance concrete in bridges. Information from these bridges has now been collected and compiled onto a compact disc (CD) for easy retrieval and viewing.

On the CD, the information is presented in two formats. The first format comprises individual compilations for each bridge. The second format consists of summary tables where information from different bridges may be compared.

The individual compilations for each bridge are divided into the following sections:

- Bridge description and photograph
- Benefits of HPC and costs
- Structural design features
- Specified properties for HPC
- Approved concrete mix proportions
- Concrete material properties measured during construction
- Research data obtained during and after construction
- Related research data obtained before construction
- Sources of data
- Relevant drawings
- Special provisions for HPC

The second format consists of ten tables that contain a summary of the primary information from the individual compilations. The tables may be used to compare data from different states and bridges.

The CD also contains a search option that allows information on a specific topic to be quickly located. For those planning, constructing, or researching their first HPC bridge, the compilation provides a wealth of background information. The information illustrates that there are many ways to achieve HPC and that one solution does not fit all cases.

Copies of the CD may be obtained from the FHWA by contacting Terry D. Halkyard by phone: 202-366-6765, fax: 202-366-3077, or email: terry.halkyard@fhwa.dot.gov.