High-Performance Concrete U-Beam Bridge: From Research to Construction

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The Louetta Road Overpass on State Highway 249 in Houston, Texas, is a high-performance concrete bridge design and construction project that is sponsored by FHWA and the Texas Department of Transportation in cooperation with the Center for Transportation Research at The University of Texas at Austin. The overpass, being constructed in 1995, incorporates high-performance concrete in the precast pretensioned U-beams, the composite precast/cast-in-place deck, and the precast posttensioned substructure. Beam concrete design strengths reach 90 MPa (13,000 lb/in.^{2}), with 15.2-mm (0.6-in.)-diameter, 1862-MPa (270-ksi) prestressing strands required to fully use the higher concrete capacity. The use of high-performance concrete in bridge construction is anticipated to be cost-effective at the time of construction and during the life of the structure. Implementing its use in bridge construction is a dynamic process that requires flexibility as new information and concerns arise. The ability of all parties involved to work as a team, with open lines of communication, is of extreme importance.

Bringing state-of-the-art materials and methods to bridge construction is a dynamic process and involves effecting changes in the ways in which a diverse group of people do business. Specifically, high-performance concrete is a state-of-the-art material that is engineered to have both high strength and improved durability. With these improved properties, its use in bridge construction is anticipated to be cost-effective not only at the time of construction but also during the life of the structure. The process of going from research to construction, that is, implementing high-performance concrete in Texas bridge construction, is discussed.

In July 1993 a cooperative agreement was initiated between FHWA and the Texas Department of Transportation (TxDOT), in cooperation with the Center for Transportation Research at The University of Texas at Austin. The 3-year research study, entitled Design and Construction of Extra-High Strength Concrete Bridges, includes development of design and construction standards and specifications for the use of high-performance concrete in bridges and construction of a bridge that optimally uses the improved properties of high-performance concrete.

The bridge in this project, the Louetta Road Overpass on State Highway 249 in Houston, was placed under contract in February 1994 and will be constructed during 1995. It incorporates high-performance concrete in the precast pretensioned U-beams, the composite precast/cast-in-place deck, and the precast posttensioned pier segments. Figure 1 is a perspective of the southbound main lanes of the bridge (*1*).

Structural Details

The Louetta Road Overpass, as shown in Figure 2, consists of two adjacent three-span bridges. The spans range from 37.0 to 41.3 m (121.5 to 135.5 ft). They consist of simply supported beams and continuous composite decks that have construction joints at the interior supports.

A transverse section of the superstructure is shown in Figure 3. The beams are 1372-mm (54-in.)-deep U-beams, the open-top trapezoidal beams recently developed by TxDOT. The beams are uniformly spaced at each support, with average spacings of 3.6 to 4.8 m (11.7 to 15.8 ft) because of the varying roadway widths.

In this project the U-beam is designed to fully use concrete with design strengths from 69 to 90 MPa (10,000 to 13,000 lb/in.^{2}). This requires the use of 15.2-mm (0.6-in.)-diameter, 1862-MPa (270-ksi) prestressing strands on a 50-mm (1.97-in.) grid spacing, which provides the large prestressing force at the maximum eccentricity needed to use the high allowable compressive stress for the high-performance concrete. A maximum number of strands (87), shown in Figure 3, is required in the outside beams of the 41.3-m (135.5-ft) middle span. The strands are straight, with the prestress force reduced at the ends through debonding of a portion of the strands. Debonding extended a maximum of 9 m (30 ft) from the ends of a few of the beams, including the beam shown in Figure 3. The researchers will be observing the behaviors of these beams, since the typical maximum debonded length used in design is 6 m (20 ft) for this beam length.

The southbound main lanes of the bridge are designed with a 55-MPa (8,000-lb/in.^{2}) deck. The northbound main lanes of the bridge deck are designed with 28-MPa (4,000-lb/in.^{2}) cast-in-place concrete, TxDOT's standard strength for cast-in-place decks. Both bridges have composite precast/cast-in-place concrete decks with 55-MPa (8,000-lb/in.^{2}) precast concrete panels. The researchers are experimenting with mix designs to achieve improved durability in both decks.

The long-term benefits of the increased strength and durability of high-performance concrete in service are undocumented. The presence of adjacent bridge decks with significantly different cast-in-place concretes not only allows comparison of the placing and curing of the two different concrete mixes during construction but also allows a comparison of deck behavior during the lives of the structures. Monitoring for a period of 20 to 30 years, similar to pavement evaluations, may be required to fully document the long-term cost-effectiveness of high-performance concrete in bridges.

The tapered, slender precast pier substructure was created to complement the shape of the U-beam superstructure for a unified aesthetic appearance. The individual piers, to be cast by the contractor, are precast hollow-core posttensioned 69-MPa (10,000-lb/in.^{2}) concrete segments. The piers are designed to consist of 1.2- to 1.8-m (4- to 6-ft)-long, match-cast segments on a drilled shaft foundation and with a tapered capital for the beam support, as shown in Figure 1. The column cross section is a 1.0-m (3.25-ft) square with clipped corners. The wall thickness is 100 mm (4 in.) on the walls opposite the two 190-mm (7.5-in.)-thick walls that each hold three posttensioned bars. Cast-in-place concrete will provide a shallow 1.2-m (4-ft)-diameter base for the transition from drilled shaft to precast segment and will also fill the lower column segments to a height of 1.5 m (5 ft) to resist vehicular impacts.

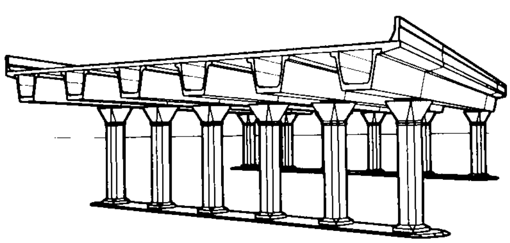

FIGURE 1 Southbound main lane of Louetta Road Overpass.

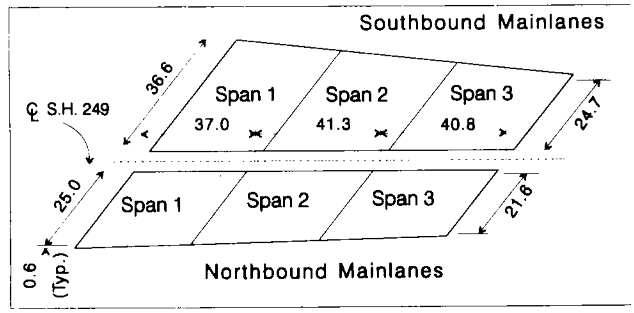

FIGURE 2 Plan view of Louetta Road Overpass (dimensions are in meters; 1 ft = 0.305 m).

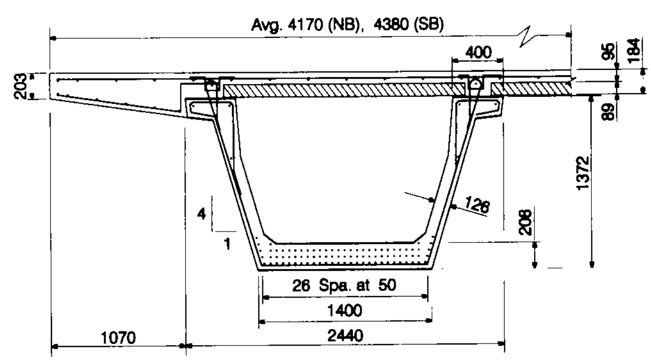

FIGURE 3 Cross section of Louetta Road Overpass (dimensions are in millimeters; 1 in. = 25.4 mm).

Bridge Costs

The use of high-performance concrete in bridges is expected to decrease construction costs because its higher strength allows for faster construction and designs with fewer beams than is possible with normal-strength concrete. Its use is also expected to decrease long-term maintenance costs because of the improved durability characteristics.

Cost comparison of the Louetta Road Overpass with similar normal-strength concrete U-beam construction is limited because of the recent development of the U-beam and, therefore, the lack of historical data. Comparison of construction costs can, however, be made with the construction costs of typical pretensioned concrete I-shaped beam bridges in Texas, which are averaging \$290/m^2 (\$27/ft)^2 of deck area for the total structure. The Louetta Road Overpass, which is part of the third large U-beam bridge project, received the low bid of \$260/m^2 (\$24/ft)^2 of deck area for the total structure. This cost is the same as that for the 12 normal-strength concrete U-beam bridges on the project and slightly lower than those of the other U-beam bridge projects let to date.

Significant construction cost reductions may not become apparent until use of the new high-performance materials and methods becomes more standard practice. In addition, studies of 20 to 30 years in duration may be needed to fully document the decreased maintenance costs anticipated with high-performance concrete bridges.

Beam Design

Typical methods were used in the design of the Louetta Road Overpass, except that the properties of high-strength concrete were used in the design of the U-beams. Design loading was the standard HS20 truck. Allowable stresses controlled the design, with ultimate state also checked. The standard AASHTO prestress loss equations were used for the design, with subsequent creep and shrinkage tests initiated to obtain a more accurate indication of losses in high-performance concrete.

Preliminary deflection measurements with a stretched-wire system attached to the sides of the U-beams indicate actual camber in the range of 60 to 90 mm (2.3 to 3.5 in.) at transfer compared with a calculated camber in the range of 65 to 100 mm (2.6 to 3.9 in.). Therefore, actual camber at transfer appears to be approximately 10 percent lower than the camber predicted by using suggested multipliers from the *PCI Design Handbook* (2) on the basis of the limited data obtained to date.

Camber growth with time is also being monitored, and limited preliminary data reduction indicates a 20 to 30 percent decrease in actual versus calculated values when the suggested multipliers at erection are used. The lower measured cambers are similar to values previously measured in closed-top box beams, which, like the U-beams, have greater stiffness than I-beams.

An interesting phenomenon due to thermal effects has been observed. The actual camber measurements in the limited data available to date have shown as much as a 20-mm (0.8-in.) variation in camber in 1 day, between the morning and afternoon readings, as the sun passes over the open-top U-beam.

As previously shown by research, the flexural tension cracking capacity of high-strength concrete is greater than that of normal-strength concrete. In the present study the U-beams were designed for a maximum tensile stress of $10(f'_{c_i})$ instead of $7.5(f'_{c_i})$ for release conditions and a maximum tensile stress of $8(f'_c)$ instead of $6(f'_c)$ for 28-day conditions. Testing of the actual concrete mix design shows that these values are adequate.

An early, relatively high modulus of elasticity is required to provide adequate beam stiffness to resist the potential for excessive camber resulting from the large prestress forces at release. The beams were therefore designed for a modulus of elasticity of 41 GPa (6 million lb/in.^{2}) at release and 28 days. Modulus of elasticity tests of the actual concrete mix used in the beams in the Louetta Road Overpass averaged 44 GPa (6.4 million lb/in.^{2}).

Concrete

The researchers are taking an active role in supporting the contractor and subcontractors in all aspects of high-performance concrete bridge construction. They provide technical expertise in developing and evaluating the high-performance concrete mix designs, working with the producers to show them what is needed and why. This method gives the producers the knowledge that they will need to independently produce high-performance concrete in future jobs.

As an example the researchers made more than 80 trial batches of beam concrete in their laboratory and at the precast plant, varying the curing methods and the types, sources, and amounts of cement, fly ash, and admixtures. This enabled the researchers to guide the precaster in the selection of materials and in the development of the actual mix design for the beams, shown in Table 1, and in achieving the required properties. Table 2 shows the actual compressive strengths of the control cylinders for the first 19 U-beams.

TABLE 1 Concrete Mix Design for U-Beams of Louetta Road Overpass

Component	Quantity	Type
Coarse Aggregate	1138 kg/m^3	Crushed dolomitic limestone, $^1/_2$" max, ASTM GR 7
Fine Aggregate	610 kg/m^3	Sand
Water	147 kg/m^3	
Cement	398 kg/m^3	Type III, Alamo
Fly Ash	187 kg/m^3	ASTM Class C
Retarder	1045 mL/m^3	Pozzolith 300R
Superplasticizer	6885-8780 mL/m^3	Rheobuild 1000

Note: 1 pcy= 0.593 kg/m^3 1 oz/cy= 38.7 mL/m^3

Prestressing Steel

During the course of the study the need for experimental verification that transfer and development lengths were adequate for 15.2-m (0.6-in.)-diameter strands on a 50-mm (1.97-in.) grid became apparent. The larger strands were found to be necessary to fully use concrete strengths greater than about 69 MPa (10,000 lb/in.^{2}).

However, in October 1988 FHWA placed a moratorium on the use of 15.2-mm (0.6-in.)-diameter strands in pretensioned concrete applications. In addition, the 50-mm (1.97-in.) grid spacing, considered essential for optimum use of the larger strands, results in a clear spacing between strands that is less than that currently allowed by AASHTO code. Approval was therefore requested from FHWA to use 15.2-m (0.6-in.)-diameter strands with 50-mm (1.97-in.) grid spacing in the project described here. Conditional approval pending results from experimental testing was received from FHWA.

Testing included casting two full-scale models of one of the U-beam designs. These beams were then instrumented with detachable mechanical strain gauges (DEMEC gauges) on both sides of the beam length to obtain strain measurements at release. Observations at release indicated that no significant strand slip or concrete cracking occurred and that the transfer length was between 457 and 610 mm (18 and 24 in.) for strands with a somewhat rusty surface condition. No testing to ultimate state was done on these U-beams.

Also cast were two 356-mm (14-in.)-wide, 1067-mm (42-in.)-deep rectangular beams, each with six 15.2-mm (0.6-in.)-diameter, 1862-MPa (270-ksi) strands on a 50-mm (1.97-in.) spacing and with a concrete strength of 90 MPa (13,000 lb/in.^{2}). The same shipment of 15.2-mm (0.6-in.)-diameter strands with a rusty surface condition was used to build these beams. These beams were also instrumented with DEMEC gauges on both sides of the beam length to obtain strain measurements. Observations at release again indicated that no significant strand slip or concrete cracking occurred and that the transfer length was approximately 457 mm (18 in.). These beams were tested to ultimate state, with one test conducted on each beam end with development lengths of 4140, 3023, 2591, and 1981 mm (163, 119, 102, and 78 in.) Even with the shortest development length of 1981 mm (78 in.), failure was in flexure, and no strand slip was observed. The use of a 15.2-mm (0.6-in.)-diameter strand on a 50-mm (1.97-in.) grid in the beams used in the Louetta Road Overpass was therefore considered acceptable and was given final approval by FHWA.

TABLE 2 Control Cylinder Strengths for U-Beams of Louetta Road Overpass

	Compressive Strength	
Time	Avg.	Range
Release (16-21 hrs.)	60.7	55.9 - 66.7
28 days	96.0	85.7 - 100.3
56 days	104.8	97.1 - 110.2

Note: Dimensions shown in megapascals: 1 ksi = 6.89 MPa

Quality Control and Quality Assurance

As the project progresses research needs evolve. One example is related to heat of hydration. Temperature measurements of the concrete in the U-beams used in the Louetta Road Overpass indicated that heat of hydration temperatures in the solid end block were in excess of 93°C (200°F); thus, this is higher than the maximum temperature typical in normal-strength concrete. As a result the researchers are conducting independent temperature studies on high-strength concrete specimens to determine the effects of high temperatures on the quality of the concrete. In addition, temperature-measuring instrumentation is being installed and monitored in the U-beams used in the Louetta Road Overpass, and corresponding controlled-temperature cylinders are being cast to determine whether deleterious effects occur because of these high temperatures.

A related aspect of concern has to do with TxDOT's specifications on the fabricator's release of prestress. The fabricators break concrete cylinders to verify that they have obtained concrete strengths to meet or exceed design release strengths. By obtaining timely acceptable release strengths, the fabricators can transfer the prestress to the beams and have optimum prestress bed turnaround times. The fabricators place the control cylinders near the webs of the beams so that they are covered with the beams and are exposed to similar temperatures. These cylinders are then tested to check concrete strengths before the release of prestress is approved.

The concern arises because these control cylinders may not attain the high, and possibly deleterious, temperatures that have been measured in the various regions of the beams and therefore may not be an adequate measure of the concrete strengths actually achieved in the beams. Limited preliminary measurements indicate that the beam concrete strength could be 10 percent lower than the control cylinder strength because of the detrimental effects of the high heat of hydration temperatures.

Therefore, additional experimental studies have been initiated to evaluate the adequacy of current specifications and develop new specifications as they are required. Additional studies are also addressing the durability aspects specified in the current definition of high-performance concrete.

Teamwork

The need for adequate communication among all parties involved is extremely important when new materials and methods are being implemented. Appropriate scheduling of meetings with all of the right people leads to fewer oversights and erroneous assumptions.

Several weeks before the February 1994 letting, a prebid meeting was scheduled by the TxDOT Houston district office and required the attendance of all contractors planning to bid on the Louetta Road Overpass project. The agenda included a presentation on the innovations included in the Louetta Road Overpass project, a discussion by the researchers on their involvement with the project, comments by FHWA, and a question-and-answer period that allowed the contractors to discuss their concerns.

After the contract was let, a partnering workshop was held in April 1994. Partnering is a new emphasis that has been implemented at TxDOT to encourage the team concept between TxDOT and the contractor and other parties. Partnering workshops are typically done on a voluntary basis, but they are encouraged by TxDOT when it is deemed necessary, for example, for unique projects. The contractor coordinates the workshop, including setting up the facility and hiring an outside facilitator. Selection of the facilitator is usually based on the contractor's previous experience with the facilitator or on recommendations received from others. Expenses for the workshop are paid by the contractor, who then submits a change order to TxDOT for reimbursement for half of the expenses.

The contractor, subcontractors, researchers, FHWA, and TxDOT personnel attend the 1- to 2-day partnering workshop. The outside facilitator leads the discussions, which include a mission statement for the project. Also included are brainstorming on issues. Possible solutions and action plans are then developed, showing the proposed activity, the party responsible for doing the activity, and the time frame in which the action is to be accomplished.

An example of the issues addressed in the Louetta Road Overpass partnering workshop was a proposal made by the contractor to use mortar joints rather than match casting for the pier segments. A representative from the contractor was designated the party responsible for developing a proposal to submit to FHWA and TxDOT, and a deadline was set for submission and response.

Following the partnering workshop, a preconstruction meeting was held in May 1994. The meeting was coordinated by the TxDOT Houston district office, with an invitation to attend the meeting extended to the contractor, subcontractors, researchers, and FHWA and TxDOT personnel. The purpose of the meeting was to discuss in detail the researchers' involvement in the project, including activities and time frames. The items discussed included the researchers' instrumentation plan and its impact on the construction schedule.

Ongoing weekly meetings between the contractor and TxDOT district personnel are occurring throughout the duration of the project. The researchers, FHWA personnel, and other TxDOT personnel are invited as needed to address the issues of concern discussed at that meeting.

The researchers and the TxDOT research project director are continually in contact. In addition, a monthly summary report of project activity is sent to the Project Advisors Committee, which is a group of local technical experts; to the project's National Peer Advisory Group, which is a diverse group of experts from around the United States; and to various other individuals, such as the contractor and FHWA personnel. The individuals receiving the monthly summary report have been extremely helpful in pointing out various aspects that should be considered in carrying out this innovative construction project.

Conclusion

Innovations in bridge construction require the ability to adapt as new information and concerns develop and the ability of all parties to work together as a team to meet the challenges. In Texas the challenges are being met, and work continues in the effort to bring high-performance concrete to the bridge-building industry.

During the course of the study various means of facilitating the implementation of research findings became apparent, and these are as follows:

1. Comparison studies of adjacent bridges, one built with and one built without the new materials or by the new methods, will better define the cost-effectiveness of the innovation in bridge construction.
2. Long-term monitoring of high-performance concrete bridges, for example, for 20 to 30 years, will be initiated immediately after construction to adequately document the actual benefits of the improved durability characteristics.
3. Studies of cost-effectiveness will be publicized to show the economic benefits of implementing the research. For example, the cost savings due to the use of longer spans with fewer beams and reductions in long-term maintenance can be documented and publicized to encourage the use of high-performance concrete in bridge construction.
4. Flexibility in the research study will allow additional experimental or analytical studies to be done as the need for them becomes apparent.
5. Research studies done in conjunction with actual construction projects allow the researchers to act as coaches, providing technical expertise in developing and evaluating the new materials and methods. Thus, the producers gain experience so that they can independently continue the innovations.
6. Research tasks include evaluation of the adequacy of current state department of transportation design and construction specifications and development of new specifications as required.
7. Emphasis is being placed on partnering with all parties involved in the implementation of the new materials and methods. A mandatory prebid meeting, a partnering workshop, and a preconstruction meeting can be included as part of the contract package.

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