Bridge Views

HIGH PERFORMANCE CONCRETE — Academia — States — Industry — FHWA — HPC

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PREFABRICATION MINIMIZES TRAFFIC DISRUPTIONS

Kevin R. Pruski, Ronald D. Medlock, and Mary Lou Ralls, Texas Department of Transportation

The goal of the AASHTO Technology Implementation Group (TIG) is to facilitate rapid acceptance and implementation of high-payoff and innovative technologies. In 2001, the TIG selected prefabricated bridge elements and systems as one area for implementation.

Prefabrication and HPC

Prefabrication provides more control over the construction environment, minimizes work-zone risks, and reduces inconvenience to the public. It also alleviates time pressures during construction by removing concrete strength gain from a project's critical path. Combining prefabrication and high performance concrete (HPC) improves concrete quality as a result of the controlled environment in which the components are constructed. The improved concrete matrix provides a more durable concrete.

Texas Experience

The Texas Department of Transportation (TxDOT) has long used prefabricated bridge members to improve constructibility. In the mid-1950s, Texas began using precast, prestressed concrete beams with standard cross sections. Now, they are the “work horse” of the Texas highway bridge construction program. Beginning in 1963, Texas developed a composite concrete deck system consisting of precast, prestressed concrete deck panels with a cast-in-place concrete topping. Acceptance of this partially prefabricated deck system was slow, but today, the use of panels is the contractor-preferred system for constructing bridge decks. Texas now routinely considers prefabrication to address traffic disruption and constructibility issues on specific projects.

The following three examples demonstrate the growing popularity of prefabrication in Texas:

• The Louetta Road Overpass project in Houston was the first bridge in the country to use HPC for both the superstructure and the substructure. This project combined prefabricated high-strength concrete beams and partial-depth deck panels with high-strength concrete precast, hollow core, post-tensioned piers.

• While planning to replace 113 spans of an elevated structure in Houston's central business district, designers realized that a conventional bridge substructure with cast-in-place bent caps would require 18 months to complete. User delay costs were estimated at $100,000 per day. TxDOT instead opted to use precast bent caps and completed the work in just 95 days.

• The Lake Ray Hubbard bridge project near Dallas is a 102-span bridge over water. Precast bent caps were used to speed construction and simplify concrete delivery for the substructure. This project used HPC with 35 percent of the cementitious materials consisting of ground granulated blast-furnace slag (GGBFS) to reduce permeability and, thereby, improve durability. GGBFS concrete has an initial slower strength gain than conventional concrete. However, the use of precast caps allowed this slower strength gain to occur off-site while foundations and columns were constructed on-site.

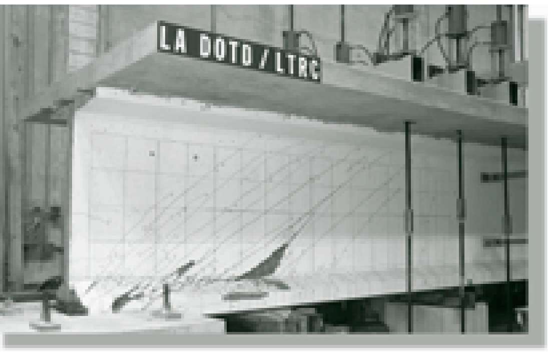
TxDOT promotes the use of HPC in its bridges. The longer curing period and strength-gain time required for some HPC mixtures can be better managed using prefabricated elements and systems. In addition, finishing and curing requirements for HPC are achieved more efficiently by using prefabricated elements. While high-strength HPC is used when needed for beam design, TxDOT is concentrating on the use of conventional strength HPC for its improved durability performance.

Summary

Prefabrication offers many advantages to the owner as well as to the general public.

SHEAR TESTS OF HIGH-STRENGTH CONCRETE GIRDERS

John J. Roller, Construction Technology Laboratories, Inc., Robert N. Bruce, Tulane University, and Henry G. Russell, Henry G. Russell, Inc.



Shear test of 72-in. (1.83-m) deep bulb-tee girder.

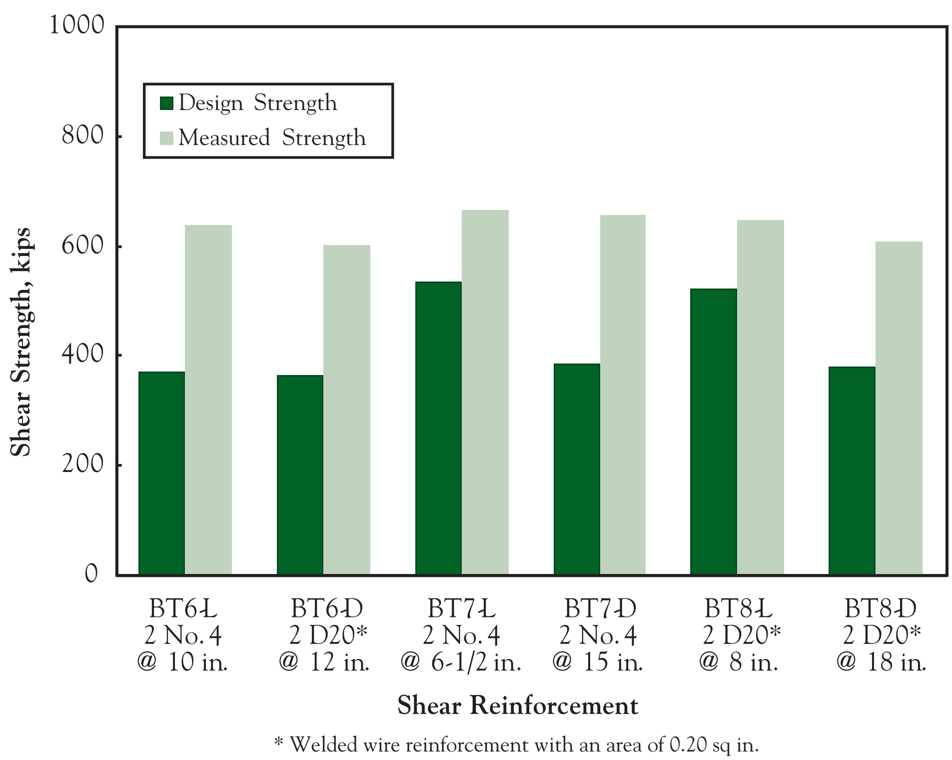
The Louisiana Department of Transportation and Development (LA DOTD) built its first high performance concrete bridge—Charenton Canal Bridge* in 1999. Construction of the State's second high performance concrete bridge is scheduled to commence in the fall of 2002. The new bridge will incorporate 72-in. (1.83-m) deep bulb-tee girders with a specified concrete compressive strength of 10,000 psi (69 MPa) and 0.6-in. (15.2-mm) diameter prestressing strands. To provide assurance that these girders will perform satisfactorily, a research program was initiated to evaluate the structural performance under shear loading conditions. This research is sponsored by the Louisiana Transportation Research Center.

Three 96-ft (29.3-m) long, 72-in. (1.83-m) deep bulb-tee girders were designed and fabricated for the research program. Details incorporated in the test girders were based on prototype bridge designs prepared by the LA DOTD. The prototype bridge used a span length of 95 ft (29.0 m) and a girder spacing of 13 ft 6 in. (4.11 m).The first girder (BT6) was designed based on the AASHTO Standard Specifications for Highway Bridges. Shear reinforcement consisted of individual stirrups at one end and welded wire reinforcement at the opposite end. Design of the other two girders (BT7 and BT8) was based on the AASHTO LRFD Bridge Design Specifications. Two different shear reinforcement designs were developed for these two girders based on two different assumptions about strand development length and the contribution of the longitudinal reinforcement to the shear strength. Girder BT7 contained individual stirrups at both ends. Girder BT8 contained welded wire reinforcement at both ends. In all three girders, design yield strengths for the individual stirrups and welded wire reinforcement were 60 ksi (414 MPa) and 70 ksi (483 MPa), respectively.

The concrete mix used for the girders had specified compressive strengths of 7000 psi (48 MPa) at release of strands and 10,000 psi (69 MPa) at 56 days. After fabrication at a plant in Mississippi, the three girders were shipped by road to Construction Technology Laboratories, Inc. in Skokie, Illinois for testing. Prior to testing, an 8-in. (203-mm) thick, 10-ft (3.05-m) wide reinforced concrete deck was cast on each girder. The high performance concrete used for the deck slabs had a specified 28-day compressive strength of 4200 psi (29 MPa).

Each girder end was tested separately to evaluate static shear strength performance. Load was applied in increments to each girder end at three load points until either the strength of the girder or the safe working capacity of the testing hardware was reached. The measured shear strength of each girder end was compared to the calculated strength based on the design material properties and applicable AASHTO specifications.

As indicated in the bar chart, measured shear strengths consistently exceeded the design strengths. The reported measured strengths for the BT7-L and BT8-L ends were limited by the capacity of the loading hardware and, therefore, are less than the true shear strength. For the four tests where the true shear strength was measured, the test results indicate design provisions of both the AASHTO Standard Specifications and LRFD Bridge Design Specifications provide comparable levels of conservatism in predicting shear strength. The tests also indicate that the use of welded wire reinforcement at a design yield strength of 70 ksi (483 MPa) is an alternative to conventional deformed bars for shear reinforcement.



Comparison of design and measured shear strengths

* *See HPC Bridge Views, Issue No. 8, March/April 2000.*

BENEFITS OF CORROSION INHIBITORS IN HPC

James M. Gaidis and Arnold M. Rosenberg, Concrete Corrosion Inhibitors Association

Although corrosion inhibitors are considered to be relatively new materials, some inhibitors have been employed successfully for over 20 years. This article briefly explains corrosion mechanisms and how corrosion inhibitors are used to extend the life of concrete bridges.

Corrosion Mechanism

When chloride ions from deicing salts or marine environments enter concrete from the surface, they can diffuse through the concrete to the steel reinforcement. The rate of migration depends on the quality of the concrete and can be reduced through the use of high performance concrete (HPC). If the chloride salt reaches the steel reinforcement, a soluble iron complex is formed and the original protective passive iron oxide layer at the reinforcement is destroyed. This soluble complex carries iron away from the reinforcement into the concrete where it oxidizes further producing a larger volume than the original iron. This causes the concrete to crack and spall. The amount of chloride necessary to initiate corrosion is generally considered to be in the range of 0.03 to 0.07 percent by mass of concrete.

Corrosion Inhibitors

Corrosion inhibitors are various admixtures consisting of chemicals chosen to interfere with the corrosion process without affecting concrete quality. In general, the effect of an inhibitor is as follows:

1. To raise the chloride threshold at which corrosion starts,
2. To slow the rate of corrosion after it begins.

Corrosion of steel in concrete is an electrochemical process that requires an anode and a cathode. Corrosion inhibitors may operate on the anode, on the cathode, or on both. The chief anodic inhibitor in commercial use today is calcium nitrite. It acts by oxidizing ferrous ions so quickly to ferric ions that they precipitate on the steel and stifle corrosion. Salt cannot attack the ferric oxide coating.

Cathodic inhibitors are usually based on amine chemistry, and adsorb tightly to the iron oxide film, interfering with the corrosion process. Mixed inhibitors operate at both the anode and cathode. Mineral or chemical admixtures that decrease the permeability of concrete against chloride or oxygen penetration also help reduce corrosion. Some of the newer inhibitors also decrease the permeability of concrete to chloride penetration. When corrosion inhibitors are used, the threshold level for initiation of corrosion is increased to three to nine times the threshold level without an inhibitor, thereby extending the time before corrosion begins.

Mix Proportions

Corrosion inhibitors are supplied as liquids and are added separately to the concrete mix in the same manner as other chemical admixtures. The quantity of corrosion inhibitor is different for each brand but generally ranges from 1 to 6 gal/cu yd (5 to 30 L/cu m). For each product, the level of corrosion protection increases with the dosage. With some corrosion inhibitors, it is necessary to adjust the quantity of mix water to compensate for water in the inhibitor. The manufacturer should be consulted to determine if adjustments are necessary.

Corrosion inhibitors are compatible with all cements and other admixtures from the same manufacturer. Since the use of a corrosion inhibitor may influence the effectiveness of other admixtures, trial mixes should be made prior to construction to verify that the proposed mix will conform with project requirements. Since some inhibitors may accelerate concrete setting times, it is important to check for slump retention and adequate setting time. Some inhibitors may require more or less air-entraining admixture, so it is wise to check with the manufacturer.

Concrete Properties

Finishing and curing concrete containing a corrosion inhibitor is usually the same as that for conventional concrete. In some cases, corrosion inhibitors significantly increase the strength at 28 days, others may slightly reduce the strength. The manufacturer's literature should be consulted prior to using an inhibitor to ensure the optimum concrete mix.

Service Life and Life Cycle Cost

The benefits of using a corrosion inhibitor can be evaluated using software known as Life-365. Life-365 is a model that computes the chloride threshold value for a given addition rate of inhibitor. Using Fick's law and the mix proportions, Life 365 predicts the time before onset of corrosion; this is the initiation period. Corrosion then takes place for a time called the propagation period, which is taken as six years, but can be changed by the user. The initiation period plus the propagation period is the service life or the time to first repair.

The model estimates costs over the whole life cycle of the project. Initial construction costs include costs of the concrete, corrosion inhibitor, steel reinforcement, and any surface protection such as a membrane or sealer. For one scenario, with a design life of 75 years, initial construction cost for the reference concrete was $3.05/sq ft ($32.84/sq m) of deck. The initial cost for HPC with an inhibitor at a dosage rate of 4 gal/cu yd (20 L/cu m) was $3.52/sq ft ($37.84/sq m). For about 18 years, the reference concrete is least expensive, after which costly repairs are needed. After 50 years without repairs, the total cost of the concrete deck with the corrosion inhibitor is only half the cost of the deck with the reference concrete.

The FHWA has long recommended a multi-pronged strategy in which several protection strategies are employed to reduce corrosion. Water reduction, mineral admixtures, adequate cover, and a corrosion inhibitor are all part of a total plan—together, these modifications add up to high performance concrete.

Further Information

Further information on the use of corrosion inhibitors in high performance concrete can be obtained from the CCIA at e-mail: info@corrosioninhibitors.org or web site: www.corrosioninhibitors.org.

Editor's Note

This article is the sixth in a series that addresses the benefits of specific materials used in HPC. The benefits of silica fume, lightweight aggregate, different cements, slag cement, and fly ash were discussed in previous issues of HPC Bridge Views.

Question

Should high-strength concrete be used for cast-in-place concrete bridge decks?

Answer No.1

by Kevin R. Pruski, Texas Department of Transportation

Generally, concrete bridge decks do not need the higher design strengths offered by high-strength concrete. Common construction problems for bridge decks can be exacerbated by requiring it unnecessarily.

Cracking caused by shrinkage is a concern for any bridge deck. Cast-in-place bridge decks are particularly vulnerable to plastic shrinkage cracking because of high evaporation rates from their large surface areas. Drying shrinkage is greater for high-strength concrete because of its higher cementitious materials content, which provides a higher percentage of paste in the concrete matrix. More paste means more shrinkage.

The current AASHTO Standard Specifications for Highway Bridges and AASHTO LRFD Bridge Design Specifications call for a minimum strength of 4000 psi (28 MPa) for concrete in bridge decks. Design strengths greater than 4000 psi (28 MPa) are rarely needed for bridge decks. Contractors typically provide considerably higher strength concrete than the design calls for to ensure that minimum contract requirements are met. A design unnecessarily requiring high-strength concrete risks even higher levels of paste, which would further increase shrinkage.

The 4000 psi (28 MPa) requirement for concrete in bridge decks is easily met by a water-cementitious materials ratio of 0.45. Lower water-cementitious materials ratios may be required to obtain low permeability. Replacing some of the cement with fly ash or ground granulated blast-furnace slag while maintaining the water-cementitious materials ratio at 0.45 produces concrete with a lower permeability but with slower early strength gain. While it may take longer to reach its specified strength, thereby prolonging the length of a project, the actual later-age strength is typically relatively higher. The addition of silica fume may be used to assist in achieving early-age strength gain for projects under tight construction schedules. Mix designs should always be developed to ensure that the constraints of each specific project are met.

Answer No.2

by Jerry L. Potter, Federal Highway Administration

High-strength concrete is generally not necessary with current bridge deck design practices and support spacings. The use of high performance concrete (HPC) for improved durability, however, generally results in concrete strengths greater than used for many current bridge deck designs. The mix proportions are controlled by the specific durability requirements, such as permeability and freeze-thaw resistance. The higher concrete strength is then a by-product.

A specified concrete strength greater than that normally achieved from HPC, when specified for durability, is ineffective for routine decks and necessitates additional construction controls. In limited situations, use of the higher concrete strengths, achieved as a by-product of the HPC use, may be cost effective. Some cost efficiency may be possible by increasing the design strength from the normal range of 4000 to 4500 psi (28 to 31 MPa) to the strengths achieved from the HPC specified for durability. However, the specified compressive strength should not exceed the expected strength from the durability requirements.

High-strength concrete should be specified for special projects that can effectively use the high compressive strength to achieve economy or other benefits. It may also be used for projects that are large enough to justify the added costs for more complex construction processes needed to successfully control and place the higher strength concrete. This would be applicable for structures with unusual framing systems and decks that require high early strengths for construction acceleration or early opening to traffic.

HPC BRIDGE CALENDAR

October 7-9, 2002
First Annual Concrete Bridge Conference, Nashville, TN. Jointly sponsored by the FHWA and NCBC. Contact NCBC at cbc@portcement.org

October 19-22, 2003
Third International Symposium on High Performance Concrete, Orlando, FL. Jointly sponsored by FHWA and PCI. Contact Paul Johal, Precast/Prestressed Concrete Institute at 312-786-0300, info@pci.org, or www.pci.org

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