ASPIRE™

THE CONCRETE BRIDGE MAGAZINE

SPRING 2013

www.aspirebridge.org

Rich Street Bridge

Columbus, Ohio

U.S. 281 BRIDGE OVER THE COLORADO RIVER
Marble Falls, Texas

I-69 TWIN BRIDGES OVER THE PATOKA RIVER
Pike-Gibson County Line, Indiana

GOLD LINE BRIDGE
Arcadia, California

DODRIDGE STREET BRIDGE
Franklin County, Ohio

Presorted Standard
U.S. Postage Paid
Lebanon Junction, KY
Permit No. 567

Photo: Archer Western Contractors.

Photo: Indiana Department of Transportation.

Photo: Metro Gold Line Foothill Extension Construction Authority.

Features

Departments

Photo: Burgess & Niple.

Advertisers Index

EDITORIAL

Photo: PCI.

Create a Lasting Separation from Your Competitor

William Nickas, *Editor-in-Chief*

Organizational excellence can mean many things in today's market. To some, it includes:

- improving customer service,
- delivering projects that exceed customer expectations, and
- building a coalition of experts to develop an innovative solution for a traditional project.

Whatever your organization's metric for excellence, the goal is the same: to create a lasting separation from your competitor. It's my belief that this lasting separation can be achieved through better communication and sound engineering.

Diversify your Team

A detailed analysis early in the project development phase can identify key components and innovative ways to meet the customer's requirements and expectations. Meeting customer expectations within the limits of sound engineering practice often creates engineering challenges. But by solving these challenges, we often find the best solutions.

Sometimes the most difficult part of solving these challenges is the process. Problem solving can create friction points between team members. Developing creative solutions to satisfy customer expectations and to solve the engineering challenges requires good communication. Understanding individual opinions, while embracing new ideas, is the basis of innovative project design and delivery. And it is exactly what our industry needs now.

One of the best ways to better understand individual opinions is through expansion of the project team. Subject matter experts in different disciplines (finance, community outreach, communications, and information technology) can often provide valuable insight that differs from that of project managers and engineers. These professionals are astute at reading audiences, understanding the undercurrents in the community, and are experts in finance and governmental strategies. They can often lend a different viewpoint because they stay above the engineering and technical details inherent in project development and design. Their ability to listen and gather critical stakeholder information can advance a project from a potential solution to *the* solution.

Standing Out

Concrete's natural robust characteristics for long service, flexibility in forming, low maintenance costs, and inherent resiliency against multi-hazard conditions result in durable, legacy bridges that help meet customer expectations and technical challenges. Advancements in material technology, which reduces construction labor requirements and increases service lives, have become a constant in today's market. And a new emphasis on more sustainable construction, which requires balancing immediate needs with environmental impacts, means that today's concrete materials continue to evolve. These new materials will be lighter, stronger, and provide a variety of new advantages and options to designers, engineers, and producers.

Over the last 20 years, the Federal Highway Administration and state departments of transportation have utilized demonstration projects to gain greater knowledge on various topics, including new concrete materials. Recently a National Cooperative Highway Research Program report captured the practices and characteristics of high-performance concrete in a synthesis titled *High Performance Concrete Specifications and Practices for Bridges* authored by Dr. Henry Russell, *ASPIRE*™'s managing technical editor. This synthesis (No. 441 Topic 43-02) and others in this Transportation Research Board program are available at http://www.trb.org/Publications/PubsNCHRPSynthesisReports.aspx

Organizational excellence, project team diversity, and material advancements are ways our industry is adapting to keep pace with the global transportation community. The *ASPIRE* team is dedicated to featuring these advancements as they relate to our industry. Keep sending in information about those great concrete bridges that highlight innovative solutions and separate us from the competition.

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Cover
The fiber reinforced grating conceals all the utilities under the deck of the Rich Street Bridge in Columbus, Ohio. Photo: Ohio Department of Transportation District 6.

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READER RESPONSE

Editor,

*I liked your message, "*Those That Show Up Help Make the Rules,*" in the Winter 2013 issue of* ASPIRE. *I absolutely agree.*

John Crigler, President
VSL
Hanover, Md.

[Editor's Response]

Thanks, John, for the note. It is a great team effort by all of us (association staff and volunteers). Association staff work hard to get creditable data into the hands of decision makers, but the volunteer committees have to carry the biggest load of creating the knowledge. And thus, "those that show up help make the rules."

Editor,

Were long-term dead load deflections a consideration during the "Evaluation of Common Design Policies for Precast, Prestressed Concrete I-Girder Bridges" described in the article in the Winter 2013 issue of ASPIRE™*? If so, what criteria were used? If not, why not?*

J. Doughty
Parsons Brinkerhoff
Raleigh, N.C.

[Author's Response]

Long-term dead load deflections were not considered in the analyses. The study was intended only to identify the relative sensitivity of three selected design policies over a wide range of span lengths, girder depths, girder spacings, etc. In actual design, some of the design outcomes used in the study may be disqualified for other reasons. However, in the authors' opinion, such disqualifications would not change the basic conclusions with respect to the relative sensitivity of the selected design policies.

Richard Brice and Bijan Khaleghi
Washington State Department of Transportation
Olympia, Wash.

Stephen J. Seguirant
Concrete Technology Corp.
Tacoma, Wash.

Editor,

The Perspective article regarding design policies for I-Girder bridges is very enlightening. Although no specific cost data are included, the implication is that substantial additional construction cost is incurred when using the more conservative standards. However, I expect that the actual cost differential is quite reasonable, especially when all life-cycle costs are included. The cost story would make a good follow-up article.

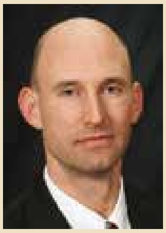
Stewart Gloyd
Olympia, Wash.

[Author's Response]

Cost analyses were beyond the scope of the study performed, and would take significant effort to assemble. However, the authors agree that the data in the article should not be extrapolated to imply substantial cost increases due to the use of more conservative design policies. WSDOT employs all three conservative policies in its standard design practice, but still finds that prestressed concrete girder bridges are the most economical, both from a first cost and life-cycle perspective.

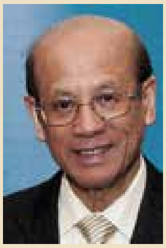
Richard Brice, Bijan Khaleghi, and Stephen J. Seguirant

CONTRIBUTING AUTHORS



Dr. Benjamin A. Graybeal is a research structural engineer at the Federal Highway Administration's Turner-Fairbank Highway Research Center in McLean, Va., where he manages the FHWA ultra high-performance concrete (UHPC) research program.

Emily Lorenz is an independent consultant in the areas of life cycle assessment; environmental product declarations; product category rules; and sustainability rating systems, standards, and codes.



Myint Lwin is director of the FHWA Office of Bridge Technology in Washington, D.C. He is responsible for the National Highway Bridge Program direction, policy, and guidance, including bridge technology development, deployment and education, and the National Bridge Inventory and Inspection Standards.

Dennis R. Mertz is professor of civil engineering at the University of Delaware. Formerly with Modjeski and Masters Inc. when the *LRFD Specifications* were first written, he has continued to be actively involved in their development.

MANAGING TECHNICAL EDITOR

Dr. Henry G. Russell is an engineering consultant, who has been involved with the applications of concrete in bridges for over 35 years and has published many papers on the applications of high-performance concrete.

Photo: Ted Lacey Photography.

CONCRETE CALENDAR 2013/2014

For links to websites, email addresses, or telephone numbers for these events, go to www.aspirebridge.org and select "EVENTS."

April 25-28, 2013
PCI Committee Days and Membership Conference
Hyatt Magnificent Mile
Chicago, Ill.

May 5-7, 2013
PTI Technical Conference & Exhibition
Hilton Scottsdale Resort & Villas
Scottsdale, Ariz.

May 12-15, 2013
Fifth North American Conference on Design and Use of Self-Consolidating Concrete
Westin Michigan Avenue
Chicago, Ill.

May 20-22, 2013
Seventh National Seismic Conference on Bridges & Highways
Oakland Marriott City Center
Oakland, Calif.

June 2-5, 2013
International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, Pa.

June 16-20, 2013
2013 AASHTO Subcommittee on Bridges and Structures Meeting
Portland Marriott Downtown Waterfront
Portland, Ore.

August 29-31, 2013
PCI Quality Control and Assurance Schools Levels I and II
Four Points Sheraton-O'Hare
Chicago, Ill.

September 4-6, 2013
Western Bridge Engineers' Seminar
Hyatt Regency
Bellevue, Wash.

September 21-25, 2013
PCI Annual Convention and Exhibition and National Bridge Conference
Gaylord Texan Resort & Convention Center
Grapevine, Tex.

October 19, 2013
ASA Fall 2013 Committee Meetings
Hyatt Regency & Phoenix Convention Center
Phoenix, Ariz.

October 20-24, 2013
ACI Fall Convention
Hyatt Regency & Phoenix Convention Center
Phoenix, Ariz.

October 28-29, 2013
ASBI 25th Annual Convention
Portland Marriott Downtown Waterfront
Portland, Ore.

January 12-16, 2014
93rd Annual Meeting Transportation Research Board
Marriott Wardman Park, Omni Shoreman, and Hilton Washington
Washington, D.C.

January 20-24, 2014
World of Concrete 2014
Las Vegas Convention Center
Las Vegas, Nev.

March 23-27, 2014
ACI Spring Convention
Grand Sierra Resort
Reno, Nev.

September 6-9, 2014
PCI Annual Convention and Exhibition and National Bridge Conference
Gaylord National Resort & Convention Center
Washington, D.C.

Correction

Winter 2013
On page 29 of the Winter issue, the prime subcontractor and major subcontractor were inadvertently left off the profile listing for the South Norfolk Jordan Bridge. The prime subcontractor was The Lane Construction Corporation, Cheshire, Conn., and the major subcontractor was McLean Contracting Company, Chesapeake, Va.

We regret these errors. An updated PDF of this article has been uploaded to the *ASPIRE* website at www.aspirebridge.org.

Relationships Spur **Success** for Burgess & Niple

High percentage of repeat clients and strong communication with stakeholders bring engineers many high-profile bridge projects

by Craig A. Shutt

Having celebrated its 100th anniversary in 2012, Burgess & Niple (B&N) takes pride in the many projects its bridge division has created through those years. Its website understates "We're over the hump and long past the uncertainties faced by start-ups." That long-term success has resulted from strong client relationships and an eagerness to tackle complex projects, especially those that require some aesthetic panache.

"We emphasize our ability to build relationships with clients and local communities, giving them a better experience than they can get from other firms," says Tom Bolte, bridge group director for the Columbus, Ohio-based company. "We focus on clear communication throughout the project and on working as a partner. We strive to avoid misunderstandings at all costs."

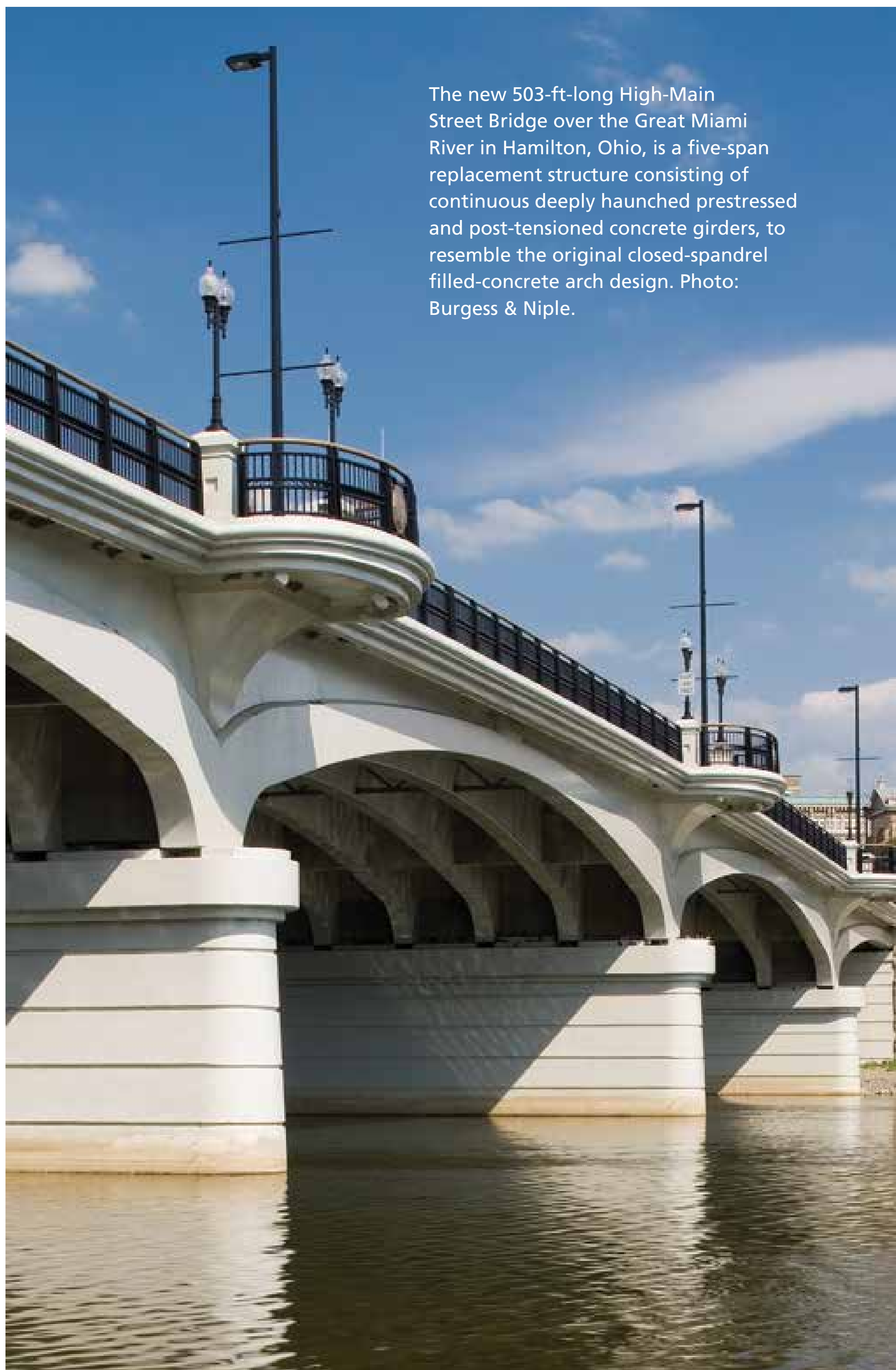
Its success in that regard can be judged by the nearly 80% of its current business derived from repeat clients. "Our experience and resources are a big part of the equation," he says. "But another key element is the confidence our clients have in us. Our business ethics, standards for quality, and concern for the communities we support are a vital part of who we are and what we offer."

Much of B&N's work has focused on complex bridges with difficult challenges, from tight sites to traffic disruptions and multiple connections. The firm also has gained recognition for its many bridge designs where aesthetics are a critical aspect of the project.

Aesthetic Needs Growing

"We design a lot of bridges that are aesthetically pleasing and become notable," Bolte says. "We are known for creating signature bridges for communities, even though we don't have a singular style." Aesthetics

'We are known for creating signature bridges for communities, even though we don't have a singular style.'



The new 503-ft-long High-Main Street Bridge over the Great Miami River in Hamilton, Ohio, is a five-span replacement structure consisting of continuous deeply haunched prestressed and post-tensioned concrete girders, to resemble the original closed-spandrel filled-concrete arch design. Photo: Burgess & Niple.

are becoming more significant for many owners, he notes. "Aesthetics are definitely an element in even our freeway bridges today," he says, noting that many departments of transportation (DOTs) have developed aesthetics manuals to ensure a design style is followed and to encourage creativity.

"Bridges often are at the center of a community," explains John Shanks, director of bridge and structure design in the Columbus office of B&N. "Sometimes, we replace historic bridges or distinctive designs that are functionally obsolete or deteriorated beyond repair and that the community doesn't want to lose."

A good example is the High-Main Street Bridge over the Great Miami River in Hamilton, Ohio. The five-span bridge features 95-ft-long precast concrete girders with deep haunches spliced together to create a historic look. Aesthetic details include balcony overlooks at piers, decorative concrete forming, ornamental crash-resistant vehicular/bicycle railing, landscaped pedestrian plazas, sidewalk brick patterning, terraced bank grading, memorial plaques, and architectural lighting.

"Spliced girders can provide designers with greater flexibility to customize the shape of the girders to meet a wider variety of aesthetic needs," Shanks says. In this case, the bridge was eligible for placement on the National Register of Historic Places and was located in the Hamilton Civic Center Historic District.

On a smaller scale, aesthetics also were a key part of the Emerald Parkway Bridge over North Fork Indian Run in Dublin, Ohio. The project comprised 4000 ft of new, separated four-lane parkway; 3000 ft of roadway widening; and twin, 95-ft-long, single-span concrete box beam bridges. The bridges included decorative arch fascia panels, ashlar limestone facing on the abutments, and aesthetic concrete railings.

The use of fascia panels is gaining popularity, Bolte notes. "Some engineers are purists and don't want to use a façade, even if it's functional. But it's impractical today to be so rigid. We don't want an obvious façade—we're sensitive to that concern—but we do want to provide an aesthetic appearance that is pleasing, distinct, and in harmony with its natural and/or civic setting."

B&N used the concept of a functional fascia treatment on the Fifth Street Bridge over the Great Miami River in Dayton, Ohio. Designers specified constant depth, prestressed concrete, interior girders and haunched, precast post-tensioned, exterior girders to invoke the appearance of the original seven-span, 620-ft-long, closed-spandrel arch bridge.

The Fifth Street Bridge in Dayton, Ohio, used haunched exterior girders to invoke the appearance of the original closed spandrel arch bridge. Photo: Henry G. Russell Inc.

The Emerald Parkway over North Fork Indian Run in Dublin, Ohio, consists of twin, 95-ft-long single-span, concrete box-beam bridges. Detailing included decorative precast concrete arch fascia panels, ashlar limestone facing on abutments, and aesthetic concrete railings. Photo: Burgess & Niple.

"There was no underside view to the bridge, which allowed us to achieve a dramatic look and keep it economical," Bolte explains. "Using a combination of girders provided a good blend of economy and aesthetics. As these ideas begin to gain notice, I expect we'll see more façade treatments of all types being used." He also expects to see more use of color additives to heighten aesthetics. "We see additives being used on buildings, but not very often for bridges."

Concrete Advantages

The desire for such aesthetic treatments often leads the firm, and their clients, to using concrete, even to replace existing steel bridges. "When owners want something unique to make the community stand out, it's often easier to achieve that with concrete," says Bolte. "Concrete aesthetics turn out very well due to the ornamental designs we can achieve with railings, posts, and beam designs."

Today, B&N designs about half of its bridges using concrete, with this number continually increasing. "It's hard not to notice the increased interest, especially in states such as Ohio," says Bolte. Ohio is moving toward concrete bridges partly due to ODOT's receptiveness of value-engineering, he notes. "Contractors come into design-bid-build situations and suggest alternatives more often today, and often those involve changing steel bridges to concrete."

As designers, Shanks notes, "We consider all ideas when deciding on the best design approach. But often, economics make concrete designs preferable." Those economics frequently are driven by the speed with which concrete can be used to construct the bridge, he notes, especially with possible delivery delays for steel superstructures.

Owners also are taking a closer look at incorporating concrete designs because of decreased life-cycle costs, he says. "There is a stronger demand among owners for concrete bridges than in the past due to their decreased maintenance issues. With the advent of high-performance, low permeability concrete, the durability of concrete has been enhanced. Also, options and methods for performing maintenance repairs on concrete have improved, allowing concrete to hold its own against steel in that regard."

Concrete durability has appeal for owners.

Concrete's durability has appeal for owners. "States that use a lot of deicing chemicals need high durability, and they're well aware of the options in concrete that can create durability," Shanks adds.

Speed Matters

Most clients also are looking to build faster to reduce user costs for disruptions. "Clients are embracing the Federal Highway Administration's 'Every Day Counts' program, and we're seeing this trend at industry-related conferences," says Shanks. "We're looking at new approaches for using precast concrete elements, which can be prefabricated and then assembled on site, to speed construction."

An example of those approaches can be seen in the Rich Street Bridge over the Scioto River in Columbus. B&N led a team that designed a five-span, three-lane, precast concrete, post-tensioned, rib-arch bridge, using lightweight, low-permeability concrete. The context-sensitive design blends with existing bridges on the river corridor to create a "family" of arch-style bridges.

The 568-ft-long Rich Street Bridge in Columbus, Ohio, features precast, post-tensioned lightweight concrete rib arches, with reinforced concrete piers and abutments. Photo: Burgess & Niple.

B&N created a three-dimensional structural model of the design using structural analysis software. The model included multiple stages of construction, incorporated the multiphased post-tensioning procedure, and considered the effects of time-dependent behavior of the concrete. This information proved especially valuable when, during the design process, the team was asked to shorten the construction schedule to complete the project in time for the city's bicentennial celebration in 2012.

Speed also was a key factor in the design of the Holden Bridge in Logan County, W.Va., for the West Virginia Department of Highways. Part of the final stages of the Appalachian Highway, the 1200-ft-long, precast, pre-tensioned and post-tensioned concrete, bulb-tee spliced-girder bridge was designed as a concrete alternative for the project. It ultimately was selected as the most cost-effective design.

In part, the design was chosen for the speed achieved with techniques such as providing 220-ft-long spans by suspending 114-ft-long, girders between the pier girders, splicing them together, and post-tensioning them to create a 1233-ft-long continuous structure on a curved alignment. Contractors also used jump forms and post-tensioned bracing to speed construction and eliminate the need for scaffolding. High-strength, sand-lightweight concrete allowed span lengths to be maximized while achieving a minimum weight.

"Lightweight concrete helps with components that need to be transported to difficult sites, and additionally, where crane replacement locations are constrained," says Bolte. "It can allow us to solve challenges by creating longer spans than we could provide otherwise."

The 1200-ft-long Holden Bridge in Logan County, W. Va., part of the Appalachian Highway, is a pretensioned and post-tensioned, sand-lightweight concrete, bulb-tee girder bridge. Photo: Burgess & Niple.

Extending Bridge Life

B&N is finding that one way to decrease time lost to closures is to keep the existing bridge open as long as possible during construction, which is a typical practice when rehabilitating existing structures. Owners too, are looking for new techniques to extend bridges' service lives rather than start new, both for time and budget savings.

Preparing bridge rehabilitation construction plans that effectively extend the service life of the bridge requires in-depth knowledge of how various bridge materials and details perform. Within its inspection division, B&N has a full-time staff of 20 bridge inspectors (all bridge engineers) and integrates bridge designers into its bridge inspection teams, providing more insight into how bridges have been built in the past, what worked well, and what didn't.

"We've pioneered a number of inspection-access techniques that allow us to inspect bridges more accurately and efficiently to determine if it's sensible to save them," says Bolte. "With the volume of traffic on bridges today that wasn't anticipated when they were built, and the requirement to keep bridges in service as long as possible, we look at saving the structure whenever possible. But there are challenges with older structures, so repairing or replacing isn't always an easy choice."

The Future

The growing requirements from owners and the increased input from community leaders have led to more communication among stakeholders and more ways to gather input from local groups. "There's certainly more public involvement in the design process today, and people expect to be asked for their feedback today," Bolte says. "Stakeholders have different ways they like to communicate about a project. Each client wants to handle that input in different ways, based on their own needs, and we adapt to their requirements on a case-by-case basis."

Also evolving are project delivery methods, with more emphasis on design-build delivery. "That's definitely increasing, due to the speed that can be achieved, as well as the economics and innovation," Bolte says. "It affects with whom we need to have relationships with for our own success. We've typically worked with DOTs as our clients, but more often today, it's the contractor who is putting together the team. That means we have to ramp up our efforts in those areas."

Creating partnerships with new clients will play well to the firm's commitment for clear communication and working closely with clients in a mutually beneficial way. "We need to continue getting to know the contractors better and collaborating with them to mitigate risk as the project proceeds," he says. "Our intent is to seek out design-build work in realms where we're already working. But I believe the quality of work we do and our communication with clients, especially in areas such as documentation and avoiding change orders, make it easy for us to adapt."

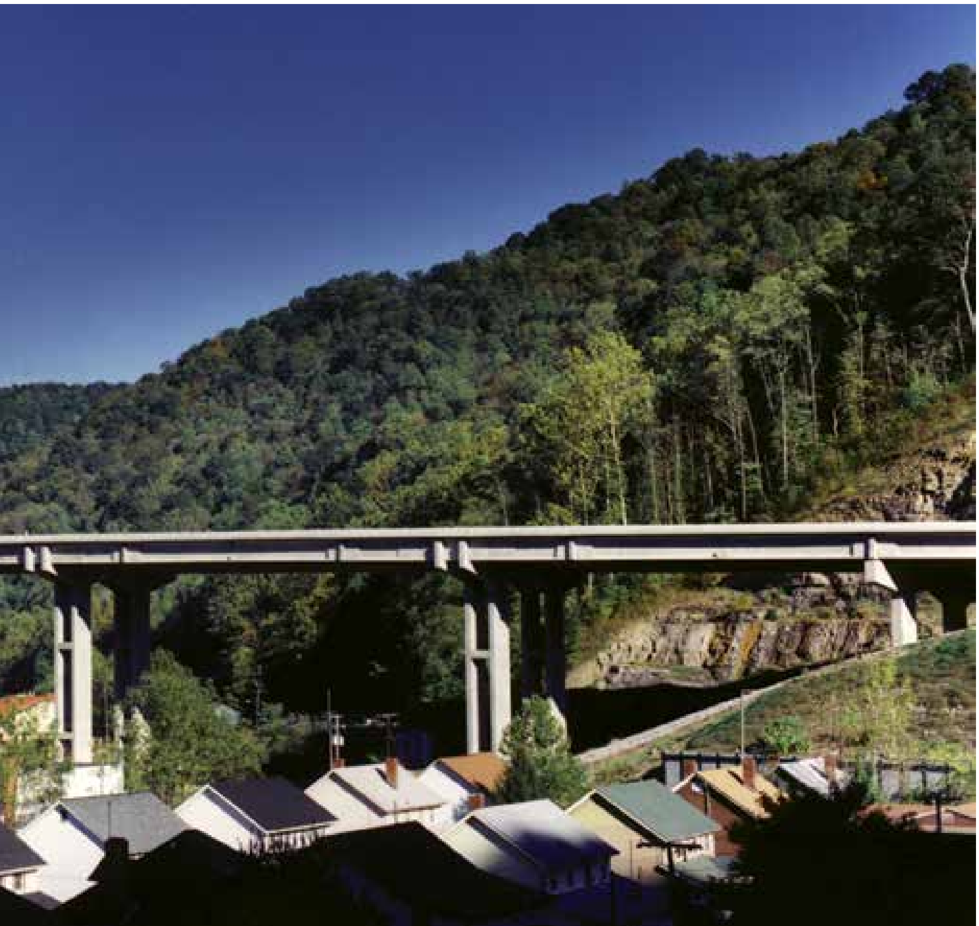
For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

100 Years of Design Excellence

Burgess & Niple (B&N) was established in 1912 in Columbus, Ohio, by Philip Burgess and Chester Niple to provide modern waste-treatment practices to Ohio. It added transportation design work in the 1950s. Today, the firm provides civil engineering services of all types to government, military, educational, and private enterprises. That work includes architecture, environmental services, land development, and utility infrastructure in addition to transportation services.

Although it operates 19 offices nationally, bridge design work is focused in seven offices around the country. The firm has performed design plan review for more than 3000 bridges for departments of transportation in Ohio and Indiana and is ranked 138th out of 500 design firms by *ENR*. It also ranked 19th on the 2012 list of "Go-To Firms" by *Roads & Bridges* magazine.

For more detail on B&N projects, see the Fall 2007 (High-Main Street Bridge) and the Fall 2012 (Rich Street Bridge) issues of *ASPIRE*.



PROJECT

U.S. 281 BRIDGE
OVER THE COLORADO RIVER

Tailor-made work approach saves time, money at Marble Falls crossing

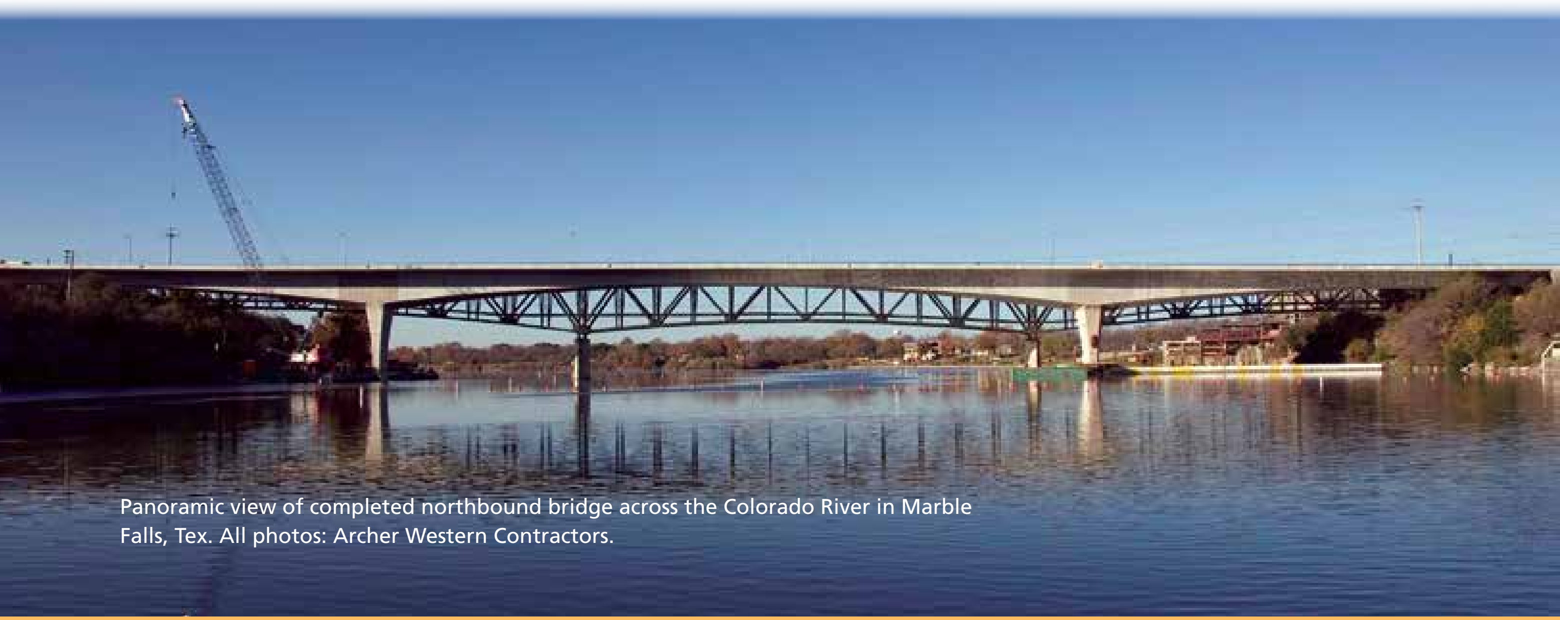
by Robert Alonso, FINLEY Engineering Group

With a little creativity, teamwork, and technical know-how, a contractor and their construction engineer were able to develop an alternative approach to the Marble Falls Bridge replacement project that won the contract and ultimately saved construction costs and time.

Started in December 2010, the $28.65 million demolition and bridge replacement project is already ahead of its expected four-year construction schedule. The first of two new segmental bridges carrying U.S. 281 over the Colorado River in Marble Falls, Tex., opened to traffic in December 2012. The twin bridges will carry two lanes each to replace a functionally obsolete steel truss bridge that was built in 1936. Designed by the Texas Department of Transportation's (TxDOT's) bridge division, the crossings include 6-ft-wide sidewalks and a fully lighted substructure and surface lighting, creating a beautiful backdrop to downtown Marble Falls.

U.S. 281 is a major north-south highway from the Canadian border to the Mexico border, and serves as an important evacuation route for the area. The 958-ft-long, straight bridge, on a vertical grade of 1.3%, consists of two parallel, three-span, variable-depth, single cell, cast-in-place, concrete segmental box girder superstructures with span lengths of 274, 410, and 274 ft.

There were several factors leading to the selection of a segmental design:



Panoramic view of completed northbound bridge across the Colorado River in Marble Falls, Tex. All photos: Archer Western Contractors.

profile

U.S. 281 BRIDGE OVER THE COLORADO RIVER / MARBLE FALLS, TEX.

BRIDGE DESIGN ENGINEER: Texas Department of Transportation, Austin, Tex.

ALTERNATE SUPERSTRUCTURE DESIGN AND CONSTRUCTION ENGINEER: FINLEY Engineering Group Inc., Tallahassee, Fla.

CONSTRUCTION ENGINEERING INSPECTION: Texas Department of Transportation, Austin, Tex.

PRIME CONTRACTOR: Archer Western Contractors, Atlanta, Ga.

CONCRETE SUPPLIER: Ingram Readimix Inc., New Braunfels, Tex.

POST-TENSIONING CONTRACTOR, FORM TRAVELER, AND POST-TENSIONING MATERIALS SUPPLIER: VSL, Fort Worth, Tex.

- The nearest river crossing detour is located more than 30 miles north.
- Limited right-of-way restricted an alignment change.
- Active recreational lake traffic in the area relies on tourists.
- Local residents have high regard for the look of the old truss bridge.

Bridge Information

There are 24 concrete segments cantilevering from each pier making a total of 48 segments per structure. The variable-depth segments have a unique tapered boat hull design in the bottom slab, which is an aesthetic treatment that matches the community's focus on recreational boat racing.

The segmental boxes have a depth that ranges from 23 ft at the interior piers to 9 ft 5 in. at the end spans, with a variable superelevation up to 5.5%. The bridge deck has a width of 47 ft, the thickness of the webs is 1 ft 6 in., and the bottom slab varies in thickness from 1 ft 10 in. to 4 ft 10 in.

Creative Approach

The contractor offered TxDOT a nearly $2 million cost savings under the construction estimate by proposing means and methods that aligned more efficiently with the contractor's crews and equipment.

"We knew we were very well-equipped and capable for this project," says Eric Hiemke, project manager with Archer Western Contractors, "but the means and methods outlined in the request for proposal (RFP) made it time intensive and cost prohibitive for our team. We had ideas on other ways to get the job done, but needed a bridge construction expert to confirm our thinking and prove that the ideas were safe, sound, and effective."

Working together, the engineer-contractor team developed an alternative design and the means and methods that not only built on the contractor's strengths, but also shortened the construction schedule and reduced the amount of falsework and number of temporary supports. The initial concept of the alternative approach was presented to TxDOT in December 2010 and the final design approved just two months later.

Working together, the engineer-contractor team developed an alternative design and the means and methods that not only built on the contractor's strengths, but also shortened the construction schedule and reduced the amount of falsework and number of temporary supports.

"TxDOT includes three options in our segmental bridge specification for construction alternates that the contractor can propose for our consideration. The allowable alternates are post-tensioning layouts, segment lengths, and erection methods. So when the contractor and their consultant approached us with their proposed changes, we were happy to work with them to make it happen," said Amy Smith, design engineer with the TxDOT bridge division.

Pier table constructed on falsework.

Partial cantilever with temporary stability support to the left of the pier.

The major changes were to revise the pier table design, segment layout, and post-tensioning specifications. While the original design called for a balanced pier table, the new design called for an unbalanced design. The innovative approach required shorter pier tables, and, therefore, less falsework. The revised segment layout allowed for only two temporary supports during construction, as opposed to the four required with balanced pier tables. This reduced the construction schedule by approximately 12 weeks.

The transverse and longitudinal post-tensioning were also modified. The

TEXAS DEPARTMENT OF TRANSPORTATION, OWNER

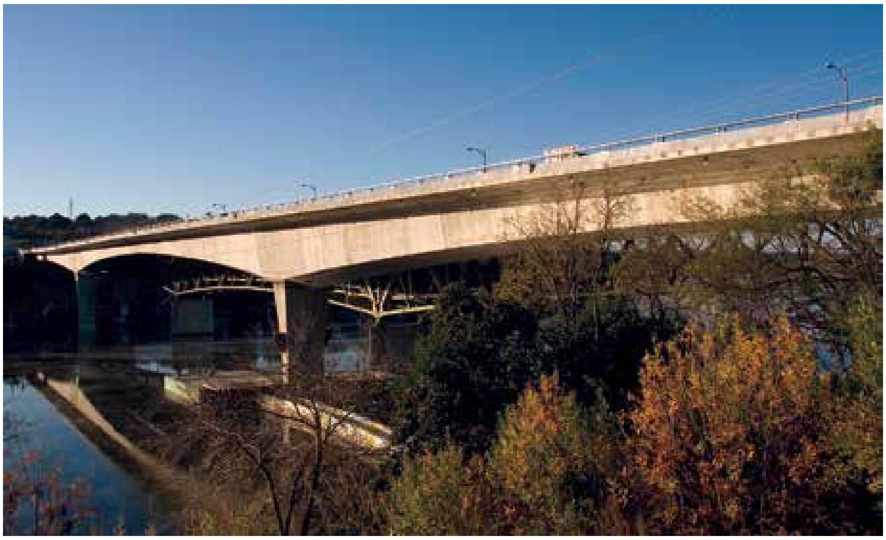
ROADWAY AND HYDRAULIC DESIGN: Jacobs Engineering Group Inc., Pasadena, Calif.

OTHER MATERIAL SUPPLIERS: Formwork–DOKA USA, Little Ferry, N.J.; Bearings–Dynamic Rubber, Athens, Tex.; Expansion Joints–CMC Capital City Steel, Buda, Tex.; Drilling–W.W. Foundation Drilling, Houston, Tex.; and Prepackaged grout–BASF, Houston, Tex.

BRIDGE DESCRIPTION: A 958-ft-long, straight bridge on a vertical grade of 1.3%, consisting of a three-span (274, 410, and 274 ft), single-cell, variable-depth, cast-in-place, concrete segmental box girder superstructure with a 47-ft-wide deck

STRUCTURAL COMPONENTS: 48 variable-depth, cast-in-place concrete segments; two concrete piers with flared columns and footings; and precast concrete footing box-forms

BRIDGE CONSTRUCTION COST: $28.65 million



Completed northbound bridge.

RFP called for three-strand transverse tendons at 2 ft 1 in. spacing. The alternative design utilized four-strand tendons at 2 ft 9½ in. spacing. This modification reduced the number of ducts, heads, grouting operations, and caps. The original longitudinal post-tensioning specified fifteen 0.6-in.-diameter strand tendons, while the alternative design outlined a combination of nineteen and twelve 0.6-in.-diameter strand tendons.

Although reducing the length of each segment required more segments, the use of the form travelers required less labor-intensive falsework. The original design called for 16-ft-long typical segments, 16-ft-long closures, 60-ft-long pier tables, and 77-ft 4-in.-long end segments. The alternative design used 14-ft-long starter segments, 16-ft-long typical segments, 10-ft-long closures, 36-ft-long pier tables, and 55-ft-long cast-in-place concrete on falsework end-span segments. The specified concrete compressive strength was 4 ksi at 24 hours. The design strength for the superstructure was 6 ksi.

Knowing that two form travelers were becoming available from another job-site just at the time the team would need them for the project saved on costs and schedule. Fabricating form travelers would have cost approximately $750,000 each and added several months to the schedule.

Aesthetics, Drawings, and Controls

For this project, the TxDOT wanted a minimal footprint in the water to alleviate boat collisions and to deter vandals from climbing on the piers. A flared column design with a seamless transition between the pier and pier table was chosen. A traditional footing was not used. The column base, which provided the connection between the drilled shafts and column, was 6-ft-deep, with the initial 3 ft below the normal water level. A precast concrete lost-form design allowed concrete for the entire column to be placed in dry conditions.

A time-dependent, staged analysis of the structure was conducted to calculate stresses and anticipated deflections during construction so that adjustments could be made in the field if necessary.

A detailed construction manual, which included the sequence of activities and detailed descriptions, was provided to the contractor. The geometry control manual gave an introduction to the construction method, guidance on typical methods based on experience with similar type bridges, and an overview about camber theory.

Geometry control software allowed the contractor to record actual camber measurements during construction so that modifications could be made immediately, if needed. Stringent control of geometry and successive correction of minor casting deviations have been required to ensure that the geometry of the bridge was maintained as each segment was added. The construction engineer and contractor's surveyor coordinated almost daily to ensure the geometry of the bridge was matching that predicted in the analysis and to make minor adjustments as necessary.

Almost any construction project can benefit from looking at ways to improve the means and methods to match the strengths of the contractor and the materials and equipment that are readily available. Sometimes, as with the Marble Falls Bridge, additional design, cost, and schedule efficiencies can be uncovered.

'TxDOT looks to balance design, function, operations, maintenance, and most importantly, safety, while still providing the same product or better.'

"In any new project, including this signature bridge for Marble Falls, TxDOT looks to balance design, function, operations, maintenance, and most importantly, safety, while still providing the same product or better," said Howard Lyons, TxDOT area engineer. "The public was very sensitive to the aesthetics of this bridge, since the lake is also used for recreation. The contractor put together a great team and the alternative concepts developed by the contractor and their engineering consultant helped to meet the expectations of TxDOT and the public."

Robert Alonso is senior bridge engineer and Orlando office manager for FINLEY Engineering Group, and project manager for the alternative segment design and construction engineering.

For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

PROJECT

I-69 Twin Bridges over the Patoka River

Many challenges overcome for longest bridge on longest new section of interstate

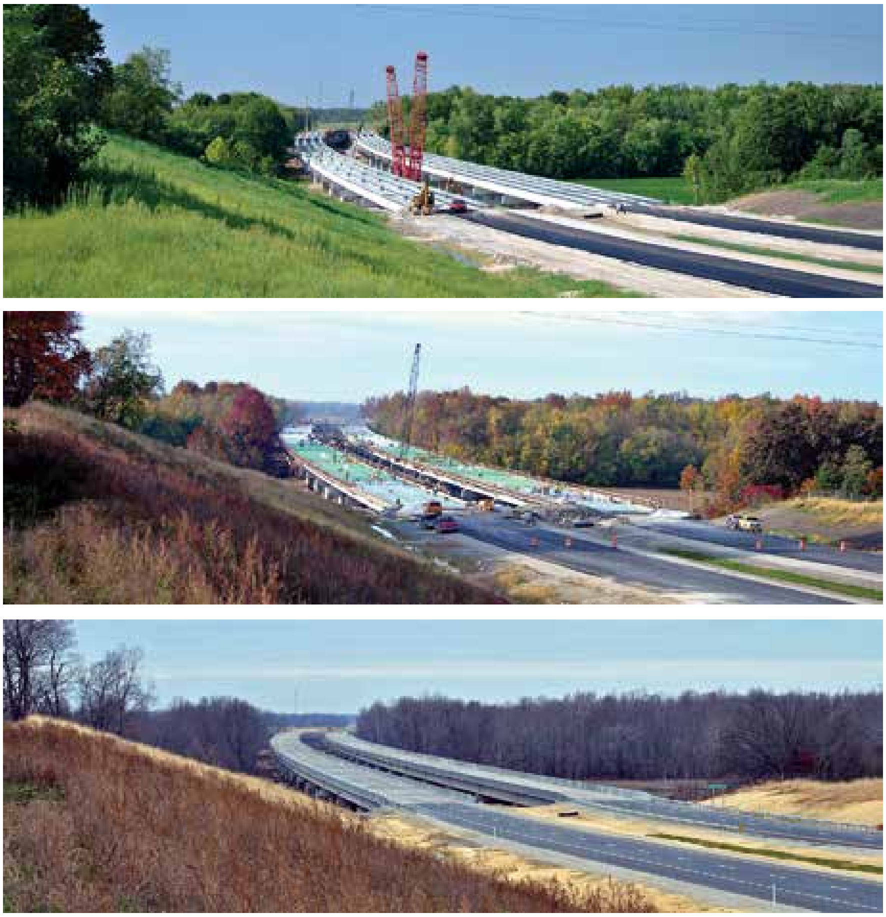
by Samuel Sarvis, Indiana Department of Transportation

Building the longest bridge on the nation's longest continuous section of new interstate highway in an environmentally sensitive area, all on an accelerated schedule, posed a special set of challenges. Add in variable rock depth in a seismic zone and months of sustained flooding, among other construction challenges, and the Interstate 69 (I-69) Twin Bridges over the Patoka River has proven a unique project.

The new stretch of I-69 between Indianapolis and Evansville, Ind., is widely regarded as a key component to the future economic vitality of southwestern Indiana, and will connect an entire region with improved access to jobs, education, and healthcare. A vision discussed for decades culminated in the 2003 Tier 1 Final Environmental Impact Statement, which was approved by the Federal Highway Administration with a 2004 Record of Decision.

Environmental, Historic Context

As part of the project's environmental commitments, the Indiana Department of Transportation (INDOT) agreed to span the entire 4400-ft-wide floodplain at the Patoka River National Wildlife Refuge and Management Area. At nearly a mile long, the bridge would be unique outside of coastal areas or navigable river crossings.



As the seasons changed, so too did the I-69 Bridges over the Patoka River floodplain as shown from the same elevated position in late August, mid-October and late November of 2012. Photos: Bernardin Lochmueller & Associates.

profile

I-69 TWIN BRIDGES OVER THE PATOKA RIVER / PIKE-GIBSON COUNTY LINE, IND.

BRIDGE DESIGN ENGINEER: Janssen & Spaans Engineering Inc., Indianapolis, Ind.

OTHER CONSULTANTS: Parsons Brinckerhoff, Indianapolis, Ind.

PRIME CONTRACTOR: Kokosing Construction Company, Columbus, Ohio

CONCRETE SUPPLIER: Irving Materials Inc., Petersburg and Fort Branch, Ind.

PRECASTER: Prestress Services Industries LLC, Lexington, Ky., a PCI-certified producer

The wildlife refuge encompasses wetlands and forest along 30 miles of the Patoka River in Pike and Gibson Counties in southwestern Indiana. The 6600-acre refuge preserves bottomland hardwood forests and is home to 380 wildlife species, including a large nesting colony for the Interior Least Tern. In addition, the bridge passes through the Patoka Bridges Historic District, which is listed in the National Register of Historic Places.

Numerous steps were taken by the project team to preserve environmental and historic resources and mitigate any impacts. Project impacts to wetlands and upland forests were mitigated above the required ratio in part by purchasing land along the bridge, which became a part of the efforts to expand the refuge. INDOT also committed matching funds for rehabilitation of historic Pike County Bridges Nos. 246 and 81, and to provide a visual buffer of trees.

From the Ground Up

In 2009, former Indiana Governor Mitch Daniels accelerated construction for 67 miles of I-69, taking advantage of recession construction prices with funding from the 2006 lease of the Indiana Toll Road. INDOT let a design-build contract for the I-69 Twin Bridges over the Patoka River in October 2010.

In an effort to minimize impacts to the wildlife refuge, designers eschewed the normal foundations for the 118 piers in favor of two drilled shafts per pier. The pier caps were 40-ft-wide by 5-ft 9-in.-thick by 4-ft 6-in.-tall supported on two 4-ft 6-in.-diameter round columns that were continuous into 6- to 7-ft-diameter drilled shafts. None of the piers, which ranged in height from 15 to 19 ft above ground, were built within the river itself, fully eliminating the need for cofferdams. Geotechnical and construction crews discovered that the soft soils that line the flood plain range in depth from 45 to 80 ft. The depth of the drilled shafts ranged from approximately 60 to 100 ft.

"Along that length there's great variation in what we found, even with the northbound and southbound bridges right next to each other," said Jared Spaans of Janssen & Spaans Engineering.

During construction, the contractor was permitted to build a causeway of stone to carry construction equipment across the river. The water flow was channeled through large metal pipes. However, sustained floods from November 2011 to February 2012 suspended construction and geotechnical surveys for the bridge, which was scheduled to open in November 2012.

"All of a sudden we woke up in April, 2012, having barely even started, and discovered we had twice the amount of rock drilling ahead of us," said Tom Graf, assistant vice president of Kokosing Construction.

The varying foundation depth changed each pier's response during an earthquake, requiring individualized analysis and detailing.

But it wasn't just the drilling depth that posed a challenge in designing and building the foundations. Much of southwest Indiana is located within the Wabash Valley seismic zone, which produced a magnitude 5.4 earthquake in April 2008. The varying foundation depth changed each pier's response during an earthquake, requiring individualized analysis and detailing. In addition, seismic restrainers were installed in the deck to prevent unseating of units at the expansion joints.

The I-69 Twin Bridges over the Patoka River as seen from air during construction in June 2012. Photo: Indiana Department of Transportation.

Superstructure

The design-build contractors were given the option of using concrete or steel beams, and the contractor chose concrete beams. If laid end to end, the beams used to build the first 67 miles of the I-69 extension would circle the 2.5-mile-long track at the Indianapolis Motor Speedway more than nine times, thanks in large part to the 244 beams needed for the twin 4400-ft-long Patoka River bridges.

As a result of a horizontal curve, the southbound structure of the twin bridges has 31 spans while the northbound structure has 30. Span lengths ranged from 140 to 154 ft with beams spaced at 11 ft 4 in. centers. For each structure, the 43-ft-wide

INDIANA DEPARTMENT OF TRANSPORTATION AND FEDERAL HIGHWAY ADMINISTRATION, OWNERS

BRIDGE DESCRIPTION: Twin, 4400-ft-long, concrete bulb-tee bridges

STRUCTURAL COMPONENTS: 244 precast concrete bulb-tee girders with an 8-in.-thick, cast-in-place concrete deck and cast-in-place pier caps, columns, and drilled shafts

BRIDGE CONSTRUCTION COST: $40 million reinforced concrete deck was cast-in-place with a thickness of 8 in. and a specified compressive strength of 4 ksi.

The 7-ft-deep, 5-ft-wide beams (BT84x60) were constructed using a sand-lightweight concrete with a target density of 125 lb/ft^3—saving about 20 lb/ft^3 compared to normal weight concrete. The beams were made continuous for superimposed dead load and live loads. Four to five spans were made continuous per unit with expansion lengths ranging roughly from 560 to 710 ft as the units varied to avoid certain site features. The beams used 0.6-in.-diameter, 270-ksi, low-relaxation strands, each strand being tensioned to 43.9 kips, or 2019 kips total for the longest girder. The longest girders had 46 strands including eight draped strands. The compressive strength of the concrete in the girders was 8 ksi. A minimum strength of 6 ksi was required at prestressing transfer.

Cranes set concrete beams for the I-69 Twin Bridges over the Patoka River. Photo: Indiana Department of Transportation.

A Journey for Concrete Beams

The largest of the beams weighed 87 tons and measured 154 ft 8 in. in length, which posed special challenges in delivery across the Ohio River and onto the jobsite. INDOT and other Indiana agencies worked closely with the contractors on permitting that navigated an array of weight and length restrictions. Police halted traffic on the I-64 Sherman Minton Bridge, which carries 80,000 vehicles per day into Louisville, when the large beams crossed. Beams had to be rerouted further still during the five-month closure of the bridge for inspections and structural repairs.

All runoff collected into bridge deck drains runs into plastic pipes along the beams and then flows into steel containment basins. In these basins, all runoff is filtered through riprap and sand to prevent spills from entering local waterways.

Concrete is pumped for a deck placement. Photo: Indiana Department of Transportation.

On Schedule

The I-69 Twin Bridges over the Patoka River was the last puzzle piece to fall into place before Governor Daniels opened the new 67 miles of I-69 for business on November 19, 2012, by leading a caravan on his Harley-Davidson motorcycle. A severe drought in the summer of 2012 allowed more fair weather days for construction. This, along with the project team bringing in additional resources, allowed the bridge to open on schedule along with the remaining highway.

"When you're working over something that long, you don't realize how many people are out there," said INDOT project manager Brian Malone. "But when you get to counting, it added up to more than 100 people each day."

Samuel Sarvis is deputy commissioner for capital program management for the Indiana Department of Transportation.

For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

Silica Fume Association

The Silica Fume Association (SFA), a not-for-profit corporation based in Delaware, with offices in Virginia and Ohio, was formed in 1998 to assist the producers of silica fume in promoting its usage in concrete. Silica fume, a by-product of silicon and ferro-silicon metal production, is a highly-reactive pozzolan and a key ingredient in high performance concrete, dramatically increasing the service-life of structures.

The SFA advances the use of silica fume in the nation's concrete infrastructure and works to increase the awareness and understanding of silica fume concrete in the private civil engineering sector, among state transportation officials and in the academic community. The SFA's goals are two-fold: to provide a legacy of durable concrete structures and to decrease silica fume volume in the national waste stream.

Some of the recent projects completed by the SFA, under a cooperative agreement with the Federal Highway Administration (FHWA), include:

- The publication of a *Silica Fume User's Manual*—the manual is a comprehensive guide for specifiers, ready mixed and precast concrete producers, and contractors that describes the best practice for the successful use of silica fume in the production of high performance concrete (HPC).
- The introduction of a Standard Reference Material (SRM)® 2696 Silica Fume for checking the accuracy of existing laboratory practices and to provide a tool for instrument calibration. This SRM is available from the National Institute of Standards and Technology (NIST).

A much anticipated research program nearing completion by the SFA is the testing of in-place silica fume concrete under service conditions. At the conclusion of this research the results will demonstrate the benefit of silica fume concrete's unparalleled long-term performance. For more information about SFA, visit www.silicafume.org.

Sliding and Rolling Bridge *Solutions*–Part 2

by Craig A. Shutt

Sliding and rolling bridges into place after assembling them nearby has gained adherents as efficient construction techniques for saving time and costs and minimizing traffic disruption. Owners, designers, and contractors are quickly learning as much as possible about these new concepts so they are ready to discuss options when opportunities arise. This series of articles looks at some of the key considerations when using these approaches to bridge construction.

Part 1 of this series considered key design considerations, including allocating duties among the construction team, superstructure and substructure concerns, and evaluating sliding forces.

This article considers falsework and related design issues. The next article will review necessary field activities during construction. The use of self-propelled modular transporters will be addressed in a subsequent article.

Falsework Design

The design for temporary falsework depends on the application, but in any form it represents a key element to ensuring the structure is safely fabricated offline and out of the critical path, allowing for accelerated bridge construction (ABC). Building falsework next to the existing bridge location allows assembly of the new components to be completed while other key elements of the construction also are underway (such as piers and abutments).

Extensive falsework and shoring requirements must be considered when sliding or rolling bridge superstructure systems into place. The falsework's constructability is critical to ensure the falsework provides the various functions required to build the bridge components and then move them into place. This means every aspect must be detailed in the shop drawings to ensure the falsework is built to perform as the specifications require.

The temporary shoring and permanent abutment must be checked for large temporary lateral forces during launching. However, if a problem arises (such as excessive settlement) during the transfer of the bridge from the falsework to its permanent support, the shoring system has to be able to accommodate and possibly support greater lateral construction loads.

For most projects, settlement of the falsework as it carries the load (during launching) of the bridge doesn't become an issue. The falsework will deflect slightly but not enough to be a concern. Even so, it is preferable to consider and evaluate this possibility to ensure the falsework is sufficiently rigid.

If the falsework does deflect too much, it will be necessary to jack up the bridge once it reaches its final landing point or transfer point if using the permanent structure to support the slide rails. A counter concern is that there can be difficulties if the falsework is too high as well.

On the West Mesquite Interchange at I-15 in Mesquite, Nev., hydraulic jacks were used to push the bridge into place. All photos: Jackie Borman, HDR.

In some cases with push/pull jacks, contractors have investigated the use of the falsework as an anchor point. This generally has not been done, as the falsework needs to be kept as light (and therefore economical) as possible. It is better to push against or pull toward something more rigid (that will ultimately act as a component of the permanent system), such as the abutments.

In some cases where space is limited, these lateral bridge-supporting devices can be built on the other side of the existing bridge from the new bridge, allowing that old bridge superstructure to be pulled out of the way and the new bridge to be moved into place behind it.

Sliding Forces

With a static coefficient of friction of 0.12, the required force to slide a 1.3-million-lb concrete superstructure is 156 kips (1,300,000 lb × 0.12/1000). This can easily be achieved with two 100-kip jacks, which are readily available.

Although a concrete bridge typically weighs about 50% more than a steel bridge, and thus a higher force is needed to move the bridge, the associated equipment and costs are not directly proportional—that is, the cost to rent the hoses, pumps, gauges, and a set of two 100-kip jacks is comparable to renting a complete system with two 60-kip jacks.

Transfer to Permanent Supports

Moving the structure from the sliding shoes to the permanent bearings is a critical step in construction that must be considered very carefully. In many cases, the bridge will be transferred from the sliding rails onto jacks and then lowered onto new permanent bearings. In some cases, the bearings under the beams can remain in place during the transfer. In any case, the bearings and guide rails should be horizontal to avoid moving the bridge uphill or downhill. Depending on

Teflon pads on rails assisted in sliding the approach slab and bridge into place on the West Mesquite Interchange at I-15 in Mesquite, Nev.

how the beams are oriented, there may need to be either grout pads or shim plates between the bearings and the beams.

It's critical to understand how the bridge will react to the shift from its temporary position to its permanent one to be certain that the shift won't create undesirable stresses. The design must account for these stresses in its temporary position as well as in its permanent location. These details become extremely important during the move, whereas they are not as critical in other types of construction.

For instance, a skew in a bridge results in the diaphragm face not being perpendicular to the abutment. This requires a transfer plate or push block between the hydraulic jack and the abutment that can handle an axial load plus a horizontal shear without damaging the end of the diaphragm. Confinement reinforcement in the diaphragm at the connection point may be needed.

Design Considerations

Design elements need to be coordinated at every stage with the construction means and methods. The engineer coordinates the move with the heavy-mover subcontractor early in the design process. The engineer must understand what equipment the contractor will be using and how it will support and load the bridge during the move and in its permanent location. Different design approaches are required to make sure that these things happen and to ensure factors such as bending over the supports and deck cracking are considered. Design details, that in other forms of construction are insignificant or can be dealt with in the field, become critical when moving a bridge into place.

Wind-speed limitations, for instance, need to be worked out with the contractor in advance so a maximum is set beyond which the construction will not go forward. This typically is set at about 15 mph, but it will be up to the contractor to determine what can be tolerated by the equipment and comply with this limit.

Overall view of the approach slab and end diaphragm of the north half of the West Mesquite Interchange at I-15 sliding into place by a hydraulic jacking system.

At every step of the process, engineers must account for the numerous stresses and how they vary during the moving process. Likewise, the contractor needs to be diligent about the quality of construction and building the bridge exactly to the plans. Small field changes can alter the load path of the entire structure due to the complexities of the movements being handled.

The contractor's specialty engineer needs to be closely focused on any field design changes that occur to ensure they are accounted for in the loading in each phase. Each part, starting with the skid shoes or roller troughs, has to be aligned with absolute precision to ensure the bridge movement can proceed easily once it starts and that the system does not bind up.

For that reason, it is wise to build redundancy into the movement-system hardware wherever possible. Adding lateral connections will only result in a minor increase in costs, but it can resolve problems that may arise. It's critical to consider every risk and worst-case scenario to decide how it will be handled. The value of extra anchor bolts in these push/pull systems versus the problems with a failed connection provides low-cost insurance, even if it ultimately proves to be unnecessary.

The key to a successful project using slide-in or roll-in construction is to think through every step: designing falsework to handle movement and transfer loads; stresses during moving, lifting, and setting the beams into their permanent place; and the like. Every factor and every possible concern must be considered against what impact it will have on every other portion of the bridge. To ensure success, the engineer, contractor, and the heavy lifting sub-contractor must work through every contingency and create a plan that will handle each possibility that could possibly arise—and be imaginative in considering what those options could be.

This is the second in a series of articles examining different approaches to accelerated bridge construction. This article was produced from interviews with Hugh Boyle, chief engineer at H. Boyle Engineering; Mike Dobry, principal structures engineer, Larry Reasch, vice president and manager of the structures department and Derek Stonebraker, structures engineer, at Horrock Engineers; R. Craig Finley Jr., founder and managing partner at Finley Engineering Group; and Steve Hague, chief bridge engineer at Burns & McDonnell.

For additional photographs or information on this or other articles, visit www.aspirebridge.org and open Current Issue.

Innovative Precast Concrete Cantilever Retaining Wall System

by Ihab Darwish and Muthiah Kasi, Alfred Benesch & Company

Challenges are incentives for the Michigan Department of Transportation to pursue innovation. Benesch responded with an innovative precast concrete retaining wall system to reduce the construction schedule and improve work-zone safety along the I-196, Baldwin Street off ramp, in the City of Grandville, Mich. The project is a major reconstruction, spanning two years with peak work in the second year. During the first construction season, westbound I-196 was constructed along with the bridges that carry westbound I-196 traffic over the CSX railroad and Buck Creek, and about 3995 ft of retaining walls. The rest of the project was constructed during the second construction season.

A new emulative design approach of precast concrete retaining walls not only reduced the construction time of the wall but helped expedite simultaneous construction of the adjacent roads and ramp in a safer manner. The project included 6762 linear ft or 160,240 ft^2 of retaining walls.

The precast concrete retaining walls are designed and detailed similar to cast-in-place concrete retaining walls. This particular design and system avoided the use of post-tensioning, which is typically used with precast concrete retaining wall systems. The precast concrete footings are erected 3 in. above a 3-in.-thick, cast-in-place concrete sub-footing. The 3-in. gap between the bottom of the footing and the sub-footing is filled with high-strength flowable grout. Precast concrete footings are cast in the plant with protruding dowels and precast concrete retaining walls are cast with grout filled mechanical splicers. This moment connection eliminates the use of welded plates and post tensioning.

The erection rate for the 12-ft-long precast concrete footing segments was 20 segments per day. Twenty precast concrete stem segments were erected in the same timeframe. The system worked well even though some of the heavier walls have many alignment changes. This innovative system reduced the construction schedule by four months.

Completed precast concrete retaining walls.

Erection of precast concrete stem segments.

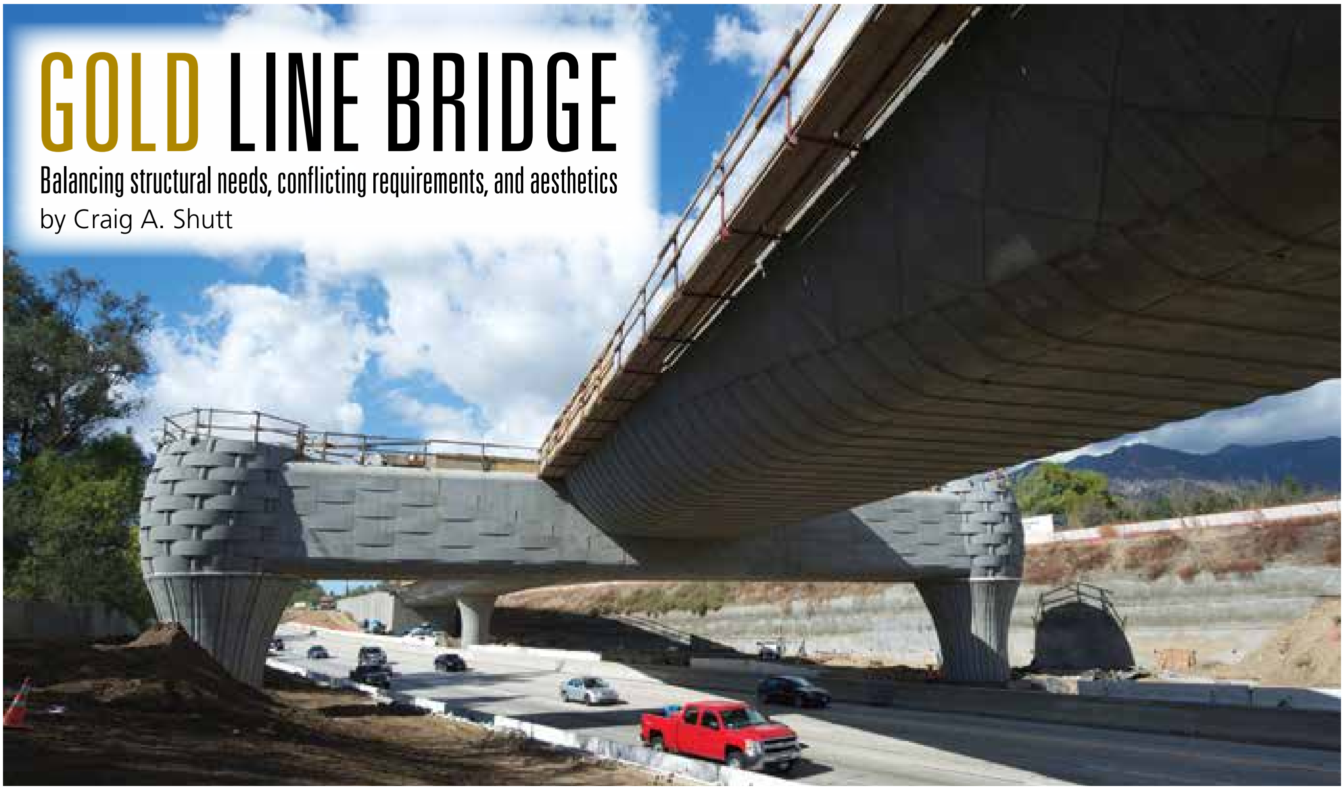
Protruding dowels from the precast concrete footings.

Ihab Darwish is a senior project engineer, Alfred Benesch & Company, Michigan and Muthiah Kasi is chairman of the board, Alfred Benesch & Company, Chicago, Ill.

GOLD LINE BRIDGE

Balancing structural needs, conflicting requirements, and aesthetics

by Craig A. Shutt



The $18.6-million Gold Line Bridge in Arcadia, Calif., features a variety of structural innovations to go with its dramatic aesthetic look. All photos: Metro Gold Line Foothill Extension Construction Authority.

Ensuring that all needs are satisfied on complex bridge projects creates challenges that can be difficult to meet. With the $18.6-million Gold Line Bridge in Arcadia, Calif., designers not only faced meeting the needs of several overlapping governmental bodies, but also incorporated a number of innovative design techniques for the first time in the state. They accomplished those goals while producing a dramatic aesthetic appearance that reflects the area's heritage.

"This was a truly collaborative process," says Habib F. Balian, chief executive officer of the Metro Gold Line Foothill Extension Construction Authority. "We learned that much can be accomplished, very economically, with early planning, the right team, and the community's support."

The 584-ft-long, dual-track bridge, which spans the eastbound I-210 freeway, kicks off a $735-million, 11.5-mile light-rail project from Pasadena to Azusa. The bridge connects the existing Sierra Madre Villa station in Pasadena and the future Arcadia station—the westernmost of six planned stations.

The bridge features three spans of 8-ft 10-in.-deep cast-in-place, post-tensioned, three-cell, concrete box girders, with span lengths of 144, 220, and 220 ft. The deck is 33-ft 11-in.-wide to accommodate two light-rail tracks and a center emergency walkway. The superstructure is supported by an outrigger bent cap that spans I-210, a single column bent, and the abutments at each end. The project required 6500 yd^3 of concrete, and 1,300,000 lb of reinforcement. Total post-tensioning force for the superstructure exceeded 30,000 kips.

Visually arresting, the bridge's superstructure features a rounded underside, with a serpentine design along its length consisting of grooves and hatch-marks visible from I-210. Column tops were constructed of

profile

GOLD LINE BRIDGE / ARCADIA, CALIF.

BRIDGE DESIGN ENGINEER: AECOM, Los Angeles, Calif.

DESIGN CONCEPT ADVISOR/ARTIST: Andrew Leicester, Minneapolis, Minn.

PRIME CONTRACTOR: Skanska USA Civil West, Riverside, Calif.

CONCRETE SUPPLIER: National Ready Mix, Irwindale, Calif.

PRECASTER: Moonlight Molds, Gardena, Calif.; placement of precast units performed by Masonry Concepts, Santa Fe Springs, Calif.

POST-TENSIONING CONTRACTOR: Dywidag Systems International, Long Beach, Calif.

OTHER MATERIAL SUPPLIERS: Reinforcement–CMC Rebar, Fontana, Calif.; Spherical Bearings–D.S. Brown, North Baltimore, Ohio; Expansion Joint Seal Assemblies–American Sheet Metal, Anaheim, Calif.; Formliners–Fitzgerald Formliners, Santa Ana, Calif.; and Prefabricated Wood Forms–Squires Lumber, Colton, Calif.

precast concrete modules to resemble woven baskets connected with a horizontal support and decorated with reed patterns extending upward.

"The Construction Authority set the mandate to create a unique gateway that reflected aspects of the San Gabriel Valley region," explains Andrew Leicester, design concept advisor. "I drew inspiration from two sources: the region's cultural history and its architecture."

[The design concept advisor] 'drew inspiration from two sources: the region's cultural history and its architecture.'

The Metro Gold Line Foothill Extension Construction Authority, an independent agency, coordinated the planning, design, and construction. It followed specifications created by the Los Angeles County Metropolitan Transportation Authority (Metro), which will operate the rail line. But because the structure spans the eastbound lanes of I-210, the California Department of Transportation (Caltrans) also has jurisdiction. That required meshing differing, sometimes conflicting, requirements.

"Whenever required, the stricter of the two criteria were always adopted," explains Patrick Nicholson, project manager for AECOM, the lead architecture and engineering firm. "When contradictions occurred, we carefully assessed the conflict and devised the best solution for both agencies."

Lights wash the sides of the bridge at night, emphasizing the basket-like appearance of the column tops and the reed-like texture of the horizontal support.

Innovative Seismic Features

The key divergence arose over seismic design, which resulted in a balanced system and several innovative features. These were necessitated by the structure's third span crossing the active Raymond Fault. "Every component of the design was driven by the seismic criteria," says Lawrence Damore, project executive for Skanska USA, the general contractor.

The key issue centered on differences in seismic design criteria from each agency, Nicholson notes. "Caltrans' seismic criteria are based entirely on displacement, preferring to engage abutment soil as early as possible in a major earthquake, reducing overall displacement demand," he explains. "Metro's criteria, partially force-based, tends to delay the engagement to reduce abutment damage." After an in-depth assessment of both criteria, it was determined that early engagement was favored. "But through thoughtful detailing, the abutment damage was also mitigated to an acceptable extent."

The structural design also used Caltrans' new methodology for analyzing bridges that cross active faults, which was issued in May 2012. The Raymond Fault makes a 70-degree angle counterclockwise with the third span's alignment. The anticipated surface fault-rupture displacement is 1.65 ft horizontally. "The breakthrough of the new methodology is that it recognizes the dynamic nature of a fault rupture instead of past analyses' emphasis on consideration of the quasi-static fault-offset component," Nicholson says.

Columns Create Challenges

"The Authority's original concept envisioned five piers, three in the center median and two on the south shoulder of the freeway. As we worked through our design, we realized we could offer a more efficient structure with just three

METRO GOLD LINE FOOTHILL EXTENSION CONSTRUCTION AUTHORITY, OWNER

OPERATOR: Los Angeles County Metropolitan Transportation Authority, Los Angeles, Calif.

BRIDGE DESCRIPTION: Three-span, 584-ft-long bridge with cast-in-place, post-tensioned, concrete box girders and precast concrete architectural column panels

STRUCTURAL COMPONENTS: 8-ft 10-in.-deep cast-in-place box girders with a 33-ft 11-in.-wide deck and cast-in-place pier caps, columns, and drilled shafts

BRIDGE CONSTRUCTION COST: $18.6 million

The structure's third span on the far side crosses the active Raymond Fault.

columns founded on 11-ft-diameter concrete shafts that are 110 ft deep," Damore adds.

The columns are founded on single, large-diameter, cast-in-drilled-hole shafts. "They represented significant design challenges, especially with seismic considerations," Damore says. Single 11-ft-diameter Caltrans Type I shafts are used for each column. Multiple 2-ft-diameter shafts are used under the abutments.

The outrigger column's basket shapes were created with precast concrete modules. Sixteen reeds per basket were used with the same curvature but with varying lengths.

A single 10-ft-diameter column with an integral bent cap is used at bent 2, while double 10-ft-diameter columns, with a hollow prestressed outrigger bent cap having a span of 115 ft are used at bent 3. The post-tensioning force for the outrigger exceeded 30,000 kips. Both abutments feature high cantilever seat-type designs.

The bridge also is the first Metro-approved bridge to have rolling-stock analysis performed. These analyses are commonly required for high-speed rail or long-span bridges. The analysis employed a specialized three-dimensional finite-element program that models the bridge structure, the light-rail vehicle (including its body and primary and secondary suspension systems), and the dynamic effects due to the movement of the vehicle along the bridge. The analysis verified that the dynamic load allowance (or dynamic amplification factor) stipulated in Metro's criteria were sufficient and that riders would not experience excessive dynamic deflection.

Dramatic Aesthetic Design

Structural considerations were complicated by the unique bridge aesthetics. "I had the same reaction as everyone when they first saw it: Wow," says Rivka Night, lead architect at AECOM. "It's very unusual and not at all a traditional design. My immediate thought was, 'Is it really going to be constructed out of concrete?' It seemed that it might be a very complicated construction because of the unusual shapes."

The artist's inspiration for the serpentine superstructure flow was the Western Diamondback rattlesnake, while the basket-like columns represent indigenous Native American handicrafts. The bridge is the first artist-designed transit bridge in the state.

The underside features a curved profile with a longitudinal wave pattern mixed with a transverse rib pattern. It's the first bridge in the state to have these attributes. Creating the serpentine soffit shape required building temporary falsework and using formliners to create the pattern. The cross-hatching detail was accomplished by nailing small pieces of chamfer to the forms.

The bridge superstructure features a rounded underside, with a serpentine design along its length consisting of cast grooves and hatch-marks visible from I-210.

Each formliner was aligned by hand to ensure the proper shape and to align the grooves and hatchmarks.

The outrigger column's basket shapes were created with 60 individual precast concrete modules, which feature 16 reeds protruding 2 to 10 ft from the top. The concrete contained black stone as well as clear, gray, and mirrored glass to create a sparkling effect that responds to atmospheric conditions.

The 60 column basket's modules doubled as formwork for closure pours of the bent-cap prestressing anchorage. The complex weaving patterns matched those of the adjacent bent caps and the column below.

"The architectural elements of the bridge are unique," says Damore. "Nearly everything on this project was specially designed and manufactured for the project and required our crews to install them using detailed craftsmanship unlike any other bridge I have been involved with."

The result of balancing the complex structural needs, conflicting requirements, and dramatic aesthetics has been a signature bridge. "It's something no one in this region has ever seen or done before," says Balian. "Hundreds of thousands of people pass by the bridge daily, and I think they will appreciate the time and attention we gave to its design."

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Dodridge Street Bridge

Franklin County, Ohio

Three-span, post-tensioned concrete girder end-anchored superstructure bridge

by Jim Pajk, Franklin County, Ohio, and Rick Engel and Dave Traini, E.L. Robinson Engineering

Bridge profile (east end). The Dodridge Street Bridge has a main span of 200 ft and two hidden end spans of 20 ft 6 in. All photos: E.L. Robinson Engineering.

The Dodridge Street Bridge over the Olentangy River serves as a gateway into Olde North Columbus, one of the oldest neighborhoods in Columbus, Ohio. The project replaced a deteriorating bridge, corrected an existing deficient roadway alignment, and carries over 14,000 vehicles per day as well as pedestrians.

In addition, several thousand pedestrians and bicycle users travel daily along the Olentangy River Greenway (ORG), which is located underneath the bridge. The 13-mile-long ORG connects the north suburbs to downtown Columbus and travels through several parks and The Ohio State University campus area.

During design of the Dodridge Street Bridge, the Franklin County Engineer's Office (FCEO) identified the need to solicit design input from the surrounding community. These opinions, coupled with river hydraulics, ongoing river restoration, upstream protected wetlands, and the extensive use of the ORG, supported the desire to provide a long-span, aesthetically pleasing structure.

Background

The original 206-ft-long bridge, constructed in 1901, was a two-span, steel through girder bridge with a timber floor system. The bridge was rehabilitated in 1952. In 1967, the entire superstructure was replaced with precast, prestressed concrete adjacent box beams. In 2010, the bridge was determined to be in poor condition.

Project Development

Five design alternatives were considered for the Dodridge Street Bridge. The alternative that was favored best satisfied the following project criteria:

- No piers within the river banks
- West abutment location out of ordinary high water
- Open inviting appearance
- Significant headroom and trail width for ORG
- Minimal disruption to existing dwellings
- Reasonable cost
- Long structure life
- Minimal maintenance associated with a concrete structure

[The alternative] required the least construction time, largely due to the use of precast concrete beam construction.

The selected alternative of a three-span bridge minimized work within the river, where the water elevation can fluctuate greatly due to an upstream reservoir controlled by the Army Corps

profile

DODRIDGE STREET BRIDGE / FRANKLIN COUNTY, OHIO

BRIDGE DESIGN ENGINEER: E.L. Robinson Engineering, Columbus, Ohio, and Janssen & Spaans Engineering Inc., Indianapolis, Ind.

AESTHETIC ADVISOR: Frederick Gottemoeller, Columbia, Md.

PRIME CONTRACTOR: J. D. Williamson Construction Co. Inc., Tallmadge, Ohio

PRECASTER: Prestress Services LLC, Grove City, Ohio, a PCI-certified producer

POST-TENSIONING CONTRACTOR: VSL International Ltd., Hanover, Md.

READY-MIX CONCRETE SUPPLIERS: Anderson Concrete, Columbus, Ohio, and Central Ready Mix, Columbus, Ohio

Erection of the precast concrete segments and view of the abutment tie-downs.

of Engineers. It also required the least construction time, largely due to the use of precast concrete beam construction.

The presence of shallow bedrock meant that the design could use short end spans with high capacity tie-downs, and avoid the expenses and construction issues related to longer end spans, which would encroach on the apartment building to the east of the site. The 200-ft-long center span was considered the optimal, upper span limit for this bridge type and necessary to meet the previously outlined concerns. The 26-ft 6-in.-long hidden end spans also avoided the removal of the existing stone east wall abutment and reduced right-of-way issues.

Construction started in July 2011 and the project was opened to traffic by the end of October 2012. The project was able to accomplish the goal of replacing the bridge while incorporating many community- and stakeholder-requested elements during and after construction.

Improvements to the ORG trail included a wider, paved path underneath the bridge and an improved railing to protect the users. The proposed bridge roadway section provides additional bridge width to accommodate wider sidewalks, vehicular barriers between the roadway and sidewalk, and consideration for future bicycle lanes. Safe and efficient detours were critical during construction. Many individuals use the bridge and the ORG beneath it to get to work or education facilities. The FCEO worked with The Ohio State University, Central Ohio Transit Authority, City of Columbus Recreation and Parks, and bicycle advocates to address user concerns during construction.

Superstructure

The structure was designed in accordance with the *AASHTO LRFD Bridge Design Specifications*. The bridge has a main span of 200 ft and two hidden end spans of 26 ft 6 in. The superstructure consists of four variable-depth precast concrete U-beams at 18 ft centers for the main span and four constant-depth U-beams for the side spans. The main span beams vary in depth from 5 ft 6 in. at midspan to 10 ft at the intermediate piers. The beam width varies from 4 ft at the soffit to 8 ft at the underside of the deck. The

Public Opinion

The Franklin County Engineer's Office (FCEO) hosted numerous public involvement meetings on key project design issues, and over 12 stakeholder groups and numerous homeowners provided project design-related opinions. Public meetings offered the stakeholders a chance to voice opinions on sidewalks, path facilities, solutions to a safe trail detour, construction-related-activity concerns, potential environmental impacts to the river, flooding and conservation easement, mobility of current pedestrians along Dodridge Street and Olentangy River Greenway (ORG), structure type and choice of material, and the importance of bridge aesthetics.

Early in the development phase, ARC Industries, located adjacent to the bridge, indicated they had a relatively high volume of special-needs individuals who used public transportation and walked to their facility across the bridge from the bus stop on the east side. Along with the structural demands of the project, the needs of the users of these adjoining and affected public facilities, especially the ORG, were considered.

The design team used this input to develop five project design alternatives. The public then provided comments on the five proposed structure alternatives and various railing, lighting, and other aesthetic features. The selected alternative provides Ohio with a unique and aesthetically pleasing bridge type. This alternative is an economical solution that provides a slender single span, resulting in a feeling of openness along the river, inviting pedestrians and bikers to travel along the ORG to this destination site.

FRANKLIN COUNTY, OWNER

BRIDGE DESCRIPTION: A precast concrete U-beam bridge with a 200-ft-long main span and 26-ft 6-in.-long hidden end spans

STRUCTURAL COMPONENTS: Precast concrete U-beams; cast-in-place concrete abutments, piers, hidden end spans, and deck

BRIDGE CONSTRUCTION COST: $7.7 million

web thickness varies from 9 to 12 in. The U-beams support an 11-in.-thick cast-in-place concrete deck with a total width of 75 ft 0 in.

The main-span concrete beams were precast in three sections, erected on falsework, and spliced with a closure pour. The end spans were cast-in-place extensions of the precast concrete main span beams. The main span and end span beams were post-tensioned together longitudinally to create a continuous structure from abutment to abutment.

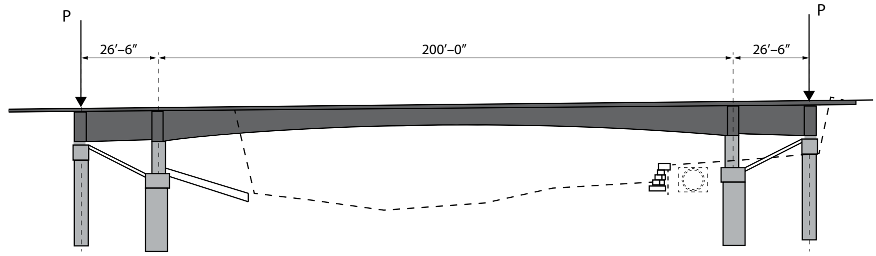
For the precast concrete beams, the specified concrete strength was 7 ksi. The use of high-performance concrete, epoxy-coated reinforcing steel, a soluble reactive silicate (SRS) sealer on the deck, and non-epoxy coating on exposed concrete surfaces, will provide a long lasting structure with minimal future maintenance needs.

Erection of the precast concrete segments on temporary towers.

Tie Downs

Tied-down end spans have been used successfully in Ohio on three bridges that have steel girder superstructures. For this project, the tied-down end spans, along with the haunching of the concrete girders at the piers, allow the middle of the center span to be relatively slender and improves the appearance of the bridge by making the bridge seem thinner and lighter. A 4-in. offset in the outer webs of the fascia girders creates a shadow line that enhances this slender visual effect.

The use of tied-down end spans for concrete girder superstructure designs presents a design challenge due to the relatively large dead load that must be resisted by the tied-down anchors. Each tied-down rock anchor located at the abutments consisted of twelve 0.6-in.-diameter, 270 ksi, prestressing monostrands placed in a conduit filled with grease. The tendons extend from the top of the abutment diaphragm to approximately 30 ft into bedrock. The tendon free length is 40 ft and the bond length is approximately 30 ft. The portion of the tendon that extends from the top of the abutment footing for a distance of 30 ft to the top of bedrock is centered in a 12-in.-diameter steel casing that allows the tendon to translate horizontally as the expansion and contraction movements of the superstructure occur.



Profile and bridge elevation view, where P is the force from twelve monostrands. Drawing: PCI.

Within the bedrock, the corrosion protection consisted of a grout-filled corrugated plastic casing placed around the bare strands. The design factored load for the 12 tied-down anchors at each abutment was 440 kips per anchor. The abutments and the piers were constructed of cast-in-place concrete in a continuous box configuration that was supported by drilled shafts socketed into bedrock.

The precast concrete beams used for the superstructure of the Dodridge Street Bridge are unique because their main structural component is the tied-down anchors located at the abutments of the two hidden end spans. These two hidden end spans were required to balance the effects of having a slender main span structure. The architectural geometry of this bridge required the smallest structural section where peak design demand occurred, posing a significant design challenge. To overcome this challenge, tied-down anchors were utilized to provide stability for the bridge which is otherwise unbalanced in its three-span configuration.

The beams were also post-tensioned in stages as dead load was applied to allow the girders to function as continuous beams, despite the appearance of a single-span gentle arch. The construction of this bridge required a careful sequencing of the post-tensioning and tied-down forces to ensure the beams were stable throughout all stages of construction and were at no time overstressed.

Aesthetic treatments to the substructure units. The end span is hidden behind the abutment.

This aesthetically pleasing structure will provide local residents with a beautiful gateway that can be enjoyed for decades. The use of a precast, post-tensioned concrete superstructure provided an economical solution and saved construction time, thus minimizing disruption to the community. The improvements made to the ORG will allow users to navigate along the trail while appreciating the bridge's aesthetic features.

Jim Pajk is a deputy engineer, bridges with the Franklin County Engineer's Office in Columbus, Ohio, and Rick Engel and Dave Traini are vice president and structures group manager, respectively, with E.L. Robinson Engineering in Columbus, Ohio.

For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

Load and Resistance Factor Rating of Concrete Segmental Bridges

AASHTO Manual for Bridge Evaluation provisions and special considerations

by Lubin Gao, Joey Hartmann, Reggie Holt, and Thomas Saad, Federal Highway Administration

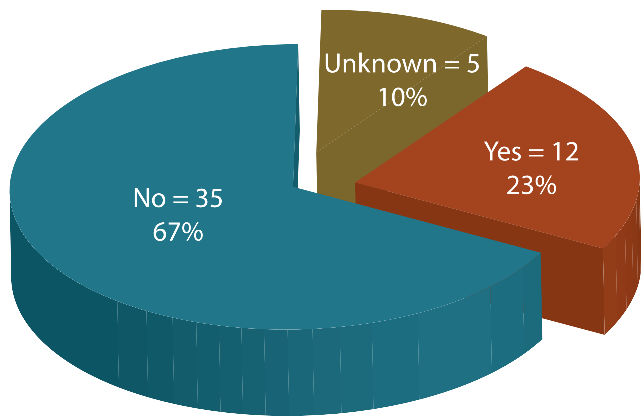
Concrete segmental construction has provided a durable and economical solution for many bridges and, as a result, more than 250 of these types of bridges have been built since the early 1970s in the United States. Concrete segmental construction has been used successfully in the construction of interchanges with complex geometric constraints and long-span bridges across navigational waterways.

Many concrete segmental bridges provide critical links in the U.S. highway system. Consequently, the economic impact resulting from unforeseen closure of one of these bridges due to functional or safety concerns will be significant. Therefore, it is important to load rate these bridges to ensure the safety of the structure and the traveling public. Furthermore, load rating will safeguard the bridge from premature deterioration due to unintended overloads.

Bridge load rating and posting are also mandated by Federal Regulation 23 CFR 650 Subpart C: National Bridge Inspection Standards (NBIS). The *AASHTO Manual for Bridge Evaluation* (MBE) further defines the methology and procedures for load rating and posting, including provisions for segmental bridges.

According to the FHWA Policy Memorandum for Bridge Load Ratings for the National Bridge Inventory dated October 30, 2006, new bridges and totally replaced bridges designed after October 1, 2010, must be load rated with the load and resistance factor rating (LRFR) method.

A questionnaire was sent to Federal Highway Administration (FHWA) Division Bridge Engineers in September 2011 to collect information about the status of the national implementation of the LRFR method. The data collected was used to develop recommendations and services to aid FHWA Division Bridge Engineers in the oversight of load rating, posting, and permitting programs and practices using the LRFR method. The responses to the questionnaire demonstrated that 23% (12) of the states had started to use the LRFR method to rate segmental bridges.



Percentage of states that have used the LRFR method to load rate concrete segmental bridges. All drawings: Federal Highway Administration.

To further support the national implementation of LRFR load rating of segmental bridges, an informational webinar was conducted on January 19, 2012, by FHWA. More than 150 individuals from across the nation participated in this webinar.

LRFR Methodology

Limit States

Since the major concern for bridge load rating is determining the vehicular live load capacity of the structure under its permanent load condition, other transient loads (wind, ice, earthquake, and the like) are generally not required to be included in the analysis. Table 6A.4.2.2-1 of the MBE further defines the limit states that should be considered when load rating different bridge types.

Loads

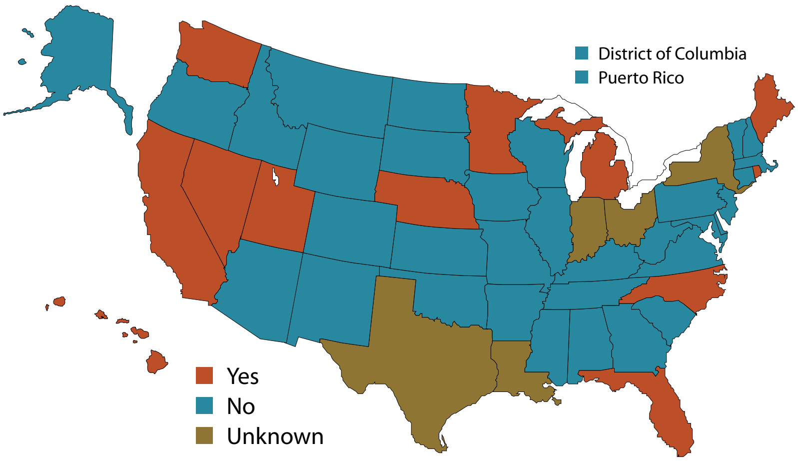
Load rating should consider live loads in the presence of all permanent loads applied to the structure and other loads that may affect the live load carrying capacity of the structure. Live loads should include the design notional load (HL-93), legal vehicles, or permit vehicles, depending on the purpose of the rating.

Legal loads are the vehicles legally allowed to use bridges in the United States or in a specific state. The Bridge Formula in Section 658, Title 23 of the Code of Federal Regulations defines the limits on configuration and axle weight for a vehicle that can legally operate on an interstate highway without special permission (such as a state-issued permit). MBE includes the configuration and axle weight of some common vehicle types to be considered during load rating such as the Routine Commercial Vehicles Type 3, 3S2, and 3-3, and Specialized Hauling Vehicles SU4, SU5, SU6, and SU7. Most states also have state-specific legal loads that also need to be considered. Permit load rating should be conducted based on the actual configuration and axle weight of a permit vehicle or vehicle group.

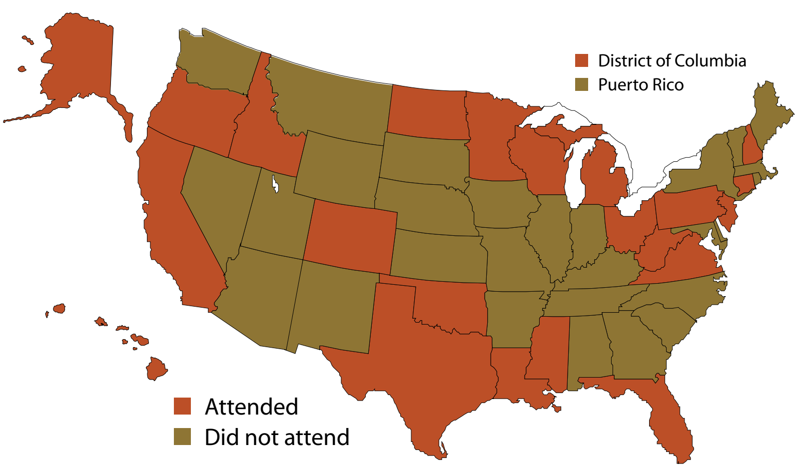
Dynamic load allowance should also be included in a load rating analysis. LRFR allows the use of a reduced dynamic load allowance for legal and permit load rating based on the riding surface condition.

Structural Reliability

In the calibration of LRFR/load and resistance factor design (LRFD),



States that have rated concrete segmental bridges.



Geographic distribution of attendees at the webinar on load rating of concrete segmental bridges.

target reliability indices were used in adjusting the probabilistic models of loads and resistances in order to ensure a consistent level of safety.

The LRFR method adopted two levels of reliability for different rating vehicles based on the expected duration of exposure. Inventory level rating for the notional design load (HL-93) used the same target reliability index of 3.5 as used in the *AASHTO LRFD Bridge Design Specifications*. Operating level rating of the design load was based on a reduced reliability index of 2.5.

To strike a reasonable balance between safety and economy, a lower, operational target reliability of 2.5 and a duration of exposure of five years were initially used for legal load rating at the strength limit state in the LRFR calibration.

For annual routine permits and escorted single-trip permits, a reliability index of 2.5 was initially targeted, and load factors in the MBE were calibrated for this level of reliability. For single-trip and multiple-trip special permits allowed to mix with traffic, a reliability index of 3.5 was used.

Structural Deterioration

Load rating should be based on the current physical condition of the structure. If there is any structural deterioration or section loss, the deterioration or section loss must be considered in load rating. The section loss or other localized deterioration can be taken into account in computing section resistances. For global deterioration, the condition factor, ϕ_c, is used to account for the increased uncertainty in the capacity of deteriorated members and the likelihood that some forms of deterioration will increase more rapidly once deterioration initiates.

Structural Redundancy

Structural redundancy affects the probability of system failure. In LRFR, the system factor, ϕ_s, is used to account for the impact of structural redundancy of the complete superstructure system on load rating. Segmental bridges are different than conventional multi-girder bridges and have unique aspects of system redundancy. These aspects include longitudinal and transverse continuity, and the number of tendons and webs.

Special Considerations for Segmental Bridges

Contract plans, construction and erection plans, as-built drawings, previous inspection and condition evaluations, and most current inspection reports are the main information sources for load rating. The load rating should always be conducted at current structural and loading condition.

Loads

In addition to dead and live loads, segmental bridges should also consider the following in their load rating:

- Locked-in forces in the structure during construction, related to:
  - construction sequence;
  - erection or construction equipment such as segment lifting system and form-travelers; and
  - temporary stressing and temporary supports.
- Primary effects of prestressing and post-tensioning
- Secondary load effects from prestressing and post-tensioning, creep, shrinkage, and other time-dependent behavior
- Temperature and temperature gradient
- Other applicable loads that may lower the live load capacity of the bridge

When applying live loads for operating level rating of the design load, legal load, and permit load at service limit states, the number of load lanes may be taken as the number of striped lanes. However, the loads shall be positioned so as to create maximum effects including, for example, on shoulders if necessary.

Also, in accordance with MBE Article 6A.5.11.3, the multiple presence factor for single lane loaded may be limited to 1.0 for operating level rating of the design load and legal load in the transverse direction.

Longitudinal Analysis

Dead load effects in a segmental bridge are affected by a wide variety of parameters, such as

- construction sequence,
- construction equipment,
- loading and erection age of segments,
- creep and shrinkage of concrete, and
- relaxation of prestressing steel.

Because of the time-dependent behavior, the dead load state of a segmental bridge changes with time. In order to rate a segmental bridge, dead load effects at the time of load rating should be determined through an analysis including the effects from construction sequence, time-dependant material properties, and loading history. Note that restraints and constraints should be appropriately applied to the analysis model to capture the real structural behavior at different stages. The change in restraints or constraints will redistribute forces within the structure. The analysis should be able to capture any locked-in forces during construction and any load redistributions resulting from time-depenent material behavior.

Transverse Analysis

Segmental box girders shall also be load rated for transverse behavior. It is possible that transverse load rating, such as tensile stresses (Service III) in the top slab, governs the live load capacity.

Limit States

According to MBE Articles 6A.5.11.4, 6A.5.11.5.1, and 6A.5.11.5.2, Strength I (or II for permit load rating), Service I, and Service III limit states shall be checked for the design, legal, and permit load rating of segmental bridges. Service III limit state specifically includes the principal tensile stress check of LRFD Article 5.8.5.

Closing Remarks

For segmental bridges, service limit states will likely control the load rating, which is contrary to what typically controls the load rating of conventional nonprestressed concrete bridges. As mentioned previously, strength limit states in LRFR/LRFD have been calibrated for uniform reliability; however, service limit states have not. Because of the growing numbers of segmental bridges that owners are incorporating in their bridge network, the initial drafts of the LRFR methodology and the current rating provisions in the MBE provided type-specific guidance for segmental bridges that had not existed previously. The results of the ongoing and future research may result in even more specific criteria in the AASHTO rating guidelines that bridge owners and engineers will use to better assess the operational performance of segmental bridges under ever-changing loading conditions and traffic demands.

____

Lubin Gao is senior bridge engineer–load rating, Joey Hartmann is principal bridge engineer and team leader, and Reggie Holt is senior bridge engineer–concrete bridge specialist with the Office of Bridge Technology, Federal Highway Administration (FHWA). Thomas Saad is a senior structural engineer with the Resource Centers, FHWA.

Nebraska's Inverted Tee SHORT-SPAN Bridge System

IT system proves quick and efficient

by Fouad Jaber, Nebraska Department of Roads

A significant number of bridges in Nebraska must cross waterways or railroads where vertical clearance is critical and the span length required is less than 80 ft. The sparsely populated area located outside of the Omaha-Lincoln metropolitan area has a flat terrain and many small streams that have to be crossed, which requires shallow superstructures.

Inverted Tee System

First introduced in 1996, the inverted-tee (IT) system is structurally efficient, rapid to build, and economically competitive. Over 100 IT bridges have been designed and constructed by Nebraska Department of Roads (NDOR) and other agencies.

The IT system consists of precast, prestressed concrete inverted-tee beams with a 6-in.-thick, cast-in-place (CIP) concrete deck. IT beams are extremely simple to produce and light to handle. The topping reinforcement is a single layer of welded-wire or mild-steel reinforcement located at mid-depth. The system can be used for a span-to-depth ratio of up to 35, making it shallower than other available precast concrete products.

The Nebraska IT series was designed in SI units and ranges from 12 to 32 in. deep (designated IT300 to IT800) in increments of 4 in. The IT beams are set at a standard 37-in. spacing, center to center, and can span up to 80 ft.

This bridge system is cost-effective for short-span bridges, despite the use of what appears to be "too many" girder lines. The IT beams are extremely simple to fabricate with standard strand and welded-wire reinforcement (WWR), and no tied reinforcing bars. The deck is formed with 32-in.-wide, ¾-in.-thick plywood sheets, which are placed into ¾-in.-wide, 1-¼ in.-deep ledges notched on each side of the web, requiring few field labor skills.

The IT shape has no top flange and has a constant web width, and its simple shape allows the use of only one set of forms for various beam depths.

Applications

The IT beam system has various applications, such as:

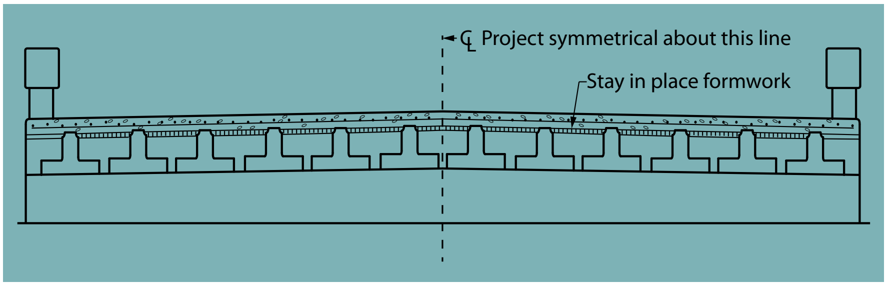
- New construction, where the superstructure depth must be kept to a minimum. This may include high flood-elevation areas and nearly flat road overpasses over flat terrain.
- New construction, where conventional on-site formwork cannot be used due to existing restrictions.
- Bridge superstructure replacement, where a greater load capacity is required for the same superstructure depth.
- Bridges where structural continuity over the support is required.

Fabrication

The two components of the concrete beam shape—bottom flange and web—are standardized such that the bottom flange width is the same for all beam depths. The web height is easily adjustable within the standardized design at 4 in. increments. Self-consolidating concrete makes this small and efficient shape relatively easy to cast. The only types of reinforcement used in the section are straight, ½-in.-diameter strands and WWR. The beams are relatively lightweight reducing some of the heavy lifting and transportation requirements typically associated with AASHTO or bulb-tee beams. The standardized element shape, with a range of beam heights and only two types of reinforcement—combined with high-quality concrete mix designs and fabrication specifications required by NDOR—provide a superior beam system for the bridges that is both efficient to manufacture and lightweight to install.

Reinforcement details of inverted-tee beam. Photo: Nebraska Department of Roads.

Typical inverted-tee in the casting yard. Photo: Concrete Industries.



General cross section of roadway. Figure: Nebraska Department of Roads.

Design

Because the IT beams are not connected in the transverse direction, except at the diaphragms and at abutment turndowns, they should behave similar to a composite I-girder system with relatively narrow spacing. After extensive grid analysis and field-testing, the NDOR policy is to use a distribution factor of S/11 per lane for shear, where S is the beam spacing, and use the flexure equations in the *AASHTO LRFD Bridge Design Specifications* for I-girders.

The single layer of slab reinforcement located at mid-slab thickness is typically No. 5 bars at 6 in. centers for transverse reinforcement and No. 5 bars at 10 in. centers for longitudinal reinforcement. Additional reinforcement is provided in the slab on structures made continuous over the piers. NDOR also requires interstate bridges to have a slab thickness of 8 in. with two layers of reinforcment and designed using the empirical method in the *AASHTO LRFD Specifications*.

The two criteria that often control the design of the IT system are the top-fiber compressive concrete stress at service load at midspan and member deflection. Bridges are designed as simple span for dead load and 100% continuous for live load. Longer spans can be achieved by providing continuity in the IT system for deck weight plus all superimposed loads.

The NDOR policy is to provide at least one alternate CIP slab or steel girder design whenever an IT system is proposed. Recently it has been the trend that the IT system is the choice of the contractor.

Recently it has been the trend that the IT system is the choice of the contractor.

The IT system is designed to be especially efficient for construction by small contractors in sparsely populated areas. IT beams can be handled with the same equipment used for precast concrete pile handling. Installation of formwork for the overhang is the most time consuming part of the deck forming, and is typically left up to the contractor to decide on the best method of construction.

Typical inverted-tee bridge. Photo: Nebraska Department of Roads.

Inverted-tee and NU I–girder used on the same bridge in Omaha, Neb. Photo: Nebraska Department of Roads.

Cost

The unit prices of the CIP slab system per square foot, as taken from records of similar projects by the NDOR, is $\$23.50/ft^2$. This average cost per square foot does not include the cost of bridge rails or substructures.

Summary

Since their introduction by Nebraska in 1996, precast, prestressed concrete IT-beam bridges have become the most dominant system in Nebraska. Developed for short to medium-span bridges, the IT beams are more cost efficient (on average) and are advantageous when spanning greater distances where depth of the structure is critical. In addition, the IT system requires no temporary field forming and is constructed quicker than CIP slab bridges. This type of bridge is excellent for projects where the construction areas are limited and where superstructure forming should be minimized.

Fouad Jaber is assistant state bridge engineer for the Nebraska Department of Roads in Lincoln, Neb.

For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

EDITOR'S NOTE

More information about the development of the IT System is available in Kamel, M. R. and Tadros, M. K., "The Inverted Tee Shallow Bridge System for Rural Areas," PCI Journal, *September-October 1996, pp. 28-43.*

Envision Emerges

A new way to track bridge sustainability available for owners, project teams

by Emily Lorenz

Envision,™ a rating system for sustainable infrastructure and developed by the Institute for Sustainable Infrastucture (ISI), was first released for public comment in July 2011. ISI is a non-profit organization founded jointly by the American Council of Engineering Companies (ACEC), the American Public Works Association (APWA), and the American Society of Civil Engineers (ASCE). Shortly after this first public-comment period, the Zofnass Program for Sustainable Infrastructure at Harvard University partnered with ISI to further develop the Envision rating system. Project certification under the Envision rating system began in September 2012.

The intent of the Envision rating system is to standardize evaluation of the sustainability of infrastructure projects. It is applicable to projects in sectors such as energy, water, waste, transportation, landscaping, and information. In the transportation sector, project types that can use Envision include airports, roads, highways, railways, public transit facilities, and bridges.

Infrastructure is critical to a functioning society. It enables humans to have clean drinking water, travel between our homes and work, and ensures a reliable energy supply. However the earth's resources are not infinite, and thus to maintain sustainable development, we must attempt to reduce negative environmental, economic, and social impacts in infrastructure design. The Intergovernmental Panel on Climate Change defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Similar to other green or sustainability rating systems, credits are grouped in categories related to environmental, social, and economic impacts. A total of 60 credits are distributed across five categories, each of which is explored further in the following sections. Within each credit, point levels are set based on meeting different levels of achievement, and points are weighted within Envision based on the importance of the credit related to overall infrastructure sustainability.

An assessor assigned to the project will determine the level of achievement that the project team has reached for each individual credit using a predetermined set of evaluation criteria. The level of achievement for the entire project is determined by the number of points achieved in the different credit categories. Envision levels of achievement include:

- Improved
- Enhanced
- Superior
- Conserving
- Restorative

In the following sections, all credits and their intents are listed. However due to space limitation, only some of the credits to which concrete bridges can contribute are discussed in more detail.

Table 1–Quality of Life Credits and Intents

Credit Category	Credits	Intent
Purpose	QL1.1 Improve community quality of life	Improve the net quality of life of all communities affected by the project and mitigate negative impacts to communities
	QL1.2 Stimulate sustainable growth and development	Support and stimulate sustainable growth and development, including improvements in job growth, capacity building, productivity, business attractiveness, and livability
	QL1.3 Develop local skills and capabilities	Expand the knowledge, skills, and capacity of the community workforce to improve their ability to grow and develop
Well Being	QL2.1 Enhance public health and safety	Take into account the health and safety implications of using new materials, technologies, or methodologies above and beyond meeting regulatory requirements
	QL2.2 Minimize noise and vibration	Minimize noise and vibration generated during construction and in the operation of the constructed works to maintain and improve community livability
	QL2.3 Minimize light pollution	Prevent excessive glare, light at night, and light directed skyward to conserve energy and reduce obtrusive lighting and excessive glare
	QL2.4 Improve community mobility and access	Locate, design, and construct the project in a way that eases traffic congestion, improves mobility and access, does not promote urban sprawl, and otherwise improves community livability
	QL2.5 Encourage alternative modes of transportation	Improve accessibility to non-motorized transportation and public transit. Promote alternative transportation and reduce congestion
	QL2.6 Improve site accessibility, safety, and wayfinding	Improve user accessibility, safety, and wayfinding of the site and surrounding areas
Community	QL3.1 Preserve historic and cultural resources	Preserve or restore significant historical and cultural sites and related resources to preserve and enhance community cultural resources
	QL3.2 Preserve views and local character	Design the project in a way that maintains the local character of the community and does not have negative impacts on community views
	QL3.3 Enhance public space	Improve existing public space including parks, plazas, recreational facilities, or wildlife refuges to enhance community livability

Quality of Life (QL)

Strategies in this category relate to a project's impact on the community. Broad credit categories include purpose, well being, and community. Table 1 lists the credits in this category and their intents. Two strategies in the Quality of Life category that relate to concrete bridges are explained in more detail in the following sections.

QL2.3 Minimize light pollution

The metric for this credit is that "lighting meets minimum standards for safety but does

Table 2–Resource Allocation Credits and Intents

Credit Category	Credits	Intent
Materials	RA1.1 Reduce net embodied energy	Conserve energy by reducing the net embodied energy of project materials over the project life
	RA1.2 Support sustainable procurement practices	Obtain materials and equipment from manufacturers and suppliers who implement sustainable practices
	RA1.3 Use recycled materials	Reduce the use of virgin materials and avoid sending useful materials to landfills by specifying reused materials, including structures and material with recycled content
	RA1.4 Use regional materials	Minimize transportation costs and impacts and retain regional benefits through specifying local sources
	RA1.5 Divert waste from landfills	Reduce waste, and divert waste streams away from disposal to recycling and reuse
	RA1.6 Reduce excavated materials taken off site	Minimize the movement of soils and other excavated materials off site to reduce transportation and environmental impacts
	RA1.7 Provide for deconstruction and recycling	Encourage future recycling, up-cycling, and reuse by designing for ease and efficiency in project disassembly or deconstruction at the end of its useful life
Energy	RA2.1 Reduce energy consumption	Conserve energy by reducing overall operation and maintenance energy consumption throughout the project life cycle
	RA2.2 Use renewable energy	Meet energy needs through renewable energy sources
	RA2.3 Commission and monitor energy systems	Ensure efficient functioning and extend useful life by specifying the commissioning and monitoring of the performance of energy systems
Water	RA3.1 Protect fresh water availability	Reduce the negative net impact on fresh water availability, quantity, and quality
	RA3.2 Reduce potable water consumption	Reduce overall potable water consumption and encourage the use of gray water, recycled water, and storm water to meet water needs
	RA3.3 Monitor water systems	Implement programs to monitor water systems performance during operations and their impacts on receiving waters

not spill over into areas beyond site boundaries, nor does it create obstrusive [*sic*] and disruptive glare." Concrete bridges can contribute to this credit because light-colored concrete requires fewer lights for the same amount of visibility. This reflectability also reduces energy costs associated with outdoor lighting because more reflective surfaces reduce the amount of fixtures and lighting required. Concrete bridges can reduce outdoor lighting requirements and can contribute to lessening the associated light pollution.

QL2.4 Improve community mobility and access

For this credit, the metric is "extent to which the project improves access and walkability, reductions in commute times, traverse times to existing facilities and transportation." This all must be considered while improving user safety and considering all modes of transportation, such as personal vehicle, commercial vehicle, transit and bike/pedestrian. There are synergies between reducing environmental impacts and reducing construction-related user delays. During initial construction, various concrete bridge types can minimize on-site construction activities, thereby lessening the amount of time that drivers are inconvenienced. Likewise, by choosing a concrete bridge that has greater durability and fewer maintenance requirements, user delays during the service life of the bridge can also be reduced. This in turn reduces energy consumption of user vehicles and the resultant emissions to air.

Leadership (LD)

Strategies in this category relate to incentivizing more-credible management and leadership related to a project's sustainability. Broad credit categories include collaboration, management, and planning. Most of the strategies in the Leadership category relate to the project team, thus aren't as related to the structural system chosen for a bridge. There are bridges where stakeholder input (LD1.4) has guided the selection of the structural system. However, no strategies in the Leadership category are explained in more detail in this article.

Resource Allocation (RA)

Strategies in this category relate to reducing a project's embodied energy and use of virgin, non-renewable resources. Broad credit categories include materials, energy, and water. Table 2 lists the credits in this category and their intents. Four strategies in the Resource Allocation category that relate to concrete bridges are explained in more detail in the following sections.

RA1.3 Use recycled materials

To achieve this credit, projects must use a "percentage of project materials that are reused or recycled." Concrete bridges can contribute to this credit by using industrial wastes such as fly ash, slag cement, and silica fume as part of the cementitious materials—with certain aesthetic (color) and early compressive strength considerations. This strategy reduces the environmental impact of the concrete and also uses by-product materials that may otherwise be disposed of in a landfill.

RA1.4 Use regional materials

The metric for this credit is "percentage of project materials by type and weight or volume sourced within the required distance." For concrete, the distance requirement is 100 miles. Using local materials reduces the environmental impact (energy and emissions) related to transporting heavy building materials. Most concrete plants (ready-mixed and precast) are close to project sites, and likewise the cement, aggregates, and reinforcing steel used to make the concrete, and the raw materials to manufacture cement, are usually obtained or extracted from local sources.

RA1.5 Divert waste from landfills

For this credit, the metric is "percentage of total waste diverted from disposal." Precast concrete girders can be reused when bridges are expanded, and concrete can be recycled as road base, fill, or aggregate in new concrete at the end of its useful life. Concrete pieces from demolished structures can be reused to protect shorelines. Most concrete from demolition in urban areas is recycled and not placed in landfills. Also important is that concrete generates a small amount of waste with a low toxicity.

RA1.7 Provide for deconstruction and recycling

To contribute to this credit, the project must use a "percentage of components that can be easily separated for disassembly or deconstruction." Precast concrete bridge girders can be reused for pedestrian crossings or other applications. To reuse components effectively,

Table 3–Climate and Risk Credits and Intents

Credit Category	Credits	Intent
Emission	CR1.1 Reduce greenhouse gas emissions	Conduct a comprehensive life-cycle carbon analysis and use this assessment to reduce the anticipated amount of net greenhouse gas emissions during the life cycle of the project, reducing project contribution to climate change
	CR1.2 Reduce air pollutant emissions	Reduce the emission of six criteria pollutants: particulate matter (including dust), ground level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and noxious odors
Resilience	CR2.1 Assess climate threat	Develop a comprehensive Climate Impact Assessment and Adaptation Plan
	CR2.2 Avoid traps and vulnerabilities	Avoid traps and vulnerabilities that could create high, long-term costs and risks for the affected communities
	CR2.3 Prepare for long-term adaptability	Prepare infrastructure systems to be resilient to the consequences of long-term climate change, perform adequately under-altered climate conditions, or adapt to other long-term change scenarios
	CR2.4 Prepare for short-term hazards	Increase resilience and long-term recovery prospects of the project and site from natural and man-made short-term hazards
	CR2.5 Manage heat islands effects	Minimize surfaces with a high solar reflectance index (SRI) to reduce localized heat accumulation and manage microclimates

engineers need to be able to determine the residual service life of the components. Precast concrete construction provides the opportunity to disassemble the bridge should its use or function change, and the components can be reused in a different application. These characteristics of precast concrete make it sustainable in two ways: by diverting solid waste from landfills and by reducing the depletion of natural resources and production of air and water pollution caused by new construction.

Other ways that the concept of reuse is facilitated with concrete components are as follows:

- Concrete pieces from demolished structures can be reused to protect shorelines and create fisheries.
- Wood forms can generally be used 25 to 30 times without major maintenance while fiberglass and steel forms have significantly longer service lives.

Natural World (NW)

Strategies in this category relate to a project's impact on biodiversity. Broad credit categories include purpose, well being, and community. Most of the strategies in the Natural World category relate to where the project is located, thus aren't as related to the structural system chosen for a bridge. The use of longer spans, segmental construction, or top down construction can be used to minimize the impact at ground level, however, no strategies in the Natural World category are explained in more detail in this article.

Climate and Risk (CR)

Strategies in this category relate to minimizing emissions and ensuring a project is resilient. Broad credit categories include emissions and resilience. Table 3 lists the credits in this category and their intents. Four strategies in the Climate and Risk category that relate to concrete bridges are explained in more detail in the following sections.

Resilience

Credits CR2.1, CR2.3, and CR2.4 relate to the ability of a structure to withstand, and continue to function to some degree, after a natural or man-made disaster. The metric for each of these credits is as follows:

- CR2.1 Assess climate threat: prepare a plan that is a "summary of steps taken to prepare for climate variation and natural hazards."
- CR2.3 Prepare for long-term adaptability: "the degree to which the project has been designed for long-term resilience and adaptation."
- CR2.4 Prepare for short-term hazards: "steps taken to improve protection measures beyond existing regulations."

Concrete bridges can contribute to these three credits because concrete structures are resistant to tornados, hurricanes, wind, floods, and earthquakes. Concrete can be economically designed to resist tornadoes, hurricanes, and wind.

In general, concrete is not damaged by water; concrete that does not dry out continues to gain strength in the presence of moisture. Concrete submerged in water only absorbs very small amounts of water even over long periods of time, and typically this water does not damage the concrete.

Concrete structures can be designed to be resistant to earthquakes. Appropriately designed concrete systems have a proven capacity to withstand major earthquakes.

CR2.5 Manage heat islands effects

The metric for this credit is "[maximize] surfaces with a high solar reflectance index (SRI) to reduce localized heat accumulation and manage microclimates." Concrete without added pigment can meet the high SRI value (29) required in this credit. Concrete bridges provide reflective surfaces that minimize the urban heat island effect and contribute to this credit. Urban heat islands are primarily attributed to horizontal surfaces, such as roads, decks, and walkways, which absorb solar radiation. Two methods of mitigating heat islands are providing shade and increasing albedo. Using materials with higher albedos (solar reflectance values), such as concrete, will reduce the heat island effect, save energy, and improve air quality.

Application

Project teams use the assessment tools provided by the Envision system to evaluate the community, environmental, and economic benefits of projects. Currently two tools are available, with two new tools projected for release after 2012. The available tools include the following:

- Stage 1—Self-assessment checklist: this tool can be used for educational purposes or to track project progress related to sustainability.
- Stage 2—Third-party, objective rating verification: in this scenario, the project team's assessment is validated by an independent, third-party verifier. This allows for public recognition of the project. Using this tool, projects can earn points in 60 potential credits within the five credit categories.

EDITOR'S NOTE

More information on this rating system can be found at www.sustainableinfrastructure.org.

Pennsylvania Turnpike Commission

by Michael Wetzel, Urban Engineers Inc., and James Stump, Pennsylvania Turnpike Commission

Typical reinforced concrete rigid frame bridge built in the 1930s. Preservation of this bridge was completed in 2010. All photos: Pennsylvania Turnpike Commission.

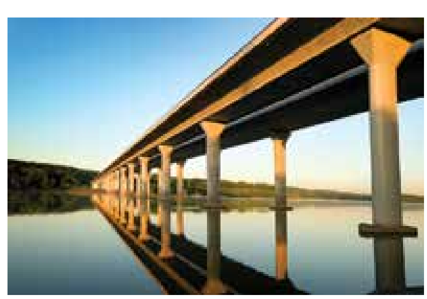
From the time the Pennsylvania Turnpike was constructed in 1940, the use of concrete has been instrumental in the construction of its bridges. Always considered the original signature bridge of the Pennsylvania Turnpike, the reinforced concrete rigid frame bridges are still providing safe passage for the traveling public after more than 70 years.

The use of concrete is still prevalent today as the Commission is in the midst of their most ambitious statewide reconstruction initiative in their history with more than 90 miles of Pennsylvania Turnpike already reconstructed, more than 20 miles currently under construction, and more than 150 miles currently in design. The program is the first complete restoration of the toll road since it was built and includes the addition of a third lane in each direction. The complete replacement of all overhead and mainline bridges is a part of this restoration with a number of the structures being replaced with prestressed concrete beams. This expansion is needed to accommodate the more than 186 million vehicles per year that travel the Pennsylvania Turnpike's 545 miles of roadway.

Recently the Commission completed a number of major bridge crossings that were all constructed with concrete. Three of these significant river crossings utilized segmental construction and are now considered the modern day signature bridges of the Pennsylvania Turnpike. These three successful projects are indicative of the advantages that can be provided by segmental concrete bridges: longer spans that provide a reduced substructure footprint and minimized environmental impacts, as well as shorter construction durations which minimize inconveniences to the tollway's customers.

The Susquehanna River Bridge, the state's first vehicular segmental concrete bridge, opened in 2007. The mile-long structure provided a variety of benefits, including speed of erection and a construction approach that provided little disruption to the constricted site. The design features twin structures, each 5910 ft long and 57 ft wide, with precast concrete, segmental spans that are typically 150-ft long and were erected using the span-by-span method.

The Allegheny River Bridge, near Pittsburgh, was Pennsylvania's first cast-in-place, balanced cantilever bridge. Completed in 2010, the twin 2350-ft-long parallel structures feature six spans, the longest of which is 532 ft. Using traveling forms, the bridge was cast-in-place using the balanced cantilever method, working from the tops of the piers.



The Susquehanna River Bridge was Pennsylvania's first vehicular segmental bridge.

The Allegheny River Bridge was completed in 2010 and is the state's first cast-in-place, balanced cantilever bridge.

The Monongahela River Bridge completed in 2012, is part of an extensive expansion to the Mon/Fayette Expressway and spans the Monongahela River near Brownsville, Pa. The 3022-ft-long bridge features seven spans, the longest of which is 518 ft. The structure was built using the balanced cantilever method. The concrete segments consist of 89-ft 4-in.-wide, dual-cell box girders with a three webs. This configuration was chosen due to the width of the structure, which consists of four lanes and a median.

The slender superstructure of the Monongahela River Bridge compliments its 200-ft-tall piers.

Finally, in the fall of 2011, the Pennsylvania Turnpike opened to traffic its twin bridges spanning the Lehigh River and Pohopoco Creek in Carbon County, which all utilized prestressed concrete bulb-tee beams. The 1539-ft-long Lehigh River structures consist of 10 spans with lengths reaching 168 ft, which were the longest prestressed concrete bridge beams to be fabricated in Pennsylvania. The 1020-ft-long Pohopoco Creek structures consist of seven spans with lengths reaching 158.5 ft.

It is expected that concrete structures will continue to play a significant role as the Commission goes forward with the management of their bridge program.

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STATE

Statewide Solutions

Missouri's Safe & Sound Bridge Improvement Project

by Ken Warbritton, Missouri Department of Transportation, and Harry Koenigs, KTU Constructors

Old bridge before construction (left) and new bridge after construction (right), Andrew County Route 98. All photos: MoDOT.

Missouri recently completed a landmark project, the Safe & Sound Bridge Improvement Project—repairing or replacing over 800 of the state's worst bridges in three-and-a-half years. The bulk of this effort involved a single design-build contract for 554 replacement structures. This landmark, state-wide contract is the focus of this article, showcasing the results achieved through innovation, speed, and volume associated with this unique partnership. The remaining 248 bridges were predominantly rehabilitation and deck replacement projects, which were performed with a modified design-bid-build process through the typical Missouri Department of Transportation (MoDOT) construction program.

Showcasing the results achieved through innovation, speed, and volume.

MoDOT envisioned this large state-wide effort to improve the overall condition of their bridge system. The single design-build effort was led by KTU Constructors, a joint venture of Kiewit Western Co., Traylor Brothers Inc., and United Constructors Inc., with HNTB and the LPA Group (a division of Michael Baker Jr. Corp.) as their design team.

The design-build contract format afforded flexibility in the choice of design standards, and in assigning and managing risks that simply wouldn't be available in a traditional design-bid-build procurement. This contract model also allowed for a dynamic process to accommodate schedule flexibility and provide overall economies of scale in prefabricating bridge elements. These factors all contributed to the overall speed of the project.

Planning

The first step in this effort was selecting the bridges to be replaced. Missouri has over 10,000 bridges on the MoDOT system, and 10% were in poor or serious condition. The project budget limited the number of these bridges that could be replaced, and the speed of the project resulted in screening out any complex or environmentally challenging sites. This way a prioritized bridge list was assembled.

Environmental screening and National Environmental Policy Act (NEPA) approval efforts began as soon as the bridge list was identified. This was performed prior to the design-build procurement in order to obtain NEPA clearance ahead of project start. Once the contract was awarded, the majority of environmental constraints were already targeted in the project construction schedule.

Speed was a central theme of the project from the start, as stated in the project goals:

- Deliver good bridges at a great value.
- Minimize public inconvenience through increased construction speed and flexible schedule.
- Complete construction by October 31, 2014.

Procurement

The procurement process started in October 2008 and consisted of a two-step, qualification or short-listing process, followed by confidential meetings with each qualified proposer to discuss its strategies and approach. The final conforming contract was signed in June 2009.

Scheduling and organization were the early challenges, which were achieved by dividing the entire state into regions that corresponded loosely with MoDOT's internal district boundaries. The schedule for each region started with the higher-standard roads and then moved into the collector road system. This proved to be a great help in managing the logistics, as cranes and prefabricated bridge components could more easily access each site, with little potential for encountering access issues due to load-restricted bridges on the existing system.

Execution

Four initial bridges were constructed in the fall of 2009, at the same time a monumental design effort for all remaining bridges was starting. The KTU strategy for execution revolved around standardizing the design process with

Number of Each Type of Bridge Structure Designed as Part of Missouri's Safe & Sound

Structure Type	Number
Adjacent core slabs	196
Adjacent box beams	116
Adjacent core slab/box beams	45
Spread core slabs	80
Spread box beams	41
Spread core slabs/box beams	23
Steel girders	8
NU girder	5
Flat slabs	17
Box culverts	15
Pipe culverts	1
Super-Cors	1
Prestressed slabs	3
Hybrid composite	3
TOTAL	**554**

a focus on prefabricated bridge elements and subcontracting a large number of bridges, grouped in packages within each region. This combination of design standardization and subcontracting led to a rapid design schedule, which was completed within one year. The design standards development and process was a significant challenge, which was met through teamwork and nearly constant communication. Once started, the schedule was relentless, proceeding at a pace of over 10 bridges designed every week. The use of constructability reviews was a centerpiece of this process, where constructors, designers, and owner staff all worked together to review the initial design solution and layout for each individual bridge. Key items which were standardized in the design included the following:

- Limited bridge types
- Standardized design elements
- Beams produced in 10-degree skew increments up to 40 degrees
- Beam lengths in 5-ft increments

The relatively shallow depths of the adjacent beams did not necessitate raising the bridge elevation and causing additional roadway work. Each bridge type included a sequence of pile foundations (both H and pipe piles), placement of a reinforced concrete cap, precast concrete beam setting with grouting and transverse post-tensioning, waterproofing, and, finally, paving an asphalt wearing/leveling surface. This system resulted in consistent construction speed while rebuilding the bridge essentially in place with no reduction in hydraulic performance.

Setting adjacent beams.

Fabrication and Delivery

The next major logistical challenge was the fabrication of precast, prestressed concrete beams. Standardization of the beam types and lengths aided in production scheduling, however the subcontracting schedule quickly became the critical path to producing the needed bridge components in advance of construction crews mobilizing at each site. Timing was critical and scheduling of finished bridge beams was monitored constantly. Not only did the beams have to be ready and pass quality checks, they had to be transported across the entire state on a tight schedule.

Teamwork was essential with suppliers and plant inspectors communicating with designers and constructors to obtain quality. Delivery and logistics were achieved through teamwork with MoDOT's Motor Carrier division. Motor Carrier permit staff and Safe & Sound staff from both MoDOT and KTU exchanged information on route selection, carrier requirements, escorts, curfew restrictions, and the overall permitting process. Close contact with the permitting staff was a key to success, since there were frequent challenges to meet when shipping over 81 miles of precast, prestressed concrete beams to remote locations throughout Missouri.

Construction began in earnest in the 2010 season, when 152 bridges were completed. A benefit of using similar bridge types is that crews got faster as they grew familiar with the process and the bridge types. Quality issues were overcome through diligent tracking and innovative resolution as well as through development of a best-practices manual (BPM). The BPM provided up-to-date guidance to prevent repeat issues and acceptable corrective measures

Prestressed concrete box beam fabrication.

developed throughout the project. This BPM was used consistently at all training sessions and in the field, undergoing multiple revisions to constantly improve quality and consistency.

The 2011 construction season was the most productive. All design work was complete and prefabrication stayed ahead of schedule to produce 281 bridges. This tremendous effort was achieved in spite of significant challenges posed by floods. First, the Mississippi River flooded extensively in southeast Missouri in the spring, followed by Missouri River flooding in the northwest and central portions of the state through late summer into fall, which eliminated access to several scheduled bridges in each instance. The project's size, schedule flexibility, and interchangeable bridge parts provided alternative bridge construction sites, and played a big role in maintaining this record-setting performance in 2011.

Fastest Bridges by Structure Type

Structure Type	No. of Spans	Time, days unless noted otherwise
Adjacent beams	1	8
Adjacent beams	2	31
Adjacent beams	3	28
Adjacent beams	4	33
Box culverts		27†
Spread beams with concrete deck		13

† night-time hours of traffic impact

Stacking and storing bridge beams on site prior to construction provided added efficiency.

Chariton County Route 11 Railroad Bridge, the final bridge of Missouri's Safe & Sound Bridge Improvement Project, completed November 8, 2012.

The final year of construction was 2012, and construction stayed at the record pace of nearly 10 bridges per week through the majority of the season, completing 117 bridges, with the final bridge of the project completed in early November—almost two years ahead of schedule.

The overall rate of construction averaged 42 days per bridge and 20 bridges completed per month, with an accelerated pace during the peak of each construction season of 10 bridges completed per week. Ten separate locations presented the option of constructing two or three bridges in close proximity, under a single road closure. Pursuing these opportunities alone saved over 400 road closure days, as compared to sequential construction. The large number of bridges also afforded the opportunity to shift construction schedules to avoid conflicts with local community events, which helped build public acceptance of the project.

Successful Completion

Overall, Missouri has shown the public will accept road closures for construction, provided the closure time is minimal and there is flexibility on timing to coordinate with local events. The overall condition of the Missouri bridge system was dramatically improved at a much faster rate than typical design and construction processes could achieve. The Safe & Sound Bridge Improvement Project is testimony to teamwork and innovation, through the use of a design-build process for a statewide system improvement.

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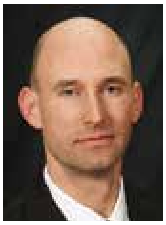
Lightweight Concrete in Highway Infrastructure



by Ben Graybeal and M. Myint Lwin, Federal Highway Administration

Structural lightweight concrete (LWC) has been used successfully in bridges and structures for a century. The benefits of using LWC are many and varied. The main benefit is in the reduction of dead load in:

- allowing bridge deck widening with few or no changes to the existing structure,
- improving seismic structural response,
- designing longer-span bridges,
- fabricating smaller structural elements and thinner sections,
- lowering handling and transportation costs, and
- reducing foundation and substructure costs.

Lightweight aggregates for LWC may be from volcanic sources, byproducts from coal burning, or manufactured by expanding shales, clays, and slates (ESCS). ESCS lightweight aggregates are the most commonly used in modern LWC construction. ESCS aggregates are structurally strong, dimensionally stable, physically durable, light in weight, highly absorptive and retentive of water, environmentally friendly, and great at controlling cracks.

Features of LWC

LWC is concrete whose density has been reduced through the use of lightweight aggregates. For use in highway bridges and structures, LWC normally uses ESCS as coarse and/or fine aggregates within the concrete mixture proportions. LWC with compressive strengths up to and above 8 ksi are possible.

In practice, a concrete with a density less than 135 lb/ft^3 is considered LWC. Concretes with densities between 120 and 135 lb/ft^3 commonly use a mixture of conventional and lightweight aggregates, while those below 120 lb/ft^3 use all lightweight coarse and fine aggregates. LWC with densities between 100 and 135 lb/ft^3 are appropriate for use in structural applications.

The use of LWC in bridges does necessitate some special considerations. The *AASHTO LRFD Bridge Design Specifications* require that special reduction factors be applied to the resistance afforded by LWC. These provisions are in the process of being updated to accurately reflect the modern LWC mixture proportions commonly deployed in bridges. Use of LWC also requires special quality control processes, including the assurance of aggregate saturation at the initiation of concrete mixing.

Research on Performance

Strong interest in the use of LWC for bridges has resulted in a series of research projects that have aimed to characterize the structural performance of this class of concrete. The National Cooperative Highway Research Program (NCHRP) Project 18-15 titled "High-Performance/High-Strength Lightweight Concrete for Bridge Girders and Decks," led by researchers at Virginia Tech, was recently published as NCHRP Report No. 733. This effort focused on structural performance of LWC with densities below 125 lb/ft^3.

The Federal Highway Administration (FHWA) research group also recognized the potential value of LWC and has recently completed a series of nearly 100 full-scale structural tests characterizing the shear, flexural, strand bond, and mild-steel bond performance of a variety of LWCs with densities of 125 to 135 lb/ft^3. This density range is commonly referred to as specified density concrete and is commonly used in structural elements requiring both reduced weight and high performance.

Currently, the FHWA research group is working with AASHTO Bridge Technical Committee T-10 to compile results from all relevant studies, develop predictive relationships, and draft proposals to update design recommendations pertaining to the variety of density ranges that occur within the LWC class of materials. The results of recent research are promising, indicating that some of the design restrictions placed on LWC decades ago may no longer reflect the performance that can be achieved with modern structural LWC.

Shear test of lightweight concrete prestressed girder at Turner-Fairbank Highway Research Center. Photo: Gary Greene, PSI Inc.

LWC in Highway Bridges

Two examples of bridges using LWC are given here.

Bridge Replacement in North Carolina

The Morganton Bridge replacement project in Fayetteville, N.C., is the first example provided of LWC use in highway bridges. This two-span replacement project consisted of widening the roadway and replacing the aging superstructure over the All-American Freeway (I-66). The project, an America's Transportation Awards winner, was completed in 10 months with the final cost being about 3% under budget.

Lightweight concrete was used in the deck of the Morganton Bridge to reduce deck weight so that the existing columns and foundations could be retained. Photo: Carolina Stalite Co.

High-Strength LWC in Georgia

To determine the practicality and performance of high-strength LWC (HSLWC) bridge girders, the Georgia Department of Transportation (GDOT) designed and constructed the center two spans of the four-span I-85 Ramp crossing SR 34 in Newnan, Ga., with HSLWC for the AASHTO BT-54 girders and normal weight concrete for the bridge deck. The precast, prestressed concrete girders have a span length of 110 ft.

From the construction experience and monitoring results, GDOT determined that HSLWC could be applied to construction practice and the LWC provided an effective material for reducing the weight of a bridge, allowing longer spans to be efficiently constructed.

Closing Remarks

LWC has been tested in laboratories and demonstrated in the field to have good structural properties for constructing durable and sustainable bridges and structures, where weight reduction is an important factor in design. Use of LWC does necessitate developing design and construction specifications to meet the specific needs of a project. Quality control and quality assurance are just as important in LWC practices as in normal weight concrete. Adequate soaking of the lightweight aggregate prior to batching, and proper evaluation of the modulus of elasticity of LWC are essential in the successful application of LWC.

It is important to work with the producers of structural LWC throughout project development. The producers can provide very useful information on design criteria and construction specifications.

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Greene, G. G. and B. A. Graybeal. 2012. *Synthesis and Evaluation of Lightweight Concrete Research Relevant to the* AASHTO LRFD Bridge Design Specifications: *Identification of Articles for Further Evaluation and Potential Revision*, Federal Highway Administration, NTIS Report No. NTIS PB2013-102358. FHWA, Washington, DC. 36 pp.

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Liles, P. and R. B. Holland. 2010. "High Strength Lightweight Concrete for Use in Precast Prestressed Concrete Girders in Georgia." *HPC Bridge Views*, Federal Highway Administration and National Concrete Bridge Council, Issue 61, May/June. http://www.hpcbridgeviews.org.

Georgia Department of Transportation achieved a 20% decrease in shipping weight using girders with a 10.0 ksi compressive strength lightweight concrete. Photo: Paul Liles, Georgia Department of Transportation.

EDITOR'S NOTE

Another source of information on good guidance and practices is the Expanded Shale, Clay and Slate Institute (ESCSI). This institute represents most of the producers of ESCS in the United States. ESCSI has a reference library of technical documents and recent papers on structural lightweight concrete on its website: http://www.escsi.org. Contact information is also given on the website.

Establishing Continuity with Precast Concrete Components

by Dr. Henry G. Russell

Continuity over the intermediate supports of multispan bridges may be used:

- to provide a continuous structure for superimposed dead and live loads, and
- to eliminate expansion joints.

The former requires full-depth section continuity involving both negative and positive moment connections. The latter can be achieved with either full-depth section continuity or deck-only continuity; often called a link slab.

For bridges with a cast-in-place concrete deck, negative moment continuity can be accomplished using reinforcement in the deck. Providing negative moment continuity with non-composite precast concrete components is more challenging but solutions that emulate cast-in-place construction have been used as described in the following examples.

Route 103 over the York River

In the Route 103 Bridge over the York River in York, Maine, positive moment continuity was established by extending the strands beyond the ends of the precast concrete beams and bending them upwards into the cast-in-place concrete diaphragm. A 7-in.-thick concrete deck was cast on the beams prior to making the continuity connections. The No. 8 reinforcing bars used to provide negative moment continuity extended from the end of the deck at the interior supports. The negative moment connection over the piers was then made using mechanical couplers because the closure was not wide enough to allow for tension lap splices.

Route 103 Bridge over the York River showing bars extending from the deck. Photo: Vanasse Hangen Brustlin.

Sibley Pond Bridge

The Sibley Pond Bridge in Canaan-Pittsfield, Maine, utilized a full positive and negative moment connection over the piers. A special detail for the positive moment connection was developed using a steel end plate and ASTM A706 weldable reinforcement. The steel plate was cast flush with the end of each precast concrete girder and anchored into the girder using two No. 9 bars welded to the inside face of the plate. Two No. 9 reinforcing bars with a 90-degree hook were welded to the outside face of each plate. Overlapping hooked bars from beams on opposite sides of the pier formed the positive moment connection using a cast-in-place concrete diaphragm.

Negative reinforcement was extended out of the ends of the precast concrete beams. The negative moment connection was made using mechanical couplers to field splice the reinforcing bars between adjacent precast concrete beams at the piers. This required the precaster to align the bars from adjacent beams to tight tolerances to ensure the couplers would line up.

Sibley Pond Bridge showing the use of mechanical couplers. Photo: Parsons Brinckerhoff.

Upton Road over Bear Creek

The Upton Road over Bear Creek Bridge, Jackson County, Ore., was Oregon's first continuous-deck, precast concrete, bulb-tee bridge. The bridge is on a horizontal alignment that transitions from a tangent to a curve using straight beams. Consequently, reinforcing bars projecting from the top flanges of the precast concrete bulb tees in adjacent spans are not parallel. To provide the negative moment continuity, bars with 90-degree hooks on both ends were lap spliced with the bars projecting from the top flanges.

Link Slab

With the link slab approach, the longitudinal deck reinforcement is extended into the link slab and spliced in a similar manner to the previous examples. Continuity is established for both top and bottom deck bars. Two important details of the link slab are to provide a bond breaker between the deck and a portion of the precast concrete beams and to ensure that no shear connections are provided between the link slab and the beams. This provides a greater length to accommodate the rotation at the ends of the precast concrete girders. A

EDITOR'S NOTE

More information about the three projects described in this article is available as follows:

- *Route 103 Bridge over the York River:* ASPIRE *Spring 2011, p. 46.*
- *Sibley Pond Bridge: Proceedings of the PCI 2012 Convention and National Bridge Conference, Paper No. 39.*
- *Upton Road over Bear Creek Bridge: Proceedings of the PCI 2012 Convention and National Bridge Conference, Paper No. 24.*

Concrete Connections is an annotated list of websites where information is available about concrete bridges. Fast links to the websites are provided at www.aspirebridge.org.

IN THIS ISSUE

www.foothillextension.org
This website of the Metro Gold Line Foothill Extension Construction Authority provides more information about the new Gold Line extension. Click on I-210 Bridge on the map for information about the bridge described on pages 22 to 24.

www.i69indyevn.org
Visit this Indiana Department of Transportation website for more information on the I-69 project that will eventually link Evansville and Indianapolis, Ind. The bridge over the Potoka River described on pages 14 to 16 is part of this project.

www.modot.mo.gov/safeandsound/
Visit the website for more details about Missouri's Safe & Sound project that resulted in 802 new or improved bridges in 3½ years as described on pages 40 to 42. An interactive map provides a photograph and details of each bridge. Before and after photographs are provided.

http://abc.fiu.edu/wp-content/uploads/2012/10/russo-fiu-presentation.pdf
A presentation titled *ABC Concrete Bridges–Continuity Considerations* related to the Safety and Serviceability article on page 46 is available to download from the Florida International University website.

Environmental

http://environment.transportation.org/
The Center for Environmental Excellence by AASHTO's Technical Assistance Program offers a team of experts to assist transportation and environmental agency officials in improving environmental performance and program delivery. *The Practitioner's Handbooks* provide practical advice on a range of environmental issues that arise during the planning, development, and operation of transportation projects.

www.environment.transportation.org/teri_database
This website contains the Transportation and Environmental Research Ideas (TERI) database. TERI is the AASHTO Standing Committee on Environment's central storehouse for tracking and sharing new transportation and environmental research ideas. Suggestions for new ideas are welcome from practitioners across the transportation and environmental community.

Sustainability

http://sustainablehighways.org
The Federal Highway Administration has launched an internet-based resource designed to help state and local transportation agencies incorporate sustainability best practices into highway and other roadway projects. The Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) is a collection of best practices to help transportation agencies integrate sustainability into their programs and projects. INVEST has three modules: system planning, project development, and operations and maintenance.

www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf
The FHWA *Bridge Preservation Guide: Maintaining a State of Good Repair Using Cost-Effective Investment Strategies* may be downloaded from this website.

www.fhwa.dot.gov/bridge/preservation/
This website provides a toolbox containing bridge-related links on bridge preservation.

Bridge Management

NEW www.fhwa.dot.gov/federal-aidessentials
This website features a central online library of over 80 informational videos and resources designed to help local public agencies—counties, cities, and towns—manage their Federal-aid Highway Program projects.

Bridge Technology

www.aspirebridge.org
Previous issues of *ASPIRE*™ are available as pdf files and may be downloaded as a full issue or individual articles. Information is available about subscriptions, advertising, and sponsors.

www.nationalconcretebridge.org
The National Concrete Bridge Council (NCBC) website provides information to promote quality in concrete bridge construction as well as links to the publications of its members.

www.concretebridgeviews.com
This website contains 69 issues of *Concrete Bridge Views* (formerly *HPC Bridge Views*), an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of concrete in bridges.

NEW www.americastransportationawards.org
Visit this website to learn about the 10 national finalists in the 5th annual American Transportation Award competition sponsored by AASHTO, AAA, and the U.S. Chamber of Commerce. A video showcasing the 10 national finalists is available at http://bit.ly/ATA2012Top10.

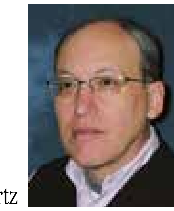
www.fhwa.dot.gov/asset/hif12029/hif12029.pdf
A new case study by FHWA titled *Bridge Management Practices in Idaho, Michigan, and Virginia* examines how three states have succeeded in implementing a bridge management system. Publication No. FHWA-IF-12-029 may be downloaded from this website.

www.dot.state.mn.us/metro/projects/35estpaul/maryland.html
Visit this website to watch the Minnesota Department of Transportation use self-propelled modular transporters to move a finished concrete bridge into position. Click on time-lapse videos to see the process in less than two minutes.

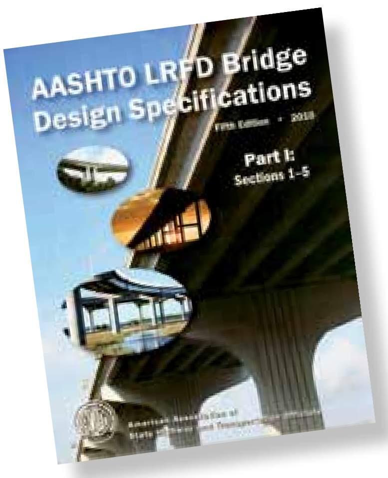
www.fhwa.dot.gov/publications/focus/12aug/12aug02.cfm
This FHWA website contains an article from the August 2012 issue of FOCUS. Links are provided to the FHWA report No. FHWA-HIF-09-004, the ASR Field Identification Handbook, and the ASR Reference Center.

www.fhwa.dot.gov/bridge/abc/docs/abcmanual.pdf
The FHWA report titled *Accelerated Bridge Construction: Experience in Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems* may be downloaded from this website.

AASHTO LRFD: *Shear Resistance, Part 2*



by Dr. Dennis R. Mertz



The AASHTO *LRFD Bridge Design Specifications* currently includes the following six different procedures to estimate the shear resistance of concrete members:

a. Article 5.8.3.4.1—Simplified Procedure for Nonprestressed Sections
b. Article 5.8.3.4.2—General Procedure
c. Article 5.8.3.4.2 reference to Appendix B5—General Procedure for Shear Design with Tables
d. Article 5.8.3.4.3—Simplified Procedure for Prestressed and Nonprestressed Sections
e. Article 5.8.6—Shear and Torsion for Segmental Box Girder Bridges
f. Article 5.6.3—Strut-and-Tie Model

Procedures a, c, and f of the six procedures were discussed in the Winter 2013 issue of *ASPIRE*™. These procedures were included in the first edition of the *LRFD Specifications* published in 1994. Procedures b, d, and e were added over the years since the original edition of the *LRFD Specifications* and are reviewed herein.

Procedure b is the current basic sectional model in the *LRFD Specifications*. It represents a refinement of the iterative modified compression field theory (MCFT) of Procedure c. In Procedure b, a factor indicating ability of diagonally cracked concrete to transmit tension and shear, β, and the angle of inclination of diagonal compressive stresses, θ, are directly calculated. In the author's opinion, Procedure b is the preferred procedure to estimate shear resistance when a sectional model is appropriate. Again, sectional models are based upon the assumption that the reinforcement required at a particular section depends only on the separated values of the factored section force effects (moment, axial load, shear, and torsion) and does not consider the specific details of how the force effects are introduced into the member. Procedure c in Appendix B5 remains only so that software written using the previous tabularized values of β and θ, while perhaps yielding slightly different solutions, remains code compliant and can be used to load rate bridges designed with the table values.

The newness of the MCFT and its perceived complication due to its iterative nature, as presented in the first edition of the *LRFD Specifications*, led to a National Cooperative Highway Research Program (NCHRP) project to find a simpler estimate of shear resistance. This NCHRP project resulted in Procedure d. Procedure d is more in line with that of the American Concrete Institute's (ACI's) approach, wherein the nominal shear resistance provided by the concrete is taken as the lesser of the resistance associated with the two types of inclined cracking: flexure-shear cracking and web-shear cracking for which the associated resistances are V_{ci} and V_{cw}, respectively. This procedure was developed concurrently with Procedure b, the refined MCFT with direct calculation of β and θ. Procedure d appears less accurate for bridges than Procedure b. In the author's opinion, the simplicity of Procedure d is no longer needed as Procedure b is just as simple.

Finally, Procedure e was brought into the *LRFD Specifications* from the AASHTO *Guide Specifications for Design and Construction of Segmental Concrete Bridges* because of the segmental-bridge community's reaction to the newness of MCFT and their inexperience with MCFT. Slowly, the segmental-bridge community is warming to Procedure b for segmental bridges as well.

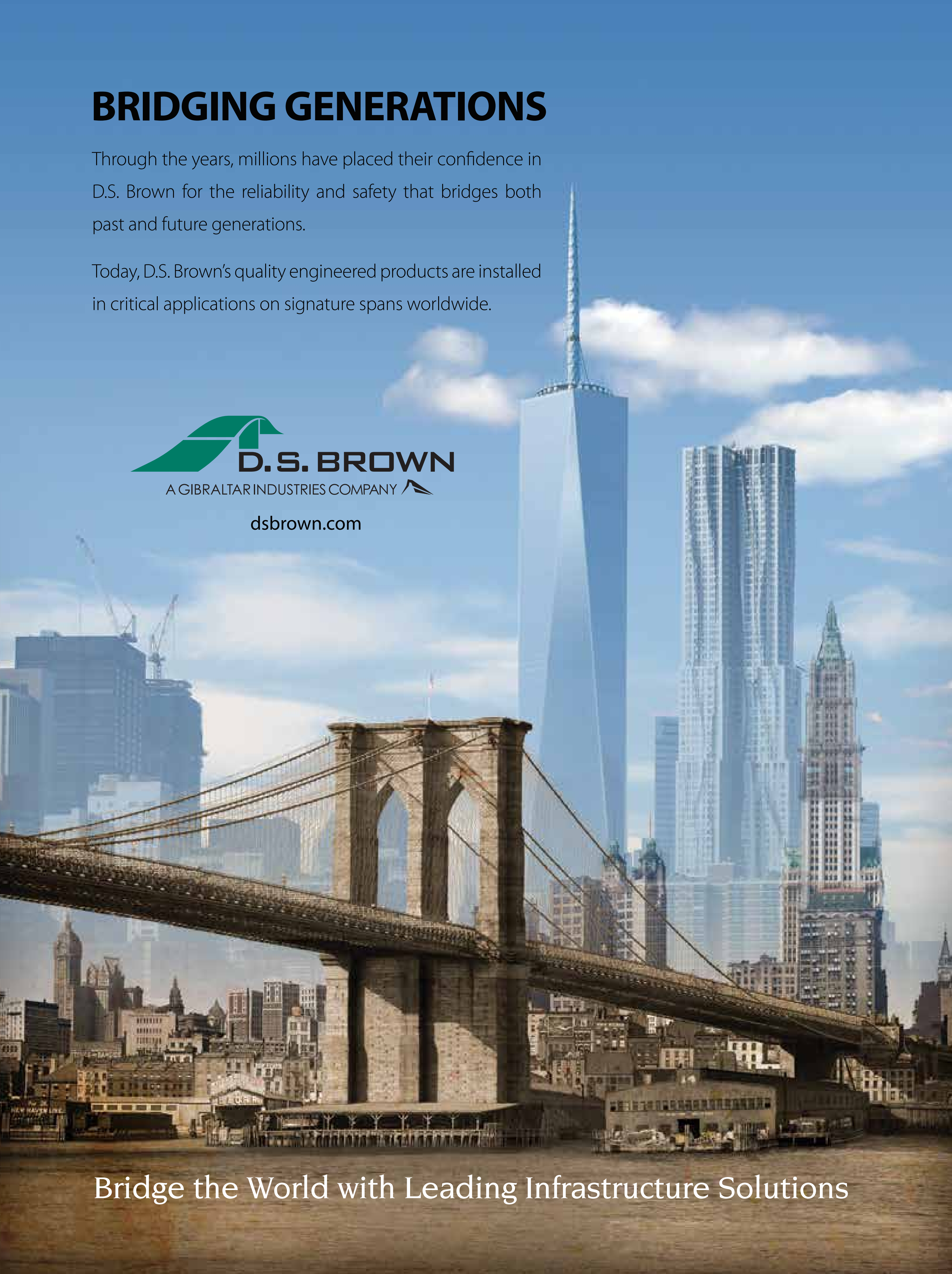
The AASHTO Technical Committee T-10, Concrete Design, is beginning an effort to reorganize and reassess the concrete design provisions of Section 5 of the *LRFD Specifications*. Most likely, these six variations in estimating shear resistance of concrete members will ultimately be consolidated.

Six Procedures to Estimate Shear Resistance

- Article 5.8.3.4.1—Simplified Procedure for Nonprestressed Sections
- Article 5.8.3.4.2—General Procedure
- Article 5.8.3.4.2 reference to Appendix B5—General Procedure for Shear Design with Tables
- Article 5.8.3.4.3—Simplified Procedure for Prestressed and Nonprestressed Sections
- Article 5.8.6—Shear and Torsion for Segmental Box Girder Bridges
- Article 5.6.3—Strut-and-Tie Model

EDITOR'S NOTE

If you would like to have a specific provision of the AASHTO LRFD Bridge Design Specifications *explained in this series of articles, please contact us a www.aspirebridge.org.*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