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THE CONCRETE BRIDGE MAGAZINE

WINTER 2013

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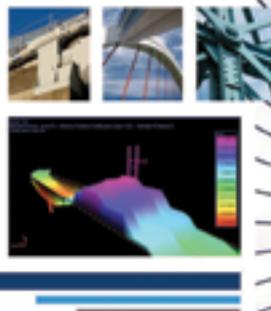
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Photo: PCI

Those That Show Up Help Make the Rules

William Nickas, *Editor-in-Chief*

Midway through my career, I had the privilege to be appointed to serve as a state bridge engineer (SBE). Twenty days later, I attended the AASHTO Subcommittee on Bridges and Structures annual business meeting in Nashville, Tenn. Three days into the meeting my head was swimming with all the things going on and, at the same time, I was totally impressed with the group of minds assembled to improve the nation's bridge specifications. At the Wednesday evening ceremony, I sat with an SBE that had been working in that role for more than 20 years. After our lengthy dinner conversation, it was clear the relationship-building experience of these meetings never gets old or stale. It was a great conversation and an experience I would never forget.

During my SBE years, I was very fortunate to have a few advisors on staff and several consultants that really assisted me while in public service. Their insight and recommendations led me to some of the most talented resources in our industry. During my tenure I learned several lifelong lessons:

- Always work to expand your network.
- Listen carefully and appreciate the perspective of those contributing. In nearly every exchange, there is a thread of advice or unique solution offered but, more importantly, seasoned wisdom that will help you someday.
- And as Thomas Jefferson said, "Nothing can stop the man with the right mental attitude from achieving his goal; nothing on earth can help the man with the wrong mental attitude."

It is very easy to get entrenched in our own companies, local organizations, and the activities of

our families and communities. Expanding and building relationships is very important, but growing our minds and knowledge base is equally important. Over the last few months, there have been several bridge conferences and symposiums and it's difficult to attend them all, but these meetings shape our industry.

While attending an Association of General Contractors (AGC) meeting, a contractor was complaining about a specification change by a Department of Transportation. The AGC president just kindly checked his notes and replied, "I see your firm did not participate in the meetings held six months ago... Those that show up help make the rules." I have never forgotten that reply.

These bridge venues always provide lessons learned, as well as exposure to ground breaking technology from both the U.S. and international engineering community. Now working as part of an association staff, my travel takes me to a variety of meetings. These events are always eye opening. The assembled audience of professional members (consultants), owners, other industry organizations, contractors and direct/indirect customers, and suppliers often lead to the next innovative, game changing widget, system, or solution.

The *ASPIRE*TM team uses these professional venues to mine material and ideas we believe will benefit our readership. During this demanding economic period, it can be challenging to attend some of these events. If your travel is limited, let this publication assist you to reach your goals safely and provide an avenue to strengthen relationships within the concrete bridge industry. I hope you enjoy this issue of *ASPIRE*, the concrete bridge magazine. 

Editor-in-Chief

William Nickas • wnickas@pci.org

Managing Technical Editor

Dr. Henry G. Russell

Managing Editor[†]

Wally Turner • wturner@pci.org

Associate Editors

Emily B. Lorenz
Craig A. Shutt

Editorial Administration

James O. Ahtes Inc.

[†]*ASPIRE*'s managing editor, Wally Turner, has returned to active military service. The entire *ASPIRE* staff wish him well, and thank him for his continued service to our country.

Art Director

Paul Grigonis

Layout Design

Tressa A. Park

Editorial Advisory Board

William Nickas, *Precast/Prestressed Concrete Institute*
William R. Cox, *American Segmental Bridge Institute*
Dr. David McDonald, *Epoxy Interest Group*
Dr. Henry G. Russell, *Henry G. Russell Inc.*

Cover

96th Street Bridge over U.S. 169

Kansas City, Missouri

Photo: Burns & McDonnell.

Ad Sales

Jim Oestmann

Phone: (847) 838-0500 • Cell: (847) 924-5497

Fax: (847) 838-0555 • joestmann@arlpub.com

Reprints

Paul Grigonis • pgrigonis@pci.org

Publisher

Precast/Prestressed Concrete Institute
James G. Toscas, President

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CONTRIBUTING AUTHORS



Richard Brice is a bridge software engineer for the Bridge and Structures Office at the Washington State Department of Transportation in Olympia, Wash.



Bijan Khaleghi is the state bridge design engineer at the Bridge and Structures Office of the Washington State Department of Transportation (WSDOT) in Olympia, Wash.



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.



Stephen Seguirant is vice president and director of engineering at Concrete Technology Corporation in Tacoma, Wash.



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CONCRETE CALENDAR 2013

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

February 4-8, 2013
World of Concrete 2013
Las Vegas Convention Center
Las Vegas, Nev.

March 18-20, 2013
DBIA Design Build in Transportation
Hilton Orlando
Lake Buena Vista, Fla.

April 13, 2013
ASA 2013 Spring Committee Meetings
Hilton & Minneapolis Convention Center
Minneapolis, Minn.

April 14-18, 2013
ACI Spring Convention
Hilton & Minneapolis Convention Center
Minneapolis, Minn.

April 15-16, 2013
ASBI 2013 Grouting Certification Training
J.J. Pickle Research Campus
The Commons Center
Austin, Tex.

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 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 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.

Corrections

Summer 2012

On page 29 of the Summer issue, the forces and coefficients of friction were incorrectly stated. In the right column, the second sentence of the second full paragraph should read, "The initial push required a total force of approximately 230 kips corresponding to 12% friction, and approximately 115 kips corresponding to 6% friction to continue moving the bridge."

Fall 2012

On page 60 of the Fall issue, the incorrect editor's note was published. The editor's note should read, "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 at www.aspirebridge.org."

On page 30 of the Fall issue, the stay-cable and post-tensioning/form traveler suppliers were inadvertently left off the profile listing. The stay-cable supplier was Tensacciai SpA of Italy, and the post-tensioning/form traveler supplier was Schwager Davis Inc., San Jose, Calif.

We regret these errors. Updated PDFs of these articles have been uploaded to the ASPIRE website at www.aspirebridge.org.

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Expanded Shale, Clay and Slate Institute Releases Internal Curing Resources



The Expanded Shale, Clay and Slate Institute (ESCSI) announces the release of several Internal Curing resources that have been developed over the last year.

Internal curing is achieved by incorporating prewetted expanded shale, clay and slate (ESCS) aggregate into the concrete mixture to deliver moisture to the hydrating cementitious materials from within the concrete. The absorbed moisture in the ESCS is not a part of the concrete mixing water and therefore does not increase the effective w/cm .

ESCSI has released an online guide for calculating the quantity of prewetted ESCS lightweight aggregates for internal curing. Users can input their mixture requirements into the guide which will calculate the minimum quantity of prewetted ESCS lightweight aggregate needed to provide the moisture for internal curing of cementitious materials in a concrete mixture. This calculator is located in the Internal Curing section of the ESCSI website: www.ESCSI.org.

“Internal Curing: Helping Concrete Realize its Maximum Potential,” an ESCSI brochure that was just released, explains the benefits of internal curing and how internal curing is the common sense addition to improve the sustainability of concrete. ESCSI also published a guide specification for internally cured concrete that can be used to modify a conventional normal weight concrete mixture to provide internal curing of the concrete by replacing a portion of the normal weight fine aggregate with prewetted fine or intermediate ESCS lightweight aggregate.

For more information about internal curing and ESCS aggregate, visit www.ESCSI.org.

Diversification Brings Growth, Innovation

Burns & McDonnell's engineering construction allows it to incorporate best practices that create innovative bridges

by Craig A. Shutt

Burns & McDonnell's 114-year history shows the firm has staying power. It owes that longevity in large measure to its diversification of services and markets, which not only helps it weather economic storms, but allows it to apply new ideas and best practices to other fields.

'Some of our competitors have retrenched in the last few years, but we've invested and grown.'

"Our diversification across many markets—transportation, energy, industrial processes, transmission and distribution, federal, and aviation,

among others—ensures that we can retain a stable base and create steady growth even as individual markets go up and down," says Ben Biller, general manager of the firm's Transportation Global Practice. "Some of our competitors have retrenched in the last few years, but we've invested and grown. That allows us to always have the resources at hand to serve our customers, and that gives them confidence in us."

Two Additions

Recent growth has been solidified by two additions: the July 2010 merger with bridge-design firm Harrington & Cortelyou Inc. (H&C) and the addition of Steve Hague, formerly with HNTB in Kansas City, as chief bridge engineer.

"Burns & McDonnell has traditionally not pursued acquisitions as a growth

strategy," says Greg Graves, chairman/CEO. "But this opportunity to merge with a highly respected firm with historic roots in Kansas City was too good to pass up." Its background with design-build projects made it especially attractive, says Biller. "Design-build is increasingly the contracting method of choice."

Formed in 1907, H&C had worked as a subconsultant to Burns & McDonnell, explains Kevin Eisenbeis, who was principal at H&C prior to the acquisition. "We had experience with design-build projects but were too small to compete for many larger projects," he says. "We also had design capabilities for bridge types they did not, such as major river crossings and movable structures. It created an outstanding strategic mix." The company cultures also were similar, as both are employee-owned.

The I-470/Route 50 Interchange in Lee's Summit, Mo., features two horizontally curved 1200-ft-long viaducts and two horizontally curved 1500-ft-long flyovers. Some 25 spans of prestressed concrete NU girders were used, saving more than \$6 million over a steel alternative. All photos: Burns & McDonnell.



Hague's addition in 2011 strengthened the company's design skills and helped expand its scope, particularly its expertise in cable-stayed bridges. "His expertise sends a strong message that we are here for the long term," says Biller.

Burns & Mac, as they call themselves, also has differentiated itself by splitting revenues evenly between engineering and construction, Biller adds. "It's an intentional balance, because it's very good for us to see both sides." The company constructs only projects it has designed, which fits with its emphasis on design-build projects. "Design-build is growing in the transportation industry, but it is definitely behind other markets. It's time it entered the design-build market on a larger scale."

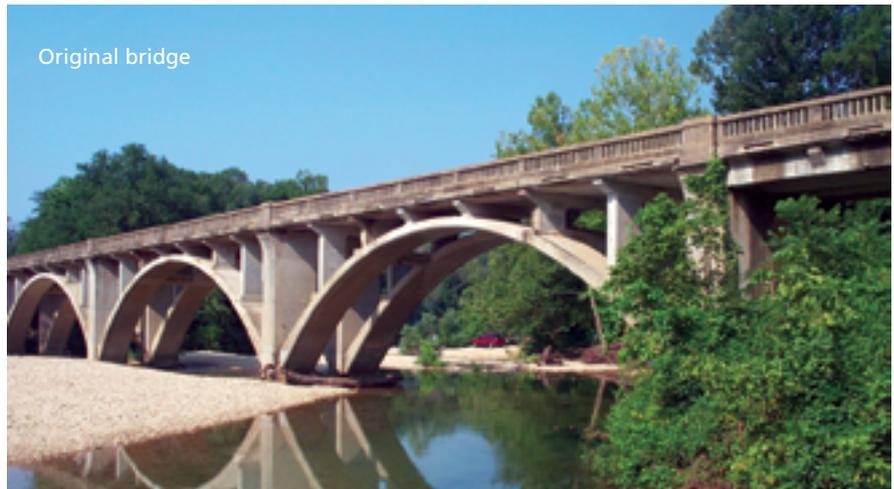
Design-Build Grows

The firm formed a Design-Build division in 1995. Headed by Don Greenwood, the group's 500 staffers work across all markets. "The division has greatly elevated our work in this delivery method, and we are now bringing it to this part of the company," says Biller.

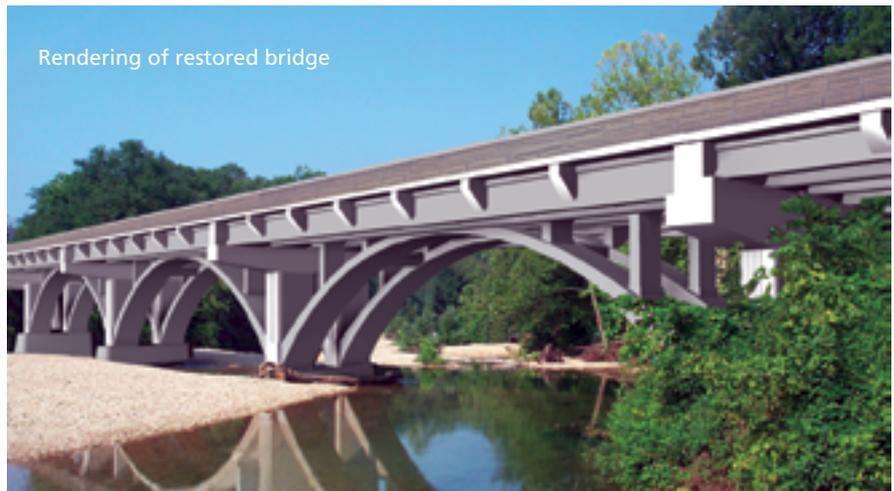
More states are embracing design-build methods...and Burns & Mac is encouraging that trend.

More states are embracing design-build methods, he notes, and Burns & Mac is encouraging that trend. Recently, Burns & Mac helped the Kansas Department of Transportation create a design-build policy that goes into effect in 2014 with the \$250-million, I-435/I-35/K-10 Interchange, phase two of the Johnson County Gateway. "They saw in us a group that knew the best practices across the country so we could create an approach for their design-build projects that would be efficient."

States are more interested in design-build methods as they are pressed to do more with less. "Design-build will continue to grow as states see what others are doing and want to tap into those efficiencies," Biller says. "It causes them to get outside their comfort zone and look at projects in new ways, which



Original bridge



Rendering of restored bridge

A precast concrete solution allowed the attractive arches on the Sinking Creek Bridge in the Ozark Scenic Riverways National Parkland to remain in place while appearing to support the bridge loads.

carries more risk. But if we can show them that those ideas have worked on other projects, the results speak for themselves."

As lead design consultant, Burns & McDonnell's recent design-build solution for the \$117-million, Daniel Boone Missouri River bridge replacement project near St. Louis maximized mobility, capacity, and safety improvements in the I-64 project corridor. Precast, prestressed concrete NU (Nebraska University) girders, used in new approach spans and a new highway overpass, contributed to the successful solution.

Railroads Support ABC

Design-build concepts help achieve faster construction, which is being aided by a variety of accelerated bridge construction (ABC) methods. The firm has significant expertise with ABC techniques, as they have long been used for railroad bridges, where the

company has substantial experience. "Railroad bridges are similar to highway bridges in their designs except for the significantly higher live loads that have to be accounted for," says Eisenbeis.

Concrete girders, especially double-cell box beams, are popular with railroad companies. The Union Pacific and BNSF railroads have created standardized designs that feature 2-ft increments of concrete spans, which simplify designs. Pretensioned T-beams, box-beams, and slab sections are also popular, due to the wide availability among precasters, which keeps prices competitive.

"Concrete provides a durable structure and a long life," Eisenbeis explains. "It offers a short production time with minimal fabrication issues, and it can be shipped to the site quickly."

Speed is of the essence in railroad projects, he says, because shoo-fies aren't practical. As a result,

With owners looking to save funds wherever possible and focusing on sustainable design, more bridges are being rehabilitated rather than built new.

contractors often take structures out of operation for only four to eight hours. That requires innovative design and construction techniques to keep trains rolling.

Often, new foundations are constructed beneath the existing structure while it remains active. Once a train passes, a span is pulled and the new one is erected, after which the bridge is reopened until the next span can be switched out. In some cases, older bridges have short spans, so two existing spans can be replaced with one new span. Piers typically are placed between existing piers, sometimes requiring a short jump-span.

"Precast concrete lends itself to that work very well, allowing us to pick girders with on-track equipment," he says. "These techniques have been in place in the railroad industry for some time, and we are now looking to adapt them to highway bridge designs."

One example is the bridge near Wellsville, Kans. A double-track, three-span, prestressed concrete, T-beam bridge replaced the existing double-track, 70-ft through-plate girder structure. The abutments and two intermediate bents used precast concrete caps with embedded steel plates to weld to the piles. The intermediate bent caps were placed while the tracks remained open, whereas, the abutment caps were placed behind the existing abutments during a track closure.

The center span was replaced in two stages, one bridge at a time, leaving one track open to traffic. The knee braces and floor beams were cut to remove the outside girders as the precast concrete abutments were placed and welded. Once half of the bridge and abutments were removed, the new T-girders were installed, and ballast and track were replaced. The other track was then closed and the other two lines of girders were removed.

Innovations Wanted

New ideas are being requested from owners more often today, Biller notes. "Owners are asking for faster construction times, more durability, and many other factors. But most importantly, they want innovation. They want to ensure they are taking advantage of the latest ideas nationwide."

Concrete options are helping the company innovate. "Span lengths, longer life cycles, aesthetic options, all are improving," says Biller. "Concrete designs offer better and better solutions as the material's durability and strength increase." Precast concrete's speed of casting also aids projects by shortening schedules," Eisenbeis notes. "In many cases, we can get precast, prestressed concrete I-beams in six weeks versus six months for steel."

Concrete spans also are getting longer, especially with segmental concepts, he adds. Even if the owners require steel beams for long main spans, the firm typically uses precast, prestressed concrete girders for approach spans. "The 100- to 130-ft approach spans are very economical in precast concrete," Eisenbeis explains. "As these sections become more efficient, we take more advantage of the longer spans and shallower sections that are available."

One help in that regard is the NU girder, which the company uses extensively. "It's a very efficient design that gives us shallower sections and more economy."

An example is the I-470/Route 50 Interchange in Lee's Summit, Mo., which consists of two, horizontally curved, 1200-ft-long viaducts over Route 50 and two, horizontally curved, 1500-ft-long flyovers above I-470. The design features 25 spans, nearly 15,000 linear ft, of prestressed concrete NU girders. Use of the

114 Years of Innovation

Burns & McDonnell Consulting Engineering was formed in 1898 by Clinton S. Burns and Robert E. McDonnell to design sewer systems, water works, and lighting infrastructure. Their first major projects came in 1900, when they designed water and light plants for the communities of Iola, Cherryvale, and Osawatomie in Kansas.

In 1930, the company changed its name to Burns & McDonnell Engineering Co., by which time it had completed 1200 projects in 34 states and Mexico. By 1948, their fiftieth anniversary, the firm had designed 2100 projects worth \$664 million.

In 1986, the company's employees purchased the outstanding stock from Armco Steel, which had acquired the firm from its partners 12 years earlier. Greg Graves was named president/CEO in 2003, the firm's sixth president. Today, the company operates 29 domestic offices as well as offices in several countries, with about 3500 employees.

efficient precast concrete sections resulted in an estimated savings of more than \$6 million in structure costs over initial steel alternate estimates.

Sustainability Emphasized

Owners are also looking for more sustainable-design concepts in all of their projects, says Biller. "They all want to know what we can do to help sustain the environment and recycle natural materials where possible. Our approach has been to be a leader in that area." The firm's Kansas City headquarters has achieved Silver LEED certification, and it has more than 300 LEED-accredited staffers.

A focus on sustainability also focuses owners on longer service life, pushing past 75 years to 100 years.



Rockhill Road over Brush Creek, in Kansas City, Mo., was constructed with cast-in-place concrete box beams.

"A key goal is to mitigate the impact of the construction process," Biller explains, especially when crossing rivers and wetlands, and to control runoff. "We don't see this changing in the future or going away."

A focus on sustainability also focuses owners on longer service life, pushing past 75 years to 100 years, adds Eisenbeis. The key is to protect the bridge from corrosion, either with corrosion inhibitors or other solutions on a case-by-case basis, he says. "The biggest impact can be made with adjustments to the concrete deck. If we can add protection there, it slows corrosion into the deck and then into the beams." A key weapon in that regard may be high-performance concrete, he notes. "We specify it for high durability and low permeability, not necessarily for high strength."

With owners looking to save funds wherever possible and focusing on sustainable design, more bridges are being rehabilitated rather than built new. "Many times, we find we can replace the superstructure and

retain the substructure to cut costs," Eisenbeis says. "Any time we can save money with practical solutions, owners are in favor of it today."

Rehabilitation isn't necessarily easier, adds Eisenbeis. "It can require as much design work as a new bridge, because extensive evaluations are needed to understand what is really there. If you have a good design plan and a good understanding of the existing components, it can work. But it may take significant effort to properly analyze the existing bridge."

An example is the firm's work for the Missouri Department of Transportation (MoDOT) when officials needed a study to upgrade existing arch bridges in the Ozark Scenic Riverways National Parkland in south central Missouri. The recommendation at the Sinking Creek Bridge included precast, prestressed concrete I-girders spanning pier to pier and spaced to miss the arch crowns. This concept puts the wider bridge deck and vehicular live loads on the new I-girders, while allowing the existing aesthetic arch ribs to remain

without carrying the increased truck loads.

Burns & McDonnell's company culture helps it adapt to changing needs and seek innovation. The firm became employee owned in 1986, with all stock owned by employees. "That changed the culture and mindset of everyone," says Biller. "Our employee-owners have a sense of pride in affecting their company's success. Our motto is, 'Work Like An Owner Today,' and employees see their job as satisfying clients."

The company's success also keeps it expanding, with two new bridge-design employees added in recent months. "Our recent success in landing and delivering projects will help us grow," Eisenbeis says. "And as we do, we'll add designers to accommodate the growth." 

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

Evaluation of Common Design Policies for Precast, Prestressed Concrete I-Girder Bridges

More-stringent owner requirements affect span capability, girder spacing, prestressing requirements

by Richard Brice and Bijan Khaleghi, Washington State Department of Transportation, and Stephen J. Seguirant, Concrete Technology Corp.



The *AASHTO LRFD Bridge Design Specifications* (AASHTO LRFD) provides bridge engineers with minimum design requirements for safe highway bridges. However, many bridge owners have adopted more stringent policies for the design of precast, prestressed concrete girder bridges. These policies specify design requirements for section properties, allowable tensile stress, and continuity.

Bridges designed using more stringent policies will be more robust and more costly when compared to bridges designed only to the minimum requirements. The most common differences include a reduction in span length, a reduction in girder spacing, or an increase in prestressing levels. This article attempts to quantify the sensitivity of common policies on the design of precast, prestressed concrete girder bridges. Span capability, girder spacing, and prestressing requirements are computed based on the minimum requirements set forth in the AASHTO LRFD. Each of the more stringent policies is then evaluated individually to understand its effect on the design. The combined effect of all the design policies is also investigated.

Survey of Design Policies

A survey of state departments of transportation (DOTs) was conducted to gauge the extent to which bridge owners deviate from the minimum requirements set forth in the AASHTO LRFD. Bridge owners were asked the following questions:

- What type of section properties policy does your state use for the design of precast, prestressed concrete girder bridges (gross, transformed)?
- What allowable tensile stress at

Table 1—Effects of more stringent design policies on span capability, girder spacing, and required prestressing force

Conservative design policy	Reduction in span capability (%)		Reduction in girder spacing (%)		Increase in required prestressing force (%)	
	6 ft spacing	12 ft spacing	6 ft spacing	12 ft spacing	6 ft spacing	12 ft spacing
Gross section properties	1.8–3.0	1.9–3.0	9.7–12.6	6.5–8.7	5.7–8.0	5.7–8.0
Zero allowable tension	4.9–5.4	4.9–5.4	22.5–27.3	15.3–17.3	11.4–12.7	11.4–14.0
Simple span analysis	2.9–3.2	2.0–2.9	13.2–17.4	6.3–10.0	7.7–9.1	6.0–8.3

Table 2—Effects of combined stringent design policies on span capability, girder spacing, and required prestressing force

Reduction in span capability (%)		Reduction in girder spacing (%)		Increase in required prestressing force (%)	
6 ft spacing	12 ft spacing	6 ft spacing	12 ft spacing	6 ft spacing	12 ft spacing
10.2–11.1	10.0–10.6	46.2–52.2	29.6–33.6	28.6–34.0	28.6–30.9

service III policy does your state have for the design of precast, prestressed concrete girder bridges (AASHTO LRFD Table 5.9.4.2.2-1, zero tension at service limit state, other)?

- What continuity policy does your state have for the design of continuous precast, prestressed concrete girder bridges (AASHTO LRFD Section 5.14.1.4 “Bridges Composed of Simple Span Precast Girders Made Continuous,” simple span moments for superimposed dead loads and live load, other)?

The responses of the 38 state DOTs that completed the survey are summarized in Figs. 1 through 3.

Sensitivity Study

The bridge sections used in this study are slab-on-girder systems composed of a cast-in-place concrete deck on precast concrete wide flange (WSDOT WF) I-girders. Interior girders are analyzed for various bridge configurations consisting

of six WF girders. The bridge deck, with haunch build-up of 3 in., is assumed to be 7.5 and 9.5 in. thick for girder spacings of 6 and 12 ft, respectively.

The maximum strength of girder concrete is assumed to be 7 ksi at transfer of prestress and 9 ksi at service limit state. The 0.6-in.-diameter strands are jacked to 75% of the tensile strength.

The baseline designs use the most liberal provisions allowed by AASHTO LRFD; transformed section properties of strand and cast-in-place deck concrete, allowable tension in accordance with AASHTO LRFD Table 5.9.4.2.2-1, and full continuity for superimposed dead and live loads in accordance with AASHTO LRFD Section 5.14.1.4. Each of these policies is varied to investigate their sensitivity individually. The results are summarized in Table 1. The ranges indicated reflect girder depths from 36 to 100 in.

The results indicate that the design policy with the least impact on girder

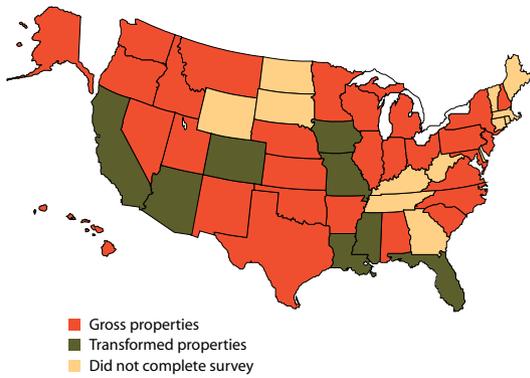


Figure 1. Survey results for section properties design policy. Drawing: PCI.

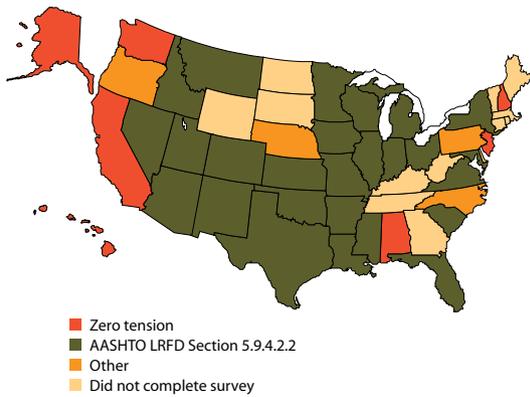


Figure 2. Survey results for allowable tensile stress design policy. Drawing: PCI.

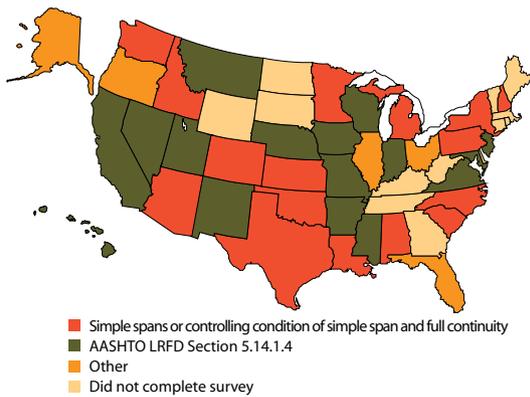


Figure 3. Survey results for continuity design policy. Drawing: PCI.

capability is the use of gross section properties. The allowable tension policy carries significantly more impact.

Combined Design Policies

Table 2 summarizes the results if all three conservative design policies are implemented relative to the baseline design. Again, the ranges indicated reflect girder depths of 36 to 100 in. In the case of the 6 ft spacing, the

reduction in girder spacing becomes impractical as the spacing becomes narrower than the width of the girder top flange. In all cases, the increase in prestressing force requires concrete strengths at transfer in excess of 7 ksi.

Benefits of Conservative Design Policies

AASHTO LRFD recommends a minimum service life of 75 years for bridges. Conservative bridge design policies leave a margin of safety for unforeseen demands over the life of the structure. Supporting reasons for the conservative design policies include the following:

- **Historical increase in bridge live load:** AASHTO design live loads have been increasing over the past few decades from HS-15 to HS-20 to HS-25, and to HL-93 in 1994.
- **Increasing use of overload trucks:** Many permitted overload vehicles cross precast, prestressed concrete girder bridges, and often exceed the AASHTO LRFD-specified design live loads. The reserve capacity due to conservative design practices allows prestressed concrete girder bridges to withstand these vehicles. Commerce would be adversely affected if these overloads could not be safely and conveniently moved.
- **Increase in number of traveling lanes:** Lane widths on some routes have been reduced from 12 to 10 ft to accommodate more traffic lanes. Reserve capacity allows prestressed concrete girder bridges to accommodate increased traffic demand and conform to the minimum requirements specified by AASHTO LRFD without strengthening or other modifications.
- **Reserve capacity for girders damaged by over-height collisions:** Over-height load collisions with prestressed concrete girder bridges often result in broken strands. Prior to repairs, the reserve capacity of the undamaged girders helps to keep the bridge in service. Repairs by splicing and re-tensioning strands result in stress levels lower than the original design. Reserve capacity allows repaired prestressed concrete girders to satisfy minimum design requirements.

- **Uncracked concrete under service conditions:** The zero tension policy ensures that prestressed concrete girders remain uncracked for flexure under service load conditions, resulting in longer service life.
- **Reduced life-cycle cost:** The conservative design policies require more prestressing strands and possibly an additional line of girders, but result in longer service life and lower life-cycle cost.

Conclusion

This study shows the sensitivity of span capability, girder spacing, and prestressing requirements to three common owner adopted design policies. These policies are more stringent than the minimum requirements set forth in the AASHTO LRFD. As expected, the designs using the owner adopted policies result in a structure that is more robust than designs using the AASHTO minimum requirements.

Span capability is the least sensitive and girder spacing is the most sensitive to the design policies. Designing based on gross section properties in lieu of transformed section properties has the least overall influence. Reducing the allowable tension stress at the service III limit state has the greatest overall influence and has the greatest impact on girder spacing requirements. ▲

Richard Brice is a software applications engineer and Bijan Khaleghi is the state bridge design engineer, both with the Washington State Department of Transportation Bridge and Structures Office, Olympia, Wash., and Stephen J. Seguirant is vice president and director of engineering with Concrete Technology Corp., Tacoma, Wash.

EDITOR'S NOTE

The full table of responses to the survey of design policies is available at www.aspirebridge.org. Click on Resources.

PROJECT

New Jersey Route 52 Causeway

Ribbon-in-space design solves horizontal and vertical alignment challenges

by Maher (Mike) Sidani and Joseph Romano, Michael Baker Jr. Inc., and David Lambert and Frank Inverso, New Jersey Department of Transportation

On May 24, 2012, the mayors of Ocean City and Somers Point, N.J., hosted a grand opening ceremony for the new, 3-mile-long Route 52 Causeway that connects these seaside communities.

Somers Point is located on mainland New Jersey, while Ocean City, a major tourist destination, lies on a peninsula to the southeast. Great Egg Harbor Bay separates the two cities and includes several small islands and four channels, two of which are navigable.

The original Route 52 Causeway over the bay consisted of four bridges:

two low-level causeway bridges in the middle and a drawbridge at each end. The New Jersey Department of Transportation (NJDOT) maintained these causeway bridges that were 1.1 miles long and in constant need of repair and in critical need of replacement.

Highway and marine traffic increased dramatically in the 70 years since the bridge was built. The narrow lanes and lack of shoulders contributed to frequent backups, more prevalent with the increase in drawbridge openings caused by a greater volume of marine

traffic. A major safety concern was the potential of storm-driven waves to wash over the low causeways, making them impassable—a significant issue as Route 52 is designated a critical coastal evacuation route for the area.

Project Split - Two Contracts

Due to the condition of the existing bridges, NJDOT split the scope of work into two staggered construction contracts. Contract A replaced the two deteriorated low level causeway bridges, while Contract B encompassed replacement of both drawbridges and



Overall view of the Route 52 Causeway from the Ocean City side, showing low level, high level, and curved alignments. All photos: Stokes Creative Group Inc.

profile

NEW JERSEY ROUTE 52 CAUSEWAY / OCEAN CITY AND SOMERS POINT, NEW JERSEY

BRIDGE DESIGN ENGINEER: Michael Baker Jr. Inc., Hamilton, N.J.

PRIME CONTRACTOR (CONTRACT A1): George Harms Construction Company, Howell, N.J.

PRIME CONTRACTOR (CONTRACT B): Route 52 Constructors: A Joint Venture of G.A. & F.C. Wagman Inc., York, Pa., and R.E. Pierson Construction Co. Inc., Pilesgrove, N.J.

CAST-IN-PLACE CONCRETE SUPPLIER (CONTRACT A1): Clayton Companies, Lakewood, N.J.

CAST-IN-PLACE CONCRETE SUPPLIER (CONTRACT B): Clayton Companies, Lakewood, N.J., and R.E. Pierson Construction Co. Inc., Pilesgrove, N.J.

PRECASTER: Bayshore Concrete Products Corp., Bay Charles, Va., a PCI-certified producer

improvements at the touchdowns at each bridge end, bringing the total project length to 3 miles. Dividing the project into two contracts was also necessary because of the \$400 million price tag, which made the Route 52 Causeway Replacement one of the largest projects ever undertaken by NJDOT.

Design Spurred Greater Competition

Originally, the bridge design called for precast concrete segmental boxes, which are faster to construct and require less access from underneath. However, only one fabricator in the region was ready to provide the specialized segmental boxes. Demand from the Gulf region following Hurricane Katrina depleted most-available concrete fabricators, resulting in higher than anticipated bids.

To increase competition, an alternative superstructure design was developed using precast, prestressed concrete I-girders. NJDOT re-advertised the revised Contract A1 in April 2006. The bids came in lower than expected making it possible to proceed with construction.

Due to the harsh marine environment, durability of the bridge designed for a 75-year service life was a major consideration.

Due to the harsh marine environment, durability of the bridge designed for a 75-year service life was a major consideration. Concrete was preferred over steel because of its exceptional durability, low maintenance requirements, and life-cycle cost



Route 52 Construction of Contract A1, while maintaining traffic on existing causeway.

advantages. The concrete elements utilized on the project included low-permeability, high-performance concrete.

Environmental Concerns Respected and Addressed

Environmental restrictions were one of the most significant construction-phase challenges. The project area is important to endangered species, protected birds, fish, shellfish, sea turtles, and plant life. Environmental permits limited the types, locations, and durations of certain construction activities.

From the start, NJDOT held regular interagency meetings to keep environmental agencies informed and demonstrate the team's commitment to protecting natural resources. Where feasible, the team developed plans for bioengineered shoreline stabilization and preserving nearby open space to help offset impacts. These efforts made environmental agencies more willing to discuss reasonable modifications to restrictions when needed. For example, in-water construction is not allowed from April 1 to June 30. Providing

justification for a permit modification to install piles within watertight cofferdams during the restricted period gave the contractor more flexibility in the project schedule, which sped project completion.

Distinct Technical Challenges Overcome

The coastal project location introduced plenty of technical challenges, including dealing with sandy, silty soil conditions. Soft soils were a particular concern under the 900-ft-long fill section on Rainbow Island. Vibro concrete columns, which had been used only once before in New Jersey, were used to stabilize the embankment rapidly and cost-effectively. Concrete columns, 18 in. in diameter that flare out at the top and bottom, were driven approximately 60 ft into the ground. Several layers of geotextile and compacted fill were placed across the tops of the columns to transfer the embankment load down to more stable soil layers.

The Route 52 Causeway consists of two, 12-ft-wide lanes in each direction, 5-ft-wide inside shoulders,

NEW JERSEY DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A dual bridge with lengths of 10,080 ft (contract B) and 7550 ft (contract A1) designed as simple span, precast, prestressed concrete girders made continuous for live load. Girders were 93.5-in.-deep precast, prestressed concrete bulb-tees spaced 8 to 11.75 ft apart. The bridge deck consists of a 6-in.-thick, cast-in-place concrete deck placed on 3.5-in.-thick precast, prestressed concrete deck panels. Piers for contract B are single-column piers with pier cap and bowtie pier. Contract A1 piers are multicolumn and use an inverted-T pile cap.

STRUCTURAL COMPONENTS: Precast, prestressed concrete girders; precast, prestressed concrete deck panels; cast-in-place concrete deck slab; prestressed concrete piles; concrete pile caps, abutments, footings, pier columns, and pier caps



Route 52 Contract B: The prestressed bulb-tee beams are supported by the high level piers.

8-ft-wide outside shoulders, and a 10-ft-wide shared-use walkway along the southbound side of the roadway. The total useable width of the roadway section (including walkways) is 84 ft representing a significant increase from the 40 ft width of the existing causeway.

Thirty-inch-square, 5 ksi, precast, prestressed concrete piles were used for the pile foundation, with a maximum pile design length of 106 ft. A waterline cast-in-place, 4-ksi concrete pile cap was selected due to economic considerations.

The top of the in-water pile cap is 2.54 ft above the mean high water elevation and is visible to passing boaters at most times. The pier is composed of cast-in-place, 4 ksi concrete hammerhead pier caps supported by



Route 52 Contract A1: The low level bridges with the fishing pier are visible.

a single column cast-in-place bow-tie column cross-section with Y-shaped double pylons at the top. High-performance concrete (HPC) was used for the pile caps, the columns, and the pier caps due to the marine environment.

The superstructure consists of nine lines of bulb-tee beams spaced at 10 ft 6 in. and a composite deck consisting of 3½-in.-thick precast concrete deck panels and 6-in-thick cast-in-place HPC. The total superstructure depth is 93.5 in. The simple span girders were made continuous for live load. Span lengths in the high level bridge vary from 137 to 166 ft. Specified design strength for the HPC used in the girders was 8.0 ksi. The girders were delivered to the site by barge from a pre-built main dock area. Epoxy-coated reinforcement was used for the entire structure.

'Ribbon in Space' an Aesthetic Delight

Typically in designing similar bridges over water, the challenge is determining how to cross a single major channel located in the middle of the waterway. The bridge profile slopes gradually up to a high point in the center, where the longest span of the bridge (166 ft) crosses the ship channel, providing visual focus of the project. With the Route 52 Causeway, there are two navigable channels located near each tie-in point of the bridge presenting a challenge to provide

...giving the bridge a dynamic and sweeping "ribbon in space" appearance...



Underside of the Route 52 Bridge over the beach thoroughfare next to Ocean City.

the required 55-ft-minimum vertical clearance for the waterways and to align the bridge horizontally with the connecting streets in Somers Point and Ocean City.

The design team carefully shaped the horizontal and vertical curves of the bridge to make the alignments as attractive as possible, giving the bridge a dynamic and sweeping "ribbon in space" appearance that conveys the speed and direction of the traffic across it. 

Maheer (Mike) Sidani is vice president and Joseph Romano is the structures department manager for Michael Baker Jr. Inc., office in Hamilton, N.J. David Lambert is the state transportation engineer and Frank Inverso is a project manager with the New Jersey Department of Transportation, Trenton, N.J.

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

EDITOR'S NOTE

The Route 52 Visitors Center Bridge, which is adjacent to the causeway, was described in the Summer 2012 issue of ASPIRE™.

Creating a Neighborhood Icon

by Jeff Parker, David Evans and Associates Inc.

The Franklin Avenue neighborhood in Astoria, Ore., is returning to the ocean at a rate of ¼ in. per year. The landslide is perpendicular to the old Franklin Avenue Bridge alignment. Constructed of timber in 1949 with an expected life span of 50 years, the bridge was marching down the hill with the rest of the neighborhood. It was due for replacement.

The new bridge is a two-span, 180-ft-long concrete structure with a decorative railing that retains the character and aesthetic charm consistent with the appearance of the historic neighborhood. The bridge features drilled shaft foundations, cast-in-place concrete columns and abutments, precast, prestressed concrete deck bulb-tee beams, and soldier piles. The approach fills use retaining walls with cast-in-place concrete fascias. Perhaps most important, the bridge incorporates 42-in.-high rails and sidewalks being used twice daily by the neighborhood's schoolchildren.

This project offered several unique challenges brought about primarily by the historic significance of the community, the limited access to the job-site, the continual movement of the soil, and the requirement for uninterrupted access to the 50 home sites within the project boundary.

The contractor erected the bridge in stages, completing one-half of the bridge at a time. This allowed continuous access for property owners, kept construction operations within the limits of the existing right-of-way, and mitigated concerns and possible damage to several historic homes located close to the project.

The bridge design incorporated techniques to account for continual ground movement. A 30-in. hole was opened around the bridge columns, on the uphill side of the landslide, and filled with bentonite-modified soil. As the earth moves, these holes start to collapse toward the columns, but the bentonite flows around the columns without placing a lateral load on them.

Astoria is the oldest U.S. settlement west of the Rocky Mountains. The bridge-design detail complements the historic neighborhood. The design was subject to the approval of the Historic Landmarks Commission, which ultimately presented the city with an award for the design.

The bridge lies just yards away from several homes; noisy, messy work was performed right outside people's bedroom windows. Given the



The two-span bridge has a decorative railing consistent with the appearance of the historic neighborhood. All photos: David Evans and Associates Inc.

constrained construction area, frequent communication with the surrounding neighborhoods and understanding their requirements were keys to success. In fact, on one of the two days that the bridge was closed for the beam placements, our construction project manager carried groceries for people living on the dead-end street. The residents were incredibly patient. At the end of the project, about 150 people attended a barbecue held on the bridge to thank the residents. 

Jeff Parker is a senior project manager, senior associate with David Evans and Associates Inc., Salem, Ore.

The bridge features drilled shaft foundation; cast-in-place concrete columns and abutments; precast, prestressed concrete deck bulb-tee beams; and soldier piles.



PROJECT

I-25 Trinidad Viaduct

Tight curves and variable depths challenge bridge designers

by Matthew Gilbert and Fred Holderness, Tsiouvaras Simmons Holderness Inc.

Interstate 25 (I-25) serves as Colorado's major north-south freeway, extending from the Wyoming state line to New Mexico. The freeway weaves through the picturesque town of Trinidad, located at the base of Raton Pass and just north of the New Mexico state line. I-25 was carried through town on an aging viaduct consisting of a combination of steel and precast concrete girders spanning over a river, three existing rail lines, a future rail line, and four city streets. The girders were corded to meet the roadway's tight curves.

Constructed in the mid-1950s, these bridges were nearing the end of their service life and required replacement. Preliminary design and environmental studies proved that realignment was not an option. The new structures needed to account for varying, highly skewed, substructure elements and complex horizontal geometry combined with reversing superelevated curves.

The reconstruction of I-25 through Trinidad provided some unique challenges. The remote small town of

Trinidad is nearly 200 miles from any major bridge construction industry, has a limited supply of skilled labor, and only one local ready-mixed concrete supplier. Based upon these concerns, the Colorado Department of Transportation (CDOT) elected to include an option for alternate structural design types but maintained the requirement to adhere to strict aesthetic criteria developed during the preliminary design and environmental assessment. A local contractor and engineering firm teamed up to develop a prestressed concrete

The final viaduct created a structure that the community was proud of and greatly enhanced the appearance below the bridges. Photo: Jeanne Sharps.



profile

I-25 TRINIDAD VIADUCT / TRINIDAD, COLORADO

BRIDGE DESIGN ENGINEER: Tsiouvaras Simmons Holderness Inc., Greenwood Village, Colo.

PRIME CONTRACTOR: Lawrence Construction, Littleton, Colo.

CAST-IN-PLACE CONCRETE SUPPLIER: Leone Sand & Gravel & Redi Mix Concrete, Trinidad, Colo.

PRECASTER: Plum Creek Structures Inc., Littleton, Colo., a PCI-certified producer

POST-TENSIONING CONTRACTOR: Schwager Davis Inc., San Jose, Calif.

tub-girder superstructure design. The awarded design bid was \$8 million less than the engineer's estimate.

The prime contractor, the precast concrete fabricator, and the contractor's design engineers devised a series of structures to meet the complex geometric requirements and address site-specific constraints. The resulting bridge layouts include four bridges over the river (two bridges for the interstate mainline and two on-and-off ramp bridges), two viaducts carrying the interstate over the city streets and rail lines, and two on-and-off ramps connecting into the viaducts.

Structural Configurations

The four river bridges consist of three-span structures using simple span, precast, prestressed concrete girders made continuous. Each bridge is about 335 ft long with skews of approximately 46 degrees.

The 1985-ft-long northbound viaduct is divided into three units and the 2057-ft-long southbound viaduct into four units. Expansion joints are provided at the end of each unit. The northern-most units NBU 2 and 3 on the northbound viaduct and SBU 2, 3, and 4 on the southbound viaduct, along with the on-and-off ramp bridges, are comprised of simple-span girders made continuous. NBU2, SBU3 and SBU4, and both ramp structures have four spans, while NBU3 and SBU2 are each five spans. These portions of the viaduct were relatively simple and contain spans no longer than 128 ft.

The largest spans, highest skews, and tightest horizontal curvatures all exist at the unit 1 sections of the northbound and southbound viaducts. The highly skewed railroad and city streets—along with the aesthetic requirement of hammerhead piers—created a staggered substructure configuration to support



The staggered piers were necessary to span the city streets and the railroad along the curved freeway alignment. Photo: Jeanne Sharps.

the four-girder-wide superstructures. The five-span northbound unit 1 (NBU1) with a length of 854 ft along the highway centerline has span lengths of 115, 131, 250, 175, and 181 ft for girders 1 and 2 and 115, 181, 256, 121, and 182 ft for girders 3 and 4.

The southbound unit 1 (SBU1) is 486 ft along the highway centerline and has a more balanced, three-span configuration and a slightly shorter span of 232 ft over the railroad. The minimum horizontal radii on the flaring NBU1 and SBU1 structures are 1000 ft and 1700 ft, respectively. These configurations made simple-span, continuous superstructures unfeasible. To create consistency, the engineering team designed a spliced, variable-depth, curved, precast concrete, tub-girder superstructure. This superstructure type, to the best knowledge of the contractor and the design engineer, was the first of its kind.

The spliced, variable-depth unit consists of both constant-depth segments and variable-depth segments; nine girder segments for each girder line are used on NBU1 and five girder segments on SBU1. The variable-depth segments over

the piers are 116 ft long and 78 in. deep at the ends, linearly increasing to a depth of 108 in. at the piers. This linear variation also tapered the bottom flange width of the girder from 54 in. at the ends to 39 in. at the deepest portion of the segment to account for the 4:1 sloping webs of the girder, an aesthetic requirement for the project.

Construction

Customized adjustable forms were constructed to allow the precaster to fabricate segments on varying radii while having the ability to cast both constant-depth and variable-depth segments. Special, drop-in internal forms reduced the weight of the variable-depth segments. The design called for a bottom flange thickness of over 40 in. at the deepest portion of the beams, which were erected over the piers on either side of the long span over the railroad. If the entire flange thickness had been precast, the girder segments would have been heavier than the 240-kips shipping limit. The drop-in forms created a precast concrete segment with a constant thickness flange; then, secondary field concrete placements were utilized to produce the necessary flange thicknesses.

COLORADO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Two curved, spliced, variable-depth, precast concrete tub girder viaducts with total lengths of 1985 ft northbound and 2057 ft southbound; on-and-off ramps; and four river bridges.

STRUCTURAL COMPONENTS: 156 precast concrete tub girders, of which 16 were variable in depth and some were horizontally curved on radii between 1000 and 1935 ft; 3162 precast concrete deck panels varying between 3 and 3.5 in. thick; 4.5-in.-thick, cast-in-place concrete deck; cast-in-place concrete hammerhead or single column piers; and cast-in-place concrete abutments and pile caps

BRIDGE CONSTRUCTION COST: \$79,528,100

AWARDS: 2012 PCI Harry H. Edwards Industry Advancement Award and Best Bridge with a Main Span Greater than 150 ft



The first curved, variable-depth precast concrete girder segment is lifted into place. The 6% super-elevation of the roadway is evident from the top of the column. Photo: TSH Engineering.

To build the structures, the engineering team developed an erection and post-tensioning sequence to meet the complexities of the structure. Segments were erected onto temporary and permanent piers with the exception of the long spans over the railroad. Temporary piers were not allowed at the railroad, requiring the use of a drop-in section erected onto strongbacks. To do this, the 116-ft-long, variable-depth segments were first erected onto the permanent piers on either side of the railroad while cantilevering out 58 ft over the railroad. The ends of the girders not over the railroad were supported on temporary towers to resist uplift from the large cantilevers. Strongbacks were placed at the ends of the cantilevers to support the drop-in segments, which weighed 260 kips and were 136 ft long.

After setting the drop-in segments, closure diaphragms were cast and the structure was post-tensioned together. Continuity post-tensioning was utilized before and after the deck was placed to reduce the post-tensioning costs. Altogether, over 101 miles of prestressing strand were utilized in the girders for the two unit 1 structures. Stressing consisted of pretensioned strand in the straight segments, internal multi-strand post-tensioning in curved segments, monostrands in the curved variable-depth segments, temporary external post-tensioning in the curved variable-depth segments, and multistrand continuity internal post-tensioning to splice segments together.

Precast, Prestressed Concrete Panels

In addition to the curved, variable-depth girders, one item that assisted with the contractor's winning bid was the use of partial-depth, prestressed concrete deck panels. The panels were used for both the interior panels and the deck overhangs. The deck overhangs varied up to 6 ft and would have required costly formwork, in particular, for the portions of the decks within the curves. The engineers designed the panels to be supported over the exterior girder's

two flanges while cantilevering to match the overhang length. These panels contained reinforcing bar projections for the Jersey-style barrier and pockets in the panels over the exterior web to allow for reinforcing bar projections from the girder to tie into the deck.

Panel layouts, panel shop drawings, and girder shop drawings were closely coordinated to accommodate the varying overhangs and curvature of the deck while meeting tolerances for the barriers. The panels were 3.5 in. thick and had a 4.5-in.-thick cast-in-place concrete deck over the top, for a total deck thickness of 8 in. for the majority of the bridges. Design engineers used self-consolidating concrete to fill in the pockets, ensuring an even bearing below the panels and sufficient connection to the girders.

Economy and Innovation

With bridge replacement funding at a premium, the original project focused on the construction of the northbound structures. Bids were accepted for the southbound structures in anticipation of acquiring additional funds to build the entire project. The economic savings of the redesign and the availability of additional funds allowed CDOT to proceed with the southbound structures. The entire project was made possible through the innovative use of



Curved precast concrete tub girders sit on temporary and permanent piers at the end of northbound unit 1. Photo: TSH Engineering.



Workers set the overhang, partial-depth precast concrete panels on one of the ramp structures. The pockets in the panels, and the use of self-consolidating concrete, create the connection between girders and the deck. Photo: TSH Engineering.

precast concrete and the collaborative design between the contractor, the designers, and the precaster. 

Matthew Gilbert is a senior bridge engineer and Fred Holderness is a principal, both with Tsiouvaras Simmons Holderness Inc., in Greenwood Village, Colo.

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



The overhang precast concrete panels reduced the amount of support brackets needed for the deck placement. Photo: TSH Engineering.

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The PCI State-of-the-Art Report on **Precast Concrete Pavements**

This report is the combination of four documents on the use of precast concrete pavement systems (PCPS) and constitutes a state-of-the-art report.

The documents were developed through a cooperative agreement between PCI and the Federal Highway Administration and cover the following: applications for precast concrete pavements, design and maintenance, manufacture of precast concrete pavement panels, and construction of precast concrete pavements.

The Curved Precast Concrete Bridges **State-of-the-Art Report**

This report details the application of curved precast concrete bridge design, fabrication, construction techniques, and considerations through the study of twelve related projects and constitutes a state-of-the-art report on this topic.

The document was written and intended to provide bridge owners, designers, fabricators, and engineers an up-to-date reference in developing precast concrete bridge solutions for curved geometric situations.

The topics include straight girders chorded from pier to pier, straight girder segments with splices within the spans, and curved precast girders. Each case study reviews project-specific information, the structural system selected, construction techniques used, and the lessons learned.

PCI Bridge Design Manual **Third Edition**

This up-to-date reference complies with the fifth edition of the *AASHTO LRFD Bridge Design Specifications* through the 2011 interim revisions and is a must-have for everyone who contributes to the transportation industry.

The third edition includes a new chapter on sustainability and a completely rewritten chapter on bearings that explains the new method B simplified approach. Eleven LRFD up-to-date examples illustrate the various new alternative code provisions, including prestress losses, shear design, and transformed sections.

The State-of-the-Art Report on

Full-Depth Precast Concrete Bridge Deck Panels

This publication serves as a guide for selecting, designing, detailing and constructing precast full-depth deck panels for bridge construction.

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Sliding and Rolling Bridge Solutions—Part 1

by Craig A. Shutt

As owners look to save costs and erect bridges faster with less interference to the traveling public, the concepts of sliding and rolling bridges transversely into place after constructing them nearby are becoming more popular. These techniques offer benefits, but they require unique considerations that can make the difference between success and failure. Both design and construction teams must understand these movement considerations.

Sliding or rolling bridges into place has become accepted by contractors due to the tighter time restrictions owners are placing on projects and their awareness of user costs for tying up either roadway access or waterways. These approaches also can help minimize environmental impact during and after construction.

In some cases, owners require this delivery method in their contract documents, necessitating designers and contractors to become familiar with the techniques as soon as they can. In these cases, clients often want to avoid employing cranes on small sites, which create economic drawbacks. On the plus side, owners don't typically provide detailed requirements for how the bridge should be moved into place. When they do, they often allow contractors to propose alternatives, ensuring the most efficient approach can be employed.

There are three typical options when considering how to move bridges into place:

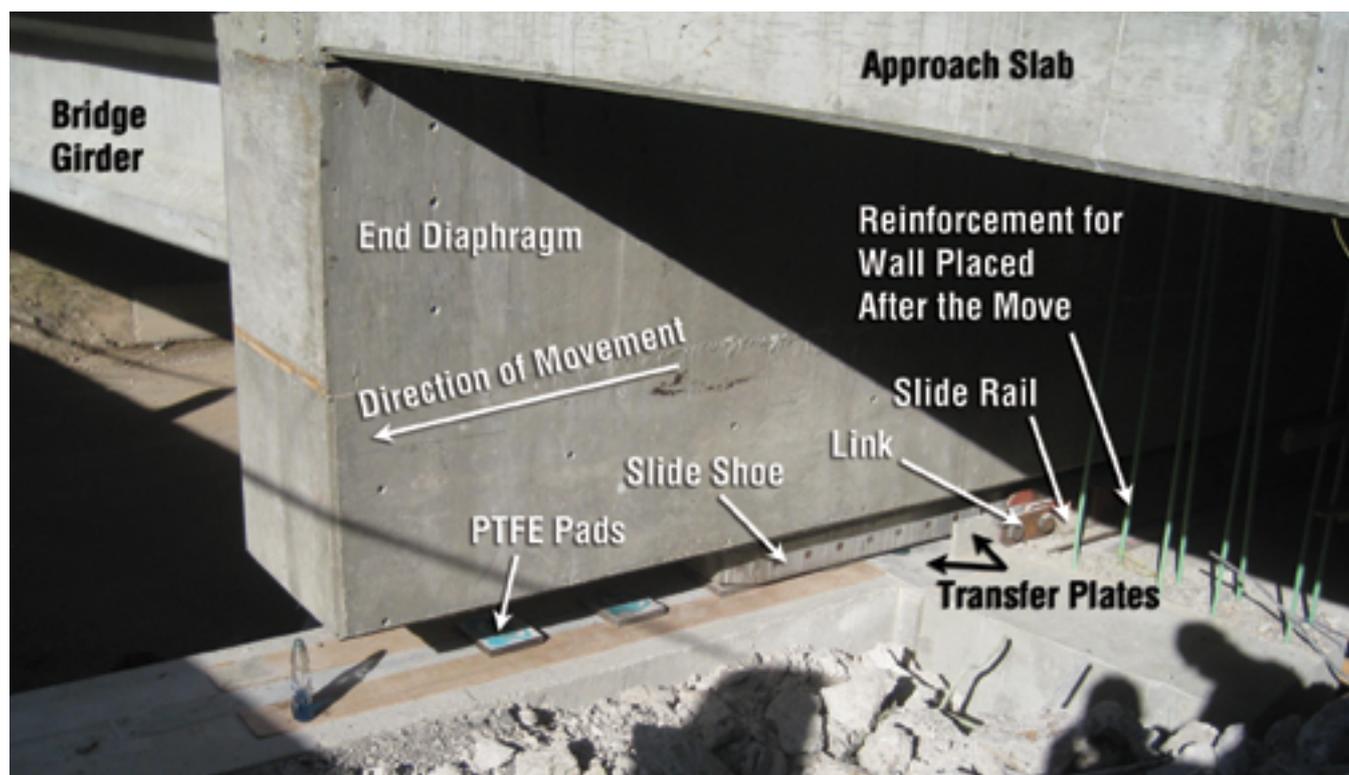
- Pushing with hydraulic jacks on rollers or pads
- Pulling with hydraulic jacks or cables on rollers or pads
- Moving with self-propelled modular transporters (SPMTs)

This article and the next in the *ASPIRE*[™] accelerated bridge construction (ABC) series will deal with design issues of the first two types, sliding or rolling the components into place. These will be followed by a look at necessary activities in the field during construction. The use of SPMTs will be addressed in a subsequent article.

Define Duties

Because few companies have deep experience with these projects yet, it is critical for engineers and contractors to define each member's duties, requirements and who will be responsible for all the means and methods. Typically, the means and methods will derive from the contractor's preference, based on the method with which the contractor is most comfortable.

In creating a construction plan, the design team should develop an ABC strategy with requirements for as-builts or contingency



As used on the I-80 bridges over Echo Dam Road in Echo, Utah, the slide shoes on the bottom of the abutment wall glide across polytetrafluoroethylene (PTFE) pads onto the permanent abutment. Photo: Michael Baker Jr. Inc.



Jacking pockets in concrete end diaphragms are shown with the jacks. Photos: Horrock Engineers.

plans and sequencing plans for closure periods for the road. Some departments of transportation have developed ABC specifications to cover additional requirements of the contractor or design-builder when utilizing ABC moving techniques. In some cases, these special provisions can become very specific. Too restrictive of an ABC specification can limit innovation during bidding.

Concrete Solutions Available

Concrete components provide many workable solutions for ABC. Some owners or contractors discourage the use of concrete when sliding components due to the added weight. The additional weight of concrete components is normally not a problem on bridge slides. The jacks typically have more capacity than needed.

The increase in weight does impact the temporary-support structure. But in general, concrete components offer no more difficulties than other materials in construction and provide benefits in speed of delivery, better durability over the bridge's service life, and less maintenance.

Lightweight concrete can be used to mitigate the dead-load considerations, although it is not essential. Other options can optimize handling needs, including prestressing, post-tensioning, and the use of cast-in-place concrete joints.

Superstructure Design

Superstructure design of ABC bridges is generally the same as that used for conventional construction. The major difference occurs at the abutment. In the conventional bridge design, the girder loads pass directly into the abutment. When the bridge is rolled or slid, either the end diaphragms of the bridge have to be

designed to support the bridge on the sliding shoes or rollers or the girders must be designed to accommodate both the sliding or rolling bearings and the permanent bearings.

Throughout the process of designing and detailing the structure, construction sequencing should remain a priority. For instance, the lower diaphragms can be unstable during girder erection in its temporary condition because the lower diaphragm is only supported vertically on the temporary supports. This produces a partial hinge. Bracing the diaphragms until all girders are set and the upper diaphragm concrete is placed eliminates this concern.

Sliding Forces

The designer should consider all the elements of the pushing or pulling system—ram, slide rail, and push blocks—when planning the process of moving the bridge into place. The pushing or pulling ram will most likely require a steel-to-steel connection, as it is the sole link allowing the structure to move. Details should allow the steel pushing or pulling block to be easily bolted on to the superstructure and then removed after the slide. Bridge skew can play a large part in the design of the pushing or pulling block.

The required force to move the bridge is a function of the weight of the superstructures and the coefficient of friction between the skid shoes and the polytetrafluorethylene (PTFE) pads over which the skid shoes slide or the rolling resistance of roller bearings. Coefficients of friction for PTFE bearings are given in the *AASHTO LRFD Bridge Design Specifications*, Chapter 14. Data are also available from product manufacturers.

Based on recent project experience, static coefficients in the range of 0.09 to 0.12 and dynamic coefficients in the range of 0.05 to 0.06 are reasonable values to consider for lubricated PTFE bearings sliding against polished stainless steel skid shoes.

The pushing or pulling mechanisms should have a capacity in excess of the calculated pushing or pulling force. Some designers recommend that the entire moving system be designed for the full capacity of the hydraulic system so the connections cannot be over-loaded by the jacking system, in case the system binds up and is not immediately detected by the operator.

Coordination early and often with the bridge-move subcontractor is highly recommended.



Push block between the hydraulic jack and the abutment must handle an axial load plus a horizontal shear without damaging the end of the diaphragm. Photo: Horrock Engineers.

Approach Slabs

In sliding- or rolling-bridge applications, moving the approach slabs along with the main span can be effective. This resolves key challenges affecting rideability of the roadway after construction and reduces closure times. Falsework and shoring can be designed to support the approach slabs during construction.

There can be dead-load deflection when casting the approach slabs on shored construction. This deflection can be handled by recognizing its impact, and the benefits in speed and ultimate road smoothness are worth the effort. Shored construction will also result in compression in the top of the slab when the shoring is removed, possibly improving its cracking resistance.

Expansion joints can be set in the approach slabs and locked into place until after the move. This allows the expansion to take place, after which the surface can be paved, if required. One team reported that this method saved critical time during the construction-launch period.

Normally, the approach slab-to-bridge connection is designed to accommodate rotation. The approach slab will need to be lifted concurrently with the bridge if the rotation on the joint during the jacking and moving process exceeds the beam limit. If the expansion joint is at the end of the approach slab, then precast concrete sleeper slabs may be needed.

Substructure Considerations

A key temporary-foundation element involves designing piles or spread footings to support the bridge in its temporary position. Pile locations can be out of line by more than 6 in., so it is critical that some tolerance is delineated for them to be welded to the slide rail-support system (which often is separate from the slide rails themselves) that will support the bridge during construction and during the move.

One easy way to accomplish this is to weld an oversized plate onto the top of the pile. The plate can then support the slide-rail supports. In most cases, the slide rails require tight vertical tolerances. Allowing for adjustments in the slide-rail elevations to ensure a smooth and level sliding surface provides the best solution.

Likewise, consideration should be given to the possibility that abutments will deflect when the bridge weight is moved into place. This typically isn't noticed in a more traditional method of construction, using cranes or launchers, because that weight is added incrementally and any deflections can be accommodated in the haunch or deck thickness. But when sliding the bridge into place, all of that significant weight is placed on the abutments at about the same time, so deflections of the permanent support from the partial and complete loading process need to be considered.

These adaptations need to be made at the design stage, as contractors must build the components to the plan dimensions to ensure the final bridge elevations match the required final profile. In some cases, when one abutment is out of line longitudinally, adjustments by the use of guide rails can be made to counteract anticipated and unanticipated movements in unguided systems.



Temporary strap tying the approach slab to the bridge deck slab. Photo: Horrock Engineers.

Some tolerance is needed to allow for minor differences in the extensions of each jack. This difference in movement will rotate the structure in plan view. Bridges have been successfully slid into place with less than a 2-in. tolerance allowance.

Construction of new substructure elements around existing elements requires consideration of stability during construction. Temporary bracing of existing substructures or top-down retaining walls (soil nails or mechanically stabilized earth) may be required to ensure stability of the system during construction. Specifications defining construction submittals or design plans for shoring of the existing bridge should be included on the plan set.

Soil nails or other bracing often are required, and their construction can make or break the schedule. Stabilizing this soil at the abutments is critical, as delays can result in all other scheduled activities being delayed as well. Significant and detailed analysis needs to be performed to ensure the temporary structures and existing spread footings, if used, will not settle once the dead loads are transferred. **A**

This is the first in a series of articles examining different approaches to accelerated bridge construction. This report 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 features, visit www.aspirebridge.org and open Current Issue.

PROJECT

The Two Medicine River Bridge

Segmental box-girder bridge complements surroundings, improves access to Glacier National Park
by Bruce Kates, Jacobs Engineering

U.S. Highway 2 is the northern-most, east-west highway crossing the United States and the Rocky Mountains. It runs along the southern edge of Glacier National Park and provides access for visitors to both the east and west entrances. On the eastern side, just outside the community of East Glacier Park, Mont., U.S. 2 crosses the Two Medicine River and the gorge that the river has carved through the ages.

Rising majestically from the steep banks of the Two Medicine River are two “twin column” piers reaching high above the stream bed to support the new, graceful, variable-depth, segmental box girder bridge. This beautiful structure is the first of its type in Montana. The box girder unit has spans of 290, 520, and 350 ft, while the three east approach spans have precast, prestressed concrete girders made continuous over the intermediate bents and span lengths of 120 ft.

Planning

During the planning stages of the project, the prices of steel and concrete were quite volatile making it difficult to estimate the cost of the structure or to reliably predict which material would result in the most

cost-effective alternative. This was part of the reason that two different structures were designed for the replacement: a concrete box girder and steel deck truss using weathering steel. Both alternatives were included in the bidding plans and contractors were encouraged to bid on either or both structures. A second aspect of the bidding process required a price for the construction cost as well as a number of days of construction to complete the project. The number of days multiplied by a specified cost per day combined with the construction cost constituted the total bid. As a result, the Montana Department of Transportation (MDT) was able to get the best value in capital cost as well as minimize the inconvenience to the traveling public.

Substructure

Concern for the slope stability of the steep river banks prompted a significant geotechnical exploration program and the borings into rock dictated careful consideration for the location of the supporting piers and bents. All substructure members are founded on drilled shafts 6 to 8 ft in diameter taken down and socketted into rock. The main piers (piers 2 and



3) feature four, 8-ft-diameter shafts with a 36 by 36 by 12 ft cap, with heavy reinforcing steel and draped post-tensioning to help resist the loads from the columns located between the shafts.

The twin column main piers are rectangular in cross section (6 by 15 ft) with tapered corners on the long sides and rustication running vertically up the center. They rise higher than the trees, then splay outward from the centerline of the pier as they approach the superstructure and transition smoothly to meet the bottom of the box section with its sloping webs. Both main piers are fixed piers so the connections

profile

THE TWO MEDICINE RIVER BRIDGE / EAST GLACIER PARK, MONTANA

BRIDGE DESIGN ENGINEER: Jacobs Engineering, Seattle, Wash.

PRIME CONTRACTOR: Ralph L. Wadsworth Construction Company, Draper, Utah

CONSTRUCTION ENGINEERS: Jacobs Engineering, St. Louis, Mo., and Nutt, Redfield and Valentine, Orangevale, Calif.

PRECAST CONCRETE SUPPLIER: Montana Prestressed Concrete, Billings, Mont.— a PCI certified producer

POST-TENSIONING AND FORM TRAVELER SUPPLIER: Schwager Davis Inc., San Jose, Calif.

MODULAR EXPANSION JOINTS AND DISC BEARINGS: D.S. Brown Company, North Baltimore, Ohio



General view of the structure nearly complete. The existing bridge is in the foreground. All photos: Jacobs Engineering, with permission from the Montana Department of Transportation.

Superstructure

The new superstructure features a single-cell, box girder with web walls sloping at 5:1 (vertical:horizontal). The depth of the box varies from 30 ft at the main piers to 11.5 ft at midspan and the ends of the side spans. The variable depth of the box provides a graceful appearance as it soars over the canyon high above the treetops. The finished deck reaches a height of about 195 ft over the streambed. It then merges with the trees as it approaches the abutment at the west end of the bridge.

The variable depth of the box provides a graceful appearance as it soars over the canyon high above the treetops.

between them and the box are continuous, with column reinforcing reaching fully through the interior diaphragms to the top slab of the box girder. With significant reinforcing steel in the box, columns, and diaphragms, and provisions for future post-tensioning and its associated reinforcement, integrated drawings were required. These drawings combined all of the details into a single three-dimensional drawing file, which could be viewed from various angles to check for spacial conflicts.

The column of bent 4 (4 by 12 ft) supporting the transition cap between the box girder and the approach spans has a similar cross section as the main

pier columns with the tapered corners and vertical rustication and a hint of a flare as the column reaches up toward the cap. The superstructure transitions from the box girder terminating in span 3, to the precast, prestressed concrete girders (MTS-72) continuing on in span 4. This requires a transition bent cap to provide bearing seats at significantly different elevations to support the special bearings beneath the 11.5-ft-deep box and the transverse shear blocks, and the smaller bearings beneath the 72-in.-deep, bulb-tee girders. Walls were cast on each end of the cap to soften the appearance of the many details coming together in this transition region.

The sloping web walls and variable-box-depth characteristics result in a bottom slab width that varies from 26.25 ft at mid-span to 18.86 ft at the piers. The web walls are 28.60 ft apart center-to-center beneath the 49.33-ft-wide top slab, which serves as the deck of the bridge. The web walls are 16 in. thick and transition to 24 in. thick through the end segment near bent 4. The top slab thickness varies with a minimum thickness of 10 in. midway between the webs and at both fascias. The bottom slab is 10 in. thick through the end segments and the outer halves of the cantilever segments, but thickens to 24 in. approaching the main piers.

MONTANA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 1160-ft-long, single-cell, post-tensioned, cast-in-place, concrete segmental box girder bridge with spans of 290, 520, and 350 ft built by the balanced cantilever method with three 120-ft-long, precast concrete, bulb-tee girder approach spans

STRUCTURAL COMPONENTS: Drilled shafts socketed into rock, twin column main piers, single cell box girder superstructure, and MTS-72 precast, prestressed concrete girders with a cast-in-place deck

BRIDGE CONSTRUCTION COST: \$24,137,375 (\$322/ft²)



Pier 2 columns complete.



Pier 2 diaphragm, column, and web reinforcing steel, all part of the pier table.

Post-tensioning is provided for cantilever construction in the top slab above the web walls using thirteen 0.6-in.-diameter strands providing 571 kips of force in each tendon, with one tendon over each web. With the non-symmetrical pier table, two tendons are added with each segment completed, with the tendons run back through the pier table to the end of the opposite cantilever. Thus each segment ultimately has two tendons anchored over each web.

In the bottom slab, continuity tendons consist of seventeen 0.6-in.-diameter strands providing 747 kips of force in each tendon. Transverse tendons in the top slab consist of four 0.6-in.-diameter strands spaced at about 3 ft providing 176 kips of force per tendon. The superstructure contains approximately 128 miles of post-tensioning strand.

The deck of the new bridge includes a 12-ft-wide traffic lane and an 8-ft-wide shoulder in both directions, with a 6-ft-wide sidewalk on the north side of the structure. The traffic rail on both sides of the bridge is comprised of a 1.67-ft-wide reinforced concrete curb with a three-beam galvanized steel guard rail mounted on top, making the total deck width 49.33 ft. This rail provides greater visibility of the surrounding scenery and the river below while protecting the motoring public.

Concrete

With respect for the relatively harsh climate of the northwest Montana winters, the specifications for the concrete of the box girders included the use of high-performance concrete. The design strength for the concrete was 6 ksi and the specifications required a value less than 1500 coulombs at 28 days based upon the rapid chloride permeability test. This required the use of silica fume and fly ash in the concrete to reduce permeability and to improve the resistance to chloride penetration (from road salts used for de-icing). The material for the box girder consistently reached a compressive strength of 9 to 10 ksi at 28 days and permeability of 1300 to 1500 coulombs at 28 days and 700 to 900 coulombs at 56 days.

With the relatively rough finish of the box girder deck, a concrete overlay was placed to provide a smooth riding surface and an additional layer of protection for the epoxy-coated reinforcing steel in the deck and the post-tensioning system. Silica fume and fly ash were also included in the overlay to reduce its permeability, and when combined with grout pumped through all of the post-tensioning ducts the durability of the structure is enhanced.



Overhead view of the Pier 2 pier table top slab forms.

Bearings

Disc bearings with polished stainless steel and polytetrafluorethylene sliding surfaces allowing low friction movement were used to support the box girder at abutment 1 and bent 4. Modular expansion joints were installed in the deck at the ends of the box girder unit. These stout joints combined with neoprene glands between the transverse rails of the joints provide significant movement capacity without allowing water to leak or flow through the joints. This prevents damage and maintenance problems for the structural elements.

With improvements to the roadway that include a straighter horizontal alignment, grades at each end of the structure were reduced from 7% to 5%, improving drainage. Local residents and visitors to Glacier National Park will enjoy this much needed improved structure for generations to come. 

Bruce Kates is a project manager and technical consultant with Jacobs Engineering in Seattle, Wash.

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

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PROJECT

SOUTH NORFOLK JORDAN BRIDGE

Virginia's new all-precast concrete bridge restores a vital transportation connection

by Jay Rohleder and Shawn Woodruff, FIGG

Less than two years after beginning construction, the new South Norfolk Jordan Bridge is open to traffic. As tall as a 17-story building, this modern bridge was constructed quickly using 856 precast concrete segments to provide an important community transportation link across the Elizabeth River between Chesapeake and Portsmouth, Va.

The previous Jordan Bridge, a steel lift span, was closed to traffic by the City of Chesapeake after being rated structurally deficient. Removing this link from the regional transportation network increased congestion throughout the area. The South Norfolk Jordan Bridge restores the connection, relieving congestion and providing added benefits to enhance the quality of life for the surrounding communities. In addition, the bridge project was accomplished using 100% private funding without the use of any local, state, or federal funding.

The South Norfolk Jordan Bridge... enhance[s] the quality of life for the surrounding communities.

The new bridge eliminates the lift span over the shipping channel and an at-grade active railroad crossing. The bridge also crosses local roads with long spans, allowing for the

continuous flow of all vehicular and pedestrian traffic on top of the bridge while ships, trains, and other vehicles pass below.

One of the challenges of replacing a lift span bridge in this location with a high-level fixed span and pedestrian friendly bridge was establishing the

bridge geometry. The site constraints included clearance requirements over the river for navigation, railroad easements on both sides of the river, and existing tie-in points to surface streets. After extensive analysis, the final bridge layout provides the required United States Coast Guard (USCG) navigation clearance of 145



profile

SOUTH NORFOLK JORDAN BRIDGE / CHESAPEAKE AND PORTSMOUTH, VIRGINIA

BRIDGE DESIGN ENGINEER: FIGG Bridge Engineers Inc., Tallahassee, Fla.

PRIME CONTRACTOR: FIGG Bridge Builders, Tallahassee, Fla.

CAST-IN-PLACE CONCRETE SUPPLIERS: Atlantic Metrocast Inc., Portsmouth, Va., and Titan America, Norfolk, Va.

PRECASTERS: Atlantic Metrocast Inc., Portsmouth, Va.; Bayshore Concrete Products, Cape Charles, Va.; and Coastal Precast Systems, Chesapeake, Va., all PCI-certified producers

POST-TENSIONING CONTRACTOR: VSL, Hanover, Md.

ft vertically and 270 ft horizontally, gentle grades for pedestrian access, and appropriate rail clearances, while integrating the bridge seamlessly into the existing transportation network, including I-464.

The final bridge layout is 5375 ft long and consists of 35 spans. The bridge approach spans are typically 150 ft long, while the main span unit, over the navigation channel, features span lengths of 190, 385, and 190 ft.

Precast for Quality, Speed

Precast concrete segmental technology was used to construct the new bridge. Each element of the bridge—the foundations, piers, and superstructure—

were manufactured in local precasting facilities and then assembled on site. Precasting offered many benefits including speed of construction and factory quality control. Precasting the 323 pier column segments and 533 superstructure segments took just one year, from March 2011 to March 2012.

Substructure

Bridge foundations consist of 24-in.-square, prestressed concrete piles for land piers; 54-in.-diameter, prestressed concrete hollow cylinder piles for piers in the water; and 66-in.-diameter, concrete cylinder piles for the bridge fender system. The use of pile foundations with above-ground footings avoided excavation of potentially contaminated soil in an existing superfund site along the west bank of the river. Pile foundations were selected for the entire project as a cost-efficient solution for the soil conditions along the alignment. A total of 961 piles were manufactured at the local precasting facilities and then installed to support the bridge piers, embankments, and fender system. The first pile was installed in the river during a groundbreaking ceremony on December 16, 2010, and the last pile was installed one year later in December 2011.

Each of the 10 by 16 by 9 ft concrete box segments for the columns were precast adjacent to the bridge site. The column segments were cast in two precasting beds using self-consolidating concrete with a specified compressive strength of 5.5 ksi. Column segments were match cast to ensure a proper fit. The precast concrete box column segments were stacked in place and then post-

The South Norfolk Jordan Bridge opened to traffic on October 29, 2012, restoring a vital transportation link in the Hampton Roads regional transportation network. All photos: FIGG.



Precast concrete segmental balanced cantilever construction using a barge mounted crane was used to construct the bridge's long main spans over the river.

tensioned vertically to build piers ranging in height from 18 ft 9 in. to 144 ft 10 in. at the main span.

Superstructure

The bridge's single-cell box girder superstructure consists of segments with a constant depth of 9 ft 2 in. for the 32 approach spans and variable-depth segments for the main span unit. These range in depth from 9 ft 2 in. at midspan to 18 ft 5 in. at the piers. All the segments are 51 ft 8 in. wide to accommodate the bridge's two 12-ft-wide travel lanes, two 8-ft-wide shoulders, and an 8-ft-wide barrier-protected pedestrian sidewalk. Superstructure segments also include a 1.5-in.-thick integral wearing surface for enhanced durability.

Superstructure segments were also match cast for proper fit and geometry control. Six casting beds were used; four for the approach segments and two for the main span segments. A concrete compressive strength of



SOUTH NORFOLK JORDAN BRIDGE LLC, OWNER

PRIME SUBCONTRACTOR: The Lane Construction Corporation, Cheshire, Conn.

MAJOR SUBCONTRACTOR: McLean Contracting Company, Chesapeake, Va.

BRIDGE DESCRIPTION: A 5375-ft-long precast concrete segmental bridge over the southern branch of the Elizabeth River. Typical spans were 150-ft long and built span-by-span. The 385-ft variable-depth main span was built using the balanced cantilever method over a navigation channel. Two 12-ft-wide lanes with 8-ft-wide shoulders on each side and an 8-ft-wide, barrier-protected sidewalk were also included.

STRUCTURAL COMPONENTS: 533 precast concrete segmental box girder superstructure segments, 323 precast concrete box column segments, and 961 54- and 66-in.-diameter precast concrete piles

BRIDGE CONSTRUCTION COST: \$90,000,000



Span-by-span construction techniques were used to build typical spans. Precast concrete segments were delivered across previously built portions of the bridge and placed on triangular trusses, working from the completed bridge.

6 ksi was specified by the design for the majority of the bridge superstructure; 8 ksi was specified for portions of the main span superstructure. Compressive strengths well over those specified were achieved for the precast concrete superstructure segments.

Span-by-span construction, with twin triangular underslung trusses, was employed to build each of the 32 approach spans. Segments were delivered over the completed bridge, loaded onto the trusses, and then post-tensioned together. The bridge's smallest horizontal curve radius, 750 ft, is one of the smallest used with span-by-span methods and underslung twin trusses.

The main span unit over the river was built using balanced cantilever construction. The precasting facility adjacent to the bridge site offered easy water access. Segments were barged to the bridge site and then lifted into place. Balanced cantilever erection near the navigation channel required close coordination with the USCG to allow vessels in the channel to keep moving.

Precasting the bridge elements allowed for construction of the piers,

approach spans, and main spans simultaneously. Pier erection started on the west end of the bridge working toward the east, while superstructure segments were being cast. To allow for delivery of precast concrete segments, approach span construction also proceeded from west to east, following pier erection. The approach span-by-span trusses reached the main span unit in early May 2012, just as the last balanced cantilever segment was being lifted into place. The trusses then were advanced past the main span unit to continue working toward the east end of the bridge.

Span erection proceeded quickly with multiple headings, and was completed in less than 14 months. At peak production, crews achieved two approach spans per week and erected six variable-depth main span segments per day.

Mother Nature was an ominous force throughout construction. The project

Column segments for piers in the river, including the 145-ft-tall river piers, were precast at the adjacent casting yard and barged to the site. They were then stacked, epoxied, and vertically post-tensioned.

site faced flooding, winter storms, and severe weather. On August 23, 2011, a magnitude 5.8 earthquake, the strongest to hit the east coast in 67 years, originated less than 150 miles from the site. That same week, Hurricane Irene made landfall in the Outer Banks of North Carolina, 100 miles south of the bridge, bringing strong winds and rains to the region. The bridge stood strong through each event without any issues.

Eco-friendly features of the new bridge include a nano-technology coating, applied to the concrete barriers, that removes pollutants from the air and provides a self-cleaning surface through a photocatalytic reaction with the sunlight. The bridge is lit at night using low maintenance, low-energy LED lights. To honor the military, the barrier rail color is designated as "dress white" in recognition of the United States Navy, a neighbor to the project. 

Jay Rohleder is a project manager with FIGG and was on-site during construction of the South Norfolk Jordan Bridge. Shawn Woodruff is a bridge engineer with FIGG in Tallahassee, Fla.

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PROJECT

RECONSTRUCTION

of the Ohio & Erie Canal Aqueduct Over Tinkers Creek

by Anthony Borrelli, Bergmann Associates



View of the re-watered Ohio & Erie Canal across Tinkers Creek. Manually operated sluice gates in the wall of the transition structure allow for regulation of canal water levels. Photo: Bergmann Associates.

Concrete allows for the successful reconstruction of a national treasure blending functionality with historic preservation

Constructed in the early 1800s, the Ohio & Erie Canal carried freight and passengers from the small towns and farms between the Ohio River and Lake Erie. This then opened up Ohio to larger ports and cities to the east and south.

Today, the surviving watered portion of the canal between Akron and Cleveland is managed by the National Park Service, including the aqueduct structure over Tinkers Creek. The canal and the associated structures are major attractions in the 33,000-acre Cuyahoga Valley National Park. The

aqueduct is the only one remaining of the four originally constructed along this stretch of the canal. It is listed on the National Register of Historic Places and is a contributing resource to the larger Ohio & Erie Canal National Historic Landmark District.

A History of Repairs

With less than 5 ft of vertical grade separation between the canal and Tinkers Creek, the aqueduct is subject to frequent flooding of the creek, exposing the structure to stream forces, scour, debris impact, and ice jams.

As a result, on-going maintenance has been needed through the years. The aqueduct has been relocated, rehabilitated, and replaced several times, most notably in 1905 when a two-span iron truss supporting a timber plank trough was installed on the original masonry pier and abutments.

In 2007, after more than 100 years of weathering and frequent flooding, the National Park Service was forced to remove the steel and timber superstructure. Under emergency action, the canal was blocked off, a steel pipe conveyance system was installed to maintain water in the canal, and a new pedestrian bridge was constructed to restore towpath pedestrian traffic. Funding was then sought to design and construct a replacement aqueduct. Ultimately, the project was selected to receive funding through the American Resource and Recovery Act.

profile

OHIO & ERIE CANAL AQUEDUCT OVER TINKERS CREEK / CUYAHOGA VALLEY NATIONAL PARK, OHIO

BRIDGE DESIGN ENGINEER: Bergmann Associates, Rochester, N.Y.

PRIME CONTRACTOR: Abcon Inc., Youngstown, Ohio

GEOTECHNICAL CONSULTANT: D'Appolonia, Monroeville, Penn.

CAST-IN-PLACE CONCRETE SUPPLIERS: Carr Bros. Inc., Bedford, Ohio, and Newcomer Concrete Services, Norwalk, Ohio



The 1905 aqueduct structure consisted of a two-span truss supporting a timber trough. Note the low freeboard to Tinkers Creek and significant debris accumulation. Photo: National Park Service.

Concrete Well Suited to Project Challenges

An intensive study was conducted to evaluate concrete, steel, and timber aqueduct alternatives. Concrete was ultimately selected for its durability and low life-cycle costs.

Concrete was ultimately selected for its durability and low life-cycle costs.

The added dead load and rigidity of the monolithic concrete construction was well suited to resist the stream forces, debris impact, and ice jams. The increased weight also helps to offset the significant buoyancy that can occur when the canal is drained and Tinkers Creek flood levels approach the top of the trough.

Debris snagging and sediment collection are also greatly minimized by the smooth formed surfaces of the concrete aqueduct bottom slab and sidewalls. Cast-in-place construction was well suited to the tight spatial constraints of the project, as well as capabilities of the small HUB-Zone (Historically Underutilized Business Zone) contractors bidding on the project. Lastly, the appearance of concrete provided a clear differentiation and textural contrast between the new aqueduct and the existing stone masonry, a key requirement of the Ohio State Historic Preservation Officer.

Concrete Details

The specified compressive strength of all the concrete was 4 ksi and featured an integral color admixture consistent with other newly constructed concrete structures in the park. For added durability, galvanized reinforcement was used throughout the structure.

Cast-in-place construction was well suited to the tight spatial constraints of the project.

Water tightness of the new aqueduct trough was a primary goal of the project. Polyvinylchloride (PVC) waterstops were used at all of the construction joints. Form ties, which pass through the formwork in most modern concrete construction, represented a potential seepage path and future maintenance concern and were not permitted. Rather, the contractor was required to externally brace all the formwork.

For added durability and protection of the concrete and reinforcement, a crystalline waterproofing admixture was used. This admixture fills small voids and microcracks with insoluble crystals



Center pier masonry reconstructed to just below the bottom of the aqueduct trough. Note the two concrete columns cast inside the pier that support the bearings for the new trough. Photo: Bergmann Associates.

NATIONAL PARK SERVICE, OWNER

BRIDGE DESCRIPTION: Two-span, concrete through girder and floor slab aqueduct supported on concrete integral abutments, and a masonry and concrete center pier

STRUCTURAL COMPONENTS: Two 96-ft-long, cast-in-place concrete through girders (7 ft 2 in. by 1 ft 8 in.), 1-ft 6-in.-thick concrete floor slab spanning 21 ft 11 in., twenty-four 7-in.-diameter micropiles with a maximum depth of 65 ft

BRIDGE CONSTRUCTION COST: \$1,857,000 (\$770/ft²)



Placement of the galvanized reinforcement for the new trough floor slab and through girder sidewalls. Photo: Bergmann Associates.

increasing the water tightness of the structure.

The New Structure

The new aqueduct consists of a 96-ft-long, two-span through girder and floor slab system continuous over the center pier. The original aqueduct cross section was considered to be a historic feature that had to be maintained. Through girders, 1 ft 8 in. thick and 7 ft 2 in. deep, make up the sidewalls of the trough, and a 1-ft 6-in.-thick concrete slab spans 21 ft 11 in. between the girders making up the aqueduct floor.

At each end, the trough is supported on an integral concrete abutment featuring a single row of five micropiles. The abutments were set back approximately 10 ft behind the existing stone abutments to avoid interferences during the micropile installation.

In order to smoothly transition from the wider, sloped earth canal section to the narrower vertical walled aqueduct section, concrete U-frame slab-on-grade "transition" structures were located at each end of the aqueduct. The joint between the transition structures

and aqueduct trough features two sets of 1.5-in.-diameter, PVC, center-bulb waterstops to prevent leakage at the joint and allow for the necessary thermal movements. Stainless-steel cover plates protect the waterstops and keep out sediment and debris.

To minimize the potential for canal water to seep under the aqueduct, concrete cut-off walls were provided at the ends of the transition structure and a 1-ft 6-in.-thick clay liner was added to the canal bottom.

The original aqueduct featured two, 4 by 4 ft "waste gates" in the downstream sidewall of the timber trough. These gates provided National Park Service staff with the ability to regulate the water levels in the canal, either after a flood event or for maintenance purposes. Replicating such large gate openings in the through girders would have compromised the structure's capacity.

Rather, two 2-ft-square, manually operated sluice gates were provided in the side wall of the southern transition structure and discharge into

3-ft-diameter, outfall pipes, buried behind the existing stone abutments, out-letting downstream to Tinkers Creek.

Pier Reconstruction

The existing 44-ft-long masonry pier was significantly deteriorated including cracked and dislodged stones, missing mortar joints, heavy vegetation growth, and settlement at the upstream end. The 112 ashlar sandstone blocks making up the pier were completely dismantled and the pier fully reconstructed as part of the project.

The bottom two courses of stones below the creek bed were removed and replaced with a new concrete footing supported on two rows of seven micropiles. This new footing not only provided long-term scour protection and a stable surface on which to reconstruct the stone masonry, but it also allowed the displaced stones to be used for stone repairs in the upper reaches of the pier.

Twin 4 by 3 ft concrete columns extending up from the pier footing were cast inside the core of the stone pier to support the stainless steel and elastomeric bearings that carry the aqueduct trough. This provided an entirely new load carrying system and avoided loading the sandstone masonry.

Various labor-intensive hand repair techniques were used to restore the historic stonework including re-tooling the exposed stone faces that featured a bush-hammered surface with smooth window pane margins, "dutchman" repairs consisting of piecing in new corners of chipped stones, and full replacement of the individual stones in some cases.

Mortar consisting of sand, hydraulic hydrated lime, and cement—and tinted to match the original mortar—was used in all of the bedding joints and re-pointing efforts.

AESTHETICS COMMENTARY

by Bradley C. Touchstone



Sometimes the most valued historical assets are created to solve a specific challenge in a clever and innovative way. Such is the case with the Ohio & Erie Canal Aqueduct over Tinkers Creek. It would be unreasonable and dishonest to rebuild the aqueduct as originally constructed. When restoration is not possible, the Advisory Council on Historic Preservation encourages us to create replacements that utilize current methods and materials to capture the essence of the original structure while avoiding mimicry.

The new aqueduct design pays homage to the original structure through the use of form, scale, and texture. At the same time, the replacement is built using the latest construction techniques and materials in a manner that is clearly of its time.

The use of concrete for the superstructure in lieu of the original materials makes perfect sense. Concrete has a unique ability to accommodate requirements for span length, durability, and water tightness. Use of form liners to develop a rusticated pattern on the superstructure face further illustrates the flexibility of this material. The patterns used soften the appearance of the bridge and will allow the bridge to age in an elegant fashion.

The resulting restoration project adheres to the guidance of the Advisory Council on Historic Preservation and subtly and cleverly updates the original structure while maintaining the mystique of this entertaining and informative aqueduct for all who visit.

A Stable Foundation

The pier and abutments feature a deep foundation system consisting of 7-in.-diameter micropiles extending into the clay and silty sands beneath the aqueduct supporting more than 1000 tons of water, concrete, and stone load. The 65-ft-long micropiles featured a concrete filled upper steel casing,

with a lower 50-ft-long grouted bond zone. In addition to their high axial and lateral capacity, micropiles were ideally suited for this project site given the small footprint of the installation equipment, the ability to drill through potential obstructions, and the need to minimize vibrations on the surrounding masonry abutments.

Bringing Back the Water

On September 22, 2011, after a year of construction, the original canal system was restored and the waters of the Ohio & Erie Canal flowed once again over Tinkers Creek as they have done for the past 166 years. Unlike its predecessors, the new, all concrete aqueduct structure will provide Cuyahoga Valley National Park and its visitors with a functional piece of history well into the twenty-first century. 

Anthony Borrelli is the New York bridge division manager for Bergmann Associates in Rochester, N.Y., and the project's engineer of record.

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



Elevation view of the new aqueduct and fully reconstructed masonry pier. Photo: Henry G. Russell Inc.



MAP-21: Moving Ahead for Progress in the 21st Century Act

by M. Myint Lwin, Federal Highway Administration

On July 6, 2012, President Obama signed into law P.L. 112-141, the Moving Ahead for Progress in the 21st Century Act (MAP-21). This is a two-year act with funding for surface transportation programs for fiscal years 2013 and 2014, which began October 1, 2012.

MAP-21 creates a streamlined, performance-based, and multi-modal program to address the many challenges facing the U.S. surface transportation system. This article provides a summary of the major funding and policies affecting the bridge and tunnel programs.

Program Restructuring

MAP-21 restructures core highway formula programs. Activities carried out under some pre-MAP-21 formula programs, such as, the National Highway System Program, the Interstate Maintenance Program, and the Highway Bridge Program, are now incorporated into the following new core formula program structure:

- National Highway Performance Program (NHPP): \$21.8 billion
- Surface Transportation Program (STP): \$10 billion
- Congestion Mitigation and Air Quality Improvement Program (CMAQ): \$2.2 billion
- Highway Safety Improvement Program (HSIP): \$2.4 billion
- Railway-Highway Crossings (set-aside from HSIP): \$0.2 billion
- Metropolitan Planning: \$0.3 billion

Most of the SAFETEA-LU discretionary programs, including the Highways for LIFE, the Innovative Bridge Research and Deployment, and the National Historic Covered Bridge Preservation Programs, have been consolidated into broader programs.

The new bridge and tunnel programs are now covered under the new provisions in section 1106 NHPP, section 1108 STP, and section 1111 National Bridge and Tunnel Inventory and Inspection Standards. These three sections of MAP-21 that address bridges and tunnels are discussed in further detail below.

MAP- 21 Highway Funding for Two Years

	SAFETEA-LU Average Per Year	MAP-21 Average Per Year
Apportioned by Formulas	\$34.3 billion	\$37.7 billion
Earmarks	\$4.4 billion	\$0

National Highway Performance Program

Under MAP-21, the enhanced National Highway System (NHS) is composed of approximately 220,000 miles compared to 160,000 miles pre-MAP-21. It includes the U.S. Interstate System, all principal arterials, border crossings on interstate and arterial routes, and highways that provide motor vehicle access between the NHS and major intermodal transportation facilities.

The NHPP is authorized at an average of \$21.8 billion per year to support the condition and performance of the enhanced NHS, for the construction of new facilities, and to ensure that investments of federal-aid funds in highway construction are directed to support progress toward the achievement of performance targets established in an asset management plan of a state for the NHS.

The NHPP funds may be used for the following purposes for bridges and tunnels:

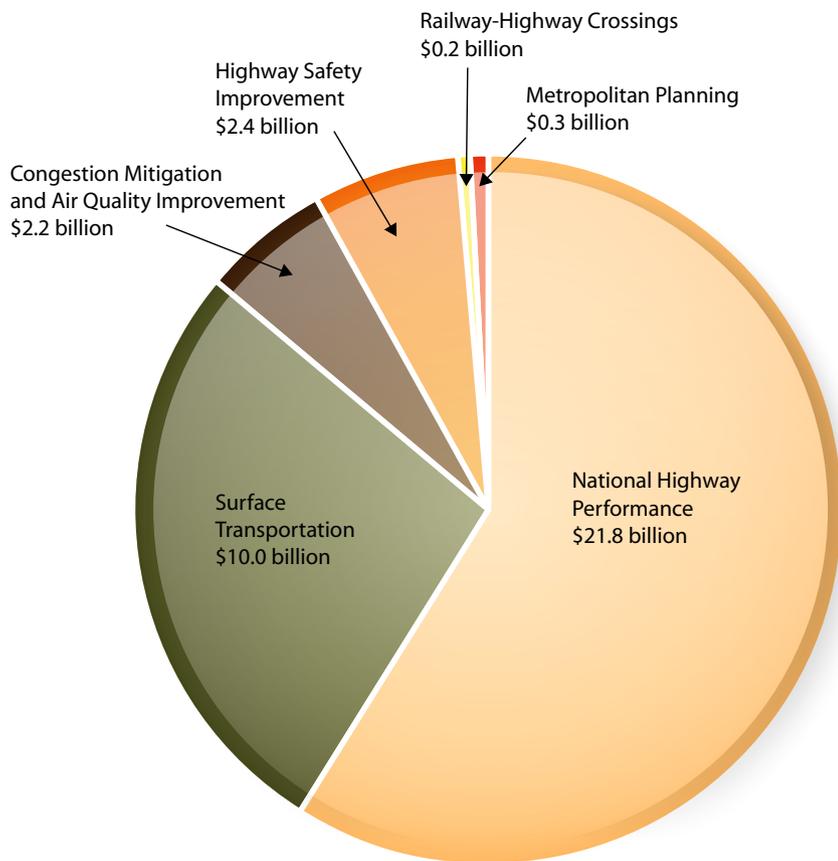
- Construction, replacement, rehabilitation, preservation, and protection (including scour countermeasures, seismic retrofits, impact protection measures, security countermeasures, and protection against extreme events) of bridges and tunnels on the NHS.
- Inspection and evaluation of bridges and tunnels on the NHS, and inspection and evaluation of other highway infrastructure assets on the NHS, including signs and sign structures, earth retaining walls, and drainage structures.
- Training of bridge and tunnel inspectors.
- Development and implementation of a state asset management plan (AMP)

for NHS, including data collection; maintaining, updating, and licensing software; and equipment required for risk-based asset management and performance-based management. At a minimum, the state AMP must include:

- a summary listing of the bridge assets on the NHS in the state and a description of the condition of those assets,
- asset management objectives and measures,
- performance gap identification,
- life-cycle cost and risk management analysis,
- a financial plan, and
- investment strategies.

MAP-21 establishes a performance program for maintaining and improving the NHS:

- States are required to develop a risk- and performance-based asset management plan for the NHS to improve or preserve asset condition and system performance. The penalty for a state's failure to implement this requirement by the required date is a reduced Federal share for NHPP projects in that year (65% instead of the usual 80%).
- The Secretary of Transportation establishes performance measures for NHS bridge conditions, and system performance. States will establish targets for these measures, to be periodically updated.
- MAP-21 establishes a minimum standard for the condition of NHS bridges. If more than 10% of the total deck area of NHS bridges in a state is on structurally deficient bridges, the state



MAP-21 restructures core highway formula programs. Graphic: PCI.

must devote a portion of NHPP funds to improve the conditions until the minimum standard is exceeded.

Surface Transportation Program

MAP-21 continues the STP of SAFETEA-LU, providing an annual average of \$10 billion in flexible funding that may be used by the states and localities for projects to preserve or improve conditions and performance on any federal-aid highway and bridge projects on any public road.

The STP funds may be used for the following purposes related to bridges and tunnels:

- Replacement, rehabilitation, preservation, protection (including painting, scour countermeasures, seismic retrofits, impact protection measures, security countermeasures, and protection against extreme events) and application of calcium magnesium acetate, sodium acetate/formate, or other environmentally acceptable, minimally corrosive anti-icing and deicing compositions for bridges and approaches to bridges and other elevated structures, and tunnels on public roads of all functional classifications.
- Construction of a new bridge or tunnel

at a new location on a federal-aid highway.

- Inspection and evaluation of bridges and tunnels, training of bridge and tunnel inspectors, and inspection and evaluation of other highway assets (including signs, retaining walls, and drainage structures).
- Development and implementation of a state asset management plan for the NHS.
- A portion of a state's STP funds (equal to 15% of the state's fiscal year 2009 Highway Bridge Program apportionment) is to be set aside for bridges not on federal-aid highways (off-system bridges), unless the Secretary of Transportation determines the state has insufficient needs to justify this amount.

Bridge and Tunnel Inspection

MAP-21 requires inspection and inventory of highway bridges and tunnels on public roads. No dedicated funds are provided for inspections, but it is an eligible use of NHPP, STP, HSIP, FHWA administrative, tribal transportation, and research funds.

In addition to inspection and inventory of

highway bridges and tunnels, MAP-21 requires the following actions:

- Classify the bridges according to serviceability, safety, and essentiality for public use, including potential impacts to emergency evacuation routes, and freight and passenger mobility.
- Based on the classification, assign each a risk-based priority for systematic preventative maintenance, rehabilitation, or replacement.
- Determine the cost of replacing each structurally deficient bridge with a comparable facility or the cost of rehabilitating the bridge.
- Update the inventories annually and submit a report on the inventories to congress.
- Not later than two years after the date of enactment of the MAP-21, each state and appropriate federal agency must report to the Secretary of Transportation, element level data, as each bridge is inspected, for all highway bridges on the NHS.
- Conduct a study on the benefits, cost-effectiveness, and feasibility of requiring element-level data collection for bridges not on the NHS, and submit a report on the results of the study to Congress.

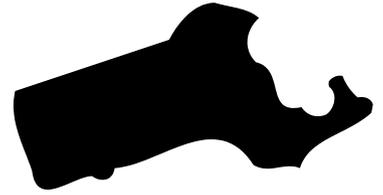
Closing Remarks

MAP-21 represents a milestone for the U.S. surface transportation and the economy. MAP-21 provides the framework and direction for investment in the nation's railways and highways for continued safety and serviceability of the transportation infrastructure. FHWA will be working together with the state transportation departments on the implementation of the provisions of MAP-21. 

EDITOR'S NOTE

As space is limited, this article addresses only the provisions that have major impact on the bridge and tunnel programs. For more detail on the requirements of MAP-21, please visit <http://www.fhwa.dot.gov/IMAP21>.

MassDOT— Concrete Bridge Pioneers



by Alexander K. Bardow, Massachusetts Department of Transportation



A typical early reinforced concrete T-beam bridge built by the Massachusetts Highway Commission. This bridge, erected in 1909, is over Palmer Brook on what became U.S. 20 in the town of Becket. Photo: Massachusetts Department of Transportation Bridge Section Archives.

The history of concrete bridges in Massachusetts is closely tied to the history of the Massachusetts Department of Transportation (MassDOT). The Massachusetts Highway Commission, the first predecessor of the MassDOT, was established by the state legislature “to improve the public roads” in 1893, during the early era of reinforced concrete bridge construction.

Early Days

In an article published in the December 1929 *Journal of the Boston Society of Civil Engineers*, Arthur W. Dean, the chief engineer of Massachusetts Department of Public Works (successor to the Highway Commission), wrote that Massachusetts “was the pioneer in this country in the use of reinforced concrete for bridges,” a distinction that Massachusetts maintains to this day.

In those early days, the highway commission experimented with reinforced concrete for a practical reason: it was difficult to obtain good rubble masonry at a reasonable cost for the construction of culverts and bridges. As stated in its January 1903 Annual Report, in order to save money, the highway commission started to use

reinforced concrete because it could be built with less-skilled labor and, as an added bonus “the resulting structure is more pleasing to look at, as well as more enduring.”

Many of these early bridges were either beam bridges with a reinforced concrete deck or closed spandrel arch bridges. At first, design services were performed by consultant engineers, but by 1904 the highway commission started to design bridges with its own in-house staff.

An early bridge designed and built by the highway commission, and the largest surviving example, is the Sisk Bridge. Built in 1910, it carries Old State Highway over the West Branch of the Westfield River in Chester, Mass., with a skew span of 110 ft and a skew angle of 30 degrees.

By the end of the twentieth century, the Sisk Bridge was showing its age, with significant freezing and thawing damage of the concrete of the spandrel walls and the outside edges of the arch. However, the rest of the arch was in very good condition. Based on the results of material testing, a structural analysis revealed that it was structurally sound to carry modern truck loads. The bridge was successfully rehabilitated in 2010, which included a slight widening with arch extensions and new spandrel walls while

retaining the existing 1910 reinforced concrete arch in the middle. (See *ASPIRE*TM Summer 2011.)

Precast, Prestressed Concrete

The introduction of prestressed concrete after World War II signaled a new era in the construction of concrete bridges in Massachusetts, and once again, Massachusetts was an early leader in the use of this material. While Massachusetts did not build the first prestressed concrete bridge in the United States, it did recognize the potential of this material for rapid bridge construction.

This realization played an important role in 1955 when—over a span of several days in August—two hurricanes, Connie and Diana, ripped across the state. The heavy rains associated with these hurricanes brought massive flooding to many waterways in central Massachusetts. Bridges were destroyed in domino fashion as debris, swept downstream by the flood waters, piled up against a bridge until it failed, and the resulting wreckage was carried down to repeat the cycle at the next bridge.

In the aftermath, 220 Massachusetts bridges in 80 cities and towns were destroyed. The devastation required a rapid construction method to replace the fallen bridges, reconnecting roads and restoring isolated communities. Massachusetts officials turned to precast, prestressed concrete beams to rapidly restore the transportation network.

Because many of these bridges spanned less than 40 ft, Massachusetts selected adjacent deck beams (voided slabs) with a membrane and asphalt wearing surface as the structure type. Two standard beam depths were selected: 17-in.-deep beams for spans of 20 to 30 ft and 21-in.-deep beams for spans of 30 to 40 ft. Bridges with spans over 40 ft were individually designed, but many used prestressed concrete deck beams or I-girders.

This decision proved to be an excellent one. Not only were the bridges replaced within two years, but many are still in service and carrying modern traffic loads today. A review of the



The Sisk Bridge in Chester, carrying Old State Highway over the West Branch of the Westfield River was originally built in 1910 by the Massachusetts Highway Commission and rehabilitated in 2010. The original reinforced concrete arch is sandwiched between new arch extensions and spandrel walls, and carrying modern highway loads. Photo: CME Associates Inc.

latest bridge inspection reports for these nearly 60-year-old bridges finds that many are still in satisfactory to good condition, and show few signs of deterioration of the prestressed concrete beams.

Modern Innovations

Massachusetts' current concrete bridge era can be traced to 1990 when the Precast/Prestressed Concrete Institute New England (PCI NE) Technical Committee began to expand by including state department of transportation engineers as committee members. Massachusetts joined in 1990, followed by Rhode Island and Connecticut. By 1994, all six New England states were represented on the committee.

At first, the committee worked to standardize precast concrete beam details, at least from the standpoint of the precaster. Individual states still retained their respective bridge details, but the precast concrete beams were designed to a standard size and cross section detailing, eliminating those individual state standards. The most important aspect of this committee was that all six states agreed to use the same basic beam details.

An example of the adjacent deck beam bridges used to quickly replace many of the smaller bridges destroyed by the hurricanes of 1955. This bridge is on Fowler Street over Warren Brook in the town of Upton. Photo: Massachusetts Department of Transportation.

The energy the committee developed in working on the standard beam details carried forward into the development of a bulb-tee beam standard for New England—the New England bulb-tee (NEBT) beam series. Although the New England standard was the AASHTO I-girder, states were finding that it had limitations in its range of applicability and there were more efficient girder shapes in use elsewhere in the country, such as bulb-tees.

Starting in March 1994, the PCI NE Technical Committee began developing an efficient bulb-tee girder section, adaptable to post-

tioning for continuity and beam splicing to accommodate longer spans. This girder design accounted for the capabilities of the region's precasters including weight and length restrictions for transport.

By July 1994, the NEBT had been sufficiently developed to warrant independent reviews. Professor Maher Tadros of the University of Nebraska, the developer of the NU bulb-tee girder, provided feedback that the PCI NE Technical Committee used to improve the girder. Next, Reid Castrodale, who was then at the Portland Cement Association, ran head-to-head comparisons of the NEBT with the AASHTO girders and PCI bulb-tee girders. These comparisons confirmed the section's capabilities.

The NEBT became the new standard New England bulb-tee girder and, when New York joined the committee and also adopted the NEBT, it became the northeast girder standard. Further, the Canadian provinces of Quebec and New Brunswick adopted the NEBT, making it an international girder shape.

The PCI NE Technical Committee continued in its trail blazing by developing and issuing standards for rapid construction. These included: precast concrete footings, abutments, wingwalls, full-depth deck panels, and railings. These details were issued in 2006, with many being incorporated into the Federal Highway Administration's manual on Rapid Bridge Construction.

In addition, the committee continued to develop new, more efficient beam shapes to facilitate rapid construction. These efforts lead to the development of the northeast extreme tee (NEXT) beam. This modified double-tee beam is intended for medium span bridges and designed to address limitations of





An example of a NEBT beam bridge developed by the PCI Northeast Technical Committee. The Massachusetts Department of Transportation has been a member since 1990. This bridge is on River Road over Mill River in Northampton, Mass. Photo: Massachusetts Department of Transportation.

adjacent box and deck beam bridges, which include complexity of fabrication, erection, and inadequate room for utilities.

The committee realized the significant advantages double-tee type beams have in span range, ease of fabrication, and their ability to accommodate utilities. Additionally, once in place, the top flange acts as a form for a conventional deck, thereby accelerating construction. The concept was brought to the committee in October 2006, the development started at the November 2006 meeting and the new beam shape standards were issued in February 2008. The committee developed beams for several overall widths while keeping the stem spacing in a NEXT beam unit constant allowing the beams to match a variety of roadway cross sections.

The beam has been further refined to include a decked NEXT beam series. In this series, labeled the NEXT-D, the top flange is now a full-depth deck cast integrally with the beam stems. Once these units are set, the deck elements are connected through closure pours creating a continuous deck element. The NEXT-D beam promises to be an important beam type for rapid bridge construction.

The Future

The Massachusetts Accelerated Bridge Program, an initiative of Governor Deval Patrick, which began in 2008 and is intended to be a laboratory of innovation, has allowed MassDOT to deploy many rapid

bridge construction concepts and beam types developed by the PCI NE Technical Committee. Massachusetts remains an enthusiastic member of this committee and looks forward to continuing the advancement of concrete bridge technology and innovative solutions in the northeast and continuing our concrete bridge pioneering legacy. 

Alexander K. Bardow, P.E., is a state bridge engineer for the Massachusetts Department of Transportation, Boston, Mass.

For more information about Massachusetts Accelerated Bridge Program, visit www.eot.state.ma.us/acceleratedbridges/.



The NEXT Beam, or Northeast Extreme Tee beam, developed by the PCI NE Technical Committee, is designed for rapid construction of bridges. This is the State Route 19 (Wales Road) Bridge in Brimfield, shown while still under construction in 2011. Photo: Massachusetts Department of Transportation.

2013 Call for Papers

Abstracts due JANUARY 31, 2013!

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PCI is accepting abstracts for technical papers to be presented at the 2013 PCI Convention and National Bridge Conference in Grapevine, Texas. Abstracts and papers will be peer-reviewed and accepted papers will be published in the proceedings.

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Submission Requirements

Abstracts should be submitted electronically. Visit www.pci.org and click on the Call for Papers button for full details and to access the submission site.

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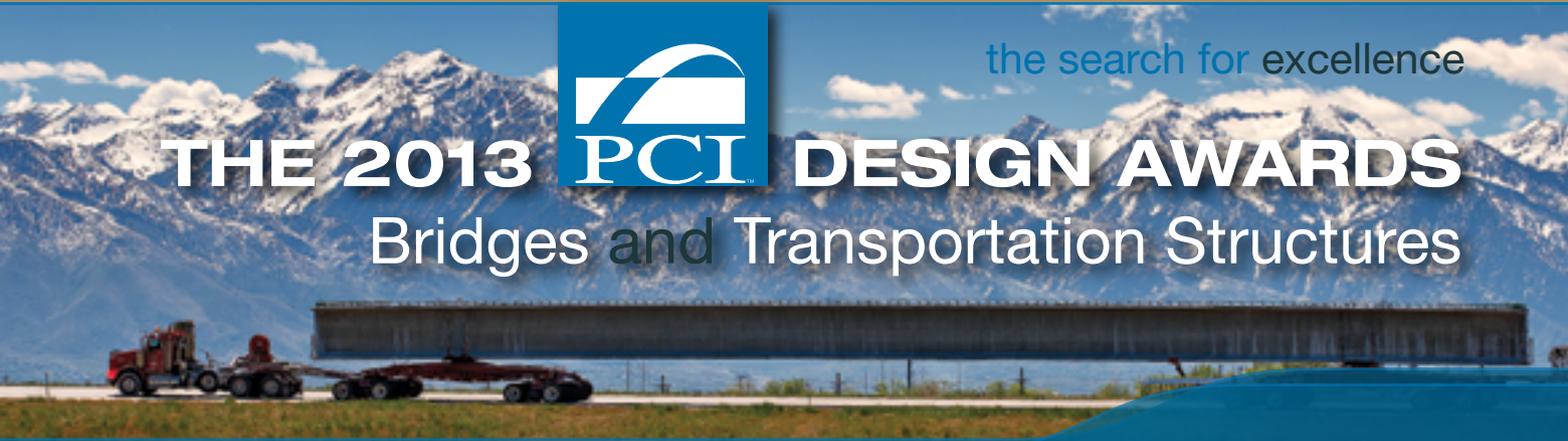
William Nickas, P.E.

wnickas@pci.org

Buildings:

Brian Miller, P.E., LEED AP

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Brian Miller, P.E., LEED AP, bmiller@pci.org

For Technical Questions

Regarding Bridges and Transportation Structures, Contact:

William Nickas, P.E., wnickas@pci.org

Proper Installation of Adhesive Anchors

Lessons learned from anchor failure, new training available

by Mallory Whaley, Concrete Reinforcing Steel Institute

Late in the evening of July 10, 2006, a section of precast concrete ceiling in Boston's I-90 tunnel came loose and fell to the pavement below, hitting a passenger vehicle and killing a woman. The cause was proved to be the incorrect use of an adhesive anchoring system in the tunnel, popularly known as "the Big Dig."

Adhesive anchoring systems are comprised of post-installed anchors that transfer loads to concrete by bonding between the concrete, adhesive, and anchors. They are useful in bridge and highway construction applications because contractors can place the concrete and come back later to attach signs, railings, lights, and more.

The National Transportation Safety Board's (NTSB's) investigation into the tunnel failure faulted the tunnel's designers and builders for using an inappropriate epoxy for the sustained load. Over time, the epoxy deformed and fractured, which allowed the anchors to separate from the concrete tunnel roof, causing the ceiling panels to fall.

One of the safety issues identified in the NTSB report was the lack of national standards for adhesive anchors at the time of tunnel design and construction. Standard practice was to follow the manufacturer's instructions on the adhesive packaging. In 2007, the NTSB requested that the American Concrete Institute (ACI) warn design and construction companies of the dangers of using incorrectly applied adhesive anchors. ACI moved to adopt new standards, but then needed a way to ensure concrete professionals were in compliance with the developed practice.

"It became evident that if we were going to put this in the code, we were going to need certification guidelines," said Neal Anderson, Concrete Reinforcing Steel Institute's (CRSI's) vice president of engineering and seminar instructor.

In response to the tunnel failure, ACI and CRSI are offering a seminar, "Adhesive Anchors: Their Behavior and Code Design Requirements," for designers and builders.

The seminar and the adhesive anchoring installer certification program, held in various locations across the country, will address the following subjects:

- Properties of common adhesives
- Lessons learned from failure
- Tension and shear failure modes
- Capacity reduction factors
- Tension and shear interaction
- Qualification standards for adhesive anchors
- Design of supplemental reinforcement



An example of a correctly installed adhesive anchor. All photos: Neal Anderson.



The hole on the left is correctly cleaned. The two holes on the right are still dusty. An epoxy adhesive will not correctly adhere to an improperly cleaned hole.



An adhesive anchor using reinforcing steel.

NTSB Recommendation

The National Transportation Safety Board's recommendation to the American Concrete Institute:

"Use your building codes, forums, educational materials, and publications to inform design and construction agencies of the potential for gradual deformation (creep) in anchor adhesives and to make them aware of the possible risks associated with using adhesive anchors in concrete under sustained tensile-load applications."

From ntsb.gov

- The importance of proper anchor installation procedures in concrete
Ideally, attendees should be able to come away from the seminar being able to:
 - read, comprehend, and execute anchor installation instructions;
 - assess ambient conditions, condition of concrete, materials, equipment, and tools;
 - determine when to proceed with installation or seek additional guidance from a supervisor; and
 - pass the written and practical exams.

At the end of the seminar, a 75-question, written test, along with two, hands-on examinations are administered. The first hands-on exam assesses vertical-down installation of an adhesive threaded rod anchor. Proper drilling, cleaning, and adhesive anchor installation techniques are evaluated. The second hands-on evaluation focuses on overhead injection of an adhesive using a retaining cap and a piston plug.

Attendees successfully completing the seminar receive 0.75 Continuing Education Credits or 7.5 Learning Hours, worth 7.5 Professional Development Hours and receive a copy of Volume 2 of *The Reinforced Concrete Design Manual in Accordance with ACI 318-11*. In addition to the in-person seminar, ACI also offers an online version titled "Adhesive Anchor Installation."

For more information, visit www.concreteseminars.com. 

Mallory Whaley is a members services/communications assistant at the Concrete Reinforcing Steel Institute (CRSI) in Schaumburg, Ill.

Klyde Warren Park—Dallas

by Mir H. Ali, Jacobs Engineering Group Inc.

When the residents and city leaders of Dallas, Tex., wanted to connect the two parts of the city separated by the depressed Woodall Rodgers Freeway, they decided to create a park with many amenities above the freeway. This public-private partnership project was funded by the Woodall Rodgers Park Foundation, City of Dallas, Texas Department of Transportation, and the Federal Highway Administration. The park is named the Klyde Warren Park.

Structural System

One of the challenges in the design was to set the park elevation at the same elevation as the frontage roads, to provide access from the frontage roads without climbing steps, while maintaining the minimum vertical clearance of 16 ft 6 in. under the deck. This required the selection of the most efficient structural system with minimum structural depth.

The deck carries the heavy loads of trees, soil, buildings, and other amenities. Another important consideration in selection of the deck structural system was to accommodate the tree root bulbs within the structural depth, so that no soil mounds had to be created to plant the trees.

The superstructure consists of two spans of about 100 ft each with post-tensioned concrete box beams made continuous over the middle support for the superimposed dead and live loads. The prestressed concrete box beams are arranged in groups of three or more. Concrete panels are placed between the beam groups to form trenches to accommodate the tree root bulbs; the trenches act like planter boxes. The concrete panels are supported on ledges formed on the sides of the edge beams.

The trenches are also used to accommodate the utility lines including a 16-in.-diameter water line, gas lines, and many fiber optic-cables, telephone lines, and electrical lines. Two utility bridges across the Woodall Rodgers Freeway were removed in phases as the utilities were relocated to the new deck.

The loads of every feature and element on the deck were accounted for in the design. The superimposed dead loads on the deck were drastically reduced by using expanded polystyrene (EPS) and engineered lightweight fill (kiln-dried expanded shale and clay) wherever planting soil was not needed. The EPS



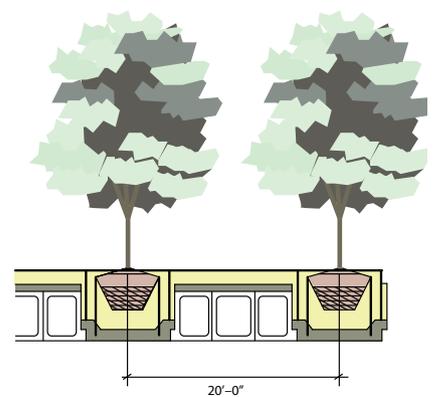
When complete, Klyde Warren Park will include a lawn, children's park, botanical garden, dog park, fountains, groves, reading and games courtyard, performance pavilion, restaurant, and rest rooms. Photo: Aerial Photography Inc., Dallas, Tex.

weighs 1.8 lb/ft³ and engineered lightweight fill weighs 65 lb/ft³ compared to the normal density of soil, which is about 120 lb/ft³.

The deck is waterproofed with a liquid-applied asphalt system, protective board, drainage mat, and root repellent. The root repellent is used to prevent the roots from growing into the waterproofing and structural elements.

Tunnel Created

By covering the freeway with the deck, it converted the depressed open freeway into a tunnel. This required the application of all the current safety requirement of National Fire Protection Association. The deck structure and the deck supports needed to be fire protected for two hours. Emergency ventilation fans were installed to facilitate the removal of smoke build up in case of a fire. Lighting was installed including transition lighting at the entrances. 



Cross section of the tree trench. Drawing: Jacobs Engineering Group Inc.

EDITOR'S NOTE

Note: This is an edited version, to read the complete article visit www.aspirebridge.org, and click on "Resources."

Mir H. Ali is manager of engineering, structures principal, Jacobs Engineering Group Inc., Dallas, Tex.



Creative Patches Save McCullough Bridge

The Conde McCullough Bridge at Coos Bay, Ore, is arguably the most exquisite showpiece in a series of historic coastal bridges along U.S. 101, the Pacific Coast Scenic Byway. Preserving this signature structure of concrete arches required a variety of innovative approaches. These included a customized, self-consolidating micro-concrete; the addition of salt to the repair mortar; and the use of a cathodic-protection system.

Designed by famed engineer Conde B. McCullough and built in 1936, the 5305-ft-long structure was the longest bridge in Oregon's highway system when constructed. It features extensive Art Deco ornate detailing throughout the bridge.



The Conde B. McCullough Bridge on Highway 101 at Coos Bay, Ore. Photo: International Concrete Repair Institute and BASF Corp.

Many sections needed to be repaired to restore the bridge. Some 20- to 30-ft-long sections received dozens of form-and-pump repairs, typically 2 to 4 in. in depth, plus numerous small hand-applied patches. These repairs required a versatile material that could adhere to the substrate, was compatible with the resistivity of the original concrete, and could be placed both in shallow and deep applications, in a confined area.

Salt Added to Mixture

Normally, it is not recommended that any salt be added to concrete, due to the risk of propagating corrosion; however, in the case of cathodic protection, electrical resistance compatibility is important to ensure uniform current distribution to the embedded reinforcing steel. Electrical resistance compatibility with a concrete exposed to 80 years of marine salt was obtained by adding table salt to the repair mortar. The volume of salt added to each bag was determined by calculating the amount of chlorides found in the host concrete.

The bridge's multilevel enclosure that housed the repair called for a lightweight, mobile concrete pump that could be used on each level and on narrow scaffold planks. Diaphragm-type, hand-operated grout pumps were placed on tight scaffold areas so the material could be pumped full depth both vertically and overhead. In these areas, complex forms were assembled to recreate the original Art Deco designs.

The portable pumps necessitated the use of a self-consolidating, micro-concrete, to ensure that the top-size aggregate was small enough to be pumped while still allowing placement up to full depth without adding any pea gravel.

Once the concrete cured, the repaired surface was sandblasted and a zinc coating was applied to serve as the sacrificial component of the cathodic-protection system. This system redirects corrosion activity that normally would occur in the steel reinforcing bars. It requires the concrete to be uniformly and electrochemically conductive, which was enhanced by the salt in the repair mortar. A low-voltage electrical current drives the corrosion into the zinc coating rather than the reinforcing bars, protecting the bridge.

It took four years to restore the south end of the bridge, and it is anticipated that the longer north end could take five or more years to complete. Meanwhile, work continues on several other Oregon bridges using this form-and-pump repair method. Through the Oregon Department of Transportation's efforts to identify and prioritize needed bridge work, many historic bridges are being saved for future generations. ▲

This article is an abridged version of an article that appeared in the November-December 2011 issue of Concrete Repair Bulletin and is published with permission of the International Concrete Repair Institute. For more information on the organization, visit www.icri.org.

Cedar Lane Bridge over Rockville Pike

by Dennis F. Campbell,
Newcrete Products

Cedar Lane Bridge over Rockville Pike in Kensington, Md., is located in the midst of an important transportation corridor. The bridge is surrounded by interstate arteries, centered in a very populated community, situated on a major school bus route, and handles an average daily traffic flow of 12,650 vehicles. Because of the bridge's deteriorated condition, a forensic investigation was conducted to determine the compressive strength and chloride ion content of the existing concrete. Analysis of the results indicated the bridge had an estimated remaining service life of five years, making the decision to replace the structure easy. The selected replacement solution needed to maintain the architectural appearance of the original bridge, accommodate pedestrian traffic, limit the disruption to the community, and be constructed on a compressed schedule.

Contract specifications for the replacement included incentives and disincentives, and allowed for 70 days for the road closure. Major steps in the design and construction of the replacement bridge included:

- establishing closure requirements and benchmarks,
- submitting and approving shop drawings, demolition plans, and erection plans,
- installing a temporary bridge and opening it to pedestrian traffic,
- fabricating and storing precast concrete elements,
- posting a detour route, and
- assembling demolition and erection equipment and readying them for use.

Geotechnical and foundation analysis showed the existing sub-grade and footings were adequate to support a new bridge and did not need to be removed. The precast, prestressed concrete system included prestressed concrete adjacent box beams; reinforced concrete pier caps; reinforced concrete abutment caps; and precast concrete architectural parapets that were created as a second cast on the fascia beams. The architectural parapets and sidewalk were initially shown as cast-in-place concrete. In order to meet the limited time requirements for the project, a precast concrete solution was developed to provide the architectural parapet and sidewalk cast on the prestressed concrete beams before leaving the precast manufacturing plant.



Erection of precast concrete pier caps. All photos: Newcrete Products.

The structure was assembled by first setting, and vertically post-tensioning, the pier caps and abutment caps to the existing pier stubs utilizing 1-in.-diameter, epoxy-coated, high-strength, threaded bars. These bars conformed to ASTM A722, Grade 150, Type II and were tensioned to 54 kips. The adjacent box beams were then placed and transversely post-tensioned using 1¼-in.-diameter, Grade 150, hot-dipped, galvanized, ASTM A722 threaded bars, which were tensioned to 120 kips. A 5-in.-thick, cast-in-place, concrete overlay on the roadway and a 4-in.-thick concrete overlay on the sidewalk completed the structure.

The concrete components consisted of 36 typical box beams, 8 thickened box beams for the sidewalk, 8 fascia beams with decorative parapets, 3 precast concrete pier caps, and 2 precast concrete abutment caps. The abutment caps were the heaviest components weighing over 62 ton each. Span lengths were each 42 ft.

Notice to proceed was given on February 14, 2011. The road was closed on June 16, with bridge erection completed on July 7. The bridge was reopened on August 6, 2011, well in time for a new school year.

Planned and orchestrated for success, the removal and replacement construction was completed in 51 days, 19 days ahead of schedule. The application of accelerated bridge construction techniques, using precast, prestressed concrete structural components provided an economical solution, met the schedule, and produced the desirable end results of this truly unique project. ▲

Dennis F. Campbell is an administrator with Newcrete Products in Center Valley, Pa.



Completed bridge.

Route 76 Bridge over Lake Taneycomo

by **Thomas P. Lohman, Horner & Shifrin Inc.**

The Route 76 Bridge over Lake Taneycomo in Branson, Mo., is the longest and oldest spandrel-arch bridge in Missouri and is generally recognized as one of the state's most notable structures. The Branson area is a popular vacation destination with an estimated 8 million visitors annually and 20,000 vehicles crossing the bridge daily. Consequently, the importance of limiting road closure during construction was paramount. Additionally, the historic significance of the bridge required that bridge preservation, rather than bridge replacement, be employed.

Built in 1931, this structure is 1085 ft long and connects the cities of Branson and Hollister. The bridge consists of five 195-ft-long reinforced concrete open spandrel arch spans with concrete deck girder approach spans. The deck and spandrel beams of the arch spans were severely deteriorated and needed replacement. The existing spandrel columns were to remain in place.

Early in the design phase, it became apparent that accelerated construction was necessary to minimize traffic impacts. Many options were explored including the use of precast concrete spandrel beams, precast concrete deck panels, and combinations of the two. Local precast concrete fabricators were consulted to determine their capabilities and preferences. Based on those discussions, two innovative uses of precast concrete were developed: precast, reinforced concrete spandrel beams and partial-depth, precast, prestressed concrete deck panels.

Existing concrete spandrel beams were spaced at 10.5 ft along the length of the arch spans. The existing beams were cast on concrete spandrel columns that carry the load to the arches. To speed and simplify construction, new precast, reinforced concrete spandrel beams were used. The beams had pockets cast in them to allow the existing column reinforcement to be re-used in the connection detail.

Spandrel beams were set on a bed of epoxy on top of the existing columns. The epoxy acted both as a leveling pad and joint sealant around the exterior of the reinforced connection. The pockets were then filled with grout. Once the process was mastered, the contractor was able to complete the work quickly, saving months of construction time.



Photo of the completed bridge. All photos: Kevin Skibiski, Horner & Shifrin.

Challenges included casting the grout pockets and handling the beams because of the reduced cross section at the grout pockets. Ninety-five beams were required, each approximately 32 ft long with a 2-ft-square cross section. The tops of the beams were sloped 2% transverse to the roadway to provide a better fit-up of the partial depth, precast, prestressed concrete deck panels.

Missouri has used partial-depth, precast, prestressed concrete deck panels as their standard method of deck construction for slab-on-girder bridges for many years. This project required the main reinforcement to be parallel to traffic on the spandrel arch spans, not transverse to traffic as is the case for more traditional slab-on-girder construction methods. This required a special design for over 30,000 ft² of 3.5-in.-thick panels, but the shape and materials of the standard panels were maintained, allowing the fabricator to use forms and materials already available. The panels were made composite with a 5.5-in.-thick, cast-in-place concrete deck.

The use of precast concrete allowed for accelerated construction, saving the contractor months of construction time. In addition to these time savings, the elements fit together so smoothly that the bridge was re-opened more than one month ahead of schedule.

The bridge was recognized as the Best Rehabilitated Bridge in the 2012 PCI Design Awards. 

Thomas P. Lohman is a project manager with Horner & Shifrin Inc. in St. Louis, Mo.



Precast spandrel beams were placed on top of the existing columns.

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.state.nj.us/transportation/commuter/roads/route52

This New Jersey Department of Transportation website contains additional information about the Route 52 Causeway Bridge Replacement described on pages 12 to 14.

www.snjb.net/

This website provides information about the operation of the South Norfolk Jordan Bridge described on pages 28 to 30. Click on Images for photographs taken during construction.

http://www.newyorkcanals.org/_pdfs/Bobel%20and%20Borrelli.pdf

The website of the Canal Society of New York contains a presentation about the restoration of Tinkers Creek Aqueduct described on pages 32 to 35.

http://www.oregon.gov/ODOT/hwy/geoenvironmental/docs/historic_bridge/coastbr.pdf

The Concrete Bridge Preservation article on page 44 mentions Conde B. McCullough, a former Oregon State Bridge Engineer. More information about Conde McCullough and his bridges is available at this 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 launched an internet-based resource designed to help state and local transportation agencies incorporate sustainability best practices into highway and other roadway projects. The Sustainable Highways Self-Evaluation Tool, currently available in beta form, is a collection of best practices agencies can use to self-evaluate the performance of their projects and programs to determine a sustainability score in three categories: 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 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. You may also complete a reader survey to provide us with your impressions about *ASPIRE*. It takes less than five minutes to complete.

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.hpbridgeviews.org

This website contains 68 issues of *HPC Bridge Views* and the first issue of *Concrete Bridge Views* an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant information on longevity, preservation, materials, and innovation in concrete bridges.

NEW www.fhwa.dot.gov/asset/hif12029/hif12029.pdf

A new FHWA case study titled *Bridge Management Practices in Idaho, Michigan, and Virginia* examines how three states 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.

NEW 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.

Bridge Research

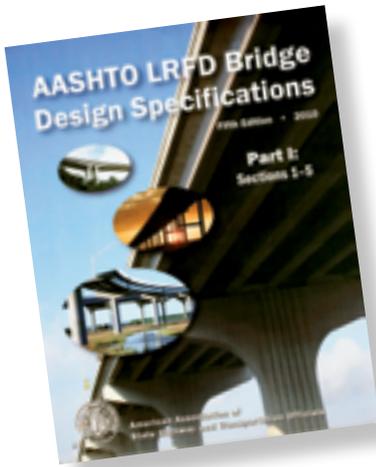
www.trb.org/Publications/PubsNCHRPResearchResultsDigests.aspx

Research Results Digest 355 summarizing key findings from NCHRP Project 10-71 titled *Cast-in-Place Concrete Connections for Precast Deck Systems* is available from this National Cooperative Highway Research Program website.

AASHTO LRFD: Shear Resistance, Part 1



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 through d are based upon the sectional design model. Procedure e is only applicable to segmental concrete box girders. Procedure f does not use the sectional method.

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. Sectional models assume that shear distribution remains uniform and that the plane sections remain plane after loading. This assumption is true

where the conventional methods of strength of materials are applicable. The sectional model is appropriate for the design of typical bridge girders, slabs, and other regions of components where the assumptions of traditional engineering beam theory are valid. Near supports, near the points of application of concentrated loads, at abrupt changes in cross section, and for deep beams where the distance between the centers of applied load and the supporting reactions is less than about twice the member depth, sectional models are not appropriate and the strut-and-tie model must be used.

Only Procedures a, c, and f of the six current procedures listed previously for estimating shear resistance were included in the first edition of the *LRFD Specifications* published in 1994. At that time, the basic sectional model of Article 5.8.3.4.2 was the procedure that is now Appendix B5 (Procedure c). It is based upon the modified compression field theory (MCFT), which is a comprehensive behavioral model for the response of diagonally cracked concrete subject to in-plane shear and normal stresses. The shear resistance in the MCFT model is a function of the calculated longitudinal strain at the mid-depth of the member, ϵ_x , the shear stress, v_u , and the concrete compressive strength, f'_c . Shear design was iterative and required entering these values into the tables for the determination of β , a factor indicating ability of diagonally cracked concrete to transmit tension and shear and θ , the angle of inclination of diagonal compressive stresses. These two variables were then used in the calculation of shear resistance.

A simplification of this general MCFT procedure was also included in the first edition (Procedure a). This simplification for certain nonprestressed sections specifies that β be taken as 2.0 and θ as 45 degrees resulting in shear resistances essentially identical to those traditionally used for these sections.

Finally, the strut-and-tie model (Procedure f)

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

was introduced in the first edition as a third procedure to estimate shear resistance where the sectional models are not appropriate.

Over the years, the number of shear-resistance procedures has grown as bridge engineers and owners reacted to the newness of the MCFT and the strut-and-tie models, and the complication of the iterative nature of the MCFT as presented in the first edition of the *LRFD Specifications*. In the next article, I will explore what the three added shear-resistance procedures (Procedures b, d, and e) represent and why they are in the *LRFD Specifications*. 

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 at www.aspirebridge.org.

PRESTRESSED CONCRETE BRIDGES



PHOTO OF ROUTE 70 OVER MANASQUAN RIVER IN NEW JERSEY (PHOTO COURTESY ARORA ASSOCIATES).

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