ASPIRE™

THE CONCRETE BRIDGE MAGAZINE

WINTER 2015

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Manhattan West

CITRUS AVENUE AND CHERRY AVENUE OVERCROSSINGS
Fontana, California

PADUCAH & LOUISVILLE RAILWAY BRIDGE J23.7
West Point, Kentucky

COTTONWOOD CREEK BRIDGE
Creek County, Oklahoma

Photo: Tom Paiva.

Photo: Alfred Benesch & Company.

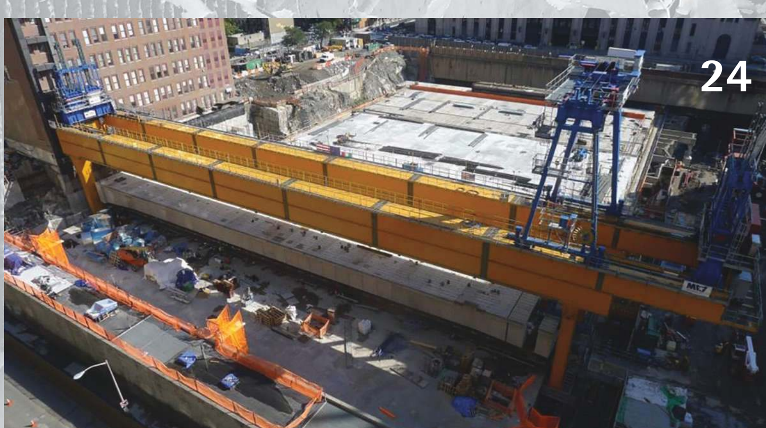

Photo: RdE USA.

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EDITORIAL

Photo: PCI.

Managing or Just Hanging on through Change?

William Nickas, *Editor-in-Chief*

In my editorial in the Fall 2014 issue, I wrote of inevitable change—how we need to support and manage it. Our work here with *ASPIRE*™ magazine illustrates the challenge. Our readers have a unique set of expectations. As a result, in the Fall issue, we launched a new series, Concrete Bridge Technology, which will cut across design, detailing, and construction questions that are often on practitioners' minds. We also concluded a regular feature on accelerated bridge construction.

With that issue, we said goodbye to Dr. Henry G. Russell, our managing technical editor. He has been a significant contributor since the very first issue of *ASPIRE* in 2007. Henry was instrumental in creating the magazine, and establishing its look, editorial standards, and credibility. We wish Henry all the best as he moves into partial retirement following a nearly 50-year career in concrete. He will remain part of the *ASPIRE* team as a contributing editor.

This issue has Dr. Reid W. Castrodale assuming the role of managing technical editor. Reid brings a rich background of 30 years experience in various facets of concrete research and design. He has written numerous papers and reports and is the author of this issue's Perspective, "Concrete Bridges: 100 Years of Advancements."

We are also very excited about the launch of another new, recurring series titled "A Professor's Perspective." Most of the stakeholders and readers of this magazine have a college experience in common. Today's engineering students face pressures and challenges unique to these times and the professional environment. Many of these pressures and challenges then become pressures and challenges for their teachers and professors. Professor Dr. Oguzhan Bayrak at the University of Texas at Austin will author the feature and explore relevant topics facing today's students and professors. We expect students to be interested in the perspective and we hope you will be too. Let us know your impressions.

When I think of my 30-year-long career, the best experiences and outcomes occurred when I was surrounded by people smarter than me. My dad always advised me of two important things while I was at The Citadel studying engineering: first, you are learning how to think and where to find answers, and second, your bachelor's degree is a learner's permit. It allows you to drive, but not by yourself. College makes available the technical knowledge and problem-solving skills that are a prerequisite to practice engineering. Our apprenticeship (engineer-in-training) develops maturity and hones the skills.

ASPIRE showcases interesting and powerful concrete projects. The story of a successful project begins with design and progresses through project management that makes the entirety of planning a reality. As the engineer matures in experience, people management and communications become necessary skills in the total picture of a career. Without these nontechnical skills, engineers may have a self-limiting career, although one may certainly find a technical focus to be very rewarding!

Alternatively, this industry often recognizes and rewards a generalist more than a specialized technical person. Skillfully managing change, whether it is simply those occurring in a magazine, or the growth and development that occurs throughout a career, will always result in accomplishment.

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Cover
A launching gantry moved the 240-ft-long, 2400-ton beams into place on the Manhattan West project located in Manhattan in New York, N.Y.. Photo: RdE USA.

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Dr. Oguzhan Bayrak is a professor at the University of Texas at Austin. Bayrak received the University of Texas System Board of Regents' outstanding teaching award in 2012 and was inducted into the University's Academy of Distinguished Teachers in 2014.

Frederick Gottemoeller is an engineer and architect, who specializes in the aesthetic aspects of bridges and highways. He is the author of *Bridgescape*, a reference book on aesthetics and was deputy administrator of the Maryland State Highway Administration.

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

MANAGING TECHNICAL EDITOR

Dr. Reid Castrodale is a structural engineering consultant with over 30 years of experience in prestressed concrete bridge design, research, and technical support. He also promotes the use of lightweight concrete for bridges.

CONCRETE CALENDAR 2015/2016

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

January 11-15, 2015
94th Annual Meeting Transportation Research Board
Walter E. Washington Convention Center
Washington, D.C.

February 2-6, 2015
World of Concrete 2015
Las Vegas Convention Center
Las Vegas, Nev.

February 6, 2015
PCI Call for Papers deadline
2016 PCI Convention and National Bridge Conference

March 9-11, 2015
DBIA Design-Build in Transportation
Henry B. Gonzalez Convention Center
San Antonio, Tex.

April 6-7, 2015
ASBI 2015 Grouting Certification Training
J. J. Pickle Research Campus
The Commons Center
Austin, Tex.

April 12-16, 2015
ACI Spring Convention
Marriott Hotel and Kansas City Convention Center
Kansas City, Mo.

April 19-24, 2015
2015 AASHTO Subcommittee on Bridges and Structures Annual Meeting
Saratoga Hilton
Saratoga Springs, N.Y.

April 21-23, 2015
International Highway Technology Summit: Cities, Transportation and People
Shanghai, China.

April 26-28, 2015
2015 PTI Convention
Royal Sonesta Houston Galleria
Houston, Tex.

April 30 – May 3, 2015
PCI 2015 Committee Days and Membership Conference
Hyatt Magnificent Mile
Chicago, Ill

May 18, 2015
PCI Call for Entries deadline 2015 PCI Design Awards

June 8-11, 2015
International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, Pa.

August 2-7, 2015
AASHTO Subcommittee on Materials Annual Meeting
Marriott Pittsburgh City Center
Pittsburgh, Pa.

October 7-9, 2015
2015 PTI Committee Days
New Orleans, La.

READER RESPONSE

Editor,
I enjoyed reading ASPIRE™ *at the Great Wall. I was glad to carry it with me and read it during my flight.*

Waseem Dekelbab
Senior Program Officer
National Cooperative Highway Research Program
Washington, DC

[Editor's Note]
Have you recently traveled with your copy of *ASPIRE*? Send us a photo and we may run it in a future issue.


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FOCUS

'We Embrace New Technology'

At the forefront of new techniques for bridge construction, CME sees changes ahead for the industry and the growth of new delivery methods

by Craig A. Shutt

Rehabilitating a 110-ft-long concrete arch bridge in Chester, Mass., which had a 30-degree skew, required using an adjustable forming system to widen the existing arch structure without adding load. All Photos: CME Associates.

Engineering design firm CME Associates has taken a lead role in a variety of new technologies and techniques gaining attention in the bridge construction industry. It has helped test new ideas and worked with organizations to develop standards. Those efforts pay off when projects need innovative solutions to more-complex challenges.

"We're involved at the national level with a number of organizations, such as the Precast/Prestressed Concrete Institute and the Federal Highway Administration, so we know what's going on around the country," explains Michael P. Culmo, vice president of transportation and structures at the East Hartford, Conn.-based firm. "We've made a big investment in actively participating in these programs to stay ahead of the curve and be prepared for new challenges, such as ground-breaking accelerated bridge construction programs taking hold in states all over the country. This ongoing effort to learn and share new advancements allows us to bring those valuable technologies to our clients when the need and opportunity arises."

An example is the work CME now provides to the Connecticut Department of Transportation (ConnDOT), which consists of managing part of its bridge program, to inject new technologies where possible. "We've worked with them regularly in the past, but now we can bring them a variety of ideas that allow them to decide whether to move forward with new techniques," he says. "We're not overly conservative. We embrace new technology."

Thriving on Challenges

The firm's interest and experience in emerging technologies has led the company to take on more complex and challenging projects. A number of those projects recently have been with the Massachusetts Department of Transportation (MassDOT), such as the "93 Fast 14." The 93 Fast 14 project used accelerated bridge construction (ABC) techniques and materials to replace 14 bridge superstructures on I-93 in Medford, near Boston, over 10 weekends during the summer of 2011.

CME developed the project concept for this \$98-million design-build project. It used precast concrete superstructure components and rapid-setting, cast-in-place concrete, which cut 3 years from the conventional construction schedule. The work was part of MassDOT's Accelerated Bridge Program, which seeks to use ABC techniques and other innovations to speed project delivery and construction.

Another complex project that is currently underway is the I-91 deck replacement in Springfield, Mass., where 750,000 ft^2 of bridge deck is being replaced with precast concrete deck panels in 156 spans. The \$200-million project was designed in less than 1 year, finishing in September 2014. "We are very proud of our team," Culmo says. "That project required hundreds of drawings, and we completed it on a very tight timeframe." These two MassDOT projects show what can be accomplished as bridge owners embrace new ideas, and more are seeing the benefits, he says. "Departments of transportation recognize that customer service is important and are willing to use new techniques to reduce road-user impacts. Our work with ConnDOT is letting them develop new decision tools, which has resulted in about 25% of the sites using ABC techniques, so the options are growing. The Federal Highway Administration has done a lot of engineering and marketing work to promote it, and it's begun to take hold."

The Worthington Bridge in Massachusetts was completed by a relatively small-sized contractor on a 60-day schedule.

Making ABC Standard

ABC is not necessarily a new technology, he notes. "Transportation agencies have been using ABC on critical projects for many years." CME was one of the first firms to make ABC techniques standard practice, he says, starting with work done for the Utah Department of Transportation (UDOT) during its infrastructure programs. These programs were fueled by the success of the accelerated infrastructure work completed in preparation for the 2002 Winter Olympics.

Even before that work, CME used self-propelled modular transports (SPMTs) to move gas-fired equipment on local roads for power-plant construction projects. Designers also had seen railroad companies sliding trestle bridges into place to minimize construction time for railway tracks that had no detours.

An example of its ABC projects is the Worthington Bridge in Worthington, Mass., where the newly developed Northeast Extreme Tee (NEXT) beams were used for the first time on a curved and skewed roadway. "The construction schedule was set at 60 days, which was fast but not excessively fast," Culmo says. "We have found that taking your foot off the accelerator a little bit can lead to significant cost savings when compared to very fast construction methods."

The project showed that ABC can be undertaken by small contractors, he says. "The project also led the design team to develop a very simple and cost-effective method of building precast concrete stub abutments on spread footings." The project received the award for Best All-Precast Concrete Solution in the 2013 design awards competition sponsored by the Precast/Prestressed Concrete Institute (PCI).

These two photographs of the Worthington Bridge in Massachusetts show the first use curved and skewed Northeast Extreme Tee (NEXT) precast concrete beams. One side of the top flange of the NEXT beam was blocked out to form the curve.

"We're very hopeful that the use of ABC will continue to grow," he says. "The benefits are so significant, both politically and for the public. It's taking hold in almost all departments of transportation." Projects in Vermont show that its benefits extend beyond highly trafficked, urban areas, he adds. "It's important for rural, less-congested areas because detours can be so long and have so much impact on communities."

CME participated in the creation of the NEXT beam, which has been a key component in some of its ABC projects. It was designed in conjunction with PCI Northeast's (PCINE's) Bridge Technical Committee, of which Culmo has been a member for 25 years. As such, he helped develop the NEXT beam as well as the Northeast Bulb Tee, guidelines for several precast concrete components (such as full-depth deck panels and

The integral abutment details used to construct this bridge in Charlemont, Mass., were adopted by PCI Northeast's Bridge Technical Committee for its Northeast Extreme Tee (NEXT) beam guidelines. Strands extending from the end of the beam have been bent up as part of the integral connection.

substructure elements), and ABC techniques.

"We had a double-tee design for train-station platforms and thought it would make a good profile," Culmo says. "We decided to make it a variable-width beam, because bridge widths vary so much in the Northeast, where the roads are so old and different. There is no such thing as a 'typical' bridge in the Northeast."

The committee expected the beam to be used primarily for short-span bridges with utilities running beneath the bridge, a common design in the Northeast, he explains. But it's being used for other locations too. "It's remarkable how often it's being used today. It looks inefficient and heavy, but it's actually very cost-effective." Many times, costs run 30 to 40% less than other short-span bridge types, he notes. It's now being used in Pennsylvania and New Jersey and continues to expand into other east coast states.

CME has used the NEXT beam on several projects, including the Worthington project and a bridge in Charlemont, Mass. That project used precast concrete integral abutment stems featuring details recommended by PCINE. The construction time on this project also was set at 60 days, which was met.

More Concrete Used

CME designed a pilot project for MassDOT focusing on ABC techniques for a three-span bridge in Holyoke, Mass. It integrated a variety of precast concrete components, including spread footings, railroad crash walls, columns, pier caps, integral abutment stems, approach slabs, and full-depth deck panels with longitudinal post-tensioning. The bridge was built in two stages in one construction season, while a similar adjacent bridge built earlier using traditional construction methods took 2 years.

"We used all the precast concrete elements we could," Culmo says.

A bridge in Charlemont, Mass., was one of the first to use Northeast Extreme Tee (NEXT) precast concrete beams for an integral-abutment bridge.

'ABC using precast concrete elements has the potential to fundamentally change the way we build bridges.'

"Precast and prestressed concrete can play a significant role in the deployment of ABC. ABC using precast concrete elements has the potential to fundamentally change the way we build bridges. The revolution in precasting beams in the 1960s might end up being the roadmap for the development of precasting all bridge elements in the future."

Even when steel girders are used, he adds, concrete plays a key role in the construction. "Virtually every bridge has a concrete substructure," he points out. "Precast concrete can be used in almost every replacement project today. We're seeing more precast concrete being used for everything. It makes economic sense to use it for pier caps, abutments, and other components."

A key obstacle to convincing clients of the benefits of designing in precast concrete comes from the mindset that detailing in concrete remains the same regardless of the format. "Owners who convert cast-in-place details to precast concrete don't always get good results because they need to adapt the design," Culmo explains. "The detailing needs to be somewhat different—and sometimes, the precast concrete detailing is better."

Abutments are the key challenge and often the most difficult part of a bridge detail, he says. "Abutment joints are the most complicated pieces, especially at corners. Integral abutments are the answer, as are semi-integral ones."

CME's expertise has led to work with clients outside of the Northeast. Precast concrete elements, including beams, were used on the White Boulevard Bridge in Collier County, Fla., a project CME developed with Collier County to create a standard bridge for a number of canal crossings in the county road

CME's 40+ Years of Service

CME was founded in 1973 as an environmental consulting firm focused on natural resource management. In the years since, CME has grown steadily and expanded the services offered to clients, branching out into civil engineering, land surveying, and architecture. In the late 1990s, CME began to develop a structural and transportation division.

Building on early successes, CME made steady investments in learning about and developing emerging technologies. This focus, coupled with a dedication to providing responsible and unique design solutions to private and governmental clients, led to rapid growth in recent years.

Today, CME is a multi-disciplined engineering firm of more than 60 professionals working in the Northeast that strives to practically apply innovative solutions to design challenges for all its clients.

network. The three-span bridge was designed with the Florida DOT bridge double-tee section, which was modified to mimic the NEXT D beam. Precast concrete pile caps supported on prestressed concrete piles were used, as was a similar pile cap for the abutments. Precast concrete parapet sections were used and connected to the deck beams using the cast-in-place concrete sidewalks as the structural connection.

Rehab Work Grows

Unique challenges also arise with rehabilitation work, which CME is seeing more often. "Transportation agencies are putting more money into maintenance and rehabilitation rather than replacement. It makes a lot of sense to spend a little money and get more years of service life from a structure." Preserving older bridges that feature dramatic aesthetic components or used older techniques can create challenges, Culmo notes. "Communities have a desire to retain bridges that are historic, but they can become very challenging to design and detail."

'It makes a lot of sense to spend a little money and get more years of service life from a structure.'

An example is the rehabilitation and widening work done for a 100-year-old concrete arch bridge in Chester, Mass. The 110-ft-long bridge had an unusual 30-degree skew. The design team retained the structure type but replaced the spandrel walls and wingwalls with minor widening to each side. They also detailed an adjustable forming system supported on temporary shoring from above. This allowed widening of the arch without imposing additional dead load on the existing arch structure. The contractor made use of the recommended forming system for the construction, which eliminated impacts to the scenic river below.

Forms were hung from temporary support girders to prevent any interruption of the river during rehabilitation of this 110-ft-long concrete arch bridge in Chester, Mass.

Delivery Options Expand

Design-build is becoming more prevalent in the United States, Culmo notes. "It provides a good contracting mechanism that can encourage innovation." It can create challenges for engineering teams, though, due to the accelerated design schedules during procurement and after award.

CME has high hopes for the Construction Manager/General Contractor (CM/GC) form. "I'm a big fan of CM/GC, which is similar to design-build, but it keeps the owner involved in all aspects of the design," he says. It allows agencies to explore new technologies with the assistance of a general contractor during the design process. "It's getting more legs, but state departments of transportation remain wary due to lack of competitive bidding. It's a great system, because the contractor adds a lot by being at the table from the beginning."

Whatever format is used, CME will continue to look for new solutions to ever more complicated challenges. It currently is helping PCINE develop a Northeast Decked Bulb-Tee beam, and is working with ConnDOT on two large railroad-bridge replacement projects using the CM/GC delivery format.

"As we move into the next generation of transportation and preservation of the highway network, we need to find ways to sustain the system without impacting our way of life," Culmo says. "ABC is a fundamental tool that can be used to reach this lofty goal. We're excited to see how we can aid that process."

EDITOR'S NOTE

For more information and details about the NEXT Beam and ABC details, see the website for PCI Northeast: www.pcine.org.

Concrete Bridges: 100 Years of Advancements

by Dr. Reid Castrodale

Perhaps you, too, have been getting the emails or have seen the announcements—2014 is the centennial of the American Association of State Highway and Transportation Officials (AASHTO). Its website, centennial.transportation.org has a lot of interesting information on the organization's activities and the advancements in transportation, and especially highways, in the last 100 years.

In the spirit of AASHTO's centennial, I began to reflect on the last 100 years of concrete bridges in the United States. Concrete bridges were already in service when AASHTO, then called the American Association of State Highway Officials or AASHO, was formed in 1914. Concrete bridges at that time were limited to short span slab, T-beam, or frame structures and some impressive arches with relatively long spans that used the compressive strength of concrete to great advantage. A few of the concrete bridges that were in service in 1914 are still in service today, a testament to the durability of the concrete as it was used in those early bridges.

Since 1914, significant advances in many areas have enabled concrete bridges to become more widely used and to achieve longer and longer spans. The wide and current use of concrete for bridge superstructures is shown by data in *Bridges by Year Built, Year Reconstructed and Material Type for 2013*, a report prepared by the Federal Highway Administration (FHWA) using the National Bridge Inventory (NBI) database (Fig. 1 and 2). For bridges built in 2012 on all systems, 78% of the number of bridges and 76% of the deck area were for bridges with superstructures classified as concrete or prestressed concrete. While there are some limitations to the precision of the NBI data when used in this way, these numbers show that concrete is being used for the superstructure system for the majority of bridges being built in the United States. Concrete is also used for the vast majority of bridge decks and substructure elements, although quantitative data for these items is not readily available.

Construction on the Third Avenue Bridge in Minneapolis, Minn., began in 1914 and was completed 4 years later. It uses open-spandrel concrete arches to span the Mississippi River. Photo: John A. Weeks III.

Today's concrete bridges differ from those of a century ago in many ways, but there are still strong similarities. Concrete has matured as a construction material, but it still has more potential to be explored. I'll take a look at several areas where changes have occurred in the last 100 years, and also consider a few opportunities for the future.

This is not intended to be an exhaustive list or a highly technical discussion. It is just intended to be a few observations from my involvement in the concrete bridge industry over the last 30 plus years, which is a brief period compared to the period over which concrete has been used in the United States.

Concrete Bridge Materials

We are using basically the same materials to make concrete that were used 100 years ago. But through refinements and new materials, we can now make concrete that

- has much higher strengths,
- can easily flow into congested areas,
- can achieve high strengths very quickly,
- can develop reinforcement in very short distances,
- has significantly reduced permeability, and
- can even absorb carbon dioxide.

These and other improvements have addressed concerns with the performance of concrete structures and have allowed advancements in the use of concrete for bridges. Many of these advances have been made possible by the introduction of new materials, especially admixtures and supplementary cementitious materials. And now, there are even new types of cement that are being developed that may reduce the impact of cement manufacturing on the environment. With the advances in concrete materials, concrete bridges can now be reasonably expected to have a service life of 75 to 100 years, if bridges are designed and constructed with the expected level of quality.

Prestressed Concrete

The innovation that has had the greatest effect on increasing span lengths for concrete bridges is the concept of prestressed concrete. This innovation—which was made possible only because of the development of high-strength steel reinforcement along with ways to anchor it and use it in concrete structures—has enabled the spans of concrete bridges to increase to a remarkable degree. Designers continue to develop new ways to employ prestressing to continue to build longer concrete bridge spans, including the splicing of large precast concrete elements. Prestressed concrete structures and elements designed in accordance with the specifications are very robust and can be expected to provide excellent service for many years.

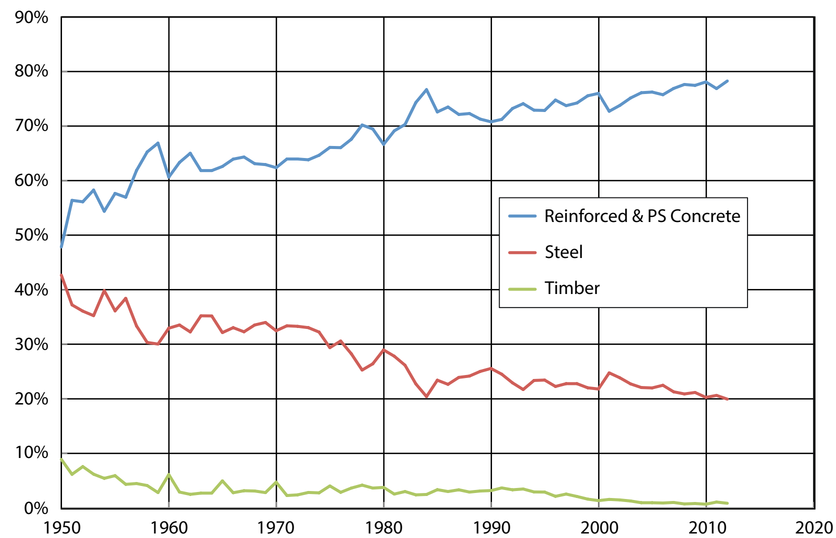


Figure 1. Relative number of new bridges constructed each year, classified by superstructure material using 2013 National Bridge Inventory data. Note: PS = prestressed concrete, which includes pretensioned and post-tensioned structures. Data source: FHWA Report "Bridges by Year Built, Year Reconstructed and Material Type" for 2013. Figure: PCI.

Concrete Bridge Design

Design of concrete bridges has changed in a number of ways, but one of the most significant for complex structures is the introduction of computers to do the many calculations that are necessary for more complex bridges such as box girders erected as cantilevers and cable-stayed structures. These and some other types of bridges have ever changing loads and stresses during construction that must be tracked and adjustments made if the final product is to perform as intended. The long-term effects of creep and shrinkage along with the effects of temperature changes and gradients are now evaluated to provide better solutions. Without the increased computational speed of computers, it would be nearly impossible to successfully build these complex structures.

Concrete Bridge Construction

As advances in materials and designs have occurred, the construction industry has kept up by finding ways to construct these longer-span bridges. Concrete bridge construction has made advances in many ways as materials, techniques, and equipment have steadily developed, allowing the construction and handling of longer spans and larger elements. Erection equipment has also been developed to allow construction of cable-stayed concrete bridges.

Public Expectations

The public has begun to raise their expectations for bridges. In some situations, they now expect aesthetics to be incorporated into new structures that occupy prominent places in public spaces. They also expect bridges to be constructed more quickly, so they will not be inconvenienced by the delays caused by construction. Fortunately, concrete bridges can address both of these expectations by the ability of concrete to take many attractive forms and also to be used in ways that accelerate bridge construction, such as prefabricating elements.

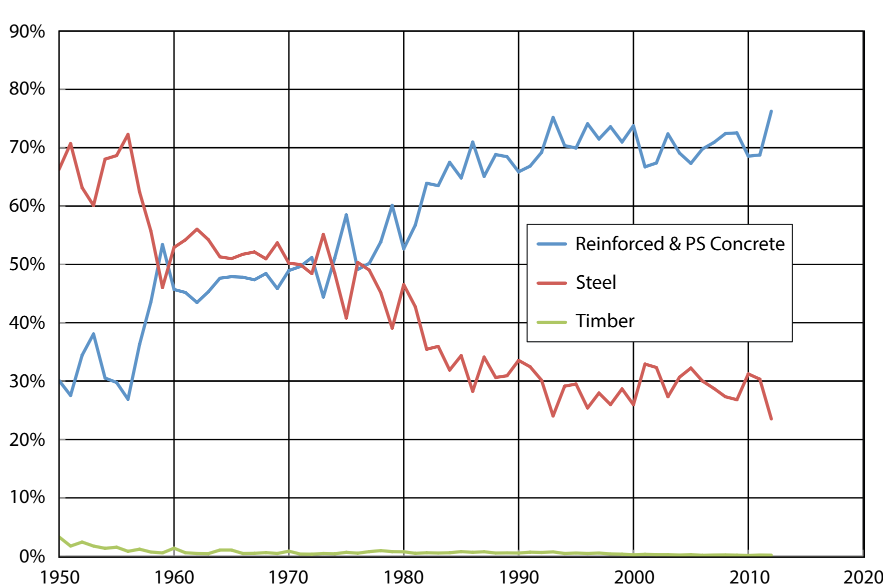


Figure 2. Relative deck area of new bridges constructed each year, classified by superstructure material using 2013 National Bridge Inventory data. Note: PS = prestressed concrete, which includes pretensioned and post-tensioned structures. Data source: FHWA Report "Bridges by Year Built, Year Reconstructed and Material Type" for 2013. Figure: PCI.

Conclusion

Much has changed since 1914 in concrete bridge construction, making possible remarkable advances in the life span and span length of concrete bridges. There is no reason to think that the pace of innovation will slow. Instead, there are many areas in which further improvements are on the horizon. I am confident that we will be able to use these advances to improve concrete bridges so that this amazing material will remain a key part of transportation structures for the next 100 years.

EDITOR'S NOTE

For the summary report of the FHWA National Bridge Inventory (NBI), see www.fhwa.dot.gov/bridge/nbi/no10/yrblt_yrreconst.cfm

Citrus Avenue and Cherry Avenue Overcrossings

by Brett Makley and Noel Shamble, T.Y. Lin International

Citrus Avenue Overcrossing. Photo: Tom Paiva.

Architectural ingenuity and structural resilience came together to create two landmark overcrossings for the city of Fontana, Calif. The two bridges incorporate characteristics of the local community, serve as gateways to the city, and are able to withstand the effects of an earthquake in the seismically active region of southern California. The Citrus Avenue Overcrossing and the Cherry Avenue Overcrossing, located just 2 miles apart along Interstate 10 (I-10) in the county of San Bernardino, are two important components of two full-interchange reconstructions.

Improvements to the interchanges were needed to alleviate congestion and ease the heavy truck traffic that travels from the Los Angeles area ports easterly through California to other states. The San Bernardino Associated Governments (SANBAG), in cooperation with the city of Fontana, the county of San Bernardino, and the California Department of Transportation (Caltrans), led the effort to reconstruct the interchanges.

The project included

- replacing the existing overcrossings with wider and longer cast-in-place prestressed concrete box girder structures,
- widening the existing precast-prestressed concrete I-girder overcrossing structures over Union Pacific Railroad's tracks, and
- widening and improving the on- and off-ramps to I-10.

The I-10/Citrus Avenue Interchange was completed in the spring of 2014. It will soon be followed by improvements to the I-10/Cherry Avenue Interchange, which is expected to be completed by early 2015. The overall project—which must be completed on-time to meet strict, accelerated funding deadlines—includes four bridges, new loop ramps, numerous retaining walls, and a major drainage channel.

Construction

The operational capacities of the original interchanges, both of which were constructed to rural standards in the 1950s, were severely challenged by the large volume of traffic created by subsequent development in the city of Fontana. To minimize traffic impacts in the area and maintain existing traffic flow, a two-stage construction technique was implemented. First, half of the new bridge was constructed parallel to the existing structure. For the overcrossings, the existing structure was then demolished and replaced. For the overheads, the existing structure was overlaid with a combination of polyester concrete and structural concrete to match the deck grades of the widening. For both structures, the two halves were connected with closure placements to create one continuous structure at each location.

Aesthetic Starting Point—Cherry Avenue Overcrossing

The starting point for the architectural design of the Cherry Avenue and Citrus Avenue Overcrossings was site context. The first structure to be developed was the Cherry Avenue Overcrossing. The stakeholders wanted an eye-catching design that would reflect the city of Fontana's growing community, while providing a special gateway for the

profile

CITRUS AVENUE AND CHERRY AVENUE OVERCROSSINGS / FONTANA, CALIFORNIA

BRIDGE DESIGN ENGINEER AND ARCHITECT: T.Y. Lin International, San Diego, Calif.

PRIME CONTRACTORS: Cherry Avenue Interchange: Ortiz Enterprises Inc., Irvine, Calif.; Citrus Avenue Interchange: Brutoco Engineering & Construction, Fontana, Calif.

PRECASTERS: Cherry Avenue Overcrossing: Coreslab Structures Inc., Perris, Calif.—a PCI-certified producer; Citrus Avenue Overcrossing: Oldcastle, Perris, Calif.—a PCI-certified producer

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

nearby Auto Club Speedway racetrack. Because Cherry Avenue is the racetrack-entrance road, stakeholders wanted the structure to be a visual landmark for everyday I-10 travelers, avid race fans, and even NASCAR national TV coverage.

With the racetrack aesthetic theme, the shape of the structure had to imply the characteristics of a racecar without creating an overly literal caricature. Having a static object convey elements such as speed, power, and motion proved to be an exciting challenge. Using modern car designs for inspiration, the team was drawn to the fluid lines on the sides of many car bodies, made by precise pinches, creases, and three-dimensional curves. Such car panels are made by running a flat, rigid piece of sheet metal through a highly-involved mechanized process.

Concrete, alternatively, has the advantage of having fluid and flexible characteristics when being placed, allowing it to convey motion more easily than a static solid. This set the team on a path of exploration based on concrete's inherent material properties. The goal was for the final solid form to reflect both the fluid behavior of the concrete placement process and the fluidity of a speeding racecar. The team was especially inspired by the latest developments in concrete form-making, such as the fabric-formed concrete process, which uses flexible geo-textile materials to create amorphous shapes.

Concrete, alternatively, has the advantage of having fluid and flexible characteristics when being placed, allowing it to convey motion more easily than a static solid.

The team arrived at the governing design strategy by combining these explorations of form with both the practical requirements of structural design (such as crash barrier safety, reinforcement layout, and the like) and an understanding of the conventional tools and techniques available to construction crews. The Cherry Avenue Overcrossing has a custom barrier that is triangular in cross section, but which follows fluid, curvilinear paths in elevation. The three-dimensional result is a constantly changing, doubly curved surface. These warping surfaces catch the light differently depending upon the view angle, producing gradients of shade and reflectivity across the structure that create intrigue at a detailed level (without using a form-liner pattern), enhance the modern aesthetic, and reinforce the overall association with movement.

Architectural features of the Cherry Avenue Interchange including walls, abutment, and overcrossing shown during construction, prior to color staining. Photo: Tom Paiva.

Cherry Avenue Overcrossing during construction. Photo: Tom Paiva.

Cherry Avenue Overcrossing during construction. Photo: Noel Shamble.

CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS) AND THE CITY OF FONTANA, OWNERS

BRIDGE DESCRIPTION: Citrus Avenue Overcrossing: 238-ft-long by 166-ft-wide, two-span, cast-in-place post-tensioned concrete box girder superstructure, with span lengths of 134 and 104 ft, with high-seat abutments and a two-pierwall bent on spread footings; Cherry Avenue Overcrossing: 237-ft-long by 127-ft-wide, two-span, cast-in-place post-tensioned concrete box-girder superstructure, with span lengths of 133 and 104 ft, with high-seat abutments and a four-column bent on spread footings

BRIDGE CONSTRUCTION COST: Citrus Avenue Overcrossing: \$4.7 million (\$155/ft^2), project cost \$32 million; Cherry Avenue Overcrossing: \$5.4 million (\$180/ft^2), project cost \$49 million

Citrus Avenue Overcrossing barrier during construction. Photo: Brett Makley.

Citrus Avenue Overcrossing Aesthetics

While the Cherry Avenue Overcrossing is the landmark for the racetrack, the team was asked to make the Citrus Avenue Overcrossing, one exit away, the gateway for the city of Fontana. Using the same fluidity concept and doubly curved barrier architecture, the city's fountain logo inspired the aesthetic theme. The central pier wall ascends and integrates into the custom barrier to create a strong, vertical motion, like the upward spouting of a fountain. From that raised central position, the curvilinear barrier lines flow out like gentle waves. As with the Cherry Avenue Overcrossing design, the abutments bulge outwards to convey a sense of strength and clear visual anchorage.

Additional Aesthetic Considerations

To further expand on the freedom of designing a custom barrier, the team also wanted to challenge the standard conventions of the relationship between the barrier wall and the barrier fence. At some point on both the Cherry Avenue and Citrus Avenue Citrus structures, the concrete barrier rises up to the full height of the 9-ft-tall fence. This not only allows the barrier to make a more pronounced statement to highway traffic below, but it also provides special gateway elements for travelers on the overcrossings themselves. Travelers pass between elements instead of just driving or walking over the highway. This visual and spatial cue is what makes

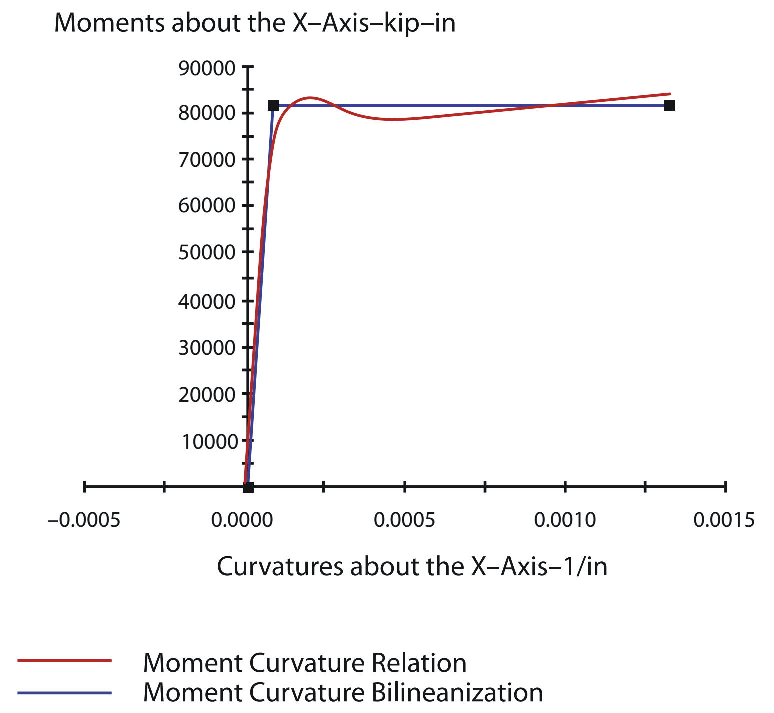
Resilience

The state of California is a highly active seismic area, especially in the fault-ridden area of southern California, making seismic resiliency one of the most critical elements of any infrastructure design. California Department of Transportation's (Caltrans') *Seismic Design Criteria* governs the seismic design of bridges in California, which supplements American Association of State Highway and Transportation Officials' (AASHTO's) criteria to meet the unique challenges of this state. Included in the criteria is a no-collapse standard to ensure that bridges will remain standing after a credible seismic event, even if the structures suffer substantial damage.

One of the key concepts of this standard is to focus the seismic energy of an earthquake into predetermined locations. In concrete bridges, this is typically done by forcing the top and/or bottom of the bridge columns and pier walls to experience and withstand displacements beyond the elastic state by forming a plastic hinge. By allowing and forcing a plastic hinge in certain locations, the damage caused by an earthquake is essentially focused there, allowing the engineer to design accordingly.

The Citrus Avenue Overcrossing substructure is comprised of two concrete pier walls (with design compressive strength of 3.6 ksi), 3 ft thick at the base with nonintegral architectural flares of 6 ft at the top. The Cherry Avenue Overcrossing substructure consists of four 5-ft-diameter octagonal columns (with design compressive strength of 3.6 ksi), with non-integral architectural flares in the transverse direction of 10 ft at the top.

The tops of the columns and pier walls are integral with the superstructure, thereby creating a location for the plastic hinges to form. In both cases, however, the base of the columns and pier walls are pinned to the footings to avoid transferring the large demands of the plastic hinge into the footings and limit the pressure on the foundations. Moment-curvature analyses were performed to help determine the displacement capacity of the plastic hinges, which were then compared to the seismic displacement demands to confirm their structural integrity.



Sample moment-curvature analysis. Figure: T.Y. Lin International.

a "gateway experience," and ultimately makes a place memorable.

In addition to the bridge architecture, the look of the many walls along the highway was an important component of the project's overall visual impact. Working with the Caltrans District 8 Landscape Architect, the team developed a detailed series of flowing, interweaving curvilinear lines that would complement both structures. The success of the fluidity concept, which governed the wall and overcrossing aesthetics of both projects, was thoroughly embraced by Caltrans District 8, which covers Riverside and San Bernardino counties. The design is now the new master theme for the aesthetic redesign of the entire I-10 San Bernardino corridor.

Brett Makley is a senior bridge engineer and Noel Shamble is a bridge architect with T.Y. Lin International in San Diego, Calif.

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

AESTHETICS COMMENTARY

by Frederick Gottemoeller

Communities often ask that a prominent bridge in their community illustrate some community landmark or characteristic, or ask that it serves as an icon of their community. With major bridges, the main structural element itself, say an arch or cable stay tower, usually serves this need. With typical highway overpasses, the structural elements are not large or particularly distinctive, which leads designers to look elsewhere for something unique.

One typical response is to use formliners to make the concrete surfaces look like some other materials that are traditional in the area. Or specific images might be inset into the concrete, say a dolphin in a waterfront community or a bison in a western environment. Or a bridge in an historic community might be festooned with antique-looking streetlights designed to look like those from the nineteenth century. Sometimes the effort even includes miniaturized versions of an arch or a cable stay tower with actual miniature stays, hoping the pattern will have an impact even when the size isn't there.

With these two bridges, their designers took a different tack. Recalling that concrete starts out in a fluid state, and realizing that recent experimentation in forming techniques have begun to free concrete from the restrictions imposed by flat plywood sheets, they decided to investigate whether the bridge itself could be shaped to meet the symbolic goals of the community. They sculpted the concrete into abstract shapes calling to mind the cars on the racetrack and the fountain that is a key part of Fontana's identity. The shapes are large enough to be appreciated even by drivers moving at 70 mph. The abstraction even extends to the retaining walls, where a wavy line calls to mind water more effectively than a whole school of inset fish.

The next challenge will be to use these new forming techniques to shape the structural concrete itself to more efficiently carry the forces on the structure. Natural shapes might be the best model. There are many amazing natural structures built without a single sheet of plywood.

Paducah & Louisville Railway Bridge J23.7

New railroad bridge pushes the limits of typical rail construction to replace a 120-year-old, 120-ft-tall trestle structure

by Scott Wojteczko and Michael O'Connor, Alfred Benesch & Company

Paducah & Louisville (P&L) Railway Bridge J23.7 was originally constructed in the 1880s as a curved, 700-ft-long, 120-ft-tall steel trestle structure. It was built along land that would eventually become the Fort Knox Army Base. Less than ½ mile down the track is P&L Railway Bridge J23.3, a structure of similar age and construction to P&L Railway J23.7, though shorter and on a tangent. These two historic freight rail bridges, known together as the Muldraugh bridges, allow the P&L to

- transport commodities across Kentucky, and
- maintain rail access for military shipments to Fort Knox Army Base (as the only rail line servicing the base).

The age and condition of the existing trestle structures had necessitated numerous repairs and strengthening measures over the past 20 years to maintain continual rail service. With repair costs mounting each year and both structures beyond their expected service lives, P&L made the decision in 2009 to move forward with the replacement of both P&L Railway Bridge J23.3 and P&L Railway Bridge J23.7.

The P&L initiated a two-phase program that would commence with the replacement of P&L Railway Bridge J23.3 and culminate with the replacement of P&L Railway Bridge J23.7. After the financial commitment that had been made in replacing P&L Railway Bridge J23.3, the P&L was awarded a Transportation Investment Generating Economic Recovery (TIGER) Grant in 2011 towards the replacement of the more-complex P&L Railway Bridge J23.7. Construction on P&L Railway Bridge J23.7 began in the fall of 2012 and was completed in the summer of 2014.

Railway Re-Alignment

The original P&L Railway Bridge J23.7 was built on a 5-degree horizontal curve spanning a valley that contained a creek, hiking trail, and Fort Knox private-access road. A large fill had been constructed on the west side of the valley to minimize the overall bridge length. Reconstruction of P&L Railway Bridge J23.7 on the existing alignment would have been highly constrained by the location of the existing steel trestle towers, with rail closures required to systematically remove and replace sections of the existing structure.

The project team elected to construct P&L Railway Bridge J23.7 offset north of the existing structure, with span lengths maximized to minimize the number of substructure units required. Piers could not be located within the existing creek, trail, and roadway. Additionally, the topography of the region is highly irregular through the valley, with vertical exposed rock faces in some locations and 50 ft of overburden material in others. The final bridge layout includes 14 spans, with maximum span lengths of 85 ft and an overall bridge length of 1031 ft. Piers reach elevations 120 ft above grade in the deepest portions of the valley. The horizontal curve across

Aerial view of completed P&L Railway Bridge J23.7, looking north. Photo: Alfred Benesch & Company.

profile

PADUCAH & LOUISVILLE RAILWAY BRIDGE J23.7 / WEST POINT, KENTUCKY

BRIDGE DESIGN ENGINEER: Alfred Benesch & Company, Chicago, Ill.

CONSTRUCTION ENGINEER: GEM Engineering Inc., Louisville, Ky.

PRIME CONTRACTOR: Haydon Bridge Company, Springfield, Ky.

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

OTHER MATERIAL SUPPLIERS: Reinforcement: Gerdau, Muncie, Ind.; and Bearings: D.S. Brown, North Baltimore, Ohio

Chorded beam layout at the east end of the bridge. Photo: Alfred Benesch & Company.

the bridge has been reduced from 5 to 4 degrees to reduce track maintenance and enhance sight distances. The bridge is within a vertical curve, with a maximum grade of 1.3%.

Substructure

Each typical pier consists of two 7-ft-diameter circular reinforced concrete columns spaced at 21 ft on center. Transverse concrete struts that are 5-ft square are in place every 30 ft of height to increase the transverse stiffness of each pier and reduce the unbraced length of the columns. Each pier column is supported by a single 8-ft-diameter, drilled-shaft foundation, with 7-ft 6-in.-diameter rock sockets. Minimum rock socket depths of 2.5 times the shaft diameter were considered, with greater lengths installed where weak or fractured rock was encountered.

The American Railway Engineering and Maintenance-of-Way Association (AREMA) design requirements for longitudinal force due to traction and braking are significant when compared to traditional highway design, with force magnitudes greater than 5% of the total superstructure dead load. Compounding the challenge of resisting longitudinal force, AREMA limits the allowable longitudinal deflection from these forces to 1 in. To meet the deflection criteria with the two-column pier approach would have required the sizing of columns and drilled shafts to be increased dramatically.

Instead of increasing the size (and cost) of all pier columns and shafts, the concept of central "rigid braced piers" was introduced to the system. The rigid braced piers were created by reducing the spacing between Piers 5 and 6 and between Piers 10 and 11 to 47 ft 6 in. and adding 6-ft-square, reinforced concrete longitudinal struts between the pier columns. These rigid braced piers provide substantial longitudinal stiffness, with the capacity to absorb the majority of the longitudinal force while meeting AREMA deflection requirements.

To ensure the longitudinal load could be distributed to the two rigid braced piers without first imposing excessive deflections on the slender piers, multiple spans were designed with fixed-fixed end conditions. This is atypical for railroad design, where spans are typically of fixed-expansion layout. The introduction of double fixity allowed the bridge to be divided into four units, with each rigid braced pier providing more than 90% of the longitudinal stiffness within their respective bridge units.

Superstructure

New railroad bridge construction commonly uses standard precast concrete box beams and slabs for span lengths up to 36 ft. When span lengths are in excess of 36 ft, it is most common to utilize steel rolled beams or plate girders with two to four beams/girders per track. Precast, prestressed concrete I-beams are not used regularly in the design of railroad bridges subject to

Pier construction at the west end of the bridge. Photo: P&L Railway.

Walkway hatches provide ladder access to pier caps for inspection of beams ends and bearings. Photo: Alfred Benesch & Company.

PADUCAH & LOUISVILLE RAILWAY INC., OWNER

BRIDGE DESCRIPTION: A 1030-ft-long, single-track ballast-deck railroad bridge with heights up to 130 ft over a deep valley on a 1432-ft radius horizontal curve, with 14 spans with lengths varying from 47 to 85 ft and a 14-ft-wide deck

STRUCTURAL COMPONENTS: Type IV, 54-in.-deep, precast, prestressed concrete I-beams; Kentucky Type 7 modified, 72-in.-deep, precast, prestressed concrete I-beams; a 10-in.-thick, cast-in-place concrete deck; piers with 7-ft-diameter columns; and 8-ft-diameter drilled shafts socketed into rock

BRIDGE CONSTRUCTION COST: $10.6 million ($10,290/linear ft)

Erection of 72-in.-deep precast, prestressed concrete I-beam in an 85-ft span, using a dual crane lift. Photo: Haydon Bridge Company.

freight loads but are more common to American Association of State Highway and Transportation Officials (AASHTO) highway bridge designs, primarily due to loading and schedule. However, precast, prestressed concrete I-beams can provide an economical solution for long-span railroad structures under the right conditions.

Precast, prestressed concrete I-beams can provide an economical solution for long-span railroad structures under the right conditions.

By reducing the concrete beam spacing beneath the track, the concrete beams can meet capacity and serviceability requirements for longer spans. Additionally, reconstructing a railroad bridge on an offset alignment allows more time within the construction schedule for a cast-in-place concrete deck to be built and cured on the precast, prestressed concrete I-beams.

Evaluation of standard Kentucky beam sizes determined that the 72-in.-deep, Type 7 modified precast, prestressed concrete I-beams could provide sufficient capacity and stiffness for the maximum 85-ft span lengths with four beams supporting the track. The beams are spaced at 3 ft 6 in., chorded along the horizontal curve. The specified compressive strength of concrete in these beams was 5.5 ksi at transfer of prestress, with a 28-day strength of 7 ksi.

Each beam has 16 straight prestressing strands in the bottom flange and six draped strands. Two additional partially debonded straight strands were included in the top flange of each beam to account for high initial stresses during shipping. These strands were detensioned before placement of the deck and diaphragms.

In addition to the 72-in.-deep precast, prestressed concrete I-beams, the 47-ft 6-in. spans within the rigid braced piers utilize four 54-in.-deep precast, prestressed concrete I-beams, also at 3 ft 6 in. spacing.

The concrete beams in each span support a 10-in.-thick, 14-ft-wide, cast-in-place concrete composite deck and parapets with a concrete compressive strength of 4 ksi. All spans are simply supported with joints in the deck at the end of each span, as is typical of railroad bridge construction. To accommodate the close beam spacing, stay-in-place forms were used for the deck.

Seismic Considerations

P&L Railway Bridge J23.7 is located in an outer ring of the New Madrid Seismic Zone; thus seismic guidelines in Chapter 9 of the AREMA manual were followed. Based on the significance of the structure, the project approach was to design P&L Railway Bridge J23.7 to behave elastically under Level 2 ground motion, with appropriate detailing measures to prevent failure in the event of a Level 3 ground motion.

Because of the multi-span irregular configuration, the code required a modal analysis to be performed. The designers used 3-D finite element modeling software to generate controlling mode shapes and natural frequencies of the structure for the design response spectrum of each level of ground motion. The modes were then combined to generate the design seismic loads for all substructure elements.

Appropriate AREMA detailing provisions were incorporated into the structure to meet performance requirements for Level 3 ground motions. Notable design and detailing provisions to improve ductility included

- no lapping of vertical reinforcement within column plastic hinge zones,
- butt-welded confinement hoops used in all columns and shafts, with maximum spacing reduced in plastic hinge zones,
- continuous welded rail specified across the structure to provide load path redundancy and increase bridge damping,
- transverse and longitudinal pier struts designed to yield prior to column yielding, forcing the initial plastic hinges to form within the secondary members, and
- foundations designed for the lesser of 1.3 times the column strength or the Level 3 ground motion load.

Summary

Reconstructing the P&L Railway Bridge J23.7 posed many significant challenges, not the least of which was how to span a 130-ft-deep, narrow, irregularly shaped valley. The project team successfully looked beyond typical railroad bridge design methods and construction materials to develop a highly maintainable, cost-effective bridge solution.

The new concrete structures in place at markers J23.3 and J23.7 provide aesthetically pleasing bridge solutions that blend well with the rocky, irregular local topography. With both new structures now in service on the new rail alignment, trains can operate at higher speeds and carry greater loads, effectively reducing travel times and increasing the efficiency with which the P&L Railway can serve its clients.

Scott Wojteczko is a project engineer and Michael O'Connor is a senior project manager with Alfred Benesch & Company in Chicago, Ill.

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

PROJECT

Cottonwood Creek Bridge

Accelerated bridge construction speeds bridge replacement

by Jason Langhammer, Garver

Accelerated bridge construction (ABC) methods were used for the first time in Oklahoma in the replacement of the Cottonwood Creek Bridge, which transports State Highway (SH) 51 over Cottonwood Creek in Creek County, Okla. When comparing the ABC technique to conventional construction methods, it was estimated that the time needed to close and detour SH 51 could be conservatively reduced by 5 months. Because the detour is roughly 30 miles, this was expected to save motorists thousands of miles and many hours of drive time around the construction project.

ABC methodology seeks to reduce construction duration and impacts on traffic. Additional benefits include improving work zone safety, eliminating temporary roadway construction, decreasing post-construction repairs to detour routes, and reducing user costs. As bridge repair and replacement becomes increasingly more important throughout the nation, transportation officials are looking to implement ABC methods.

The original Cottonwood Creek Bridge was built in 1961 and when it was deemed functionally obsolete, Oklahoma Department of Transportation (ODOT) selected this site to consider ABC because of the site accessibility of the deteriorating bridge. To construct the new bridge on the existing alignment, the contractor had to first construct the substructure elements under the existing bridge—while it remained in service.

Oklahoma's Decision

ODOT recognizes the benefits of ABC and selected the Cottonwood Creek Bridge to serve as a pilot project to evaluate the benefits of ABC techniques for its state. Additionally, ODOT could

The proposed bridge beside the existing bridge while it is still in service. The proposed bridge was constructed on temporary supports. All Photos: Garver LLC.

profile

COTTONWOOD CREEK BRIDGE / CREEK COUNTY, OKLAHOMA

BRIDGE DESIGN ENGINEER: Garver, Tulsa, Okla.

PRIME CONTRACTOR: Manhattan Road & Bridge Co., Tulsa, Okla.

PRECASTER: Coreslab Structures, Tulsa, Okla.—a PCI-certified producer

The hydraulic jack used to horizontally pull the spans into place. The spans were guided by a track and supported on polytetrafluoroethylene (PTFE) pads to reduce friction.

The new pier fully constructed under the existing bridge with new girders on the temporary pier adjacent to it. The existing bridge is still in service.

apply the knowledge gained through this pilot project to other projects where ABC techniques are feasible and prudent.

There are several options to consider when constructing a bridge in an expedited manner. During the Cottonwood Creek Bridge project's preliminary engineering phase, several ABC methods were investigated, including the use of prefabricated bridge elements and various structural placement methods. Site topography, hydraulic adequacy, vertical and horizontal clearances, site accessibility, existing facility geometry, user costs, and total construction costs were also considered.

After evaluating all factors, a transverse sliding/skidding bridge move was selected to replace the existing bridge on the existing alignment. Using this method, the existing new superstructure was constructed on temporary supports adjacent to the existing structure. A track system and sliding shoes were then used to move the bridge into position on top of new piers and abutments. This allowed the existing bridge to stay in service while the new bridge was constructed, lessening the impacts to motorists.

The new bridge's clear roadway width is 40 ft, which is 12 ft wider than the existing 28-ft-wide bridge. The spans also change from six, 45-ft-long steel spans to three spans of prestressed concrete bulb-tee girders (two 70-ft end spans and one 120-ft center span). This span configuration eliminated potential geometric conflicts between the existing and proposed structures and allowed work outside of the Cottonwood Creek channel.

The prestressed concrete bulb-tee beams have a larger structural depth, which created a lower bearing elevation than the existing superstructure. This lower bearing elevation allowed the proposed substructure to be constructed below the existing in-service bridge.

Equipment used for drilled-shaft construction could not fit under the existing bridge. For this reason, the drilled shafts were located outside of the existing bridge's footprint.

Placing new piers underneath the existing bridge also proved a challenge. Drilled shaft foundations are typically used in Oklahoma, but the equipment used for drilled-shaft construction could not fit under the existing bridge. For this reason, the drilled shafts were located outside of the existing bridge's footprint, and long-span pier caps were utilized. Using long-span pier caps in the traditional rectangular configuration are not the most structurally efficient; therefore a T beam configuration was utilized to increase capacity and structural efficiency.

At each end of the bridge, driven piling would typically be used to resist dead, live, earth-pressure, braking, and wind loads. Again, equipment used in piling installation would not fit under the existing bridge. This resulted in positioning the new abutments in front of the existing ones, allowing for their construction while the existing bridge was in service.

This configuration required specific design strategies related to lateral earth pressure. Similar to the piers, drilled shaft foundations were constructed outside of the existing bridge's footprint. For this configuration, the design had to account for lateral earth pressures and the potential for excessive lateral deflections.

OKLAHOMA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 260-ft-long, prestressed concrete beam bridge with spans of 70, 120, and 70 ft

STRUCTURAL COMPONENTS: 72-in-deep bulb-tee girders; cast-in-place concrete deck; and cast-in-place pier caps, columns, and drilled shafts

BRIDGE CONSTRUCTION COST: $3,809,500

A constructed soil nail wall in front of the existing abutment. The wall allowed for the construction of the proposed abutment under the existing bridge to facilitate the shortest detour duration.

To reduce the earth pressures and assist in constructability, a soil nail wall was put in place at abutment locations.

Due to tall embankments around the creek crossing, as well as limited space for transport equipment, the transverse sliding method was best suited for the site. Transverse sliding/skidding systems are often employed for structures over rivers where adjacent construction will not impact traffic and where it's not viable to transport in prefabricated pieces.

Construction

Construction of the bridge occurred in two phases. The first phase involved constructing the substructure elements under the existing bridge and the superstructure on temporary supports adjacent to the existing bridge. Once complete, the second phase required closing and detouring traffic on SH 51, removing the old bridge, sliding the new bridge spans onto the support structures, and performing the final bridge and pavement connections.

Once the substructure was constructed under the existing bridge and temporary structures were built outside the existing bridge, the contractor constructed the new bridge on the temporary supports. Once the new bridge was ready to be moved, the existing bridge was demolished, and the new bridge was jacked vertically to place the guide track and sliding shoes. Then, hydraulic jacks were used to pull the new spans into place horizontally. The pulling method was chosen over pushing method due to the forces imparted at the permanent and temporary support connection.

The new first and third span in place, and the center span being moved. The highway was detoured and the existing bridge demolished prior to moving operations.

Removing the guide track after the spans were slid into place.

This photo shows placement of concrete for the approach slabs and pavement.

After the new end spans were in place, the roadway approach pavements were constructed. In less than 11 days of closure time, normal traffic operations resumed.

Jason Langhammer is a bridge team leader and project manager for Garver in Tulsa, Okla.

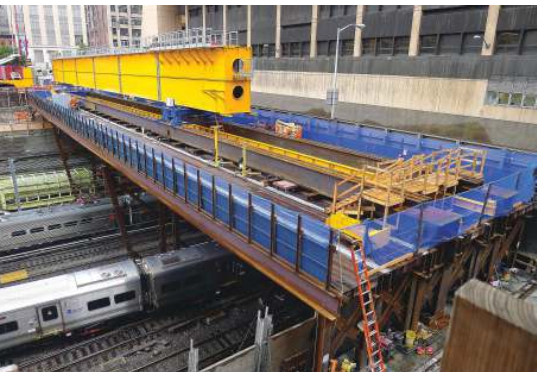
For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

PROJECT

Platform Spans Manhattan

Innovative launching gantry sets 2400-ton beams to create platform spanning 15 rail lines for high-end development in the sky

by Phil Marsh, McNary Bergeron, and Andrea Travani, Rizzani de Eccher USA



A temporary protection platform was built over the rail lines, which served as the underslung bed from which the launching gantry was assembled and began setting beams. All Photos: RdE USA.

Precast concrete bridge components continue to offer solutions to new challenges, achieving longer spans and greater load capacities. Those capabilities were optimized for a unique project in Manhattan, in the heart of downtown New York, N.Y., that used bridge construction technology in a novel fashion. It features 2400-ton segmental concrete box beams spanning 240 ft to create a platform from which will rise two 1000-ft-tall, class A office skyscrapers, a 60-story luxury condominium tower, a boutique hotel, mixed-use retail space, and an expansive pedestrian plaza linked to the new High Line Park on Manhattan's west side.

This innovative and challenging solution was devised when Brookfield Office Properties sought to connect the two portions of its 7-million-square-foot development that spanned 15 railway lines and related electrical services near Penn Station in Manhattan, where development area is scarce. The developers wanted to create a platform on which they could build a parking structure topped by a public plaza with two high-rise office buildings flanking the site.

Officials contacted the Manhattan West project construction manager to discuss the possibility of using a launching gantry to build a 240 by 480 ft steel platform over the existing rail lines, located in an open trench 55 ft below street level. The idea was to use some overhead equipment to avoid disrupting activities at track level. Because of the high level of activity at track level, no columns or supports for the platform could be built at rail level. But the steel solution was problematic due to the weight of the girders. Instead, RdE came up with the idea of a segmental platform to span the gap and contacted the construction engineer to start working on the design of this record-length bridge.

The future office buildings' columns will not bear on the platform itself. The core structures of the building will be founded on bedrock, while the curtain-wall columns will penetrate through deck openings in the platform and extend down to track level. The smaller columns for the parking structure will bear on the platform and support the pedestrian plaza above it.

The site provided major challenges. The project would have to be built in the heart of Manhattan over some of the busiest railway tracks in the world without touching down at track level. Crews had to absolutely ensure the integrity of the girder setting process, to ensure no slippage or accidents would interfere with the rail service. Rail service outages to allow work at track level were available for no more than 2 hours at a few limited times.

Transverse Launching Gantry

The design features sixteen 2400-ton segmental beams, each comprising

The launching gantry moved the 240-ft-long, 2400-ton beams into place after they had been post-tensioned. The beams were lowered using a hydraulic cylinder, pin, and slotted-bar system to prevent accidental slipping.

profile

MANHATTAN WEST / NEW YORK, NEW YORK

PRECAST PLATFORM DESIGN ENGINEER AND CONSTRUCTION ENGINEER: McNary Bergeron & Associates, Broomfield, Colo., and Old Saybrook, Conn.

OVERALL PROJECT CONSTRUCTION MANAGER: Turner Construction Co., New York, N.Y.

MANHATTAN WEST PROJECT CONSTRUCTION MANAGER: Rizzani de Eccher USA, Bay Harbor Islands, Fla. and Pozzuolo del Friuli, Italy

SUBSTRUCTURE DESIGN ENGINEERS: Entuitive, Toronto, Canada

PRECASTER: Jersey Precast, Trenton, N.J.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Tensacciai, Milano, Italy

A C-hook on the launching gantry was used to lift each segment and set it on three screw jacks, where it was leveled and positioned against the previous match-cast segment.

37 to 39 match-cast precast concrete segments that span the 240-ft opening between the two sides of the development. The beams were set in place with a custom-built launching gantry that worked from overhead to construct and set a beam. The gantry ran on rails running parallel to the abutments that supported the beams.

Prior to beginning the installation, a steel temporary protection platform was built over the rail lines. This horizontal space not only protected the rail lines as work was set up, but it served as the underslung bed from which the launching gantry could be assembled and the initial beams could be set into place. After the first two beams were set, the temporary platform was dismantled and the underslung assembly bed was moved to the permanent platform and used as the stage from which subsequent beams were fabricated.

All 39 segments for one beam could be stored in a 6100-ft^2 yard on the site. The segments, made with 9.5 ksi concrete, could be double-stacked because of the vertical web design of the box, which allowed direct transfer of load from the box above to the webs of the box below. That cross-section geometry allowed the construction sequencing to be simplified and maximized the small available space for staging the segments.

The gantry picked each segment from the staging area using a C-hook that lifted the segment beneath its top slab and carried it into place on top of the underslung equipment. Each segment was set onto three screw jacks to be positioned and aligned with the previous match-cast piece. The segment joints were then epoxied and the first stage tendons were post-tensioned on the underslung bed using the launching gantry. The beam was then moved to a second location on the platform where additional work was performed including tensioning of the remaining tendons using a specially designed and fabricated custom-stressing platform.

Hydraulic System Lowered Beams

The gantry moved smoothly and quietly, considering the immense size and weight of the beams being placed. The gantry could move 10 ft per minute and lowered the beams into place at a rate of 0.5 ft per minute. The lowering system consisted of hydraulic cylinders with pins and slotted bars. The pins held the beam in place while the bars were lowered into the next holes, after which the pins were removed and the beam lowered into the next slot via the hydraulic action. This slow, methodical approach ensured that the beam remained under the team's complete control at all times and eliminated any concern that the lowering process could slip, causing the beam to fall onto the tracks.

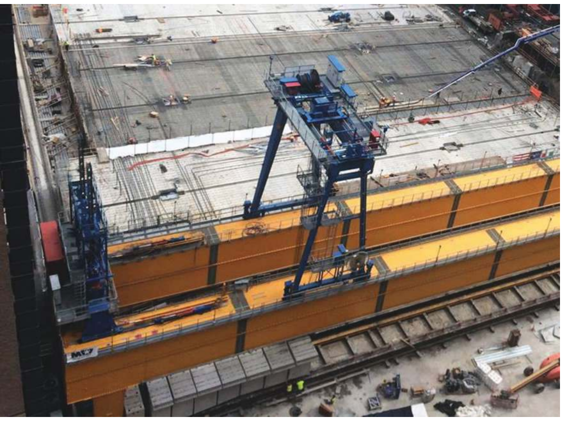
Each beam required 100 tons of post-tensioning, using twenty 37-strand and fourteen 31-strand tendons. The 16 girders create a platform 480 ft wide with a 12 ft depth.

All of the segments for a span were delivered to the site and placed in a storage yard prior to assembly. Segments were double-stacked to maximize storage space.

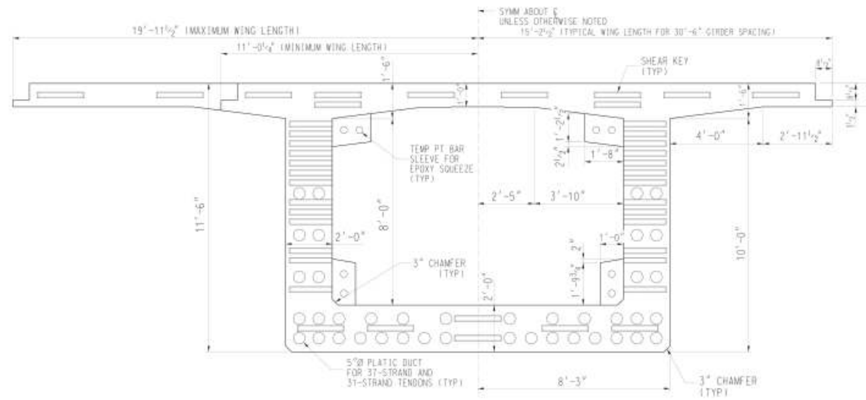
BROOKFIELD OFFICE PROPERTIES, OWNER

SUPPLIERS: Launching Gantry Designer & Supplier: DEAL, a subsidiary of RdE USA, Italy and Florida; Launching Gantry Operator & Platform Erector: Metropolitan Walters LLC, New York, N.Y.; Platform Bridge Bearings: Mageba, Bulach, Switzerland; and Drilled Caissons & Foundation Contractor: Posillico Civil & Drilling, Farmingdale, N.Y.

BRIDGE DESCRIPTION: Sixteen 2400-ton segmental concrete box beams spanning 240 ft create a platform from which will rise two 1000-ft-tall, class A office skyscrapers, a 60-story luxury condominium tower, a boutique hotel, mixed-use retail space, and an expansive pedestrian plaza linked to the new High Line Park on Manhattan's west side



This view shows segments being placed in the foreground. Reinforcement was being placed for the 6-in.-thick, cast-in-place concrete slab that completed the platform.



This figure shows typical segment dimensions. Each girder is supported by four bearings located directly below the webs of the end-anchor segments

The project offers great potential for developers in highly congested, high-demand areas.

The platform was designed as three distinct sections to allow for movement of the completed structure. Cast-in-place concrete was placed between the end anchor segments to create a rigid diaphragm across each of the three solid structures. The beams and the joints between them were covered with a 6-in.-thick, cast-in-place concrete slab. Conduit was installed in the cast-in-place slab to contain power and control systems for the ventilation system, track and platform lighting, security cameras, power, and other needs.

Pre-engineered steel armored openings were created in the flanges of the beam segments to allow for columns to be installed later. Armored openings were also placed in the webs of the box girders to create ventilation holes to evacuate smoke in case of a fire on the tracks below. Every other girder has these web openings and a fan room for the ventilation system. Smoke would be drawn up through the holes to street level if necessary. The platform also acts as a fire-break with a 4-hour fire rating.

In a typical segmental box girder, the diaphragms would have small access openings of approximately 10 ft^2. However, the end diaphragms for the platform required an opening of 100 ft^2 to ensure adequate area for the ventilation system. Typical end diaphragm details wouldn't work, so instead the diaphragms were placed outboard of the webs and bearings between adjacent girders to provide torsional restraint for the deck system. Numerous form-saver reinforcing bar and duct couplers also were used on end-segment faces to provide the necessary connections to the cast-in-place diaphragms.

As was expected with the magnitude of compressive stress in the structure, small cracks were observed at locations of high-stress concentration such as at the armored openings after post-tensioning. All cracks were relatively small (< 0.01 in.) and were sealed with methacrylate crack sealer.

The members of the construction team worked together closely throughout the project to ensure it ran smoothly under challenging conditions in producing a first-of-its-kind structure. Although the structure is not strictly a bridge, the construction of a platform over an active and busy railway addressed many of the same issues that more typical bridge structures encounter, but on a massive scale.

Girder in the background is shown in the second-stage stressing position. This view also shows the post-tensioning anchorages and large end opening for ventilation.

The project offers great potential for developers in highly congested, high-demand areas where the urban environment generates a lot of activity and little maneuvering room for construction, much less development.

This innovative and creative solution can be customized to a variety of urban situations, with the combination of top-down construction and precast concrete's off-site fabrication creating speedy construction with little disruption to the area and a high level of safety. It offers a new and fast way to literally create high-end real estate for development out of thin air. A

Phil Marsh is a project engineer with McNary Bergeron in Broomfield, Colo. Andrea Travani is a project manager with Rizzani de Eccher USA in Bay Harbor Islands, Fla.

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

EDITOR'S NOTE

For more on the specific challenges this project had to meet, see the Concrete Bridge Technology article in this issue.

Structural Engineering Education

From Hardy Cross' teachings to Dean Van Landuyt's arch bridge and a few additional thoughts

by Dr. Oguzhan Bayrak

When I was first approached by the editor-in-chief of *ASPIRE*,™ William Nickas, I was presented with an important opportunity and a challenge to share my thoughts on educating bridge engineers for the twenty-first century. I accepted this responsibility because I view teaching as the most important part of my job at the University of Texas. In this context, teaching ranges from teaching formal classes on our main campus, to the teaching that takes place in the Phil M. Ferguson Structural Engineering Laboratory where I conduct research and teach graduate students.

With this new series, I will share my perspectives on educating structural engineers, drawing from lessons learned in research projects I have supervised. I will also provide an opportunity for students and bridge design professionals to voice their opinions with the goal of making bridge engineering an even more exciting profession for many. As a starting point, in this issue, I would like to share some thoughts that served me as guiding teaching principles over the years.

Educating Structural Engineers Is Not Simple

Examples of best structural engineering products exist at the intersection of structural form and function. The most daring structural forms are often not functional or at least not ideally functional. The most functional designs appear to be ordinary.

In my view, striking a balance between structural form and function can only be achieved through a successful combination of applied science principles that form the very foundation of structural engineering and the art of

West 7th Street Bridge in Fort Worth, Tex., the world's first precast network tied arch bridge Photo: Hossein Yousefpour, the University of Texas at Austin.

hiding complex structural behavior in simple structural forms that make up a structure. Hence, by definition, "good" structural engineering exists between competing interests: structural form and function.

Let us take a look at the world's first precast concrete network arch bridge (the West 7th Street Bridge in Fort Worth, Tex.), shown in the photograph, as an example. This architectural marvel does a good job of hiding many complex behavioral problems in a neat and clean appearance to the casual observer.

Like the profession itself, the education of "structural engineers in the making" exists in between two competing factors: disciplined ways of thinking and a freedom to create. In the eyes of the students, there is a fine line between a well-organized series of lectures and overly regimented classes. As was stated by Hardy Cross in the early 20th century, student aversion to an overly regimented learning environment is rooted in the intellectual freedom needed to create. As a result, as educators, we must try to balance the learning environment in our classes through highly organized lectures and more open-ended design assignments and projects.

Structural Engineers Must Think

For practicing engineers, the need to have the time to think may be at odds with highly constrained schedules and budgets. Nevertheless, structural engineers must find the time to organize and rationalize their thinking and consequently make decisions in their designs.

In my view, as structural engineering professors, we must think before our students. The importance of accommodating questions, both pertinent to the lecture and seemingly off-the-wall, cannot be over-emphasized. When addressing a question raised by one student, the rest of the class benefits by witnessing how the professor thinks, how he/she rationalizes and proves his/her point.

At times, providing multiple explanations to the same question is equally important to actively demonstrate how several rational solutions to the same problem exist. In essence, this teaching principle can also be referred to as leading by example; in this case, by thinking in class. As the students witness their professor provide rational explanations leading to good structural engineering solutions, they will develop similar habits in tackling complex, real-world structural engineering problems.

Structural Engineering Is an Applied Science

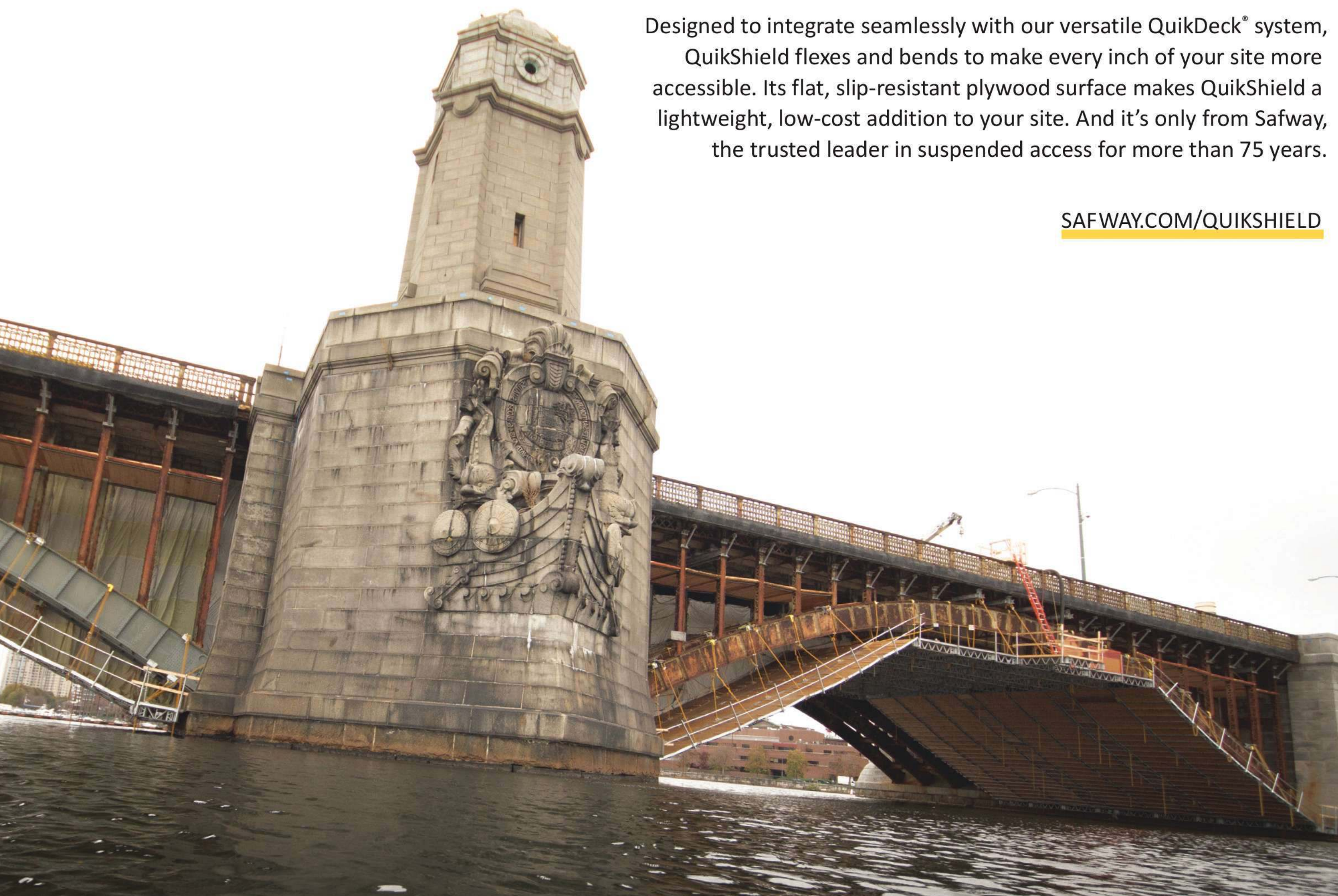
A good structural engineering professor should remember and remind his or her students the fact that structural engineering is not pure science. Often, conservative assumptions are made to simplify complex design processes and the focus is kept on the big picture. All structural designs should be simplified to the extent possible but they should not be overly simplified.

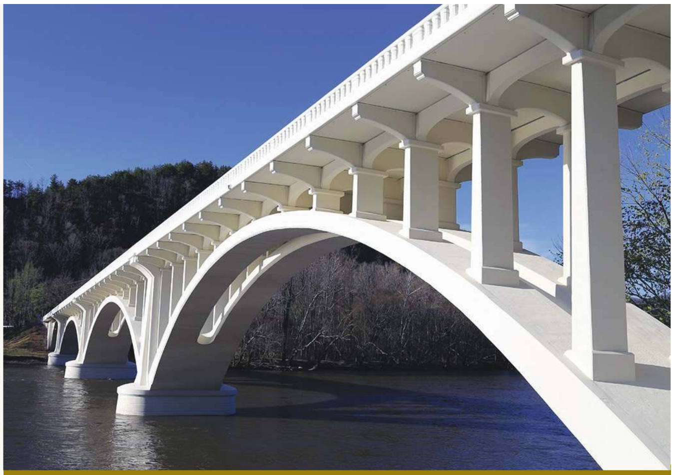
Let us use the example of the network arch shown in the photograph once again. It is important to recognize that the example given in the figure is the work product of a structural designer with three decades worth of experience (Dean Van Landuyt formerly of the Texas Department of Transportation [TxDOT]). Considering the unique features of this bridge, Van Landuyt decided to engage Ferguson Laboratory researchers at the conceptual design stage to identify and discuss several important aspects of structural behavior and ultimately simplified the design process to the extent possible. Further, Ferguson Laboratory researchers worked with the designer and contractor to ensure the safety and stability of this unique bridge during construction.

Conclusions

In my view, some of the most important traits of the structural engineering profession, and hence education, have been described in this article. A genuine appreciation of those concepts is absolutely essential to the education of the next generation of structural engineers and bridge engineers.

With this inaugural article, I wanted to share some of my thoughts and views on structural engineering and bridge engineering. More specifically, I have discussed the principles that have guided me as an educator and researcher in structural engineering. I hope you find this new series of articles interesting and valuable.





The rehabilitated Wolf Creek Bridge. Photo: Brian Hall.

Wolf Creek Bridge

by Thomas Brian Hall, AECOM, and John Scott Hastings, Tennessee Department of Transportation

The French Broad River traverses through the scenic mountains of eastern Tennessee, intersecting SR-9 (U.S. 25/70) in Cocke County near the town of Del Rio. To bridge the river, the Tennessee Department of Highways and Public Works designed and contracted the construction of the structure in 1926. This historic structure, referred to as the "Wolf Creek Bridge" by locals, is an exceptional asset in the Tennessee Department of Transportation's (TDOT's) inventory. It is the second oldest open-spandrel concrete arch bridge in the state, as well as one of the longest.

Time for Major Overhaul

Although maintained by TDOT through multiple small scale repair projects over the recent decades, it was determined that a major rehabilitation was needed to preserve the structure. Some of the options that were examined included in-place rehabilitation and constructing a new bridge to eliminate the sharp curves in the roadway approaches on each end. The in-place rehabilitation method was chosen due to

- the bridge's eligibility for the National Register of Historic Places,
- its complex architectural details, and
- the opportunity to expedite construction by avoiding permitting and right-of-way obstacles for a new structure.

TDOT oversaw the design of the rehabilitation, and AECOM managed the construction engineering and inspection on TDOT's behalf. The contractor was awarded the $8.7-million rehabilitation contract in 2011. Working as a team, TDOT, AECOM, and the contractor completed one of the most-unique rehabilitation projects in TDOT's history. The completed bridge preserves the appearance of the original structure, and will be around for many generations to enjoy in the future.

Many Tennessee Firsts

Spanning over 629 ft with two closed arch spans and three open-spandrel arch spans, the bridge was closed for approximately 2 years in order to complete the rehabilitation. The center cross section of the arches was preserved as well as the pier bases protruding from the river surface, but most of the remaining structure was demolished. The structure was rebuilt from the pier bases up, utilizing precast and cast-in-place concrete components, as well as many other unique materials.

The project included

- construction of a haul road in the river,
- demolition of the existing structure (except the arches and piers),
- hydro-demolition of portions of the concrete arches,
- repair of the arches,
- reconstruction using precast and cast-in-place bridge components,
- epoxy injection repair, and
- grading, paving, and guardrail installation.

The use of shrinkage-compensating concrete, self-consolidating concrete, a polymer-modified concrete overlay on precast concrete deck panels, and vertical and horizontal hydro-demolition were all firsts for bridge rehabilitation in Tennessee.

The river posed its own challenges during the construction phase, as the south bank experienced significant soil loss due to excessive rain and high flows, and it was encroaching on the embankment supporting Norfolk Southern's railway tracks—potentially undermining their stability if left unchecked. The selected solution could immediately reinforce the railroad embankment and could be utilized in the permanent bank-stabilization construction. It involved the first use of a bioengineered (vegetated) soil-stabilization retaining wall on a TDOT project, and was constructed this fall.

Thomas Brian Hall is a project manager with AECOM in Nashville, Tenn. John Scott Hastings is a civil engineering manager I with the Tennessee Department of Transportation Structures Division in Nashville.

2016 Call for Papers–

Abstracts due February 6, 2015

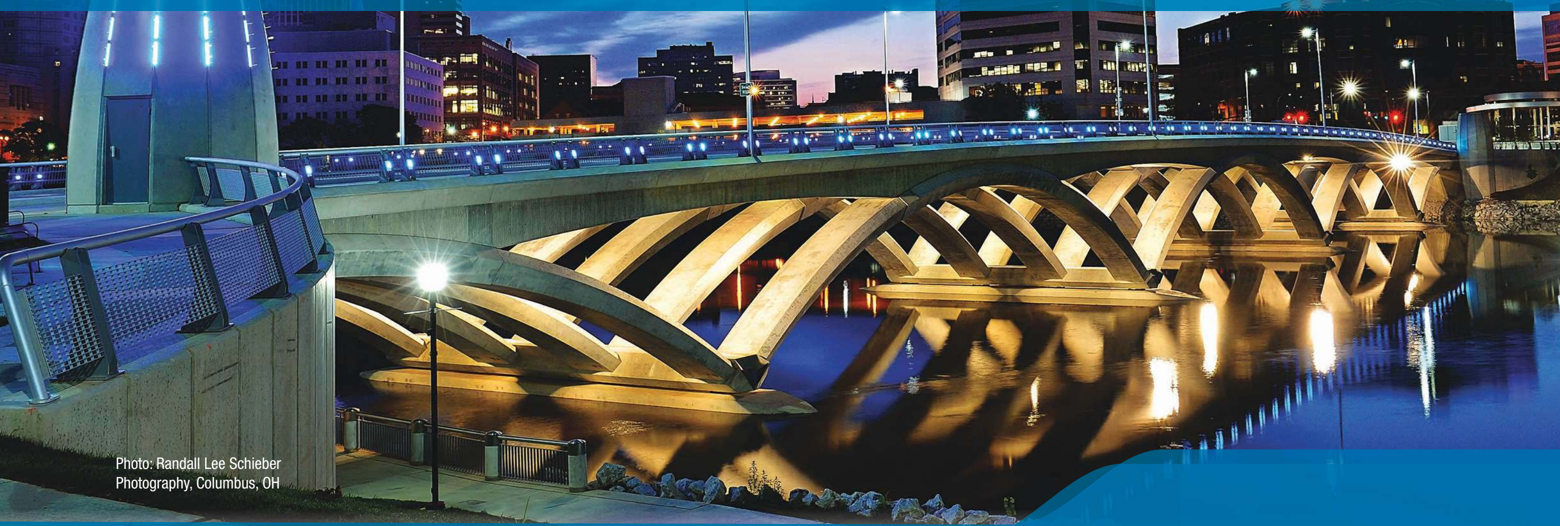


Photo: Randall Lee Schieber Photography, Columbus, OH

PCI Convention and National Bridge Conference

At the Precast Show, March 3-6, 2016

Nashville, TN.

PCI will soon be accepting abstracts for technical papers to be presented at the 2016 PCI Convention and National Bridge Conference which will be held at The Precast Show in Nashville, TN. While abstracts may be submitted on any relevant topic to the precast concrete industry, abstracts that focus on the high performance of precast will be given preference. Abstracts and papers will be peer-reviewed and accepted papers will be published in the proceedings.

The PCI Convention and National Bridge Conference is the premier national venue for the exchange of ideas and state-of-the-art information on precast concrete design, fabrication, and construction. The event provides an outstanding opportunity for networking, education, and sharing of ideas. Don't miss out on this excellent opportunity to share your knowledge– submit your abstract today!

Submission Requirements

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

The 2016 Call for Papers submission site will open November 2014.

Contact:

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Building Bridges Faster, Safer, Cheaper

SHRP2 advances structures solutions to nationwide implementation

by Matthew J. DeMarco, Federal Highway Administration

The Federal Highway Administration (FHWA), in partnership with the American Association of State Highway and Transportation Officials (AASHTO), is responsible for implementing the tools and products delivered by the Transportation Research Board (TRB) under the Second Strategic Highway Research Program (SHRP2). SHRP2 adheres to the principles of the original SHRP model—a focused, time-constrained, management-driven program designed to complement existing research programs. And like SHRP, with technical product development administered by TRB and national implementation co-administered by FHWA and AASHTO, SHRP2 addresses many of the most pressing needs related to the nation's highway system including

- the high toll taken by highway deaths and injuries,
- an aging infrastructure, and
- congestion stemming from inadequate capacity.

As such, the over-arching goals of the program remain to "Save Time—Save Money—Save Lives."[1]

To expedite adoption of SHRP2 innovations and solutions, the partners launched the *SHRP2 Implementation Assistance Program* (IAP) in early 2013 to provide direct financial and technical support to early adopters of SHRP2 products. The collaborative approach that drove SHRP2 research—including nearly 150 state department-of-transportation-supported research efforts—is being carried through into implementation to ensure the needs of potential users are incorporated into every stage of technology transfer.

Currently in full swing, the assistance program has thus far delivered 34 products through four IAP rounds, engaging all 50 states in over 250 technology deployment projects. Two more assistance offerings in 2015 will deliver 11 new products, as well as additional awards for several products previously offered.

Of the SHRP2 solutions delivered to date, six products under the *Renewal* focus area support improved bridge design, construction, and maintenance, including selection of geoconstruction technologies, bridge design for accelerated and long-life construction, concrete element nondestructive inspection methods, and construction performance specifications. These products are described in more detail in the following sections.

Ground penetrating radar technology being evaluated under the R06A Nondestructive Testing for Concrete Bridge Decks project. Photo: Rutgers University under SHRP2 contract, 2013.

R02—GeoTechTools

GeoTechTools is a comprehensive, web-based application containing information on more than 50 geoconstruction technologies applicable to transportation infrastructure, including bridge foundations, abutments, and approach embankments. The two primary components of this comprehensive toolbox are a *Catalog of Technologies* and a *Technology Selection Assistance System*. GeoTechTools was developed to assist engineers involved in project development, scoping, and/or the execution of highway projects make more informed decisions on geotechnical issues to reduce risk and minimize construction surprises.[2]

R04—Innovative Bridge Designs for Rapid Renewal

The Innovative Bridge Designs for Rapid Renewal: ABC Toolkit includes design standards, examples, and standard drawings for complete prefabricated bridge systems, and proposes specification language for accelerated bridge construction. The R04 focus is on providing accelerated bridge construction (ABC) options for small-to-medium "bread-and-butter"

Recently completed Kittery Overpass Bridge, Kittery, Maine. This ABC project utilized precast concrete cantilevered abutments, precast concrete Northeast Extreme Tee (NEXT) Deck Beams, and precast concrete approach slabs for rapid construction. Photo: Federal Highway Administration.

bridges. It also complements the national goals of the Everyday Counts ABC program for prefabricated bridge element systems (PBES), slide-in bridges, and geosynthetic reinforced soil/integrated bridge systems (GRS-IBS).

To date, R04 IAP demonstration projects have been completed in Missouri, Rhode Island, Maine, Kentucky, California, with work underway in Arizona, Michigan, and Wisconsin. The range of bridge component applications includes integral beam and deck systems, precast concrete piers and abutment walls, slide-in bridge systems, and GRS-IBS component systems.[3]

R06A—Nondestructive Testing for Concrete Bridge Decks

The large number of concrete bridge decks in poor structural condition is one of the biggest problems affecting bridges in the United States. Nondestructive testing (NDT) techniques have the potential to quickly and reliably characterize under-the-surface concrete bridge deck conditions, including delamination above and below reinforcing mats, vertical cracking, concrete deterioration, and reinforcement corrosion. Information on a number of geophysical-based NDT bridge deck evaluation technologies is summarized in the web application NDToolbox, available at www.NDToolbox.org. More detailed information on these and other technologies will soon be available in the new manual to be released by the Turner Fairbank Highway Research Center in early 2015.[3]

R07—Performance Specifications for Rapid Renewal

Thoughtfully developed performance specifications are important for ABC projects, particularly when new structure design and/or construction technologies are being deployed. Performance specifications allow contractors transitioning to new construction methodologies to meet the goals of the new construction methods/components, while at the same time modifying their current practices to fit the needs of the project. To help reach these goals in rapid renewal environments, the R07 project developed a suite of performance specifications for various highway project types and contracting scenarios, as well as implementation guidelines to address project selection, specification development, risk allocation, and the transition from methods to performance specifications.[3]

R19A—Service Life Design for Bridges

As limited resources demand enhancing the operational life of existing and new bridges, designing for service life is gaining importance. To provide procedures for systematically designing for service life, the R19A project developed the *Design Guide for Bridges for Service Life*, which can be used for both new and existing bridges. The guide includes new concepts and approaches that offer improvements to current practice and have the potential to enhance the service life of bridges. Although originally intended for medium-sized, bread-and-butter bridges, the guide is applicable to a broad range of bridge design and material and component selection issues related to an equally expansive array of working environments.[3]

R19B—Service Limit State Design for Bridges

When individual bridge components such as bridge bearings, deck joints, and columns and piles deteriorate at different rates, bridges can be closed for costly repair far too often over the structure's service life. Designing bridge components and systems to service limit states extends the service life of the entire structure, yields significant savings through reduced maintenance, and reduces safety risks for workers and road users. The R19B project[3] developed new design codes, performance measures, and implementation tools to lead to longer and more predictable bridge service life, as well as proposed changes to the *AASHTO LRFD* (Load- and Resistance-Factor Design) *Bridge Design Specifications*.

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Matthew J. DeMarco is a SHRP2 renewal program engineer—structures with the structures technical service team at the FHWA Resource Center in Lakewood, Colo.

EDITOR'S NOTE

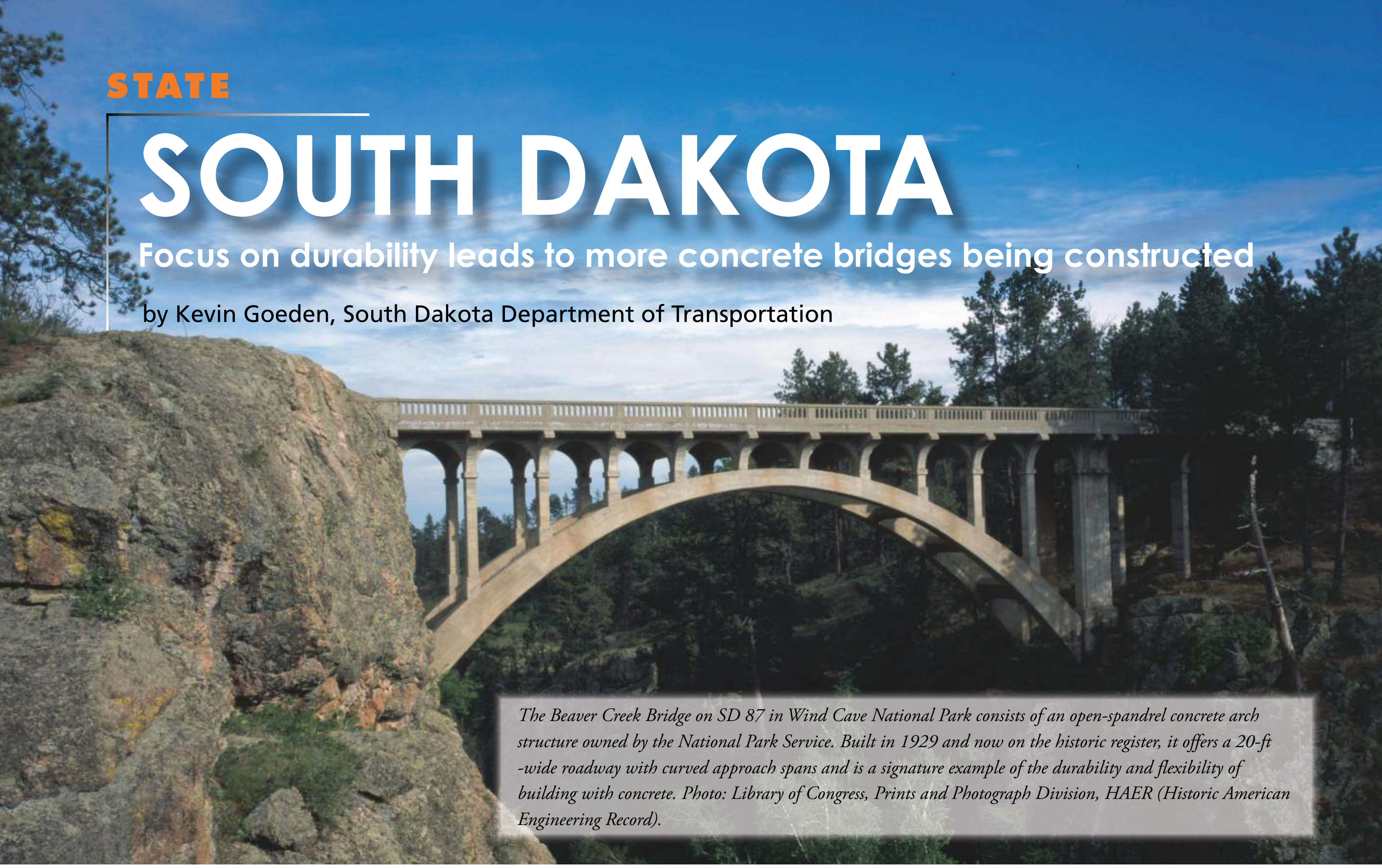
For more information on the Innovative Bridge Designs for Rapid Renewal: ABC Toolkit, visit www.trb.org/Main/Blurbs/168046.aspx.

STATE

SOUTH DAKOTA

Focus on durability leads to more concrete bridges being constructed

by Kevin Goeden, South Dakota Department of Transportation



The Beaver Creek Bridge on SD 87 in Wind Cave National Park consists of an open-spandrel concrete arch structure owned by the National Park Service. Built in 1929 and now on the historic register, it offers a 20-ft -wide roadway with curved approach spans and is a signature example of the durability and flexibility of building with concrete. Photo: Library of Congress, Prints and Photograph Division, HAER (Historic American Engineering Record).

In recent years, the state of South Dakota has focused its attention on designing bridges for longer life and addressing maintenance concerns earlier to alleviate replacement needs. These efforts, along with continued investigation of new concrete mixtures and different types of reinforcement, are aimed at increasing durability throughout the state network.

The South Dakota Department of Transportation (SDDOT) owns approximately 1800 structures and local governments own approximately 4000 structures that are included in the National Bridge Inventory. The majority of the bridges in South Dakota consist of relatively short spans, with the average state-owned bridge being about 40 ft wide and 210 ft long. Of the state-owned bridges, concrete superstructures are the most common type, making up approximately 65% of the total. The oldest concrete bridge in the state-owned inventory dates to 1924, while the oldest precast, prestressed concrete-girder bridge was built in 1959.

One of the oldest bridges is the scenic Beaver Creek Bridge on SD 87 in Wind Cave National Park, which consists of an open-spandrel concrete arch structure owned by the National Park Service. Built in 1929, it offers a 20-ft-wide roadway with curved approach spans and is a signature example of the durability and flexibility of building with concrete.

Over the past 9 years, SDDOT has constructed on average about five new bridges per year on the state-owned highway system and about 10 on the local government-owned system. The bridges built on the state-owned system typically are either cast-in-place continuous concrete slab spans or cast-in-place concrete slabs on prefabricated girders. The supporting girder types are either precast, prestressed concrete I-shaped or steel I-shaped sections.

SDDOT has a long and favorable history of performance with cast-in-place continuous concrete slab-span bridges. Jointless bridges that have cast-in-place concrete deck slabs on precast, prestressed concrete girders that are made continuous for live load and have integral abutments have also performed very well, albeit with a shorter history of experience.

An example of a typical slab span is the Davis Bridge on U.S. 18 over the Vermillion River, built in 2013. It features four continuous spans, with two interior spans of 47.5 ft and two end spans of 38 ft. The roadway is 40 ft wide.

Preservation a Top Priority

SDDOT has been in a preservation mode with its highway system in recent years, which has reduced the number of new bridges it has constructed. Bridge preservation has long been a significant portion of SDDOT's bridge project programming. Its goal has been to extend the lives of existing bridges by addressing

This bridge on U.S. 18 over the Vermillion River near Davis, S.D., built in 2013, features four continuous spans, with two interior spans of 47.5 ft and two end spans of 38 ft. The roadway is 40 ft wide. Photo: South Dakota Department of Transportation.

maintenance needs early rather than have to replace the bridges later.

Decks have been a major focus of South Dakota's bridge-preservation program. Since the mid-1970s, SDDOT has been applying concrete overlays to existing bridge decks containing uncoated reinforcing steel, and eliminating or replacing deck joints wherever possible. Initially these 2-in.-thick overlays were latex-modified concrete. More recently a low-slump, dense concrete type has been used. Some of these earlier deck overlays are now having a second overlay applied. As a result of the overlay program, SDDOT has replaced very few bridge decks over the years.

At about the same time that the rigid deck-

Decks have been a major focus of South Dakota's bridge-preservation program.

overlay program was initiated for existing bridges, SDDOT began designing new bridges with integral abutments and jointless concrete decks with increased clear cover (2 ½ in.) and incorporating epoxy-coated reinforcing steel. These bridge decks are proving to be very durable, even with South Dakota's relatively severe winter climate.

Our focus on longevity and preservation is driven in part by our concern over availability of reliable and adequate long-term funding. Our goal is to effectively design bridges for long-term durability with minimum required maintenance and within the available budget. The uncertainty in our funding sources makes it imperative we use our budget wisely each year.

Concrete Use Grows

SDDOT has been using concrete more often in recent years due to its cost competitiveness, especially for the relatively short-span applications that are common in the state. Its favorable durability history with concrete bridges and long-term maintenance considerations also are factors. As a result, about 80% of the bridges being built today on the state-owned system are concrete, while virtually all of those being built on the local-owned system are concrete.

Local fabricators work closely with SDDOT to keep designs efficient and cost effective. Since they can now provide longer spans (up to 130 ft), our thinking about design options has changed. As a result, longer bridges that had been built with steel girders in the past are now being replaced with concrete designs in some cases.

The Liberty Road Bridge over I-90, at the east entrance to Ellsworth Air Force Base, was constructed in 2002. It features eight girder lines of Type 72M prestressed concrete girders with spans of 129 and 119 ft and a 60-ft-wide roadway. Photo: South Dakota Department of Transportation.

An example of the span lengths being used is the Liberty Road Bridge over I-90, at the east entrance to Ellsworth Air Force Base. Constructed in 2002, it features eight girder lines of Type 72M prestressed concrete girders with spans of 129 and 119 ft and a 60-ft-wide roadway.

SDDOT keeps up to date with new techniques being used in its state and others. The 8th Street Bridge in Custer, a locally owned structure, recently was completed using geosynthetic reinforced soil (GRS) abutments. The precast, prestressed concrete deck units consist of 10 side-by-side solid slab sections, with a 24-ft span over French Creek, which were grouted in 2 days, according to the precaster.

SDDOT continues to evaluate potential improvements in concrete (especially high-performance concrete). It is currently utilizing Class F fly ash in deck concrete to densify the matrix and reduce permeability. In the past, the department has tried techniques such as using well-graded aggregate mixtures to try to control cracking.

Recently, in an effort to gain a 100-year service life, SDDOT has utilized stainless-steel reinforcing bars in a few projects, and is considering allowing other alternative corrosion-resistant bar materials such as dual-coated, metallized-steel reinforcing bar with an epoxy topcoat (ASTM A1055). These approaches are being used for major projects and on complicated, urban interchanges where maintenance or replacement would be disruptive.

SDDOT does not design many bridges with special aesthetic treatments, although it does frequently use special surface finishes on concrete slabs, girders, and barriers. Often, this consists of special color treatments and may be coordinated with local wishes. SDDOT has also used formliners on substructures, along with colored surface treatments, in a few cases.

Mostly, designs are presented for clean, smooth lines adhering more to the "form follows function" aesthetic principles and shy away from special add-on type treatments. We believe the clean lines of concrete look good by themselves.

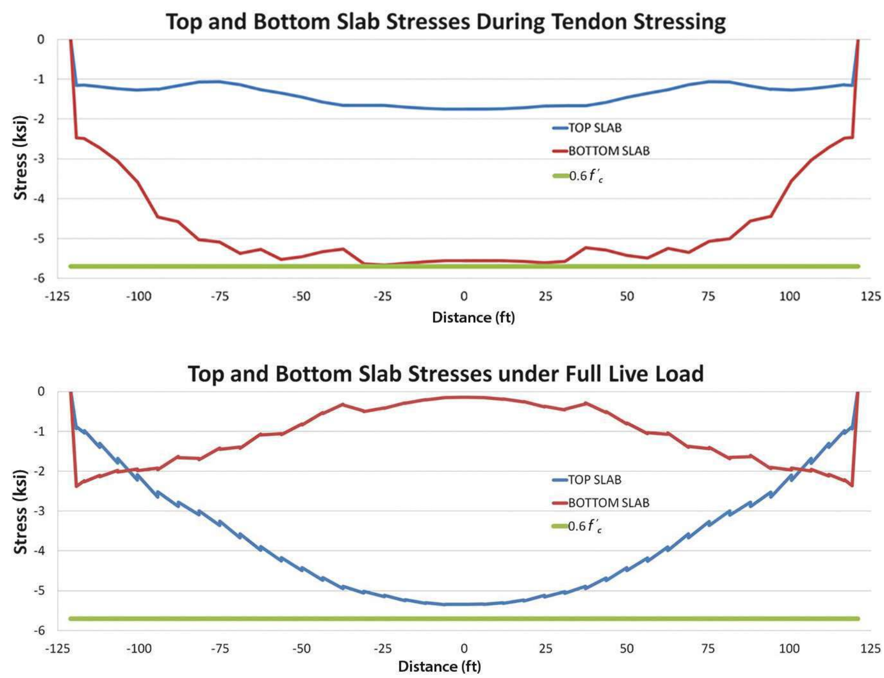
Kevin Goeden, P.E., is the chief bridge engineer with the South Dakota Department of Transportation in Pierre, S.D.

The 8th Street Bridge over French Creek consists of 10 side-by-side precast, prestressed concrete solid slabs with a 24-ft span. Photo: Gage Brothers.

Manhattan West Platform Challenges

by Phil Marsh, McNary Bergeron, and Andrea Travani, Rizzani de Eccher USA

This new *ASPIRE*™ department highlights some of the detailed engineering topics and key issues that significant projects bring to light. The editors asked the engineer of record and contractor on the Manhattan West project in New York City to detail six specific challenges they faced in achieving the owner's goals. For an overview of the project, see the article beginning on page 24.



These two charts show how the stress conditions at the top and bottom slabs of the box beam change from initial tendon stressing to full-service load conditions. All Figures and Photos: RdE USA.

The Manhattan West platform project had a number of significant challenges that had to be addressed during the design process. These were unprecedented and took careful calculations to meet the unique design constraints required of the precast concrete components. Six of the key challenges that had to be met were:

1. Compressive Stress Limits. Because of the long span and heavy design loads, the beams were highly post-tensioned. Design calculations showed that after a beam was completed, the compressive stress at the bottom of the beam would be 5.6 ksi, which was very close to the initial compressive stress limit of 5.7 ksi ($0.6f'_c$). During post-tensioning operations, the reduced cross-sectional area due to the ungrouted ducts would have caused the compressive stress limit to be exceeded. Therefore, a 360-kip counterweight was placed on the beam near midspan to temporarily reduce the precompression in the bottom slab until grout was placed in the ducts and could cure.

After the grout had become an effective part of the girder cross section, the counterweight could be removed, and the stress in the bottom slab remained just below the limit. At this initial condition, the top slab was also in compression, but at a stress between 1 and 2 ksi.

In the final, fully-loaded design condition, the stresses reverse with the top slab being in a high compression of 5.5 ksi, once again, very close to the limit, and the bottom slab being near zero compression. The high compression in the top slab became an important design consideration when detailing the openings for future columns.

2. End-Anchor Segment Integration. The end-anchor segments were 4 ft 2 in. long, weighed 56 tons, and contained twenty 37-strand anchors, six 31-strand anchors, four 9-strand transverse tendons, twelve 1.25-in.-diameter permanent post-tensioning bars, eight 3-in.-diameter bars for lifting, and bearing recesses. In all, 9000 lb of reinforcement was required in each end-anchor segment, with more than 200 form-savers per segment.

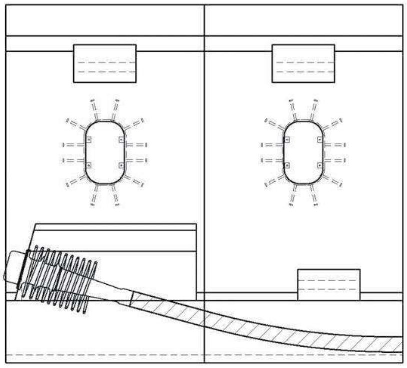
That was a lot of material to fit into these relatively small end segments, which had to be kept as short as possible due to shipping-weight limits. All of these elements had to be carefully integrated to make it possible to successfully build these segments.

A lifting shoe with a 900-ton design capacity was stressed down to each anchorage group of an end segment. Each shoe was attached to the beam with four bars that each had a capacity of 450 kips. The four shoes provided a total lifting capacity of 3600 tons, which was 150% of weight of the 2400-ton beam. The increased capacity was required by the railroad to ensure no problems were encountered lifting the loads over live rail traffic.

The distance between the beam seat and the bottom of the end segment was about 12 in. That space was needed for two 380-ton temporary jacks as well as the permanent bearing. Spherical bearings were used on the project because of their compactness. The largest bearings were designed for a 2500-ton ultimate load.

The relatively short end segments were required due to weight limits for transporting the pieces to the site. Each lifting shoe was designed with a 900-ton capacity and was attached to the beam with four bars.

Creating the large column openings in the beam flanges created challenges due to the high compression in the top slab. Openings were armored with 1.5-in.-thick steel plate to assist with the stress flow.



Elevation showing the tight-radius plastic duct that was used to deviate the 31-strand tendons in two segments.

3. Future Column Openings. Providing 5 by 5 ft clear openings in the platform to allow for construction of future building columns created additional challenges. The openings create significant stress concentrations in the top slab. The openings straddled the longitudinal closure joints between beam flanges and were armored with 1.5-in.-thick steel plates anchored into the concrete with shear studs.

Because the segments are only 6 ft long, it was not possible to place an entire column opening in one segment, so the armor plates were spliced at segment joints. After beam stressing was complete, the plates were welded together at joints with complete penetration field welds. Bent plates were welded into place after the adjacent beam was placed to complete the structural enclosure of the column opening across the closure joints. This connection provided construction tolerance between flanges of adjacent girders.

In addition to the armor plate, six No. 9 bars that were cast into segments were spliced across the longitudinal closure placement on each side of the column opening using mechanical couplers. The bars were necessary to resist the splitting force in the concrete due to the high stress concentrations at the openings. Initially, there were concerns about properly aligning these bars, but no problems were encountered. Debris plates enclosed the bottom of the openings to protect the tracks during construction and act as stay-in-place forms for the cast-in-place concrete slab.

4. Bottom Tendon Anchorages. The design required that some tendons be anchored within the span. These 31-strand tendons were anchored in one segment and deviated in the next because the tendons and blister details would not fit into the bottom blister of a single 6-ft-long segment. The first segment contained the anchor hardware and anchor block with a straight length of duct. The adjacent segment contained tight-radius plastic duct with a 20-ft-diameter bend radius to deviate the tendon to horizontal. This approach was possible because the bottom slab was 2 ft thick, as required to resist the high compression forces.

5. Movement Joints. The completed structure was separated into three pieces by longitudinal joints to accommodate movement. The movement joints had to accommodate significant movement in all directions. The approach that was ultimately used provided ± 3 in. of differential deflection, ± 3.5 in. of longitudinal movement, and ± 1.5 in. of lateral movement between adjacent girders. The joints were covered by simply supported cast-in-place concrete slabs supported by steel angles embedded in the flanges of the box girders. Stay-in-place deck forms were successfully used to form the slabs. The design loads on the joint slabs were not large, so elastomeric bearing pads and a stainless-steel sliding surface were used.

6. Coordination. Ninety-six containers, which were shipped from Italy, were placed into a 250 by 90 ft staging area. Not only did the staging area hold the containers, but at times it also held multiple contractors performing their work. This required an extensive amount of coordination to ensure an efficient process throughout the project execution.

The challenges presented by this unique project were met with creative, innovative solutions that give us insight into how best to approach similar conditions should they arise in the future. Close communication and sharing of technical insights and expertise ensured that the project met the developers' budget and schedule. The Manhattan West platform solutions offer potential for future projects where tight conditions, long spans, and heavy loads must be addressed.

Phil Marsh is a project engineer with McNary Bergeron in Broomfield, Colo. Andrea Travani is a project manager with Rizzani de Eccher USA in Bay Harbor Islands, Fla.

EDITOR'S NOTE

For more on this project, see the Project article beginning on page 24.

Porter Creek Bridge

by Farshad Mazloom, Kie-Con

Aerial view of stage I construction, with new girders flanking the existing bridge. All Photos: Kie-Con.

Porter Creek Bridge was advertised for public bid based on a single-span, cast-in-place concrete box-girder bridge in December of 2012. Contract was awarded in early 2013 with a tight contract schedule, not considering the anticipated heavy rain during the winter season. The bridge was opened to traffic in 2014.

The new bridge was designed to replace a five-span concrete bridge built in 1935. The precaster proposed using seven, 78-in.-deep by 160-ft-long wide flange girders. These girders are, to date, the longest non-spliced precast concrete girders in California. The precast concrete girder solution eliminated the need for any falsework in the creek, which is an environmentally sensitive habitat. This solution allowed the bridge work to continue during the annual environmental-hold period, which starts on October 15 of every year. A major key to the success of the project was how quickly the calculated decision was made by the general contractor, owner, and engineer to approve the value-engineering proposal for the bridge.

All girders set for stage II, after removal of the old bridge.

Design

During the value-engineering design phase, it was discovered that the girders had to travel under an existing historical monument just 1 mile west of the bridge; this tight headroom was the major factor in determining maximum height of the girders. Once the girder height was determined, it was just a matter of simple calculations to design the quantity of girders

Stage II truck waiting to offload.

Setting last girder for stage II.

needed for the bridge.

A detailed study of the transportation route was done by the transportation company in order to ensure the stability of the girders during shipping. California is known for its short and tight radius freeway ramps. The routing to the project site consisted of

- 7 miles of narrow and winding minor roads,
- 100 miles of seven major congested freeways, and
- numerous on and off ramps.

It was determined that ramps along the route have a 10% cross slope. Analysis was done to ensure that these girders did not become unstable as they enter and exit the freeway ramps. The wide flange girders have a greater lateral moment of inertia, as well as having their center of gravity toward the bottom of the girder.

At the precaster's option, all 56 of the 0.6-in.-diameter prestressing strands were designed as straight strands, with 18 strands debonded for lengths up to 40 ft. The amount of prestressing force in the Porter Creek girders necessitated 6 ksi concrete at time of transfer and 9 ksi concrete at final. A self-consolidating concrete was used for these girders, which reached a strength over 6.5 ksi in 10 hours and exceeded 10 ksi in 7 days.

During design, the precaster and designer increased the gap between the end of the girders and vertical face of the abutment back walls to 6 in., which also reduced the girder length to 159 ft. This provided more field tolerance which was needed due to the extreme length of these girders. The 6-in. gap was then filled with cast-in-place concrete, as were the end diaphragms. The majority of the reinforcement used in the girders was welded-wire reinforcement.

Transportation, Installation

Four girders were initially shipped to the site, with two installed on each side of the old bridge. One of the exterior girders was directly under a power line. This required a well-detailed plan established by the general contractor and coordinated with the power company. The power line was de-energized during the installation of the girders. The deck was cast on the two pairs of girders, which allowed traffic to be shifted onto the new structures for the second stage of construction. During the second phase, the old bridge was demolished and the final three girders were installed to complete the final structure. Stay-in-place steel pan forms were used to support the deck slab.

Farshad Mazloom is a project manager with Kie-Con in Antioch, Calif.

EDITOR'S NOTE

For more information on the Porter Creek Bridge, see the October 2014 article published in Concrete Products at www.concreteproducts.com/features/8608-bulb-tee-sunset-kie-con-ushers-california-wide-flange-girder-into-mainstream-specs.html

CONCRETE CONNECTIONS

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.pcine.org
More information on the PCI Northeast Bulb-tees and NEXT beams can be found on the PCI Northeast website. The development of these beams was mentioned in the feature article about CME Associates Inc., on pages 6 to 9.

http://centennial.transportation.org/default.htm
This is the website celebrating the centennial of the American Association of State Highway and Transportation Officials (AASHTO) which was mentioned in the Perspective on pages 10 to 11.

http://www.fontana.org/index.aspx?NID=2150
Visit this City of Fontana, CA, webpage for more information about the I-10 interchange projects at Citrus Avenue and Cherry Avenue that are described on pages 12 to 15.

https://www.arema.org/files/library/2013_Conference_Proceedings/Design-Construction_of_P_and_L_Railway_Bridge_J23-3-West_Point_KY.pdf
This article from the 2013 AREMA Conference gives more information on the P & L Railway Bridge covered in the article on pages 16 to 18.

https://garverusa.com/markets/transportation/96/cottonwood-creek-bridge/
This webpage on the Garver website gives additional details about the Cottonwood Creek Bridge, which is discussed on pages 20 to 22, including a video illustrating the methods used for constructing the bridge.

http://manhattanwestnyc.com/
This website describes the features of the real estate development, which will be built above the Manhattan West Platform that is mentioned in the project article on pages 24 to 26 and the Concrete Bridge Technology on pages 38 to 39. Under the "Innovation" tab, a video is available that describes the construction of the platform and how it fits into the site and development plans.

http://www.fhwa.dot.gov/goshrp2/
The SHRP2 program was the focus of the FHWA article on pages 34 and 35. This website provides more information on all SHRP2 products, including research reports, toolkits, training information, web-based applications, webinar training, and upcoming offerings under the Implementation Assistance Program. Additional information may also be found on the TRB and AASHTO websites.

http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubR19AGuide.pdf
This link is to the document titled *Design Guide for Bridges for Service Life*, which was mentioned in the FHWA article on page 35.

www.NDToolbox.org
This webpage is for the NDToolbox that is mentioned in the FHWA article on page 35.

http://youtu.be/SJv-9vd7pc8
Visit this link to view a video of the delivery and erection of the girders for Phase I of the Porter Creek Bridge project that appears on pages 40 to 41.

Bridge Technology

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

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

www.concretebridgeviews.com
This website contains 77 issues of *Concrete Bridge Views* (formerly *HPC Bridge Views*), an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of concrete in bridges.

www.fhwa.dot.gov/bridge/lrfd/webinar.cfm
This FHWA website provides access to 13 webinars about implementation of the Load and Resistance Factor Rating Method.

Bridge Research

NEW http://www.fhwa.dot.gov/publications/research/infrastructure/structures/14084/index.cfm
FHWA has released a report titled "Design and Construction of Field-Cast UHPC Connections" (FHWA-HRT-14-084) which is available for download as a PDF on this website.

www.concreteresearchnetwork.org/
The American Concrete Institute Foundation has established a Concrete Research Network at this website to provide a forum for collaboration among funders, researchers, and users that will generate research proposals in response to industry needs, disseminate research findings, and champion the process for adoption of new or improved methods of concrete design and construction.

www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/
This database contains a list of projects sponsored or conducted by the Federal Highway Administration's Turner-Fairbank Highway Research Center and the Exploratory Advanced Research Program. It is updated as new information is collected.

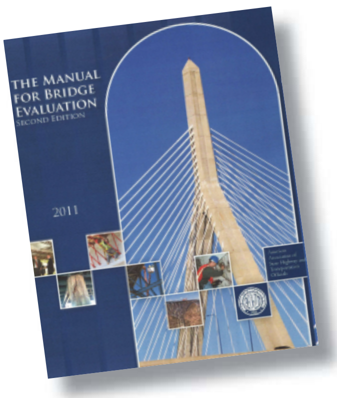
www.trb.org/main/blurbs/170409.aspx
The FHWA has released a tech brief that discusses bond strength tests of concrete with a unit weight between that of traditional lightweight concrete and normal weight concrete.

www.fhwa.dot.gov/publications/research/infrastructure/structures/hpc/14041/14041.pdf
This website contains a technical summary of the FHWA report titled *Splice Length of Prestressing Strand in Field-Cast Ultra-High Performance Concrete Connections.*

AASHTO LRFD

Load Rating Concrete Bridges: Part 3

by Dr. Dennis R. Mertz



Material	Limit State	Load Level: Design – Inventory	Load Level: Design – Operating	Load Level: Legal	Load Level: Permit
Reinforced Concrete	Strength I	mandatory	mandatory	mandatory	n/a
	Strength II	n/a	n/a	n/a	mandatory
	Service I	n/a	n/a	n/a	optional
Prestressed Concrete	Strength I	mandatory	mandatory	mandatory	
	Strength II	n/a	n/a	n/a	mandatory
	Service I	n/a	n/a	n/a	optional
	Service III	mandatory	n/a	optional	n/a

NOTE: n/a = not applicable for the associated load level.

The load rating of concrete bridges using the load and resistance factor rating (LRFR) methodology of Section 6, Part A of the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Bridge Evaluation* (MBE) is summarized in the adjacent table adapted from MBE Table 6A.4.2.2-1.

As indicated in the table, the specified strength limit states are mandatory while the newly included service limit states are for the most part optional. Note that while MBE Table 6A.4.2.2-1 indicates that the Service III limit state is optional at the legal load level for prestressed concrete, it is mandatory for segmentally constructed prestressed concrete.

In previous columns, the mechanics of the LRFR methodology—the load-rating equation, where the loads, load factors, and resistance factors can be found, and the purposes of the different load levels—was discussed.

Let's discuss the intent of the limit states, specifically the optional service limit states. The strength limit states of the LRFR methodology are much the same as those of the older load factor rating (LFR) methodology. In general, they check the remaining load-carrying capacity to reach a moment or shear limit at the specified load level.

The service limit states check the remaining load-carrying capacity to reach a stress limit. When applied, these limit states protect the bridge against specific damage.

The Service I limit state is suggested by the MBE for reinforced and prestressed concrete bridges under the permit load level. The stress limit for the Service I limit state is 90% of the yield strength of the reinforcement, either nonprestressed or prestressed, for all loads factored by a load factor of one. The Service I limit state allows cracking of the concrete but precludes yielding of the reinforcement. Thus, cracks can form and open but should close after passage of the legal or permit load. A prudent owner should consider using the Service I limit state to protect against permanent deformation and open cracks.

The Service III limit state at the design load level at inventory is identical to that of the *AASHTO LRFD Bridge Design Specifications* with a live-load load factor of 0.8 and with all of the other loads factored by a load factor of one. It is mandatory for prestressed concrete bridges. The stress limit for the Service III limit state is the modulus of rupture. The MBE suggests the Service III limit state for prestressed concrete members at the legal load level, but with a live-load load factor of 1.0. The specification of the load factor of 1.0 is appropriate as the LRFD-specified load factor was developed specifically for the nominal HL-93 live-load model as opposed to the legal truck configurations. Again, a prudent owner should consider using the Service III limit states to protect against cracking of prestressed members under legal loads.

With that, our series of discussions on load rating concrete bridges using the LRFR methodology of the 2011 edition of the MBE are complete.

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.*