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SUMMER 2014

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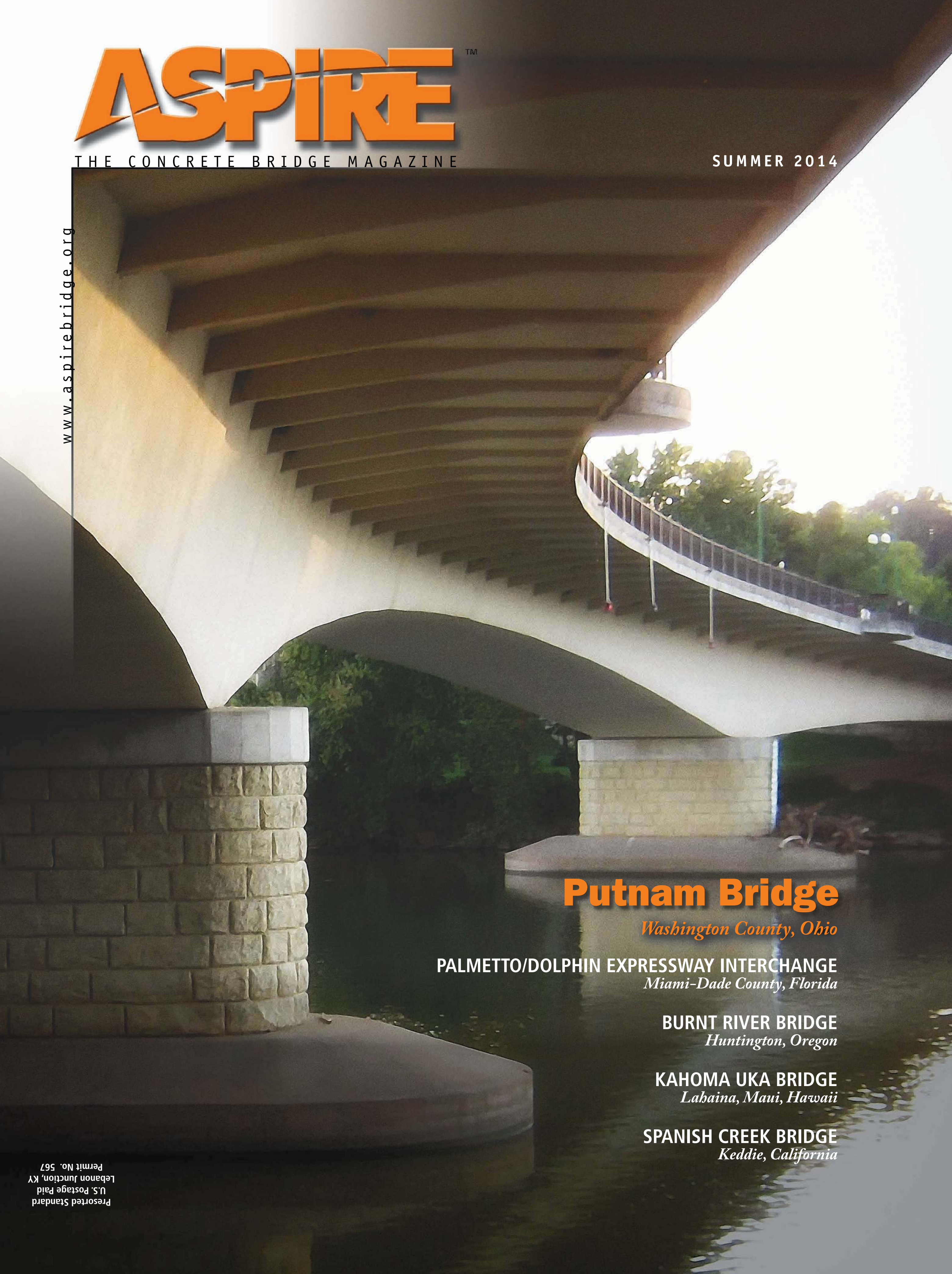

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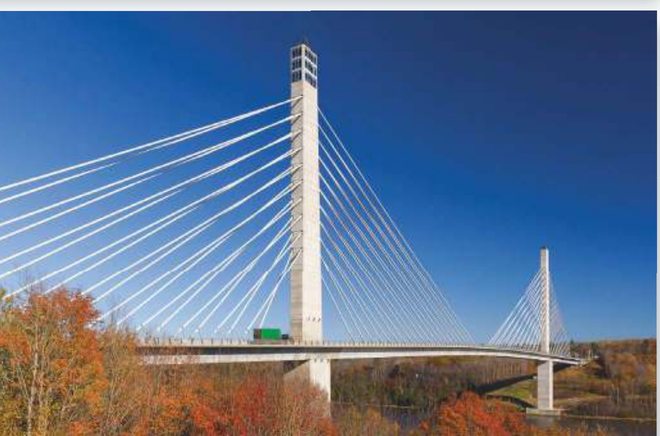

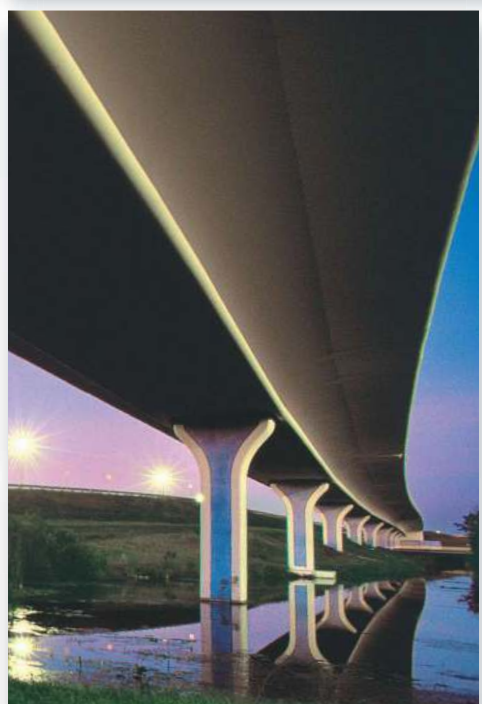

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EDITORIAL

Photo: PCI.

Technique is Cheap

William Nickas, *Editor-in-Chief*

In the Winter 2014 issue of *ASPIRE*™, Dr. Henry Russell commented in his editorial about specifications related to concrete materials and designing for service life. The editorial caused several readers to comment on the need for better service life prediction models for structures and their materials. In my Spring editorial, a futurist helped set the tone for the benefits of extending our thinking and moving beyond our engineering and construction constraints. In this issue, we want to continue to think in the future tense.

The Perspective in this issue is by Dr. Ben Graybeal of the Federal Highway Administration. In it, he examines the motivation for much of the past research on concrete materials. Given significant progress in the past several decades, Graybeal cautions of the risk to not engage the research community in a new level of challenges. He concludes by proposing four key topics that he sees as ripe for a strategic investment of research capital. Read his article beginning on page 10.

I took notice of an article about an avalanche of debate created by a statement by Harvey Littleton at a conference in 1972. Littleton is the son of Dr. Jesse T. Littleton, renowned director of research for Corning Glass Works and inventor of Pyrex glassware. Littleton commented, "Technique is cheap." To calm the debate, Littleton later stated, "All I meant by that is technique is available to everybody, that you can read technique, if you have any background. Technique in and of itself is nothing. But technique in the hands of a strong creative person takes on another dimension."

Strong creative engineers together with experienced and talented contractors can reshuffle the deck on how bridges are developed and delivered. Such teams create concepts for alternatives from which the best evolve to meet the requirements of a project. The challenges can be a large program of bridges for a state such as we've seen in Missouri or Pennsylvania or just a single off-system bridge found in every community in the nation.

These system approaches often introduce new levels of complexity. When bridges are built in the traditional way—piece by piece—the construction sequence allows some relief and redistribution of stresses during assembly. Complex systems approaches can lock in stresses during construction, which together with restrained thermal movements, may introduce significant stresses in the structure. One of Graybeal's proposed research topics involves this issue.

We have many techniques available to us to address the challenges created through today's more sophisticated structural demands and solutions. As Littleton said, "… technique in the hands of a strong creative person takes on another dimension."

Concrete is the ideal material for the nation's infrastructure. It is capable of assuming practically any shape. Today's materials technology allows superior durability and longevity. And still, we are finding astonishing new ways of refining the materials and new methods of construction such as

- hardening vulnerable locations like girder ends and pier caps under expansion joints,
- utilizing compressed concrete in vulnerable locations to increase long-term durability,
- providing multiple levels of protection in the newest post-tensioning systems,
- integrating use of high-performance and ultra-high-strength materials at connections, and
- layering technologies using resilient, impermeable materials at the riding surface so that bridge decks can reach a 100-year service life even on salted northern highways.

Let's dare to dream. As Graybeal concludes, "Visionary research can propel us through another century of concrete innovation."

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Cover
The Putnam Bridge in Washington County, Ohio, is a testament to the timeless aesthetic of concrete bridges. For more information on Washington County's bridges, see the feature on page 38.
Photo: Julia David, Barr & Prevost.

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

Photo: Ted Lacey Photography.

Correction

Spring 2014

On page 13 of the Spring 2014 issue, the post-tensioning material supplier was inadvertently left off the profile listing. The post-tensioning material supplier was DSI/Dywidag-Systems International, Bollingbrook, IL.

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

CONCRETE CALENDAR 2014/2015

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

July 21-25, 2014
PCA Professors' Workshop
PCA Campus, Skokie, Ill.

July 27-August 1, 2014
AASHTO Subcommittee on Materials
The Depot Renaissance Minneapolis Hotel
Minneapolis, Minn.

September 6-9, 2014
PCI Annual Convention and Exhibition and National Bridge Conference
Gaylord National Resort and Convention Center
National Harbor, Md.

October 26-30, 2014
ACI Fall Convention
Hilton, Washington
Washington, D.C.

October 27-28, 2014
ASBI 26th Annual Convention
Hartford Marriott Downtown
Hartford, Conn.

December 4-5, 2014
2014 National Accelerated Bridge Construction Conference
Hyatt Regency, Miami, Fla.

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.

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

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

PCI Precast/Prestressed Concrete Institute

The PCI State-of-the-Art Report on
Seismic Design of Precast Concrete Bridges

Seismic design of precast concrete bridges begins with a global analysis of the response of the structure to earthquake loadings and a detailed evaluation of connections between precast elements of the superstructure and substructure. Because modeling techniques have not yet been implemented for jointed details, the focus of this report is on procedures for the evaluation of system response and the detailing of connections for emulative behavior.

Seismic analysis procedures are discussed with the primary emphasis on force-based analysis procedures. Displacement-based analysis and computer modeling are also discussed. Relevant seismic design criteria of early years are summarized along with the current criteria of the AASHTO Specifications, Caltrans criteria, Japan's bridge design, and the New Zealand Bridge Manual requirements.

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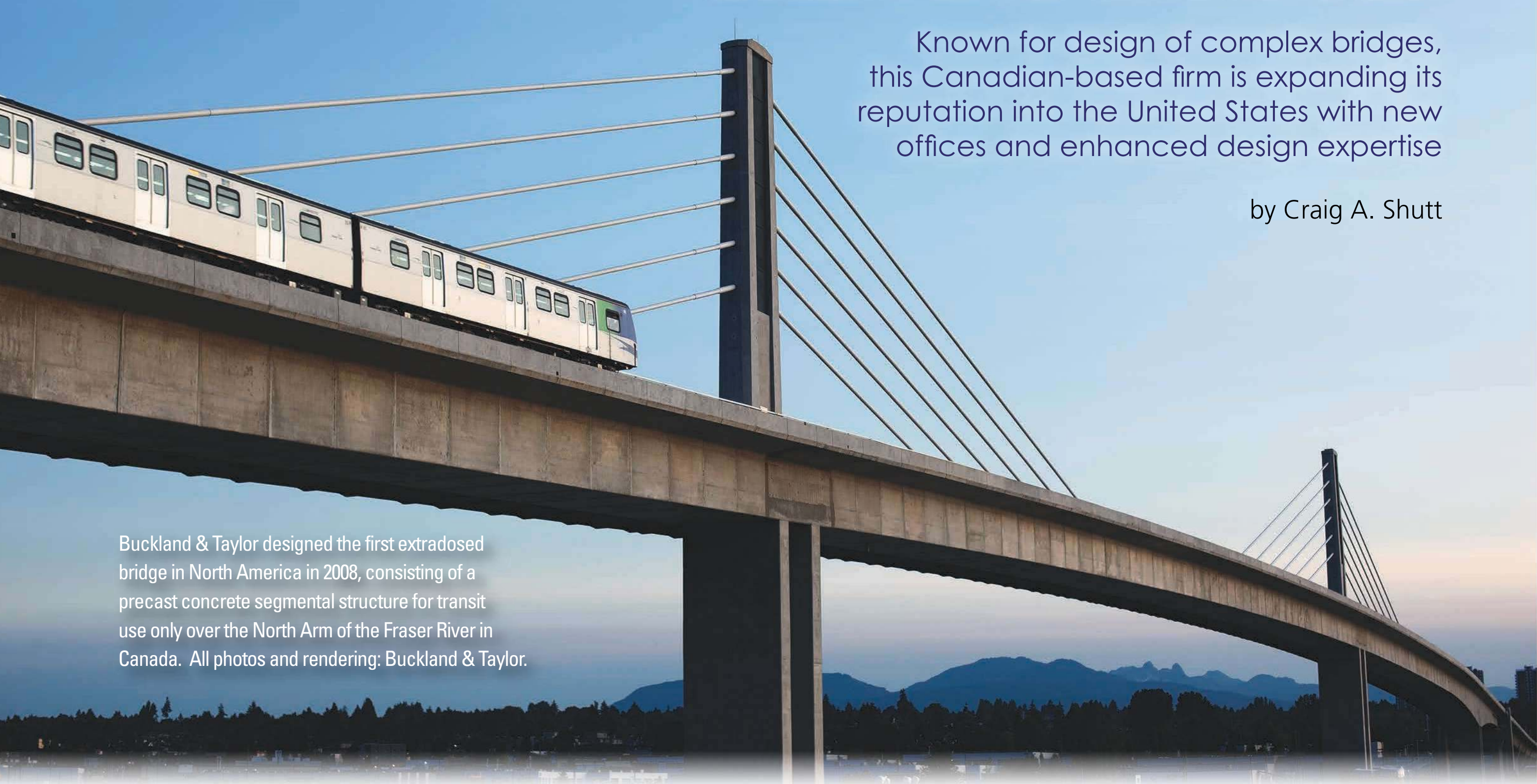
Known for design of complex bridges, this Canadian-based firm is expanding its reputation into the United States with new offices and enhanced design expertise

by Craig A. Shutt



Buckland & Taylor designed the first extradosed bridge in North America in 2008, consisting of a precast concrete segmental structure for transit use only over the North Arm of the Fraser River in Canada. All photos and rendering: Buckland & Taylor.

During its 42 years of operation, Buckland & Taylor (B&T) has developed a reputation for taking on complex projects, often with cable-stayed or suspension bridge designs. In recent years, B&T has also been expanding its business into the United States and bringing a wider range of project types with them. B&T's bridge experience in the United States began with construction and erection engineering on complex projects. Since 2010, as work to replace America's infrastructure increased, B&T has expanded its scope to provide design services on projects of varying complexity.

"We're known for doing cable-stayed bridges, but I'd like to change and broaden that perception," says Darryl Matson, president and CEO of the North Vancouver, BC, Canada-based engineering firm. "And we've taken a very strategic and systematic approach to expanding our business and changing that view."

Adds Scott Roux, vice president of U.S. operations, "of the more than 2000 projects we've completed, the vast majority are bread-and-butter, short- and medium-span bridges. We have a reputation for being the foremost expert on cable-stayed bridges and being well-versed in suspension bridge designs. But we are working to educate clients about our capabilities beyond these long-span, complex bridges and assure them that we can execute less complex, smaller designs with great success too."

An example can be seen in the 80th Street Overpass in Delta, BC, Canada. The $12-million, grade-separation structure over BC Rail comprises a 107-ft-long, two-lane bridge featuring precast concrete box beams. The simplicity of B&T's design helped win the job for the design-build team with both savings in cost and minimal rail traffic disruption.

Even so, the firm's capabilities with complex projects and innovation have led it to create a variety of world firsts. Among these is the Alex Fraser Bridge in British Columbia in 1986, which provided the first use of a composite-deck for a cable-stayed bridge.

The firm's reputation for cable-stayed bridges has developed since the firm's earliest days, Matson says. "Cable-stayed bridges are high-tech designs, and we've consciously tried to grow our expertise in that area since the company was started," he says. "They're incredibly cost-effective designs, especially with main spans of 750 to 2000 ft. They're fairly straight-forward and efficient structurally, and that's a good combination."

Cable-stayed bridges' use of concrete or steel girders varies, he notes, depending on the situation and bridge length. But the towers, deck, and other components almost always are concrete. "Cable-stayed bridges can be said to really be concrete bridges hiding a little bit of steel."

Extradosed Designs Expand

The firm is taking its knowledge of cable-stayed bridges and applying it to extradosed bridges on a more regular basis, Matson notes. Five such projects have been completed in North America, and B&T has been involved in four of them—and the fifth, in Texas, was designed by an engineer now working in the company's New York office. "Our firm easily has the most experience with

The St. Croix River Crossing from Oak Park Heights, Minn., to St. Joseph, Wis., features an extradosed bridge design, in which post-tensioned box-girders are supplemented with post-tensioning outside the box sections. The external post-tensioning helps support the loads but provides a shallower cable inclination and shorter towers.

North American extradosed bridges," says Roux.

The concept features post-tensioned box-girders with post-tensioning outside the box sections, which serve much like the cables in a cable-stayed bridge but have a shallower inclination, Roux explains. "It precompresses the deck, so loads are shared between the cable stays and the girders. Extradosed bridges can fill an interesting niche in span length for cable-stayed bridges, and they're quite cost-effective at those lengths."

The design has been used in Europe and Asia for decades and has spread to other countries in past years for medium-length spans. "It's taken a long time for them to work their way over here," says Matson. "They're very effective, because there's a gap in the 350- to 750-ft span length, where it is harder to make a cable-stayed span efficient. That length is where extradosed bridges are most effective, so they're being considered more often."

The firm designed the first extradosed bridge in North America in 2008, a precast concrete segmental structure for transit use only over the North Arm of the Fraser River between Vancouver and Richmond, BC. The structure features two 143-ft-tall pylons and two approach piers on each side. The 590-ft-long main span provides comfortable clearance to the 492-ft-wide main navigation channel, while the 456-ft-long side span easily clears the 187-ft-wide north navigation channel. "The substructures avoided direct encroachment on the environmentally sensitive shoreline areas of the Fraser River," explains Matson.

The most recent extradosed project is the St. Croix River Crossing from Oak Park Heights, Minn., to St. Joseph, Wis., which is scheduled to open in the fall of 2016. A joint design-bid-build project of the Minnesota and Wisconsin Departments of Transportation, the new four-lane structure connects highways on either side of the St. Croix River, replacing an 80-year-old lift bridge. The total length of the bridge is 5579 ft. It features a 3360-ft-long main bridge with five, 600-ft-long extradosed segmental concrete spans and several segmental concrete box girder approach spans.

"The extradosed design was chosen due to the natural environment," Roux says. "The DOTs wanted smaller towers so as not to overwhelm the site with higher towers required by cable-stayed designs." The towers use cast-in-place concrete

The $12 million 80th Street Overpass in Delta, BC, Canada, is a design-build project encompassing 500 ft of road upgrades, retaining wall designs using lightweight backfills, and a 107-ft-long concrete bridge.

The South Fraser Road project, a public-private partnership completed on a design-build basis, involved 16 bridges along a 25-mile-long, four-lane highway in Vancouver, BC, Canada. The bridges feature mostly precast, prestressed, concrete girders due to site conditions and the ability to reduce costs by repeating the design and gaining efficiencies of scale. From top, Ladner Trunk Road, Highway 99, and BNSF viaduct.

with large cutouts and fins to add visual interest. The bridge also features a shallow section, which challenged the designers. "The DOTs liked the low maintenance and high durability aspects of concrete, and this design eliminated two towers in the river, which saved material cost and construction time. It was one of our most complex assignments to date, in terms of design."

Throughout its history, B&T has thrived on such complexity, says Matson. "We really love a challenge, something that takes a lot of structural understanding as well as requiring solutions that have never been used before. We strive for innovation in our designs, to come up with a better mousetrap that's cost-effective."

A recent complex project required designing 16 new bridges on the South Fraser Road, a 25-mile-long, four-lane highway along the south side of the Fraser River in Vancouver, BC, Canada. Delivered in a design-build format as a public-private partnership (P3) project, it used primarily precast, prestressed concrete girders to complete bridges with single spans ranging from 34 to 164 ft.

"We are best known for our long-span bridge work, but our workload is actually well balanced between long-span bridges and projects with a variety of more conventional bridges, including new design, inspection, load rating, and rehabilitation," says Matson. "There are challenges associated with bridges of all sizes, and we take on all of them."

The precast, prestressed concrete girders and partial-depth precast concrete deck panels used for most bridges on the project helped control costs, he explains. "The repeated use of standardized details on many bridges drove down construction costs by amortizing the initial set-up costs over several bridges. Vancouver has a very capable precasting industry, and we made use of forms that local precasters already had available, contributing to cost-effective designs."

P3 Projects Popular

The company is doing more P3 projects, says Matson. "P3 projects are definitely growing, and it fits with our background. We've been doing design-build projects for 20 years, and they've become a fairly significant portion of our business." The company's founders, Peter Buckland and Peter Taylor, worked originally with fabricators and erectors, so constructability and contractor relationships have been ingrained since the company began.

P3 projects put more emphasis on durability, operations, and maintenance. "In a sense they are the natural evolution to the fundamental design principles and relationships Buckland & Taylor preached early on," he says. The P3 approach was one driver for the design on the South Fraser Road project, notes Roux. "With P3 projects, you want to find solutions that are repeatable and offer efficiencies. You also want to maximize durability, because the concessionaire will be maintaining the project."

While P3 projects generally put more emphasis on long-term durability than most public projects can, Matson says, and they can take more risks. "In some cases, the concessionaire will build more bridge than is currently needed to anticipate adding revenue in the future. They will sometimes pay upfront for higher-quality materials that will guarantee longer life and pay off in the long run. Governments can't always take that approach."

B&T's relationships with contractors make them prime candidates for these projects, Roux says. "Other companies have to really press to get involved, but our phone often rings with calls from contractors wanting our involvement. It's a nice position to be in." For one recent project, the Tappan Zee Bridge in New York State, the firm was invited to join all four teams bidding on the $3.2 billion project. In those cases, the company picks a preferred team and works with it exclusively.

"Our experience level on design-build and P3 projects is unmatched in North America," says Roux. "It's a big differentiator for us. Canada has been at the forefront of P3 projects, and the trend is moving into the United States. That's great for us."

Such projects also have frustrations, he says. The firm worked on a bid for the Goethals Bridge replacement in New York City, N.Y., and the designers' plan offered the lowest initial cost and the highest technical score. But the plan's 30-year operation and maintenance budget came out higher than others, so they lost the bid. "Engineering is further from the final decision point in P3 projects, and we often can't influence those costs, which is sometimes frustrating."

ABC Solutions Grow

P3 projects also are driving innovations in accelerated bridge construction (ABC) techniques, says Matson. "The faster the bridge is finished, the faster it creates a revenue stream. There are getting to be tremendous time pressures on all types of bridges." The St. Croix project, for instance, was a design-bid-build project completed on a design-build schedule, says Roux. "Typically, design-bid-build projects have more forgiving design schedules, but time was of the essence. We were going flat-out to finish, and it was done in record time. It was really intense."

"There's definitely more ABC usage today," says Matson. "Owners are more open to ideas due to time constraints. We're seeing more possibilities for sliding bridges into place and other alternatives." Owners also are more interested in rehabilitating bridges or replacing only the superstructure and retaining piers to obtain speed and cost benefits. "Demolishing a bridge and building new can take 2 or 3 years, and the public can't do without the bridge for that long," says Matson. Even reusing the original alignment can save significant time.

Several creative ABC techniques were used to build the new Capilano River Bridge in West Vancouver, BC, Canada. The existing two-span, steel-truss bridge was slid upstream of its original alignment to serve as a temporary bridge during construction. The new structure, which included concrete piers and deck, was erected on the existing alignment, speeding construction and minimizing construction needs.

'Systematic' Expansion

B&T's focus on large, complex projects has led to dramatic growth in the past four years. "In 2010, we saw the substantial size of upcoming major projects," Matson explains. "We asked how we could do as much work as possible with big, signature projects. At our size then (70 people and one office), we estimated we could do only one project. We wanted more, but that meant we'd have to grow and find people to bring onto projects."

The firm devised a plan that has led to six offices and 185 people. It currently works on four major projects of more than $1 billion in size. "We anticipate staying at this size into 2015," he says. "But we're tracking 13 projects currently that are in excess of $1 billion. So we may need to grow again in the future to gain more of this business."

B&T also is expanding its skill set, with such projects as the Oculus, the $3.7 billion Multi-Modal Transportation Hub in the World Trade Center complex in New York City, which will open in 2015. "It's a challenging and complex project that stretches our expertise, which is what we like most," Roux says.

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

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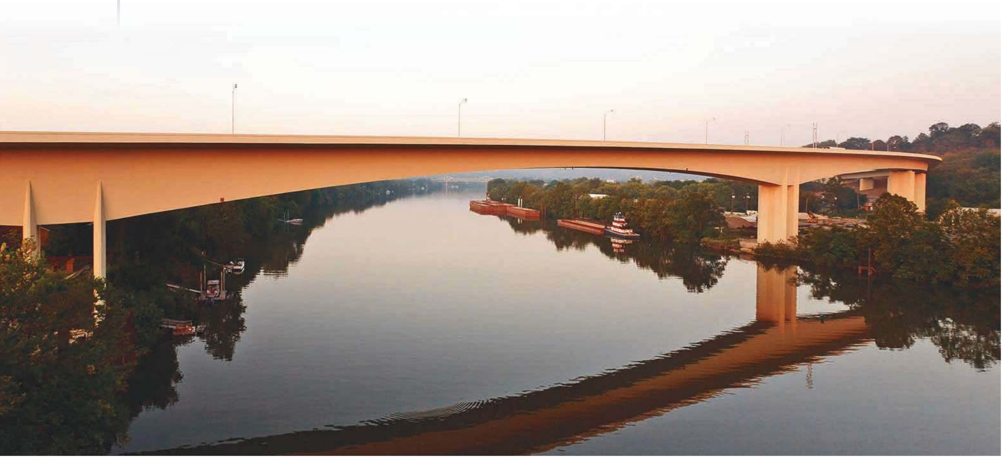
A Vision for Structural Concrete Research

by Benjamin A. Graybeal, Federal Highway Administration



The combination of prestressed concrete and segmental construction allowed a main span length of 760 ft for the Kanawha River Bridge, W.Va. Photo: T.Y. Lin International.

From the advent of portland cement concrete in the early 1800s, to the construction of the first reinforced concrete bridges in the United States in the late 1800s, to today's widespread use of concrete throughout the physical infrastructure, the technology of concrete has been continually advancing. These two centuries of progress have brought about structure types, construction methods, and material properties that could scarcely have been imagined when Aspdin, Vicat, and others were rediscovering the long-forgotten Roman secrets of castable stone. These advancements have largely resulted from systematic investigations that build on past knowledge to expand future applications. Research, whether geared toward addressing an immediate challenge or grasping a potential opportunity, has been the key methodology employed in the steady advancement of concrete technology.

Looking back over the past few decades reveals many game-changing advancements that have enabled our sector's current successes. Prestressing allows for dramatic increases in structural efficiency by shifting the stress state in the concrete toward its strength in compression. Admixtures, most notably high-range water reducers, allow for modification and enhancement of fresh and hardened properties, thus enabling the tailoring of concrete to specific applications. Reinforcements with enhanced strength and durability properties have allowed for the construction of robust, efficient structures. These sorts of advancements emanate from perceptive recognition of challenges and opportunities.

Supplemental cementitious materials enhance the performance properties of concrete. From left to right, Class C fly ash, metakaolin, silica fume, Class F fly ash, slag cement, and calcined shale. Photo: Portland Cement Association.

Challenges

Today, the challenges faced by our infrastructure demand innovative solutions and continual advancement. The clearest path to success is through systematic research that address today's pressing needs while also striving toward transformational innovations that can continue structural concrete's role as the cornerstone of our structural systems. The concrete bridge community needs to balance its research priorities to ensure that near-term challenges are addressed while also striving for broad-based advancements in our foundational technology.

All too often in recent years, research funding organizations have been unwilling or unable to leverage their funds to create a strategic vision for the future of structural concrete. Instead, research dollars have been disproportionately directed toward bandage solutions that, at best, provide short-term relief to an applied engineering concern. These types of research are necessary, but through collaboration, coordination, and a willingness to strategically engage promising solutions, our researchers can also deliver the transformative innovations that will change the way concrete is used in the future.

This method of strategically directing applied engineering research toward pressing challenges is not new. One recent example is the push toward accelerated bridge construction. Accelerated bridge construction stems from the need to reconstruct degraded infrastructure with minimal impact to users. The build-out of our roadway infrastructure was primarily green-field construction, while the current reconstruction phase is space- and time-constrained in ways that can preclude traditional construction techniques. Dozens of innovative solutions have been developed to address this situation, many revolving around prefabrication and heavy-lift technologies that allow for increasingly larger portions of the infrastructure to be constructed off-site and outside the critical path. Collaboratively, the bridge community has funded and executed the needed research.

The systemic challenges facing the use of concrete in infrastructure

The concept of accelerated bridge construction is changing the way that bridges are replaced, such as the Massena Bridge in Iowa. Photo: Iowa Department of Transportation.

are quite familiar. In an ideal world, concrete would express enhanced mechanical properties allowing for greater structural efficiencies and more cost-effective structures. Concrete would be dimensionally stable during the hydration reaction, allowing for a reduced likelihood of cracking. Concrete would be less permeable and more resistant to cracking, thus increasing the durability of the composite. Concrete would be more sustainable. And innovations, regardless of the type, would be sufficiently robust to stand up to the rigorous demands placed on conventional solutions.

The way to address these concerns and achieve our goals is to strategically invest in the conduct of research that addresses tomorrow's needs today. Yes, funding is always constrained and research carries inherent risk, but the risks of not effectively engaging the research community to help address these challenges is even greater. A lack of focus on strategic challenges will result in a status quo mentality and eventually an atrophic community that is only able to look to past solutions for guidance in addressing present challenges.

Strategic Opportunities

From my vantage point, I see four key topic areas that are ripe for advancement through strategic investment of research capital. The first is *crack mitigation in structural concrete systems*. Advancements in concrete matrix design that reduce permeability are for naught if the concrete is overly susceptible to cracking. Concrete can be designed to have greater tensile strength, less shrinkage, and narrower cracks. Advancements in this topic area will allow for structures whose durability in aggressive environments, such as bridge decks, can exceed today's service life estimates.

The next is *alternative concrete matrices*. Over the past few decades, researchers investigating the fundamental performance of concrete and similar heterogeneous binder-based systems have developed concrete-like materials that use different chemical reactions to glue together the matrix. Some of these alternative concretes offer similar mechanical performance to conventional concrete but with the added benefit of being tailorable to specific construction situations while also being more sustainable. Innovation in this area will significantly broaden the applicability of concrete to include a much larger toolbox of mixture proportions adapted to suit a wide range of applications.

The third relates to the performance of concrete structure under *combined loadings*. Traditionally, concrete research has tended to investigate performance attributes through isolation of variables. Although this method does provide for reasonable first-order assessments of performance, it does not address the synergistic effects that occur at the structural system level when time, mechanical response, and durability response become intertwined. Topics such as the service and ultimate performance of concrete bridge decks subjected to decades of truck loading and intermittent deicing salt application are of immediate interest.

The fourth pertains to the emerging classes of concrete with *enhanced material properties*. Concretes are available today that can exhibit more than 20 ksi of compressive strength, more than 1 ksi of tensile strength, sustained post-cracking tensile capacity, and diffusion coefficients more than an order of magnitude less than today's conventional concrete. One-for-one replacement of conventional concrete with these emerging concretes may not be economically appropriate due to the higher material costs and the lack of structural benefits. In short, there is a need for research to assess the most appropriate applications of these concretes, to develop the necessary design specifications, and to work with owners to implement this emerging class of concrete.

The Future

Strategic investments aimed at addressing our biggest challenges will pay dividends in the future. As a community, we have the opportunity to align our resources with our needs. Visionary research can propel us through another century of concrete innovation.

Structurally optimized, ultra-high-performance concrete, pi-girder superstructure bridge in Buchanan County, Iowa. Photo: Benjamin Graybeal, Federal Highway Administration.

PROJECT

LESS LEADS TO MORE

Innovative design and construction methods result in full-project build-out

by Craig Finley Jr., Finley Engineering Group Inc.

For nearly 30 years, the Florida Department of Transportation (FDOT) has been working towards improving the 26-mile-long Palmetto Expressway in Miami-Dade County to safely accommodate significant, predicted traffic-volume increases. With combined-team ingenuity, engineering prowess, and alternative delivery methods, the largest and final portion of the massive undertaking, the Palmetto/Dolphin Expressway Interchange, is scheduled to be complete in the fall of 2015.

Bridging the Gap

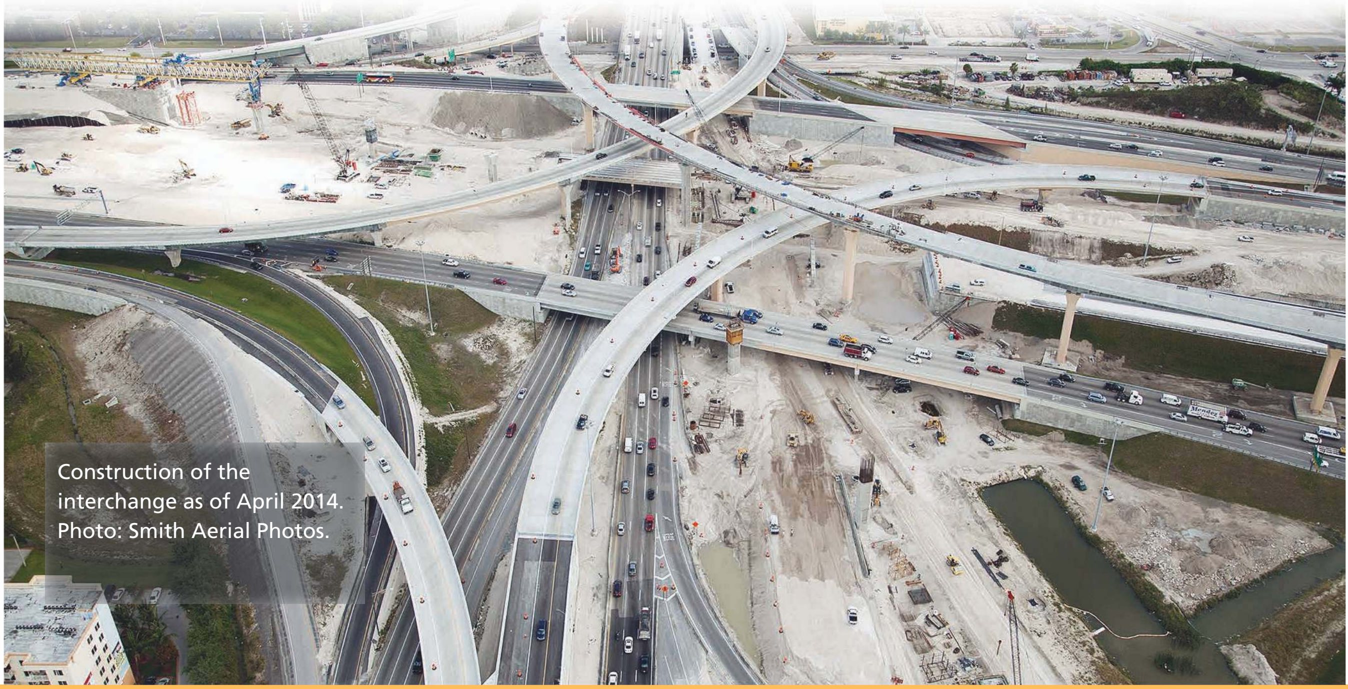
Section 5 of the 12-part, 20-year Palmetto Expressway reconstruction project, is a $558 million design-build-finance project that reconfigures a 16-mile stretch of expressway where SR 826 (Palmetto Expressway) and SR 836 (Dolphin Expressway) meet adjacent to the Miami International Airport. More than 430,000 motorists use the interchange daily, making maintenance of traffic one of FDOT's primary concerns.

A Tall Order with Low Clearance

The project includes the full reconstruction and modification of two existing interchanges, adds one travel lane in each direction, widens and/or replaces bridges, increases shoulder widths, reconfigures entrance and exit ramps at all interchanges, and improves drainage, signalization, lighting, and signage. The design-build team introduced a redesign that included FDOT's desire to reintroduce three expressway access points, which would have been lost with the original design plan.

'Using non-traditional shaped piers, adjusting the footing size to accommodate conditions, and increasing span lengths all helped improve maintenance of traffic sequencing.'

"Using non-traditional shaped piers, adjusting the footing size to accommodate conditions, and increasing span lengths all helped improve maintenance of traffic sequencing, which was critical to accelerating the project schedule," said



Construction of the interchange as of April 2014. Photo: Smith Aerial Photos.

profile

PALMETTO/DOLPHIN EXPRESSWAY INTERCHANGE / MIAMI-DADE COUNTY, FLORIDA

PRIME DESIGN CONSULTANT: BCC Engineering Inc., Miami, Fla.

SEGMENTAL BRIDGE DESIGN AND CONSTRUCTION ENGINEER: Finley Engineering Group Inc., Tallahassee, Fla.

CONSTRUCTION ENGINEER AND INSPECTION SERVICES: AIM Engineering and Survey Inc., Lehigh Acres, Fla.

PRIME CONTRACTOR: Community Asphalt Corporation, Condotte America Inc., and The de Moya Group Inc., joint-venture LLP, Miami, Fla.

This is a major route to Miami International Airport with more than 430,000 motorists using the interchange daily. Photo: Finley Engineering Group Inc.

Jose Munoz, president, BCC Engineering Inc. "Advance planning, which allowed the foundations for the last segmental bridge to be built much earlier in the schedule, was another critical aspect."

Adding Up the Pieces

The project includes four precast concrete segmental bridge ramps. The last of these is currently under construction. All four bridges, with a total of 783 segments, traverse the core of the interchange and comprise 25% of the overall project effort. The bridge decks are 46 ft wide, box depths vary from 9 to 12 ft, and total bridge lengths range from 1100 to 2450 ft. The specified concrete compressive strength for the segmental box girder superstructure is 6.5 ksi, with the substructure at 5.5 ksi. The total deck area is 360,718 ft^2, with 7764 linear ft of bridge.

The top slab thickness varies from 9½ to 19 in. and is transversely post-tensioned. The longest span is 266 ft, with the tallest pier measuring 81 ft. The prestressing steel is 7-wire 0.6-in.-diameter, low-relaxation, grade 270 strand. The post-tensioning stressing force was 77 to 80% of the guaranteed ultimate tensile strength. All continuity tendons are external and use diabolos to deviate the tendons.

The segmental bridge ramps are the third level of the interchange with horizontal curve radii down to 590 ft and a maximum superstructure deck height of 95 ft above ground. All the bridges are supported on 24-in.-square prestressed concrete pile foundations—designed for 250 tons compression and 25 tons tension—and reinforced concrete piers and caps.

Bi-directional Innovations

To meet the challenges, design and construction innovations were employed both from the bottom up and the top-down.

At the base, the geometric shapes of the footings for the segmental bridges vary to accommodate the limited space and the prestressed concrete piles. In addition to the challenging geometric shapes, the orientation of each footing is specified for that particular pier. All footings are designed to accommodate hurricane-level windforces, overturning movements from the launching gantry, and out-of-balance cantilever conditions. To minimize future traffic disruptions, foundations for bridges typically slated for construction later in the project were installed earlier in the schedule.

Most notable and significant among the design solutions, however, was the top-down construction approach to accommodate the incredibly tight site geometry. The project is adjacent to a major runway and a large residential building, a canal runs through the middle of the site, and the new elevated interchange, which is in the airport glide path, had to comply with strict Federal Aviation Administration height limits for both permanent and temporary structures.

Top-down construction was used to accommodate the small site and minimize traffic interruptions. Photo: Finley Engineering Group Inc.

FLORIDA DEPARTMENT OF TRANSPORTATION AND MIAMI-DADE EXPRESSWAY AUTHORITY, OWNERS

POST-TENSIONING CONTRACTOR: VSL, Hanover, Md.

OTHER MATERIAL SUPPLIERS: Overhead gantry and casting machines, DEAL, Bay Harbor, Fla.; Bearings and expansion joints supplier, The D.S. Brown Company, North Baltimore, Ohio; and Casting and erecting segments, Rizzani De Eccher, Bay Harbor, Fla.

PROJECT DESCRIPTION: Four horizontally curved, precast, segmental, post-tensioned concrete bridge ramps with a total length of 7764 ft

STRUCTURAL COMPONENTS: 783 precast concrete segments; cast-in-place reinforced concrete pier caps, piers, and pile caps; and 24-in.-square prestressed concrete pile foundations

The 460-ft-long, 475-ton gantry used on the Palmetto Interchange. Photo: Condotte.

The segment casting yard was located approximately 16 miles away and had two casting cells, which enabled the fabrication of an average of eight segments a week for a total of 783 segments. Photo: Rizzani De Eccher.

Balanced cantilever construction uses a 460-ft-long, 475-ton, self-launching overhead gantry. The self-launching overhead gantry was designed to build the bridges outward from the piers. As a result, temporary ground supports were eliminated and segments were stabilized off the pier caps. The use of variable-depth segments from 9 to 12 ft deep and weighing 62 to 86 tons helped to satisfy the vertical clearance limitations, improved maintenance of traffic sequencing, and made the project more economical by reducing the weight of the segments and the amount of material.

The pier caps, designed to support the balanced cantilever during construction, include loop tendons through the caps to tie down the launching gantry and curved balanced cantilever superstructure. Jacques Combault, technical director, at Finley Engineering Group, explained, "In addition to their vital functional role in the construction process, the pier caps contribute to the overall aesthetics, an important factor considering the prominent location of the interchange."

Alternative Concepts

Three of four alternative technical concepts accepted for the segmental bridges were

- the use of external tendons and diabolos,
- haunched segments, and
- polystyrene core forms on piers.

FDOT allowed the use of diabolos for the first time for the segmental bridges based on the advanced design and demonstration of their successful application on segmental bridges in other states. This eliminated the use of traditional bent steel pipes, the segment weight was reduced, and it allowed for variable tendon geometry and continuous external tendon ducts. The external tendons provide the extra benefit of reduced maintenance costs through improved future access for tendon replacement, as well as upgrading and stressing of any single strand inside the box.

Haunching the segments allowed for an increase in span lengths, reduction in the amount of temporary supports adjacent to the highway, and an overall simplification of the interchange, which resulted in fewer segmental bridges and elimination of expansion joints. This also increased the efficiency of post-tensioning and provided the capacity to support the launching gantry.

Employing polystyrene in the hollow pier columns cores (except for solid bases and caps) eradicated the need for interior formwork, thereby reducing the amount of concrete material and overall mass of the structure.

Less Can Be More

"This is a very complex project because of the sheer volume of work—45 bridges on five different levels all over very large traffic volumes," commented Vorce. "The project is 75% complete, and we're on budget and on schedule."

In the end, the key to this project's success was that everyone worked together as a team," said Raul Vega, CEI projector coordinator, AIM Engineering and Survey. "For example, designers and reviewers worked side-by-side during shop drawing reviews. Comments were addressed right away so we were able to complete this process in 21 days, 7 days ahead of schedule."

Budget constraints, maintenance of traffic, and site conditions were in the forefront throughout the project. To move this large transportation project forward, FDOT had the foresight to expand their options in terms of both delivery methods and technical concepts. Working as a team, the owner, designers, and contractors developed and employed creative "less is more" solutions that brought about greater results within a given amount of resources.

Craig Finley Jr. is president of Finley Engineering Group Inc. in Tallahassee, Fla.

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PROJECT

BURNT RIVER BRIDGE REPLACEMENT PROJECT

Connecting precast concrete deck panels with ultra-high-performance concrete

by George Bornstedt and Craig Shike, Oregon Department of Transportation

As part of an ongoing effort to develop methods and materials that increase concrete bridge deck durability, the Oregon Department of Transportation (ODOT) recently constructed the U.S. 30 Burnt River Bridge replacement project located near Huntington in rural eastern Oregon. This Federal Highway Administration (FHWA) Highways for LIFE (HfL) project demonstrated precast, prestressed high-performance concrete (HPC) deck panels composite with precast, prestressed concrete bulb-tee girders and ultra-high-performance concrete (UHPC) connections in a 160-ft-long, single-span bridge.

The Burnt River Bridge consists of four 90-in.-deep precast, prestressed concrete bulb-tee girders supporting fifteen 8½-in.-deep, precast, prestressed HPC deck panels that are 9.5 ft wide and 30.8 ft long. The bridge is located on a 15-degree skew and has a 28-ft-wide clear roadway. The bridge spans the Burnt River and a Union Pacific railroad mainline.

Burnt River Bridge in October 2012. Photo: Oregon Department of Transportation.

profile

BURNT RIVER BRIDGE / HUNTINGTON, OREGON

BRIDGE DESIGN ENGINEER: Oregon Department of Transportation, La Grande, Ore.

CONSTRUCTION ENGINEER: McGee Engineering, Corvallis, Ore.

PRIME CONTRACTOR: Hamilton Construction Co. (Oregon), Springfield, Ore.

PRECASTER: Knife River, Harrisburg, Ore.—a PCI-certified producer

UHPC SUPPLIER: Lafarge North America Inc., Calgary, Alberta, Canada

ODOT's Goals

ODOT's primary purpose in developing precast, prestressed concrete decks is to provide a deck system with increased durability including abrasion resistance. Precasting and curing deck panels in a controlled plant environment results in a superior product with enhanced attributes. These attributes include high strength, abrasion resistance, and reduced cracking. Cracks provide a path for corrosion and, thereby, compromise long-term durability of the deck. Use of precast concrete decks is expected to eliminate most, if not all, deck cracking leading to significantly improved durability and better long-term performance.

HPC Deck Panels

The Burnt River Bridge project is an extension of ODOT's abrasion-resistant deck research. This demonstration project has allowed ODOT to develop design standards and specifications for HPC precast bridge deck panels and UHPC connections for use on this project and future accelerated bridge construction (ABC) projects. The 8.0 ksi HPC used in the precast, prestressed concrete deck panels was based on ODOT-funded abrasion-resistant concrete research conducted by Oregon State University. The connection design for the Burnt River Bridge project was based on FHWA research.

The long-term vision for ODOT includes increased use of precast concrete deck panels. ODOT anticipates use of both post-tensioned concrete panels and panels with cast-in-place UHPC joints and connections. The method used will depend on the structure type and option that provides the best value.

Precast concrete deck panels provide the following advantages:

- Improved durability with high-strength concrete and high-quality aggregate
- Faster construction by taking advantage of precasting off site and then erection on site
- Improved quality because panels are constructed under factory conditions in a controlled environment

High-performance, precast concrete deck panel erection over an active Union Pacific railroad mainline. Photo: George Bornstedt.

UHPC Connections

The precast concrete deck panels, precast concrete girders, and concrete bridge substructure were designed by traditional methods according to the Fifth Edition of the *AASHTO LRFD Bridge Design Specifications*, the PCI *Bridge Design Manual*, and the ODOT *Bridge Design and Drafting Manual*. The panel-to-girder connections were based on FHWA research where steel-fiber-reinforced UHPC was used successfully to connect precast concrete members.

The deck panels for this project were reinforced with prestressing strands in the deck's transverse direction and non-prestressed steel reinforcement in the longitudinal direction. The longitudinal, epoxy-coated, No. 5 bars in the transverse panel-to-panel connections can be fully developed in less than 6 in. with steel-fiber-reinforced UHPC. For field applications, FHWA recommends a 6-in. bar lap as a practical minimum. To develop the longitudinal deck bars and sufficiently connect the precast concrete panels, a UHPC design strength of 14 ksi at 14 days and 17 ksi at 28 days was specified on this project.

In order to develop composite action between the deck panels and girders, UHPC was used in the panel to girder connection shear pockets and built-up haunch sections. Due to the strength properties of UHPC and as a cost savings, a haunch width less than the full girder flange width was used. As defined in the AASHTO LRFD Specifications, interface shear design takes into account the roughness of the

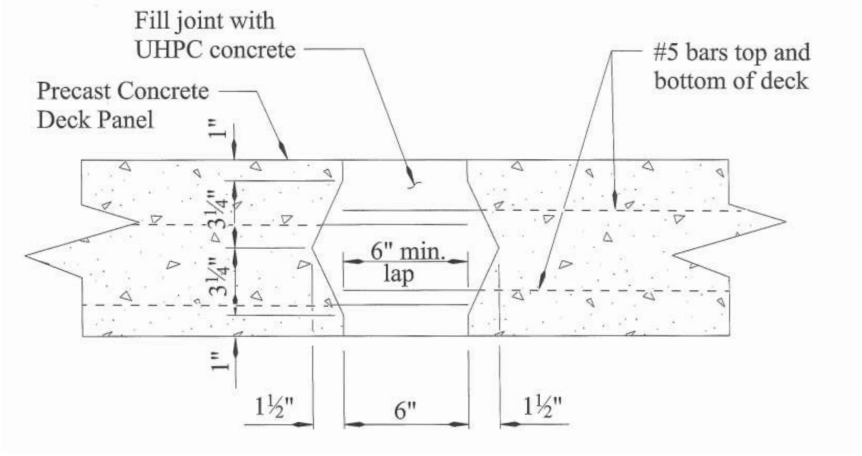
OREGON DEPARTMENT OF TRANSPORTATION, OWNER

PROJECT DESCRIPTION: 160-ft-long, single-span bridge with high-performance precast concrete deck panels over 90-in.-deep, precast, prestressed concrete bulb-tee girders and ultra-high-performance concrete connections

STRUCTURAL COMPONENTS: Four 160-ft-long, 90-in.-deep prestressed concrete bulb-tee girders; fifteen 8½-in.-deep, 9.5 ft-wide by 30.8 ft-long, 8.0 ksi, precast, prestressed high-performance concrete (HPC) deck panels; and 17.0 ksi, ultra-high-performance concrete connections in the transverse deck panel joints, shear pockets, and interface shear haunches

BRIDGE CONSTRUCTION COST: $2.95 million

AWARDS: 2014 Alliant "Build America" Award, Associated General Contractors of America—First Place for Highway & Transportation Projects Under $10 million



Ultra-high-performance concrete, keyed-joint detail used to connect the precast concrete deck panels for the Burnt River Bridge project. Figure: George Bornstedt.

interface shear surfaces. The tops of the precast concrete girders can easily be roughened while the precast concrete deck panels have a smooth underside. Therefore, designs need to assume a smooth concrete interface shear surface for the cohesion and friction coefficients. Even though the AASHTO LRFD Specifications now allows for an interface shear reinforcement spacing of up to 4 ft, ODOT uses a maximum spacing of 2 ft.

To cast the haunches, UHPC was placed in the joints and shear pockets through a sealed wood chimney or chute that provided approximately 1 to 2 ft of static head, as required. With the excellent flowability of UHPC, no mechanical vibration or pumping was required. To maintain the steel fibers in suspension, vibratory equipment was not used. Based on UHPC research test samples cast with these methods, annular spaces such as shear pockets and haunches can be completely filled without air voids normally found with traditional grouts.

The 6-in.-wide precast concrete deck panel joints, shear pockets, and leveling coil bolts. Photo: George Bornstedt.

Precasting and curing deck panels in a controlled plant environment results in a superior product with enhanced attributes.

Compressible foam backer rod was used to form the haunch sections. Seals based on standard mortar-tight specifications are not adequate to contain and maintain the integrity of the UHPC. The foam backer rod must form a tight seal to contain the very fluid UHPC mixture. To contain UHPC in areas of superelevation or cross-slope, exposed joints and shear pockets require a plywood seal or cover. If plastic-coated form grade plywood is used to contain and cover exposed areas of UHPC, no additional measures are required for curing. Curing times vary from 3 to 7 days depending on environmental conditions.

ODOT's Future Intentions

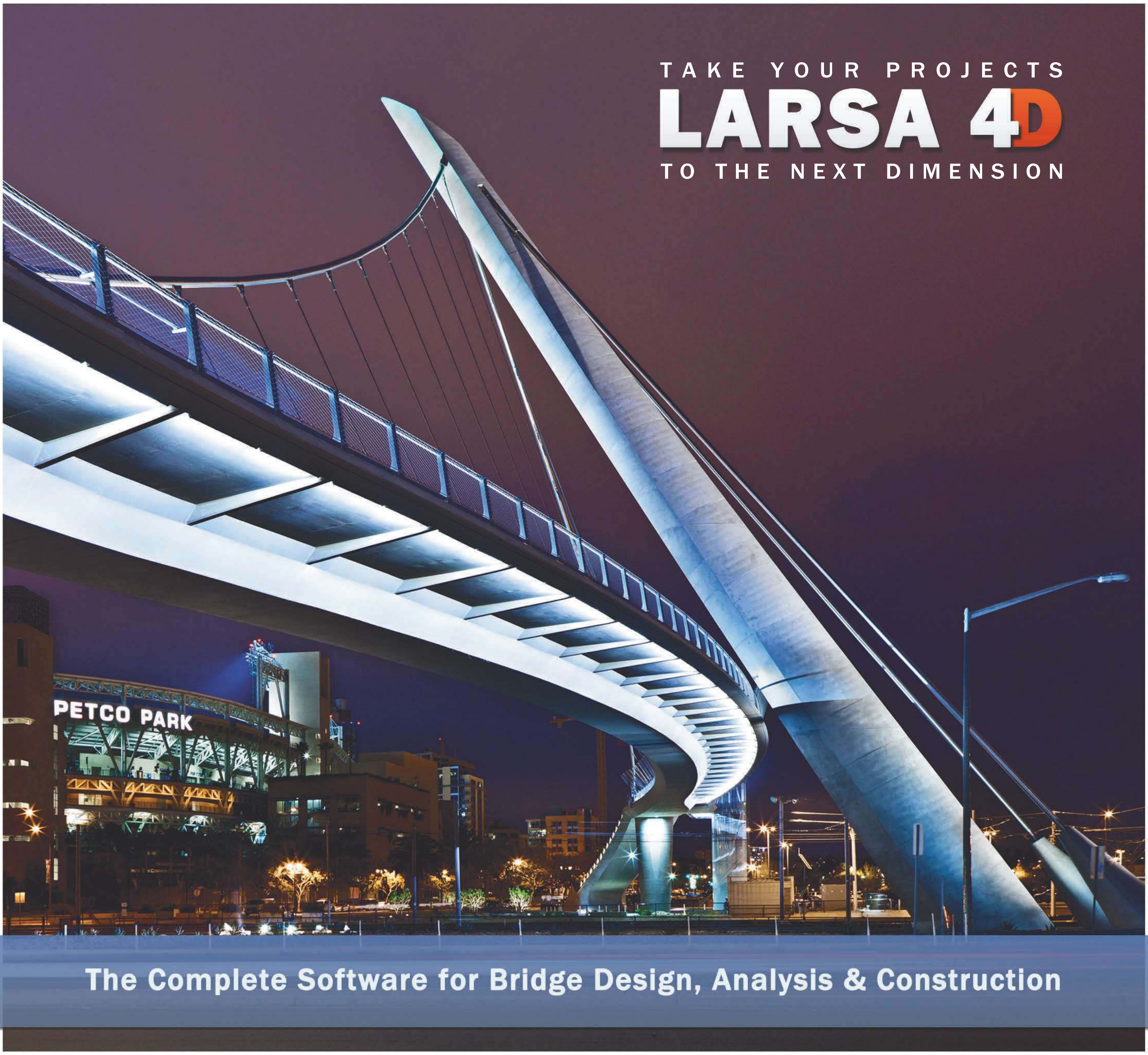
ODOT anticipates that precast concrete deck panels will have a greater initial cost than cast-in-place concrete decks. Therefore, precast concrete deck panels will be more desirable on higher-volume routes where the improved durability will result in significantly lower future maintenance costs. In such cases, the life-cycle cost for precast concrete deck panels may be less than that for a cast-in-place concrete deck.

The projects designed to date have used relatively few precast concrete deck panels per bridge. Although ODOT does not have a threshold for minimum number of panels to make precasting competitive, the agency understands that bridges with more panels should be more economical for precasting. ODOT does not believe that the initial projects have demonstrated the true cost of supplying precast concrete deck panels.

ODOT is pleased to have precast concrete deck panels as an available option. It believes that there will be future projects where durability or ABC will favor precast concrete deck panels over traditional construction. ODOT also sees a future where precast concrete could be the predominate deck type in the state of Oregon.

George Bornstedt is the interim Region 5 bridge manager for the Oregon Department of Transportation in La Grande, Ore. Craig Shike is the Oregon Department of Transportation's bridge operations and standards managing engineer in Salem, Ore.

Casting the 6-in.-wide precast concrete deck panel joints and haunches for the Burnt River Bridge project. Photo: Oregon Department of Transportation.



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KAHOMA UKA BRIDGE

by David Fujiwara and Eric Matsumoto, KSF Inc.

Elevation view of Kahoma Uka Bridge. Photo: Chad Nikaido.

In order to improve the quality of life for the western Maui community, the Hawaii Department of Transportation (HDOT) assessed the input from the public and made the dream of a Lahaina Bypass into a reality. The bypass provides an alternative route to Honoapiilani Highway in the vicinity of Lahaina town, which alleviates traffic congestion and improves circulation of vehicles in the area. This new roadway also contains a truly unique structure to traverse Kahoma stream.

The final design of Kahoma Uka Bridge was selected after considering a myriad of structural types and construction methods. The evaluation process included the desired span length, existing conditions, environmental impacts, material strengths and capabilities, aesthetics, and cost. As a result, the community was presented with a horizontally curved, 60-ft-wide, 360-ft-long, single-span, low-profile, inverted tied arch bridge that neither obstructs the scenic view nor interferes with the stream environment below.

Request for Proposals

In 2006, the contractor was awarded the design-build contract to complete phase 1A of Lahaina Bypass. Based on the request for proposal requirements, the design team developed a straight, 350-ft-long, single-span, inverted tied arch bridge with a constant cross slope of 2%.

A Cultural Discovery

Work on the project was halted in May 2007 when 30 acres of historical agricultural terraces were discovered in the path of the new roadway. To respect this culturally significant site, native Hawaiian groups and lineal descendants were consulted. With their input, a plan was developed to re-align the roadway toward the ocean and away from the terraces. The bridge, which was previously straight, now required a horizontal curve with a radius of 1200 ft and superelevation. This new configuration significantly magnified the complexity of the structure. With the full cooperation and dedication of everyone involved, the redesign of Kahoma Uka Bridge expeditiously proceeded in September 2009.

profile

KAHOMA UKA BRIDGE / LAHAINA, MAUI, HAWAII

BRIDGE DESIGN ENGINEER: KSF Inc., Honolulu, Hawaii

PRIME CONTRACTOR: Hawaiian Dredging Construction Company Inc., Honolulu,Hawaii

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

OTHER MATERIAL SUPPLIERS: Reinforcement, Associated Steel Workers Ltd., Kapolei, Hawaii; Friction pendulum bearings, Earthquake Protection Systems Inc., Vallejo, Calif.

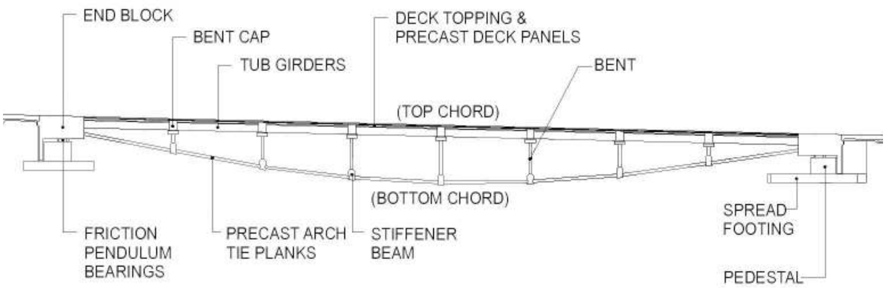


Diagram of Kahoma Uka Bridge. Diagram: Vivian Takagaki.

Bridge Substructure

Kahoma Uka Bridge is supported by spread footings at both abutments. Footings are 4 ft thick and cast with 6.0 ksi concrete. Above the footings are 9-ft-high pedestals. Two friction pendulum bearings are situated at the top of each pedestal. These bearings allow the bridge to expand, contract, and rotate without imposing significant horizontal loads and moments on the structure and foundation. Each bearing has an 88-in. effective radius of curvature that results in a dynamic period of 3 sec. Displacement capacity of the bearings is 10 in.

Bridge Superstructure

The inverted tied arch bridge consists of an innovative combination of precast, post-tensioned, and cast-in-place concrete. In order to produce a 360-ft-long curved bridge that does not require intermediate supports, 270 ksi post-tensioning strands and high-performance concrete are utilized. All superstructure concrete has a minimum specified compressive strength of 8.0 ksi.

Kahoma Uka Bridge's top chord is comprised of 5-ft-wide by 4-ft 9-in.-deep precast concrete tub girders; 3.5-in.-thick, stay-in-place, precast concrete deck panels; and a 5.75-in.-thick, cast-in-place concrete topping. The girders are connected to the deck to form a composite section that supports vehicle loads. Due to the shape of the structure, the top chord is also subjected to tremendous axial forces, bending moments, and torsion.

There are six lines of tub girders that are placed longitudinally between abutments. The tub girders are framed with eight chords to produce the curved horizontal alignment. These girders are supported by end blocks at the two abutments and seven cast-in-place bents spaced at approximately 42 ft between the end blocks. Bents consist of five 1-ft 4-in.-thick columns with variable widths that form arched openings. Heights of these members vary from 10 to 25 ft. High-strength steel bars connect the bents to the stiffener beams below.

The bridge bottom chord is comprised of the stiffener beams and 10 lines of precast concrete arch tie planks that are also framed with eight chords. Stiffener beams transfer forces between bents and arch tie planks. These beams also provide stiffness to the inverted arch by bracing individual precast concrete arch tie planks at each end. The 1-ft 4-in.-deep by 5-ft-wide precast concrete arch tie planks encase the continuous post-tensioning strands. These high-strength strands transfer loads to the end blocks and provide compressive and lifting forces in the bridge. In order to address the twisting associated with the curved shape of the structure, post-tensioning tendons vary from nineteen 0.6-in.-diameter strands on the inside of the curve to twenty-seven 0.6-in.-diameter strands on the outside.

Top and bottom chords are connected to the cast-in-place concrete end blocks at each abutment. The 11-ft-deep end blocks, where the forces from the top and bottom chords and reactions from the bearings converge, also anchor the continuous post-tensioning tendons.

Construction Phase

Construction of the Kahoma Uka Bridge commenced in December 2010. Falsework for this project was designed to have the least impact on the environment. A 65-ft-long truss, which spanned Kahoma Stream, was installed. Thus, construction was allowed to proceed without disruption to the stream.

Shoring towers were placed below each of the seven bents. Sand jacks were also

Precast concrete tub girders are placed on the cast-in-place concrete bents. Photo: Chad Nikaido.

HAWAII DEPARTMENT OF TRANSPORTATION, OWNER

PROJECT DESCRIPTION: Horizontally curved, 60-ft-wide, 360-ft single-span, low-profile, inverted tied arch bridge

STRUCTURAL COMPONENTS: 80 precast concrete planks and cast-in-place concrete beams for the bottom chord; 48 precast concrete tub girders with 3.5-in.-thick precast concrete deck panels and a cast-in-place concrete deck topping for the top chord; cast-in-place concrete bents, end blocks, and footings; post-tensioning; and friction pendulum bearings

BRIDGE CONSTRUCTION COST: $27 million

AWARDS: 2013 ASCE Hawaii Outstanding Civil Engineering Achievement Award, 2014 ACEC Hawaii Grand Conceptor Award

Falsework truss installed to span Kahoma Stream. Photo: Eric Matsumoto.

Post-tensioning ducts and anchor heads are placed in the end block. Photo: Eric Matsumoto.

utilized at each tower. These temporary supports allowed the contractor to construct the bridge at a pre-cambered elevation. Once the structure was self-supporting, the contractor was then able to lower the falsework in a controlled manner.

The planks were cast with five 4⅝-in. diameter ducts for the continuous post-tensioning tendons. These members were also stressed in their simply supported condition for transportation and handling purposes with four tendons, each comprised of four 0.6-in.-diameter strands.

As the precast concrete components were fabricated, abutment spread footings and pedestals were constructed. Above the pedestals, friction pendulum bearings were placed. A three-dimensional drawing, verified with manual calculations, was created to locate each member. This process was challenging because the structure has a horizontal curvature, parabolic bottom chord, longitudinal slope, superelevation, and pre-cambering. Due to the effort expended in developing the drawings, the contractor was able to efficiently place all precast concrete components.

Continuous post-tensioning ducts are spliced at the stiffener beam of the bottom chord. Photo: Eric Matsumoto.

Cast-in-place concrete end blocks were then constructed above the friction pendulum bearings. Due to the size and function of these components, the concrete mixture was proportioned to address heat generation that occurs when placing mass concrete within the forest of reinforcing steel required to resist all forces. The concrete for the bottom portion of the end blocks was placed concurrently with the stiffener beams that connect the ends of the planks that form the bottom chord. Above the stiffener beams, cast-in-place concrete bents linking the top and bottom chords were then built.

Upon completion of the bents, the top chord was constructed. Due to the tremendous axial forces, bending moments, and twisting, a considerable amount of reinforcing steel was placed in all top-chord components. To ensure a quality product, a high level of attention was also paid to these concrete mixture proportions, handling of materials, and placement of concrete. To increase the durability of the traveling surface, polypropylene/polyethylene macro-fibers and alkali-resistant glass micro-fibers were added to the deck concrete. This blend of fibers increased the fatigue endurance limit and toughness and decreased micro- and macro-cracking. In addition, admixtures were incorporated to minimize bleeding, increase workability for proper placement, and reduce plastic shrinkage.

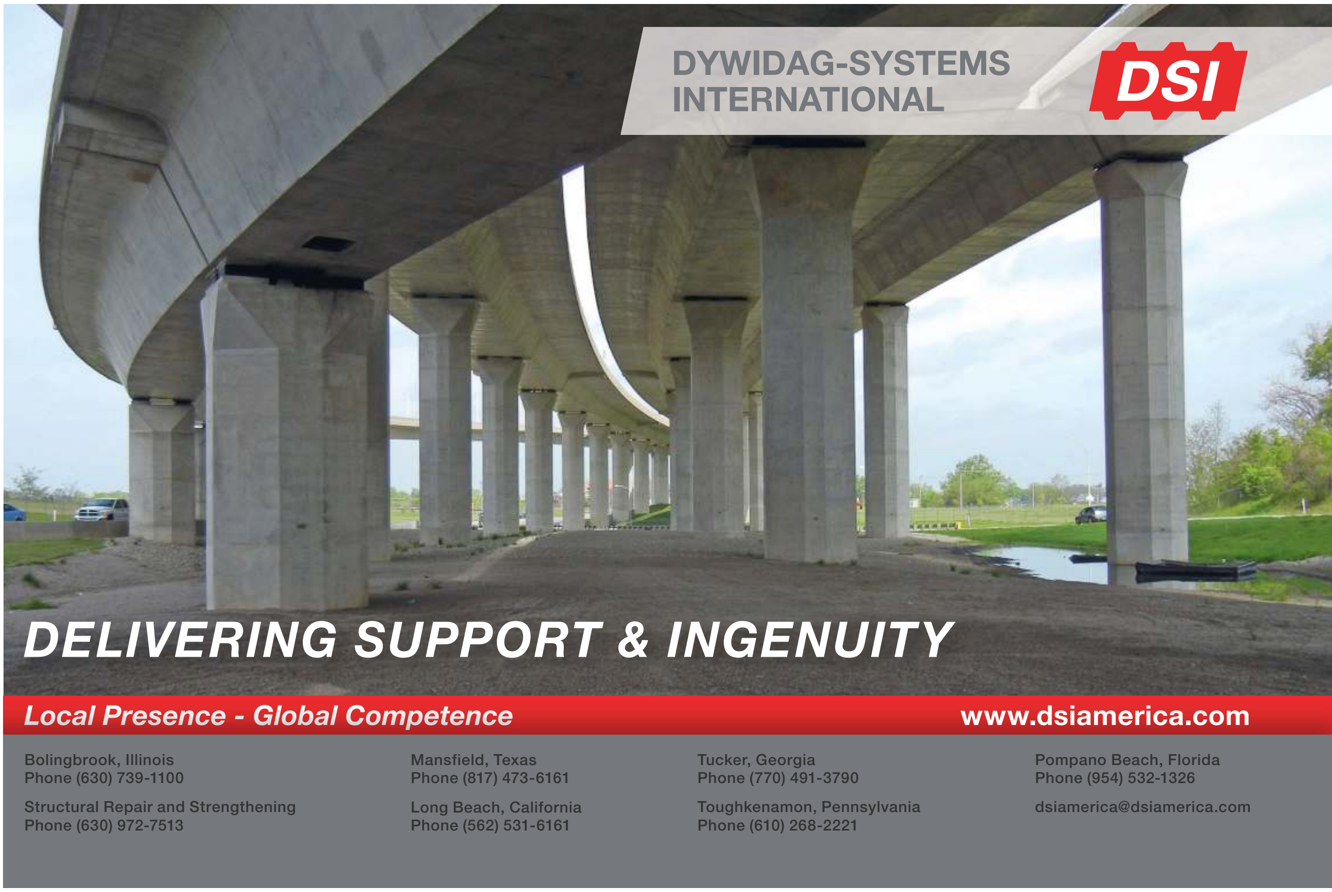
Once the deck was sufficiently cured, post-tensioning strands were placed in the bottom chord arch tie planks and stressed. The tendons were then anchored at the rear face of the end blocks. At the completion of this stage of construction, the structure was self-supporting.

Sand jacks were then released in a controlled manner, which minimized stresses in the structure and ensured the safety of workers below. The bridge then settled into its final position. Vertical deflections and horizontal displacements were subsequently monitored. Measurements compared closely with results from the three-dimensional, finite element analysis.

Conclusion

In retrospect, the collective efforts from HDOT and the contractor's design-build team produced the desired outcome. Engineering projects of this magnitude have historically encountered numerous obstacles throughout the construction process. However, issues that arose were easily and immediately rectified due to the cooperation of all parties. As a result, in March 2013, the long-awaited Kahoma Uka Bridge was opened to the public.

David Fujiwara is president and Eric Matsumoto is a structural engineer with KSF Inc. in Honolulu, Hawaii.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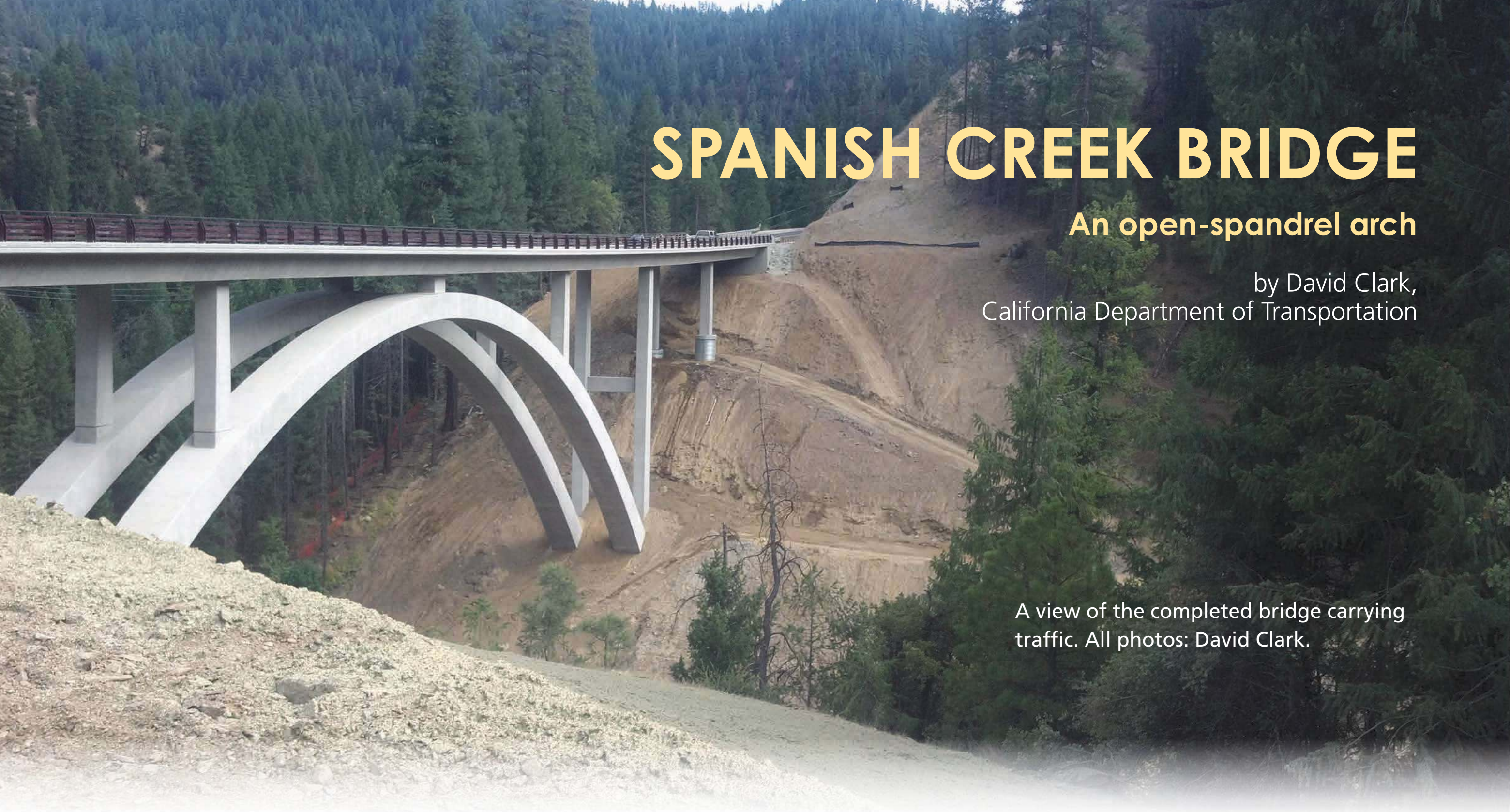
SPANISH CREEK BRIDGE

An open-spandrel arch

by David Clark,
California Department of Transportation



A view of the completed bridge carrying traffic. All photos: David Clark.

A new, open-spandrel arch bridge located in the Sierra Nevada mountains of California now becomes the latest major structure to be constructed in the Feather River Canyon. This rugged and scenic canyon has been designated a historic district as well as a National Scenic Byway. It is the home to numerous railroad and highway bridges, tunnels, retaining structures, and hydroelectric facilities, many of which are also designated historic structures.

The graceful lines of the new Spanish Creek Bridge will do well to complement this setting. The Spanish Creek Bridge and State Highway 70 provide a primary route in and out of Quincy, a logging town 10 miles to the south of the bridge. Because there are few alternative routes in this area of the Sierra Nevada Mountains, the Spanish Creek Bridge is critical to local traffic and the economy.

New Bridge Needed

The Spanish Creek Bridge cost approximately $29 million dollars to build and marks the 11,000th transportation project funded by the American Recovery and Reinvestment Act of 2009. It replaces a bridge that was built in 1932, which had two 12-ft-wide lanes with no shoulders. After 80 years of service, the existing bridge was beyond its expected service life and was becoming increasingly expensive to maintain. It was located in an active seismic area but it did not meet modern seismic criteria.

The new structure is on a tangent with a grade sloping downward to the north at just over 2%. It is a conventionally reinforced concrete box girder capable of supporting oversized loads up to 360,000 lb, whereas the load limit for the old bridge was set at 80,000 lb. Rising to a height of approximately 170 ft over Spanish Creek, the bridge length is 630 ft. The 350-ft-long arch span is one of the longest conventionally reinforced spans in California. The bridge deck is 43 ft wide, which includes two 12-ft-wide traffic lanes and two 8-ft-wide shoulders.

The solid twin arches are approximately 8 ft square at the base and taper gradually in depth to 5.5 ft at the crown. The spandrel columns are solid with outside dimensions of 4 by 5.8 ft and tapering to 4 by 4 ft at their tops. They vary in height from 83 ft at the ends of the arch to 10 ft at the center of the arch. The superstructure consist of cast-in-place multicell (five-cell) reinforced concrete box girders with span lengths of 74 to 95 ft.

profile

SPANISH CREEK BRIDGE / KEDDIE, CALIFORNIA

BRIDGE DESIGN ENGINEER: California Department of Transportation, Sacramento, Calif.

PRIME CONTRACTOR: C. C. Myers, Rancho Cordova, Calif.

OTHER MATERIAL SUPPLIERS AND CONSULTANTS: Foundation report, Kleinfelder, Sacramento, Calif.; Temperature monitoring system, Engius IntelliRock, Stillwater, Okla.; Concrete cooling system design, CTLGroup, Skokie, Ill.; Piling contractor, Drill Tech Drilling and Shoring Inc., Antioch, Calif.; Tieback contractor, Neil's Controlled Blasting, Newcastle, Calif.

PROJECT DESCRIPTION: 630-ft long, seven-span, open spandrel arch supporting a conventionally reinforced, cast-in-place concrete, box girder

Environmental Impact

Spanish Creek has been recognized as a temperature-sensitive fish habitat and has been monitored over the years to support the study of this environment. A result of these studies is that there is extensive temperature data available for Spanish Creek. Data recording the diurnal temperature changes of Spanish Creek were used to determine that cooling water could be pumped directly from the creek to cool the concrete and then returned to the creek after it was heated by the concrete without making a significant impact on the water temperature.

The natural diurnal temperature change of the water was close to 10°F at the time of year when the concrete was placed. The temperature increase due to the returned cooling water was estimated to be less than 2°F.

An additional concern was that of increased pH value in the creek caused by the possible introduction of alkalis from the concrete into the creek. The system was designed so that the cooling water remained in the cooling tubes and never directly contacted the concrete. Thus the pH of the creek was not affected.

Environmental clearances were obtained to implement the cooling system and the Spanish Creek waters were used to cool the hydrating concrete at a significant cost savings compared to using conventional chillers. Wireless temperature sensors were employed to monitor the temperature changes of the water in the same way the concrete temperatures were being monitored.

A concrete bucket on a crane was used to keep the deck placement progressing when a concrete pump truck moved to a new position.

The box girder cells have a depth of 5.2 ft and a width of 7.2 ft. Top and bottom flange thicknesses are 8 and 6 in. respectively. The web thickness is 8 in.

The superstructure contains epoxy-coated reinforcing steel, while all other structural elements were constructed with non-coated steel bars. An additional measure to reduce corrosion and extend the service life of the deck was to apply a 0.75-in.-thick polyester concrete overlay to the new 8-in.-thick concrete deck. The overall bridge is designed for a 75-year service life. Concrete compressive strengths vary by structural element with concrete for the arches and piers 2 and 6 being specified at 6.0 ksi, the thrust blocks at 4.0 ksi, and all other structural elements at 3.5 ksi. All specified compressive strengths are at 28 days.

This picture shows some of the installed micropiles in the foreground and drilling in the background.

Site Necessitated Mass Concrete

The geologic material that the bridge is founded on consists largely of highly fractured and foliated phyllite and metasandstone. The ends of the arches are founded on seventy-seven 7-in.-diameter micropiles,

CALIFORNIA DEPARTMENT OF TRANSPORTATION, OWNER

STRUCTURAL COMPONENTS: Conventionally reinforced concrete box girders, open spandrels, twin concrete arches, 250 yd^3 concrete thrust blocks, micropiles, and cast-in-drilled hole piles

BRIDGE PROJECT COST: $29 million ($1075/ft^2)

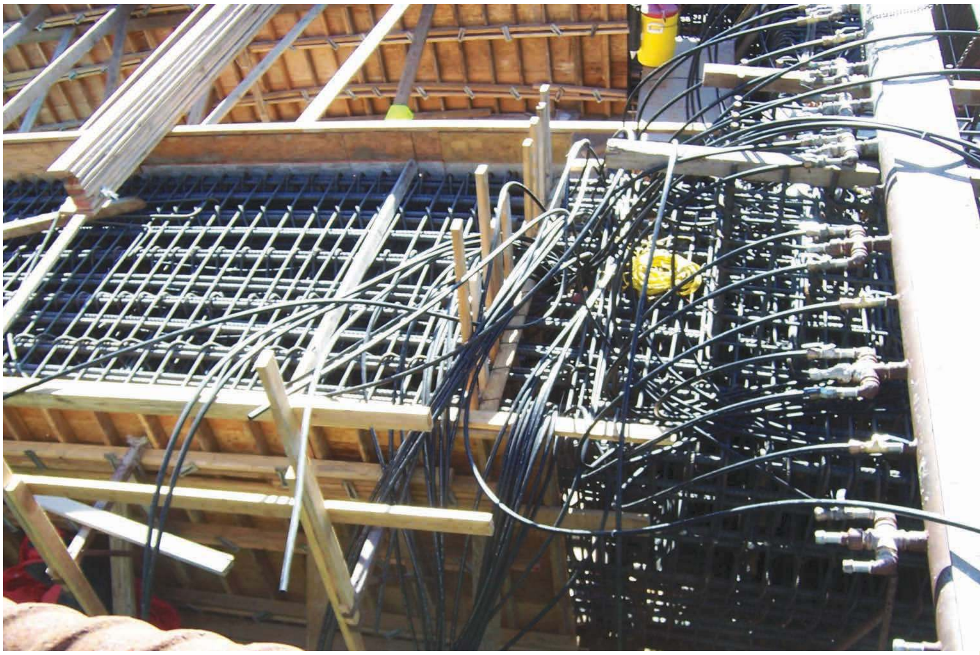
AWARDS: 2013 *Engineering News-Record* "Best of the Best" Highway/Bridge Project Award; 2013 *Engineering News-Record* Best Highway Bridge Project, Northern California; 2013 Excellence in Transportation – Major Structures Award; 2012 California Transportation Foundation, Finalist—Structure Project of the Year; 2012 & 2013 Caltrans Partnering Success In Motion (2 Gold Awards); 2013 International Partnering Institute – John L. Martin, Partnered Project of the Year Award (Ruby Award); 2013 Associated General Contractors of America (AGC) – California Excellence in Partnering, Projects under $50 Million; 2013 Associated General Contractors of America (AGC) Meeting the Challenge of a Difficult Job – Heavy Engineering Classification Constructor Award, AGC-California (C.C. Myers, Inc.); 2012 Caltrans Safety Award; and 2013 American Society of Civil Engineers Sacramento Chapter-Geotechnical Project of the Year each grouping capped with 250 yd^3 concrete thrust blocks. These large concrete elements meet the criteria for mass concrete.

These large concrete elements meet the criteria for mass concrete.

This photo shows the strand jacks mounted on the completed arches lowering the first stage arch formwork.

Contract specifications required the implementation of a concrete cooling plan to remove some of the heat generated within the concrete while curing and help prevent excessive temperature differentials that could lead to cracking. It would also reduce the possibility of secondary ettringite formation, a chemical reaction that is deleterious to the service life of the concrete.

The concrete for the arch was placed in a series of five ascending segments. Each of the arch segments had cooling tubes installed throughout their reinforcing bar cages to cool the hydrating concrete from within. The segments were also fitted with temperature sensors that were wirelessly connected to an internet-based monitoring site. The site was remotely accessible with the data being available in real time to those people given the pass code.



The polyethylene cooling water tubes are shown coming out of a manifold assembly and entering one end of an arch section, which is ready for concrete placement.

Segments were also fitted with temperature sensors that were wirelessly connected.

This temperature monitoring system allowed the efficient placement and removal of thermal blankets and space heaters as needed to control temperature differentials.

Falsework was constructed on top of the completed arch; it supported formwork for the superstructure.

Construction

Falsework used for this bridge was built in two stages. The first stage supported just the arch. Once the concrete for the arch was placed and cured, the first stage falsework was removed and a second tier of falsework was erected on top of the arch to support the superstructure formwork.

Summary

This was a challenging structure to build in many respects, but the result of overcoming the challenges is a new structure that fits well in the canyon it traverses, both aesthetically and with its improved capacities.

David Clark is a structure representative and resident engineer for structure construction, Division of Engineering Services, California Department of Transportation (Caltrans) in Chico, Calif.

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

AESTHETICS COMMENTARY

by Frederick Gottemoeller

It is great to see that arches are making a comeback. Too often, structural type decisions are influenced by assumptions that what was economical somewhere else will also be economical here. In recent years, we have seen many concrete segmental box girders and even continuous bulb-tee bridges in this span range, even in locations like this one that seem ideally suited to an arch. The fact that this elegant bridge was also economical to build shows that each site needs to be looked at with a fresh eye. The conventional wisdom might be wrong.

If you ask a non-engineer to sketch a bridge it will almost always look like an arch. The form is in our collective memory. When an arch is placed in a steeply sided canyon, such as this one, the visual interaction of the arch and the canyon walls directly evokes the forces at work. Anyone can intuitively understand what's happening, even if they can't express it in words. That's what makes arch bridges so memorable.

The elegant simplicity of this bridge makes it more memorable than most. The Swiss do this kind of arch very well; this bridge reminds me of the best of their bridges. The simplicity begins with the decision to use a box girder for the deck. This keeps the spandrel spans the same as the side spans, establishing a constant span rhythm all of the way across the bridge and reducing the lines of spandrel columns to a mere three. The full-width box girder also conceals all of the diaphragms and webs that would otherwise make the upward view of the bridge complicated and distracting. The spandrel columns are also simple rectilinear shapes. Finally, the taper of the arch ribs adds a subtle grace note that makes the ribs look less massive than they are.

It is clear that Caltrans is proud of their work here. They have constructed an overlook where visitors can view and appreciate the bridge. It is well worth the money.

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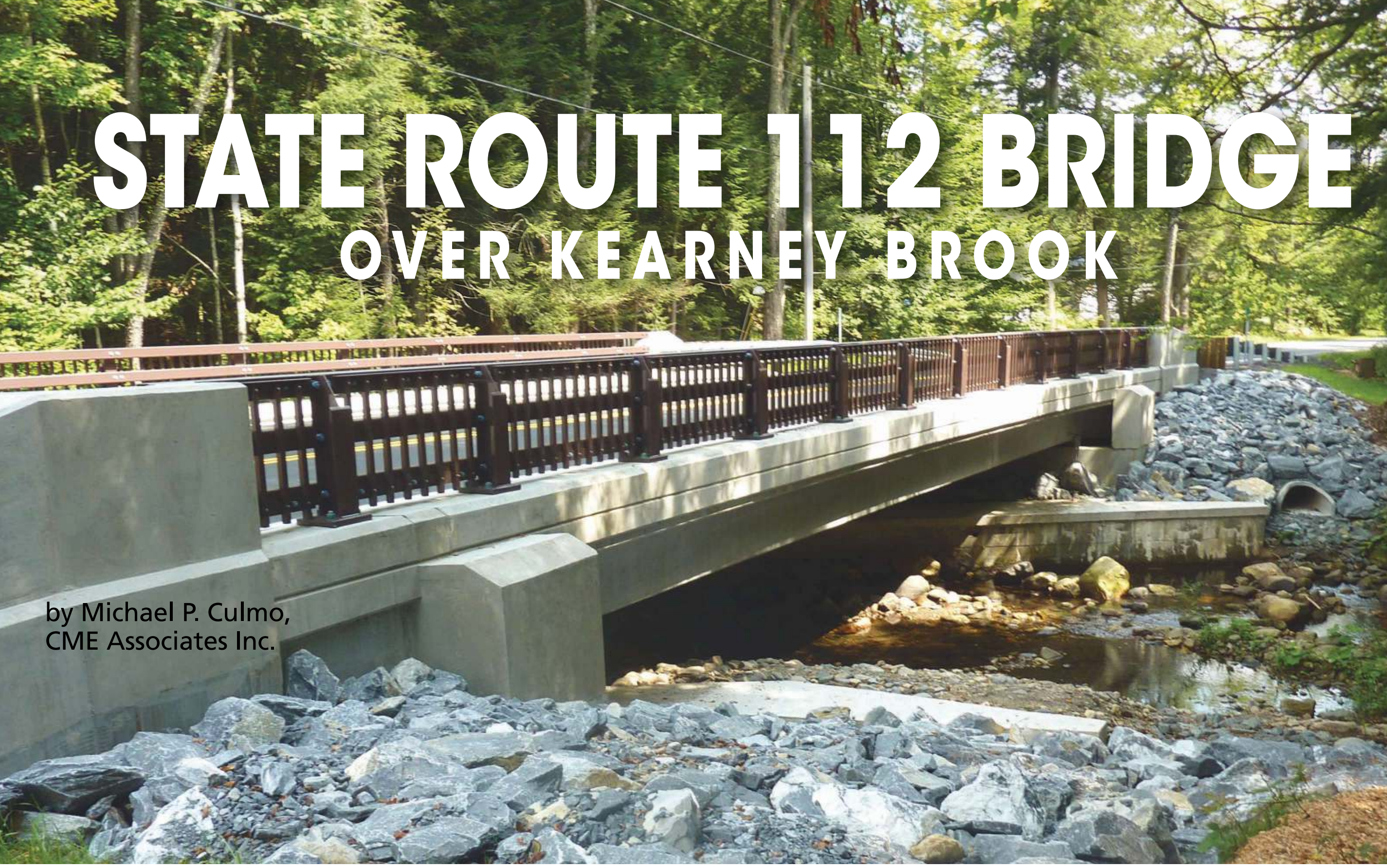


STATE ROUTE 112 BRIDGE OVER KEARNEY BROOK

by Michael P. Culmo,
CME Associates Inc.

Final configuration of the State Route 112 Bridge over Kearney Brook. Photo: Massachusetts Department of Transportation.

The Massachusetts Department of Transportation (MassDOT) is nearing the completion of an Accelerated Bridge Program (ABP), which has a goal of reducing the number of deficient bridges on an accelerated schedule. The ABP has embraced innovation—especially including the use of accelerated bridge construction (ABC)—in order to deliver projects faster, with better quality, and with less impact to the traveling public and environment. The State Route 112 Bridge that spans over Kearney Brook, in Worthington, Mass., is an excellent example of this use of innovation.

The existing bridge needed to be replaced due to significant deterioration. The original scope of the project was based on using adjacent box beams supported on conventional cast-in-place concrete abutments. Because the roadway crossing the brook is on a horizontal curve, the box beams would need to be chorded on the curve. The plan was to close the roadway during construction. The detour around the site was only 1 mile; however, the impact of the detour on the rural town would be significant because local roads would need to be used.

During preliminary design, MassDOT made a decision to use ABC to reduce mobility impacts. At the same time, the department had adopted a new prestressed concrete beam shape called the Northeast Extreme Tee (NEXT) beam. It is a double-tee beam developed by the PCI Northeast Bridge Technical Committee for intermediate span bridges up to approximately 80 ft long.

NEXT beams were a perfect choice for the for the 62-ft-long, single-span crossing. The design team selected a 32-in.-deep NEXT F (form) beam with a 4-in.-thick top flange used to support an 8-in.-thick composite, cast-in-place concrete deck. Once erected, the flange provides a safe work platform. The specified compressive strength of the concrete for the beams was 8.0 ksi. The forming of the deck is limited to the side and end forms.

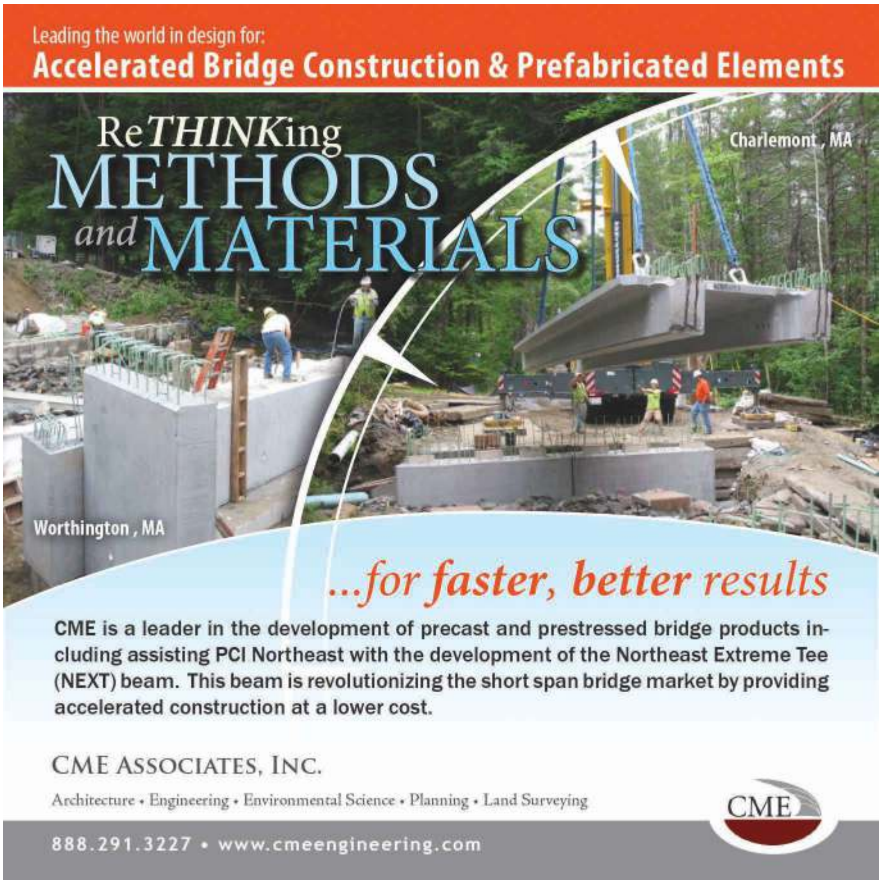
Design Challenges

The geometry of the single-span bridge is curved and skewed at 30 degrees, which would put the flexibility of the NEXT beams to the test. The first challenge was the horizontal curvature. The radius of the roadway resulted in a variation of the deck edge of approximately 10 in. when measured from a chord line. The NEXT beams were developed to accommodate this type of curvature. The beams were laid out on tangents, and the curvature was accommodated by varying the width of the fascia beam overhang along the beam length.

MassDOT commonly leaves existing substructures in place to act as scour countermeasures. To accomplish this, the span length was increased to allow for construction of the new abutments behind the existing abutments. This eliminated work in the river channel. The depth to the bedrock was too deep for open excavation and too shallow for an integral abutment, so the design team decided to use a shallow spread footing foundation.

Precast Concrete Details

The design team used precast concrete substructure details that were developed by the PCI Northeast Bridge Technical Committee, including precast concrete spread footings, abutment stems, wingwalls, and approach slabs. Precast concrete footings were placed on temporary leveling bolts and connected to the substrate with a thin layer of flowable fill. The wingwall stems were connected to the footings with



grouted splice couplers. The abutment stems were detailed with concrete-filled corrugated steel pipe voids that were connected to the footings via projecting dowels. The height of the stems resulted in only minor moment demand on the connection. The resulting detail was essentially a gravity abutment. Using corrugated pipe voids provided a very durable and inexpensive connection with significant adjustability for tolerances during construction.

Above: Precast concrete footing installation for the State Route 112 Bridge over Kearney Brook. Right: Precast concrete abutment stem installation. Photos: William E. Dailey Precast LLC.

MassDOT has been using unique details for concrete approach slabs for many years. Approach slabs are designed to span over potential settlement areas directly behind abutments. Most agencies detail the approach slabs as a reinforced concrete pavement section. In Massachusetts, the slabs are set slightly below grade (below the pavement structure). This facilitates the installation of precast concrete approach slabs because the grade tolerances can be significantly relaxed while the proper seating of the slab is ensured.

On this project, the precast approach slabs were supported by the abutment stem on one end and by the soil on the other end. The precast concrete slabs were set on temporary supports and then the void under the slabs was filled with flowable fill, which is a cost-effective solution when compared to non-shrink grout. The adjacent approach slabs were connected to one another using a small closure pour with looped reinforcing bars.

The top flange of NEXT beams can be easily adjusted for each project to accommodate various roadway widths. The addition of curvature places an added complexity to the geometry of the bridge. The width of the fascia beam overhang was varied over the length of the beam to form the desired curvature with concave curvature on one side of the bridge and convex curvature on the other.

Construction Schedule and Bid

MassDOT has replaced several bridges in a matter of days using ABC, with both large-scale bridge moves and prefabricated bridge elements. In this case, adding the substructure construction made weekend replacement unfeasible. The NEXT F beams also require a cast-in-place concrete deck, which would need time to cure.

The goal of the schedule was to reduce the duration of the roadway closure and resulting mobility impacts. The design team felt that it was feasible to construct the bridge in as little as 3 weeks; however, construction at that pace can come

Precast concrete approach slab installation for the State Route 112 Bridge over Kearney Brook. Photo: William E. Dailey Precast LLC.

Resiliency

The State Route 112 Bridge over Kearney Brook was designed for seismic loads. Longitudinal forces such as seismic loads were resisted through the use of precast concrete integral backwalls attached to the ends of the NEXT beams. The integral backwalls were cast as secondary concrete placements in the fabrication plant. Longitudinal seismic forces in the superstructure are resisted by the passive earth pressures acting on the integral precast concrete backwalls, thereby reducing the size and cost of substructures.

at a financial cost due to the need for overtime, additional equipment, and the risk of bidding a tight schedule. The project specifications limited work to a normal work week with a single shift. The idea was to build the bridge rapidly, while limiting the pressure on the price and the workers. The final bid schedule was set at 60 calendar days (42 work days), which is much faster than conventional construction.

Very rapid bridge installations can lead to cost increases that can exceed 50%. The goal of this project was to build in a reasonably fast timeframe, balancing construction speed with cost effectiveness. This approach paid off. The bid price for the entire project was approximately $28,000 less than the engineer's estimate.

Construction

Construction followed the anticipated schedule. The old bridge demolition and excavation for the substructures took 7 days. Installation of precast concrete elements took 16 days, and deck casting and railings took 21 days (including curing time for the deck). Approach work and site clean-up filled the remainder of the 60-day schedule. One of the most time consuming portions of the work was the partial removal and capping of the existing abutments.

There is a misconception that ABC is only for large projects and large contractors. For the Worthington project, the exact opposite was the case. A local contractor performed the work. The use of precast concrete elements for large portions of the bridge requires little labor and equipment on site. There is very little formwork that needs to be placed and removed. During most of the construction, there were only a handful of workers on site. The only task that required more labor was the casting of the deck on top of the NEXT beams. Even with this task, there was minimal need for forming, which reduced on-site labor.

State Route 112 Bridge over Kearney Brook. Photo: Massachusetts Department of Transportation.

Northeast Extreme Tee (NEXT) beam installation showing the curvature of the flange. Photo: CME Associates Inc.

There is a misconception that ABC is only for large projects and large contractors.

Conclusion

The State Route 112 Bridge over Kearney Brook in Worthington is an excellent example of how precast concrete elements can be used to accelerate bridge construction, even on a bridge with complex geometry. The 62-ft-long, single-span bridge has a 30-degree skew and a curved alignment. Prestressed concrete NEXT beams, with variable top flange widths for the fascia beams, easily accommodated the roadway width, skew, and curvature. The innovative precast concrete gravity abutments proved to be cost effective and easy to construct. Thanks to precast concrete elements and forward-thinking design, the bridge was built rapidly, economically, and with reduced mobility impacts—accomplishing all of the project's goals.

Michael P. Culmo is vice president of transportation and structures for CME Associates Inc. in East Hartford, Conn.

Team members for the State Route 112 Bridge over Kearney Brook included CME Associates Inc., design engineer, Woodstock, Conn.; J. H. Maxymillian Inc., prime contractor, Pittsfield, Mass; Calderwood Engineering, precast specialty engineer, Richmond, Maine; and William E. Dailey Precast LLC, a PCI-certified precaster, Shaftsbury, Vt.

FHWA

Ultra-High-Performance Concrete Connections

A robust solution for prefabricated bridge element system construction

by Benjamin A. Graybeal, Federal Highway Administration

The use of prefabricated components in the construction of highway infrastructure provides many advantages. However, it also frequently necessitates the use of field-deployed connection details. These details must facilitate component installation while simultaneously providing a robust structural system that meets or exceeds the performance that can be obtained through conventional construction processes. Demand for the use of prefabricated components is growing, as is the need for connection systems that provide enhanced performance.

Advances in the science of concrete materials have led to the development of a new class of cementitious composites. Ultra-high-performance concrete (UHPC) exhibits mechanical and durability properties that make it an ideal candidate for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement.[1,2] Connections between prefabricated bridge components have proven to be a promising application for field-cast UHPC.[3] These connections can be simpler to construct and can provide more robust long-term performance than conventional connection designs.

UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 ksi and sustained post-cracking tensile strength greater than 0.72 ksi. UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.

Availability of UHPC

UHPC is composed of a variety of constituents that are combined to create the composite. UHPC may be locally produced according to project specifications or may be obtained from a product supplier.[4] Because UHPC, like conventional concrete, is defined in terms of the properties of the composite material, it must be recognized that multiple formulations may produce similar composite systems.

Placing operation for the field-cast, ultra-high-performance concrete. All photos: Federal Highway Administration.

Cementitious Composite

The cementitious composite portion of a UHPC is frequently composed of portland cement, silica fume, fine aggregates, chemical admixtures, and water. UHPC formulations may also include small coarse aggregates and supplementary cementitious materials. The sophistication of the UHPC cementitious composite as compared to conventional concrete has led to the development of preblended UHPCs. This production and distribution model is similar to that commonly used for many of the proprietary grouts and patching materials frequently deployed in the construction of the public infrastructure.

Steel Fiber Reinforcement

The exceptional mechanical properties of UHPC can be largely attributed to the fiber reinforcement contained in the concrete. These properties cannot be achieved without inclusion

Connection detail on underside of precast concrete deck panel.

Bridge deck after grinding, grooving, and opening to traffic.

of specific fibers that afford appropriate fiber efficiency, a topic influenced by fiber type, geometry, volume fraction, dispersion, and orientation. The most common steel fiber deployed in UHPC applications is a 0.008-in.-diameter by 0.5-in.-long straight fiber with a specified minimum tensile strength of 290 ksi. Buy America provisions of federal law apply to the use of steel fibers in federally funded transportation projects. Domestic production of this type of fiber is now available.

UHPC Connection Concepts

The mechanical properties of UHPC allow for the redesign of connection details between prefabricated concrete bridge elements. UHPC displays high compressive and tensile strength along with internal micro-reinforcement that helps distribute stresses, limit crack widths, and provide passive confinement to embedded discrete reinforcements. Through these mechanisms, UHPC can develop embedded reinforcements in far shorter distances than can conventional concrete.

The simplest and most common connection concept involves the lap splicing of reinforcing bars. In UHPC, the tension development length of reinforcement is a fraction of the length observed in conventional concrete. For example, ongoing and recently completed research at the Federal Highway Administration (FHWA) indicates that an embedment of eight times the bar diameter can allow for the development of the yield strength of ASTM A615 Grade 60 reinforcing bars in many common connection configurations.[5,6] Thus, adjacent precast concrete elements can be connected to each other through the use of protruding straight lengths of reinforcement in comparatively narrow connections. This type of UHPC connection detail is most commonly deployed to connect adjacent elements such as prefabricated concrete bridge deck panels.

Connections where interface shear dominates the response can also be redesigned through the engagement of UHPC. This connection location commonly occurs between bridge girders and prefabricated bridge decks, wherein the composite action of the superstructure system must be ensured through the use of appropriate connection details. With UHPC, the connection detail can be revised so that the interlacing of discrete reinforcements is reduced and the reliance on the field-cast grout performance is increased.[7] Adjacent components can be fabricated such that discrete connectors are exposed on each side of the connection and the UHPC provides the tensile and mechanical performance to stitch the components together. The UHPC can flow into tight spaces and thus a continuous hidden connection detail without any pockets can be deployed.

Conclusion

Dozens of highway bridge projects that engage field-cast UHPC connections between prefabricated concrete elements have been completed in the United States over the past few years. States having deployed UHPC connections to date include New York, Iowa, Oregon, Montana, and Pennsylvania. Additional projects are underway during the 2014 construction season, with the largest being the redecking of the Pulaski Skyway in Newark, N.J.

Design and construction guidance for UHPC connections is being developed concurrent with these innovative applications. FHWA anticipates publishing a guideline late in 2014.

Field-cast UHPC connections provide new opportunities to create robust structural systems composed of prefabricated components. Research has demonstrated the performance of these connection concepts in the laboratory. Deployments are now demonstrating the constructability, field performance, and robustness of these systems in bridge inventories across the country.

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EDITOR'S NOTE

For additional information on UHPC technology, please visit FHWA's UHPC web page at https://www.fhwa.dot.gov/research/resources/uhpc/.

ALASKA

Concrete bridges in extreme and remote environments

by Leslie Daugherty and Elmer Marx, Alaska Department of Transportation & Public Facilities

Hyder Dock Trestle. All photos: Alaska Department of Transportation & Public Facilities.

Concrete bridges are a practical way to deal with Alaska's many design and construction challenges, including short construction seasons, remote locations, temperature extremes, seismic demands, and coastal environments. Currently, 44% of Alaska's state and local bridge inventory is concrete, but concrete accounts for approximately 80% of the new bridges built by the Alaska Department of Transportation & Public Facilities (DOT&PF). The state's oldest concrete bridges date back to the 1930s, but innovative girder shapes and enhanced materials allowed for the development of the Alaska DOT&PF's preferred superstructure type—the prestressed concrete decked bulb-tee girder.

Evolution of Concrete Bridges

Different configurations of precast, prestressed and post-tensioned concrete bridges were built during the 1970s and 1980s, including an impressive example of an early segmental, cast-in-place concrete box girder bridge—the award-winning Gastineau Channel Bridge. The Alaska DOT&PF designed the bridge in 1979 to replace the only link from Alaska's capital city, Juneau, to neighboring Douglas Island, where a significant portion of its population lives. This three-span bridge is 44 ft wide and has a total length of 1286 ft. The 620-ft-long center span is comprised of two 250-ft-long cantilevers from the piers and a 120-ft-long suspended span. Both vertical and longitudinal post-tensioning were used and contributed to the bridge's graceful shape.

Since the early 1970s, Alaska DOT&PF has been designing precast, prestressed concrete decked bulb-tee girder bridges using high-strength concrete (HSC). Decked bulb-tee girders are similar to concrete I-girders, but the upper flange is wide enough to also act as the bridge deck. Using this girder shape eliminates the need to cast and cure a conventional concrete bridge deck, greatly accelerating the superstructure construction time. In addition, by being precast, the entire superstructure has higher strengths and receives better quality control.

Initially, design concrete strengths were 5.5 ksi at transfer of prestress and 6.5 ksi at 28 days. It was presumed that improved durability would be one benefit of the increased concrete strength and no performance requirements such as chloride permeability, abrasion resistance, or freezing and thawing resistance were specified. Forty years and hundreds of bridges located in extreme environments have proven this assumption to be true. By the late 1990s, concrete strengths at transfer of 7.5 ksi and 28-day strengths of 8.0 ksi were specified. The need to consistently obtain the high release strength in a short period of time (typically around 18 hours) resulted in actual 28-day concrete strengths of 10 ksi or higher. As the specified concrete release strength has increased, there has been no change in the daily production cycle and no significant cost increase has occurred.

With the adoption of HSC, longer bulb-tee girders could also be designed. The Alaska-style decked bulb-tee girders come in standard depths of 42, 54, and 66 in. Typical girder spans range from 85 ft for a 42-in.-deep section to 145 ft for a 66-in.-deep section. Longer span lengths are technically feasible, but transportation from the precaster to the jobsite becomes an obstacle.

The typical top flange width of the decked bulb-tee girders varies from 6 to 8 ft with a maximum possible width of 8.5 ft. A typical two-lane bridge consists of five or six girders, depending on the girder length and required roadway geometry. The deck is an integral component of the flexural system and is designed to remain in compression under all service load combinations. Alaska DOT&PF policy limits tensile stress after losses to zero under the service limit state.

Shear keys and tabs, typically spaced at 4 ft along the longitudinal joints of the interior flanges, are used to connect adjacent girders. At the weld-tab locations within the shear keys, steel plates are welded to embedded inserts of adjacent flanges for a rigid connection. Next the shear keys and longitudinal joints are filled with high-strength grout to complete the shear transfer and for corrosion protection. Most decked bulb-tee girder bridges then receive a waterproofing membrane and asphalt riding surface, which has proven to be effective at keeping water from entering the joints and underside of the superstructure.

Durable to the Elements

The long-term durability and wear-resistance of bulb-tee decks has proven to be outstanding. There has been almost no girder-related maintenance required on the 273 bridges of this style built since 1973. Although traffic volumes are low with respect to other states, Alaska has more severe environmental conditions. Studded tire and chain usage is high and may occur for up to 6 months per year. Deicing chemicals are frequently used in the corrosive maritime regions where snowfall is heavy and the number of freezing and thawing cycles is large. Most of Alaska's population is located in coastal areas, so corrosion-resistant bridges are important.

Geography is another factor that makes the durability of concrete structures so critical in Alaska. Although there are only approximately 1000 state and locally owned highway bridges in Alaska, these bridges are spread over a geographic land area of about 570,000 square miles. In other words, Alaska is roughly equal in size to one-fifth of the 48 contiguous United States—an area larger than Texas, California, and Montana combined. An added complication is that some bridge sites are accessible only by boat or plane. Limited access to such remote bridges off the road system and those several hundred miles from the nearest commercial services means that it's critical to select bridge types and features requiring little to no long-term maintenance.

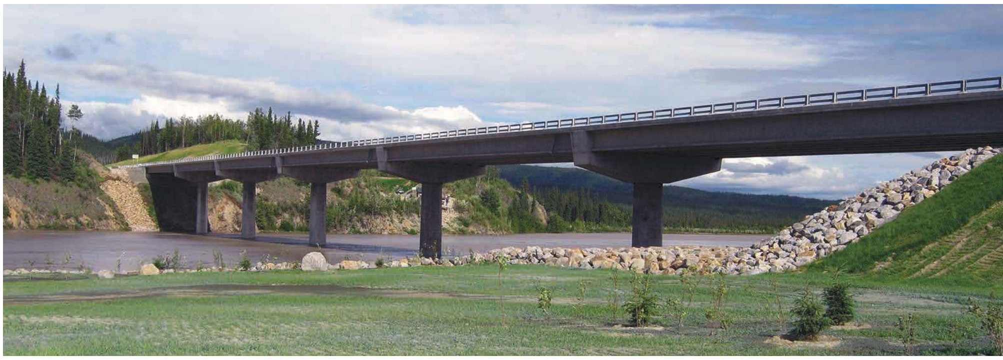
Currently, there is only one prestressed concrete girder manufacturer in Alaska, whereas steel bridges are typically fabricated outside Alaska. By eliminating the need to ship girders from out of state, in-state precast concrete girders typically offer considerable savings. With the decked bulb-tee girder, bridge construction time is also significantly reduced. A typical highway overpass is often built in less than 3 months from mobilization of equipment to bridge railing installation. This is particularly important in Alaska where the construction season is short (sometimes less than 3 months) and cast-in-place concrete is not readily available outside the major population centers.

Decked bulb-tee girders aren't without some disadvantages. They are heavy and bulky to transport, require one or more cranes for placement, and the shape has limited use for curved roadway alignments. Experience has shown fewer problems occur when intermediate concrete diaphragms are used compared to steel bracing, but concrete diaphragms are heavier with more time and cost required for forming and placing.

More Active than California

Another significant consideration when designing bridges in Alaska is the state's high seismicity. Alaska is the most seismically active state in the United States and earthquakes in the state have released nearly 25% of all of the world's earthquake energy over the last century. This year marks the 50th anniversary of the 1964 Good Friday Earthquake, North America's largest recorded earthquake (moment magnitude 9.2). Besides the four minutes of shaking, the subsequent liquefaction, landslides, tsunami, and aftershocks contributed to the loss of life and extensive property damage. The Alaska Earthquake Information Center estimates that damages totaled $300-400 million in 1964 dollars.

The Gastineau Channel Bridge, as seen from a kayak at sunset.



Newly completed Tok Bridge near the city of Tanana.

Picking a bulb-tee girder for winter construction of the Hicks Creek Bridge.

In general, Alaskan highways do not have alternative routes. If a bridge in most parts of the state were to be damaged by an earthquake, transportation would be severely impacted. This makes the resilience and health of our bridges essential to life and commerce. Although seismic design for Alaskan bridges focuses primarily on the substructure system, decked bulb-tee girders have shown to be a reliable superstructure choice that act uniformly and perform adequately under seismic loading.

Overall, the Alaska DOT&PF has been highly satisfied with the performance of its concrete bridges. Low life-cycle costs, minimal maintenance, and excellent durability have proven advantageous for the state. The state plans to continue using concrete bridges wherever possible.

Leslie Daugherty is a bridge engineer and Elmer Marx is a senior bridge engineer for the Alaska Department of Transportation & Public Facilities in Juneau, Alaska.

CREATIVE CONCRETE CONSTRUCTION

Lightweight Concrete Used for NEXT Beam Project in Maine

by Reid W. Castrodale, Expanded Shale, Clay and Slate Institute, and
Rita L. Seraderian, Precast/Prestressed Concrete Institute Northeast

Bridge open for traffic. All photos: Town of North Haven, Maine.

Detail view of closure joint with headed studs.

The Beach Bridge in North Haven, Maine, was replaced in 2013 using precast, pretensioned NEXT beams constructed with lightweight concrete. This is the first bridge designed and constructed using lightweight concrete NEXT beams. The project was a joint effort of the town of North Haven and the Maine Department of Transportation.

The use of lightweight concrete beams allowed the designers to reuse the existing pier and to avoid design of a new foundation in difficult soil conditions. Eliminating reconstruction of the existing pier shortened the closure of the bridge during construction, which was beneficial because the bridge provides the only access to several homes, the local fishing wharf, and a popular beach. Using lightweight concrete also reduced the beam weight for shipping and handling, an important factor because the bridge site was located on an island and all construction materials for the bridge had to be transported 12 miles by barge to reach the site.

The self-consolidating, sand-lightweight concrete used for the beams had a design compressive strength of 6 ksi, a maximum plastic density of 120 lb/ft^3, and a spread of 22 to 28 in. A ¾ in. to No. 4 gradation of expanded shale lightweight coarse aggregate was used.

The bridge utilizes the NEXT D section in which the top flange serves as the final bridge deck. An extra 0.5 in. of concrete was added to the standard 8-in.-thick top flange thickness as a wearing surface. The beams are 28.5 in. deep with an 8-ft 4-in.-wide top flange. Using NEXT D beams simplified construction by reducing the requirement for field-placed concrete at this remote site. The two beams used for each of the two spans were connected by an 8-in.-wide longitudinal closure joint that was filled with conventional concrete after erection. Span lengths are 56 ft 5 in. and 39 ft 5 in. Construction began during the winter, the girders were set in late April, and the bridge was reopened by early June, just in time for the summer fishing and beach season.

Reid W. Castrodale is director of engineering for the Expanded Shale, Clay and Slate Institute, based in Chicago, Ill. Rita L. Seraderian is executive director for Precast/Prestressed Concrete Institute Northeast in Belmont, Mass.

View of completed bridge from beach.

ESCSI
Expanded Shale, Clay and Slate Institute

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The **Expanded Shale, Clay and Slate Institute (ESCSI)** is the international institute for manufacturers of expanded shale, clay and slate (ESCS) aggregates produced using a rotary kiln. Please visit www.escsi.org for more information.

Construction has recently begun on the Pulaski Skyway, a major bridge rehabilitation project in the New York City area. This bridge will use lightweight concrete (LWC) for almost 1 million square feet of precast concrete deck panels to improve the load rating of the bridge and to reduce seismic demands. A paper on the Pulaski Skyway will be presented at the National Accelerated Bridge Construction (ABC) Conference in Miami, Florida, on December 4 & 5, 2014.

On December 3, the day before the National ABC Conference begins, ESCSI invites you to attend a two-part workshop ***"Lightweight Concrete – A Tool for Accelerated Bridge Construction."***

This workshop will:

- introduce advantages of LWC for ABC, including durability
- give designers ideas about how to use LWC on projects, including reports on the Pulaski Skyway and the emergency span replacement of the I-5 Bridge over the Skagit River
- present factors to be considered when designing with LWC
- review proposed revisions to the *AASHTO LRFD Design Specifications*
- introduce the concept of internal curing using lightweight aggregate

To learn more about the 2014 National ABC Conference and register for the LWC workshops, visit the conference web site at www.2014abc.fiu.edu.

WASHINGTON COUNTY, OHIO

by Roger Wright, Washington County

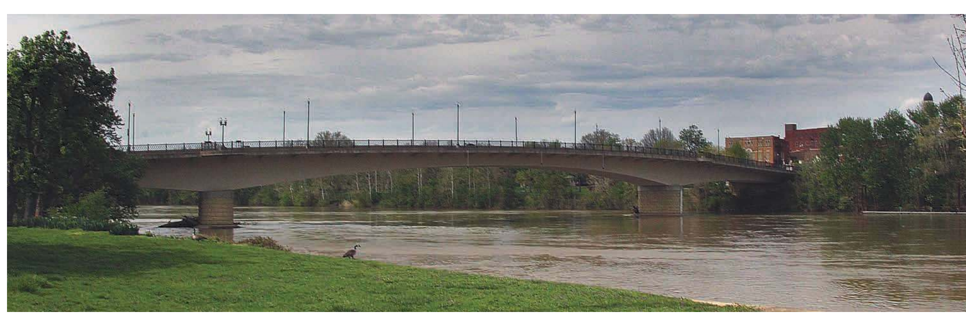
Washington County is located in southeast Ohio and was established on July 26, 1788. Events that led up to this establishment were due to the perseverance of two men, General Rufus Putnam and Reverend Dr. Manasseh Cutler. General Putnam was superintendent of the colony of 47 pioneers who settled Marietta, Ohio, on April 7, 1788, the first organized settlement in the Northwest Territory.

Today, Washington County remains one of the largest counties (by geographic area) in Ohio at 641 square miles. Washington County has responsibility for 341 miles of two-lane county roads and 381 county bridges. While the oldest bridges still in service are wooden covered bridges—Hune 1879, Shinn 1886, and the Bell 1888—Washington County also has a number of very old concrete bridges. Of the 381 county bridges, 244 of them are made of some type of concrete, ranging from concrete slabs to precast concrete box beams. The Craven Bridge and the Lavelle Bridge are both simple-span concrete slab bridges built in 1910. Other than routine maintenance, these bridges have served the residents of Washington County for over 100 years and are still in good and satisfactory condition, respectively.

Putnam Bridge

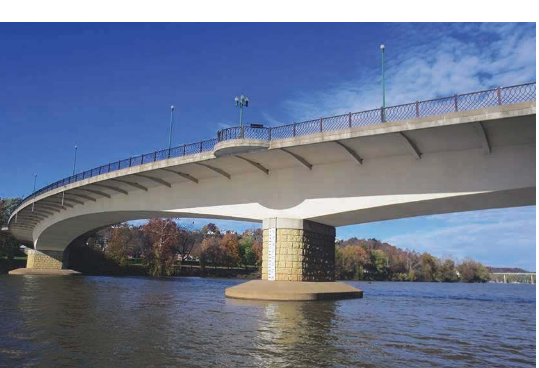
Washington County is also home to the Putnam Bridge, Ohio's first cast-in-place concrete, segmental, box-girder bridge. The Putnam Bridge spans the Muskingum River, in the pioneer city of Marietta. Construction began in June 1998 and was completed in September of 2000, replacing a 1914 steel through-truss bridge. The original design was by HNTB of Cleveland, Ohio, with a value engineering re-design by Finley McNary Engineers Inc. of Tallahassee, Fla. Construction of the bridge was done by Kokosing Construction Company Inc. of Fredericktown, Ohio, and completed at a cost of over $8 million.


Putnam Bridge piers 1 and 2 south elevation. Photo: Julia David, Barr & Prevost.


South elevation. Photo: David White, Washington County Commissioner.

The Putnam Bridge has a three-span superstructure with a main span length of 321 ft and two side spans of 182 ft, for an overall length of 686 ft. It carries four lanes of vehicular traffic and two sidewalks. Spans 1 and 2 are curved with a 738 ft radius at the centerline and span 3 is tangential to the approach. This allowed the bridge to be partially constructed while keeping the existing through-truss open. The bridge was cast in place with form travelers using the balanced cantilever method of construction. The variable-depth, single-cell box girder segments, with cantilevered wing slabs, are typically 69 ft wide and 16 ft long. The segments were transversely post-tensioned through the top slab and cantilevered wing slabs, with each segment having one full-width transverse strut. The box segments have variable-depth, inclined webs and variable-thickness bottom slab with longitudinal post-tensioning in the top and bottom slabs. Segment depths vary from 8 ft 2.5 in. to 18 ft 0.5 in.

A concrete post-and-pedestal railing separates vehicular and pedestrian traffic and an aesthetic steel pedestrian railing replicating the 1914 bridge railing is located along the exterior edge of the sidewalk. The Putnam Bridge sidewalks also have scenic overlooks above the two piers. The concrete abutments and piers utilized formliners to mimic the existing sandstone found on the historic buildings adjacent to the bridge.


Putnam Bridge north elevation. Photo: Dale Arnold, Jones-Stuckey.

Roger Wright is Washington County engineer in Marietta, Ohio.

Chambers Creek Bridge to the Beach

by Myles Parrish, BergerABAM

Underside view of the 106-ft-long span over the railroad tracks. The 30-ft-wide viewing platform is at the left edge of the photo and the stairs to the beach are to the right. All photos: BergerABAM.

Chambers Creek Properties in University Place, Wash., was once a 930-acre sand and gravel mine that was redeveloped for public recreation by Pierce County's Department of Public Works and Utilities. The property includes 2½ miles of beach that was inaccessible to the public until construction of this pedestrian bridge linked it to the trail system and provided a safe crossing over a BNSF Railway mainline.

The vision was to create a pedestrian-friendly bridge that projects an elegant, flowing ribbon with an ever-changing panoramic view of Puget Sound islands, the park, the golf course (host to 2015 U.S. Open), and the Olympic Mountains. The bridge's alignment, plan, and profile were carefully conceived to fit the natural lay of the land and yet allow for the repetition of elements, making precast concrete the right solution.

The 844-ft-long bridge features 12-ft-wide, 29-in.-deep, precast concrete, single-cell box girders with post-tensioning for continuity. The precast concrete girders include one 106-ft-long span and nine 60-ft-long spans, seven of which were cast with a 325-ft horizontal radius. All cast-in-place concrete components of the superstructure, including the stair units (two, 60-ft-long spans), viewing platform (two, 39-ft-long spans), and crossbeams were detailed with the same profile and 29-in. depth as the precast concrete girders.

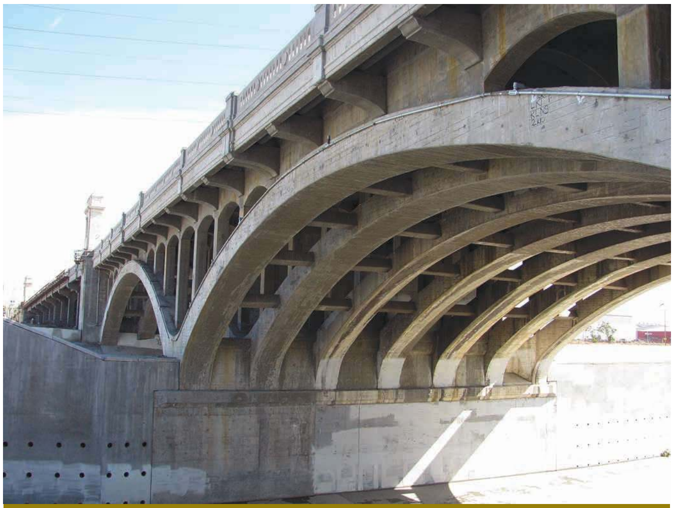
The 106-ft-long span over the BNSF tracks achieves a minimal span-to-depth ratio of 44. This girder was designed to carry self-weight and construction loads with pretensioning only until it could be integrated through post-tensioning with adjacent spans. This facilitated compliance with the railroad restriction to accomplish erection within a 40-minute window. Another notable feature of this long span is that the apex of the bridge profile coincides with the midspan, and pretensioning was designed to induce camber to fit the vertical curve.

This elegant, ribbon-like bridge makes 2½ miles of beach accessible to the public by providing for safe crossing over a BNSF Railway mainline.

Another design consideration was the marine environment, which warranted provisions for enhanced durability, including marine-specific mixture proportions, polyethylene post-tensioning ducts, and epoxy-coated reinforcement. The bridge was finished with a light cable railing system that fits well with the structural aesthetics and was adapted to serve as a throw screen over the tracks.

The final product is a simple, handsome structure that fits well in its surrounding aesthetic environment. It is recognized in the community as a treasured recreational asset and was awarded the 2011 Smart Communities Award by the Governor.

Myles Parrish is a project engineer with BergerABAM, in Federal Way, Wash.



Bridge arch spans across the Los Angeles River.

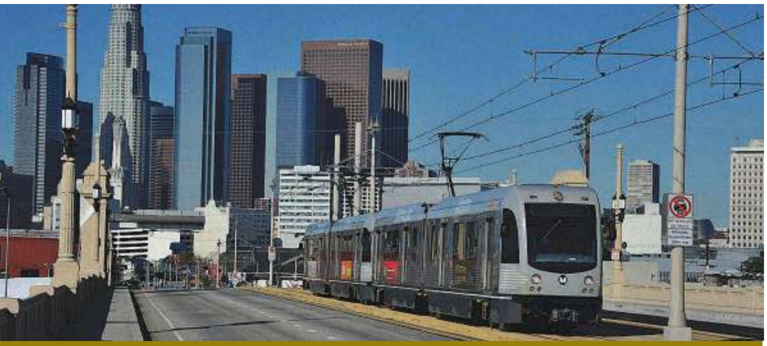
1st Street Bridge over Los Angeles River

Preserving a historical monument

by Romeo Firme and Gary Buelow, Atkins

The 1st Street Bridge, inspired by the civic architecture of Paris and Rome, spans over the Los Angeles River near downtown Los Angeles. After more than 80 years of use, the historic bridge needed to be widened and improved to accommodate the ever-increasing transportation demands of a mega-city. In its ultimate configuration, the bridge has capacity for two new tracks of the Metro gold line and 18,000 motorists a day.

A unique set of challenges was posed by the modification of the existing bridge to accommodate a double track light rail transit corridor and meet current design standards; construct the widened portion; and re-use the triumphal arches while maintaining traffic on the bridge, local roads, and 15 sets of live railroad tracks.



Completed bridge with the Los Angeles skyline. All Photos: Atkins North America.

A Historic-Cultural Monument

In keeping with the neo-classical architecture, the widened north side of the bridge was built with the same aesthetics as the original bridge. The bridge portion over the Los Angeles River consists of two identical deck arch spans on a central pier with pylons at each end. The graceful open spandrel arch has vertically curved concrete arch ribs with equally spaced vertical columns supporting floor beams and a deck slab. The girders have cathedral arches and the exterior girders have ribbed overhangs. The spandrel columns, which are part of the arches above the river, are arched in shape and highly decorative.

At the ends of the arches and at three other locations, massive 200,000-lb masonry blocks in the shape of Roman triumphal arches rise above the river piers. Behind the piers are projecting balconies with benches. The plain frieze is finished with an architrave cornice. The structure is heightened above this entablature with a wide panel bearing plain incised rectangles, finally surmounted by stepped rows of narrow horizontal blocks.

The neo-classical detail extends to the entablature pattern on the fascia girders and to the bracketing for the sidewalk. The railings are simple arcades replicating the historic railing at the south side of the bridge. Bridge lights are replicas of the original lantern electroliers, serving to recreate the look of the bridge when it was first opened in 1929 during the City-Beautiful era in Los Angeles.

Modifications to the Existing Structure

The existing structure was modified to accommodate two lanes of vehicular traffic in each direction, two pedestrian sidewalks, and two new railroad tracks. Of these loads, the biggest challenge was to accommodate two sets of train tracks, as these were much heavier than the truck loads in the original design. To mitigate the additional weight, the

Triumphal arch.

superstructure had to be modified to increase flexural and shear strength. The substructure, including the foundation, had sufficient capacity to resist the additional train loads.

At the west and east approaches, the additional live load was resisted by increasing the sectional properties and resistance of the structural elements underneath the train tracks. Two reinforced concrete tee-beams were strengthened by removing and rebuilding a thicker deck with additional reinforcement. Concrete was also added at the beam stem within the bay. At the arch span, a waffle slab was used with the sole purpose of distributing the train loads directly to the top of the arch beams.

The additional dead loads triggered a seismic review and retrofit to sustain the maximum credible earthquake. Initial diagnosis of the existing bridge showed vulnerabilities in the transverse direction at the central pier of the arch spans. To mitigate this, in-fill walls were placed between the openings to increase the transverse stiffness and resistance and reduce the seismic displacement demand. The greater transverse stiffness increased the overall structural stiffness, resulting in lower seismic displacement demands in both the longitudinal and transverse directions.

Tee-beam strengthening.

For the seismic analysis, a sophisticated 3-D finite element analysis was developed to model the rib arches, spandrel beams, spandrel columns, and cross beams. Non-linear material properties for reinforced concrete members were included to capture the plastic hinging behavior. A similar analysis was performed on the widened portion.

Widening a Portion of the Bridge

The bridge was widened to the north by approximately 26.25 ft to accommodate two westbound traffic lanes and a sidewalk. The widened portion would also house the five re-used triumphal arches and replicate the neo-classical aesthetics at the rails, stairs, and lamp posts similar to the south side of the bridge.

To maintain the aesthetics at the arch span, the sizes and spacing of the rib arches, spandrel beams, and spandrel columns were retained. The center pier and nose were extended north with the same width to maintain channel hydraulics. Similar extensions were made at the west and east pylons at the ends of the arch spans.

A different bridge type was selected for both the west and east approaches. Due to the limited vertical clearance over Santa Fe Avenue and Myers Street, precast concrete girders were selected in lieu of cast-in-place construction as the latter required a falsework system that would further impede the vertical clearance. Even with the precast concrete girders, both Santa Fe Avenue and Myers Street still needed to be lowered to provide 15-ft standard vertical clearance. This involved re-profiling of the roads, utility relocation, and new drainage.

Reuse of Arches, Replication of Aesthetics

Five massive, 200,000-lb masonry triumphal arches were wire cut from their bases and carefully relocated to the widened portion by crane. The contractor used a special lifting apparatus for this purpose. The triumphal arches were then bolted to their new pedestal bases using 18 vertical and four horizontal high-strength rods.

The intricate aesthetics at the exterior girder were included in the forms of the precast concrete girders. At the barrier, the simple balustrade features were shaped into the barrier forms. Finally, the fluted concrete lamp posts were precast to match the existing lamp posts at the south side.

Romeo Firme is the California structures group manager and Gary Buelow was the project manager during the construction phase of the project for Atkins in Orange, Calif.

Murray Morgan Bridge

by Matthew Lengyel, David Evans and Associates Inc.

On February 1, 2013, the Murray Morgan Bridge spanning the Foss Waterway in Tacoma, Wash., reopened to traffic after being closed for more than 5 years because of its load rating. The current, all-concrete, port-approach structure of the Murray Morgan Bridge, which replaced the original timber structure, is more than 55 years old. It is also historically significant to the city of Tacoma because it is one of the first all-precast concrete bridges built in the United States. A funding package totaling $57 million allowed a design-build rehabilitation project to begin in 2011, which ultimately allowed this historic bridge to be reopened in time for its 100th year anniversary celebration that was held on February 15, 2013.

After more than 55 years of service in a marine environment, the current bridge was still fully functional with no load posting restrictions and showed much less deterioration than the steel truss portions of the bridge. Although this was a testament to the durability of concrete, areas of cracking and spalling in high-stress areas, as well as corrosion of prestressing strands and other deficiencies, dictated that the port approach be rehabilitated along with the rest of the bridge to meet the project's 75-year service life extension.

The design-builder developed a unique solution within the boundaries of the project's performance specifications to repair the hollow precast, prestressed concrete columns of the substructure. The solution utilized a two-component, rigid polyurethane system of poured structural foam to support the interior faces of the hollow concrete columns, while the exterior faces were repaired and encapsulated. The 2-lb density foam had a compressive strength of about 0.3 ksi when fully cured and sufficiently supported the interior faces of the hollow columns during construction. The structural foam also increased confinement capacity of the columns in the plastic hinge zones, which improved the seismic response of the structure.

Murray Morgan Bridge port approach looking east – final deck and lane configuration.

Murray Morgan Bridge port approach looking southwest.

Murray Morgan Bridge port approach with repairs to the tops of the columns in place. All photos: David Evans and Associates Inc.

The design-builder was also able to reduce initial project costs within the performance specifications of the project, when it came to rehabilitation of the precast, prestressed concrete deck girders. The performance specifications dictated that all load-rated structural elements needed to meet a rating factor of 1.25. Originally 25 broken strand locations were identified, primarily in the outer girder lines, and would need to be spliced. However, because the lane configuration on the bridge was changing, as part of the rehabilitation project, the design-builder was able to eliminate the need to repair 13 broken strand locations. This was because the remaining strands in the deteriorated girder locations were sufficient to meet the rating factor requirement, with the new lane and loading configuration.

The reopening of the Murray Morgan Bridge has not only improved the daily lives of Tacoma commuters, it also re-invigorated their love for their cultural history. Additional information on this project can be found in Paper 27 “Rehabilitating Precast Concrete History Using Design-Build Delivery” that was presented at the 2013 PCI Convention and National Bridge Conference.

Matthew Lengyel is the Olympia bridge practice leader with David Evans and Associates Inc. in Olympia, Wash.

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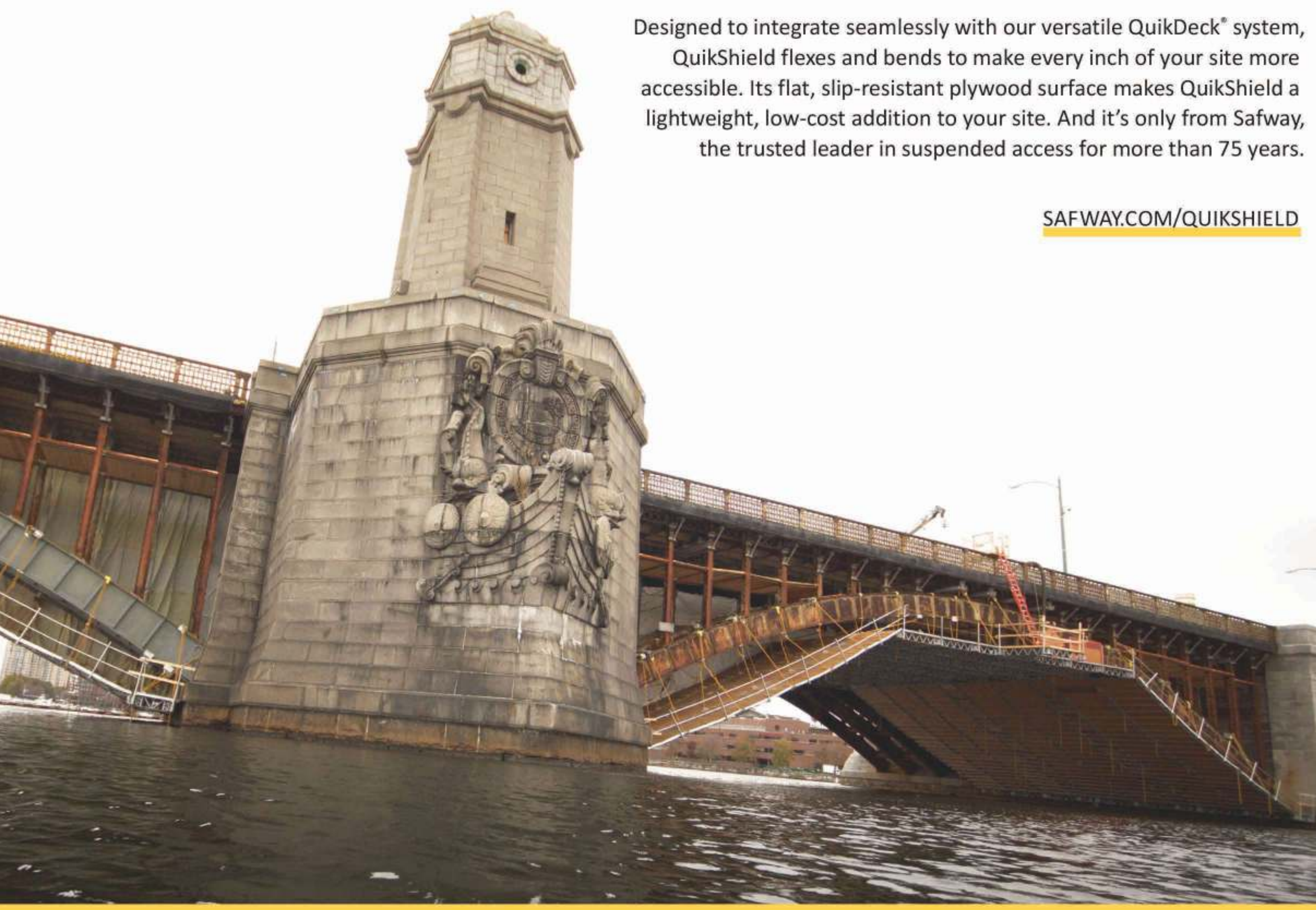

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CONCRETE CONNECTIONS

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.826-836.com
This website has more information about the Palmetto/Dolphin Interchange project described on pages 12 to 14. Additional photographs and a time-lapse video showing the operation of the gantry crane are available.

www.tinyurl.com/BurntRiverBridge
Visit this website for a time lapse video by the Oregon Department of Transportation showing construction of the Burnt River Bridge described on pages 16 to 18.

www.fhwa.dot.gov/research/resources/uhpc.cfm
This Federal Highway Administration (FHWA) website is the location of considerable information about ultra-high-performance concrete as described in the FHWA article on pages 32 to 33.

www.fhwa.dot.gov/publications/research/infrastructure/structures/hpc/13060
A report titled *Ultra-High Performance Concrete: A State-of-the-Art Report for the Bridge Community* (Pub. No. FHWA-HRT-13-060) is available at this website. The report includes information on materials and production, mechanical properties, and structural design and testing. An extensive list of references is provided.

Bridge Technology

www.aspirebridge.org
Previous issues of *ASPIRE*™ are available as pdf files and may be downloaded as a full issue or individual articles. Information is available about 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 75 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/publications/research/infrastructure/structures/ltbp/13051/
The FHWA technical report titled *LTBP Bridge Performance Primer* is available at this website. The report is intended to provide a comprehensive definition of bridge performance that will be the foundation for carefully designed research studies in the Long-Term Bridge Performance (LTBP) Program. The report describes the barriers and complications that hinder the understanding of bridge performance and identifies the measures by which bridge performance is currently defined. The report divides bridge performance into specific issues, identifies the most critical issues, and describes the types of data necessary to analyze these issues.

www.trb.org/main/blurbs/170201.aspx or **http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubR19B.pdf**
TRB's second Strategic Highway Research Program (SHRP 2) Reliability Project R19B has released a prepublication, non-edited version of a report titled *Bridges for Service Life Beyond 100 Years: Service Limit State Design* that explores design codes critical for bridges to reach a service live of beyond 100 years. The report also addresses performance measures and design procedures that utilize criteria to maximize the actual life of a bridge system.

http://vimeo.com/83863944
The video on this website highlights the benefits of SHRP 2 ABC Toolkit for using accelerated bridge construction techniques on standard bridges. It features the replacement of the I-84 bridge over Dingle Road in New York State.

www.abc.fiu.edu/wp-content/uploads/2013/07/ABC-User-Guide-for-posting1.pdf
This Florida International University website contains a user's guide to the National ABC Project Exchange, which is a nationwide repository of projects that have incorporated Prefabricated Bridge Elements and Systems (PBES) with other innovative strategies to accomplish the objects of accelerated bridge construction.

NEW www.fhwa.dot.gov/goshrp2/
Visit this website to learn about SHRP solutions to solve real problems.

Bridge Research

NEW 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.

NEW 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.*

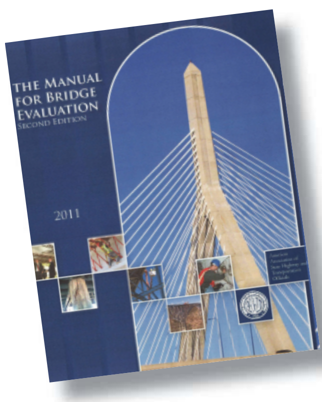
NEW http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w201.pdf
The NCHRP Report titled Calibration of AASHTO LRFD Concrete Bridge Design Specifications for Serviceability is available at this website.

www.trb.org/shrp2/researchreports
Are you looking for a research report from the second Strategic Highway Research Program? Nearly 110 reports organized by focus area and topic are now available as free downloads from this website.

NEW www.trb.org/main/blurbs/170412.aspx
The Colorado Department of Transportation has released a report that examines the freeze-thaw resistance of internally cured concrete so as to improve performance of the concrete.

Load Rating Concrete Bridges: Part 1

by Dr. Dennis R. Mertz



The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures (SCOBS) adopted the load and resistance factor rating (LRFR) bridge-evaluation methodology as an acceptable load rating procedure in the first edition of the AASHTO *Manual for Bridge Evaluation* (MBE) in 2005. The MBE includes the probability-based, calibrated LRFR method along with the more traditional, uncalibrated strength-based load factor rating (LFR) method. The LRFR method includes rating for both the traditional strength and newer service limit states.

The Federal Highway Administration (FHWA) mandates that LRFR be used for bridges designed by the *AASHTO LRFD Bridge Design Specifications* using HL-93, after October 1, 2010. For other bridges, the LRFR or LFR methods are allowed. Nonetheless, the calibrated LRFR methodology yields more reliable load ratings in all cases, though not uniformly higher nor lower ratings.

The LRFR rating method in Part A of Section 6 of the MBE consists of three rating levels: design, legal, and permit load rating. Design load rating uses the HL-93 live-load model and provides a comparison to today's design standard. The design load rating is not used for operational decisions but only for reporting to the National Bridge Inventory (NBI). Legal load rating uses the bridge owner's legal loads as the live-load models and provides ratings to make load posting, bridge replacement, and rehabilitation decisions. Finally, permit load rating uses the candidate permit loads and provides ratings to make permit-issuing decisions.

The LRFR bridge-evaluation methodology considers both strength and service limit states. The strength limit states—Strength I for design and legal load rating and Strength II for permit load rating—are required for all bridges (see Table 6A.4.2.2-1 in the MBE). Several concrete-bridge specific limit states are included in the three levels of LRFR bridge evaluation. The material-specific limit states are service limit states with most of them being optional.

LRFR for concrete members includes two new service limit states. At the design load rating level, prestressed concrete members are required to be rated using the Service III limit state, which controls cracking just as in the *AASHTO LRFD Bridge Design Specifications*. At the legal load rating level, the Service III limit state becomes optional for prestressed concrete members. At the permit load rating level, the Service I limit state is optional for both prestressed and reinforced concrete members, and guards against yielding of the reinforcement and permanently open cracks in the concrete.

The new service limit states in LRFR are not only limited to concrete structures. The Service II limit state, which controls yielding of the steel members and permanent deformation, just as in the *AASHTO LRFD Bridge Design Specifications,* is required at the design load rating level and the legal load rating level, but is optional at the permit load rating level for steel members.

All of the service limit states were deemed necessary by the developers of the LRFR bridge-evaluation methodology to protect bridges and allow no damage under both legal and permit loads. AASHTO SCOBS, however, decided to allow the individual bridge owners to decide if the optional service limit states would be applied in their jurisdictions. If applied, these optional service limit states would result in less damage to bridges, but more posted bridges and fewer issued permits.

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.*

Special Notice

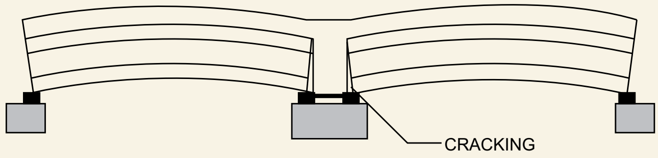
BRIDGES COMPOSED OF SIMPLE-SPAN, PRECAST CONCRETE GIRDERS MADE CONTINUOUS

This Special Notice explains Article 5.14.1.4—Bridges Composed of Simple Span Precast Girders Made Continuous (also known as Continuous for Live Load Bridges). As the name states, these bridges are made by erecting single-span, precast concrete girders and then connecting them over the supports with a cast-in-place concrete diaphragm and deck slab to establish full-depth positive and negative moment connections. The girders carry their own dead load and the slab dead load as simple spans, but all subsequent loads are carried as continuous spans. Deck reinforcement provides the negative moment resistance.

The drawback to this design is that the girders will camber upward due to creep and shrinkage. In contrast, differential shrinkage between the deck and the girders causes the giders to deflect downward. Temperature gradients also affect the camber. If the net camber is positive, a positive moment develops and the connection cracks, as shown in the figure. For this reason, Article 5.14.1.4.9 requires a positive moment connection at the joint.

An analytical study in NCHRP Report 322[1] suggested that any positive moment cracking at the joint resulted in a loss of continuity because the crack has to close for continuous beam behavior to occur. However, experimental work reported in NCHRP 519[2] and confirmed by others[3] showed this is not necessarily true. Cracks in concrete, even at cold joints, are jagged and aggregate interlock provides frictional forces. Thus, the connection can tolerate some cracking and still provide continuity.

When NCHRP 519 was published, Article 5.14.1.4 contained a provision stating that the connection could be considered continuous if the net stress at the bottom of the diaphragm from superimposed permanent loads, settlement, creep, shrinkage, temperature gradient, and 50% of live load was compressive. Because this was already in the



American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications* and it was consistent with the experimental results showing the connection could tolerate some cracking, the provision was retained as Article 5.14.1.4.5.

Given that calculation of the diaphragm stresses is complex, there was a desire for a simple rule. At the time, the Tennessee Department of Transportation had a provision requiring the girders be aged 90 days before continuity was established. This was adopted as Article 5.14.1.4.4, which requires that the engineer provide a positive moment connection with a strength of 1.2 M_{cr} and specify in the contract documents that the girders are to be at least 90 days old when continuity is established.

The reasoning given in the commentary is that by 90 days, 60% of the creep and 70% of the shrinkage in the girder is theoretically gone. The behavior of the system will be dominated by differential shrinkage of the deck so the possibility of positive moment cracking significant enough to affect continuity is very low.

In effect, the provisions and commentary of Article 5.14.1.4 give the designer four options:

1) Provide a positive moment connection with a strength of 1.2 M_{cr} and require the girders to be at least 90 days old at the time continuity is established. Experience in Tennessee shows there is no reason to specify a minimum age longer than 90 days unless some unusual situation suggests that significant upward camber may occur after 90 days.
2) Provide a positive moment connection with a strength of 1.2 M_{cr} and use the provisions of Article 5.4.2.3, with k_{td} = 0.7, to establish the minimum age at which continuity can be established (commentary).
3) Use the provisions of Article 5.14.1.4.5 and consider the bridge continuous if the net stress at the bottom of the diaphragm from superimposed permanent loads, settlement, creep, shrinkage, temperature gradient, and 50% of live load is compressive.
4) Calculate the actual restraint moments and determine the degree of continuity from the analysis (Article 5.14.1.4.2).

If the connection does not provide full continuity, the effect of partial continuity must be considered as required in Article 5.14.1.4.5.

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3. Newhouse, C. D., C. L. Roberts-Wollman, and T. E. Cousins. 2007. "Comparison of Strands and Bars for Positive Moment Connection of Continuous Precast Concrete Bulb-Tee Girders," *PCI Journal*, May/June.

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