ASPIRE™

THE CONCRETE BRIDGE MAGAZINE

SPRING 2014

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Safe & Sound

Missouri

ZILWAUKEE BRIDGE
Zilwaukee, Michigan

FULL-SPAN PRECASTING OF RAILWAY BRIDGES

FAIRMOUNT LINE BRIDGES
Boston, Massachusetts

SATUS CREEK BRIDGE
Toppenish, Washington

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE
Seattle, Washington

Photo: Michigan Department of Transportation.

Photo: The Louis Berger Group Inc.

Photo: Washington State Department of Transportation Visual Engineering Resource Group.

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Photo: PCI.

Thinking in the Future Tense

William Nickas, *Editor-in-Chief*

At two separate, transportation-related meetings in 2013, engineers in attendance heard addresses by futurists. I thought, "What an intriguing career!" My mind began to speculate, "Do they really predict the future? Can they help a person regarding a career or personal decision? Do they have insight into investing?"

Exploring the subject a little further, I found a book by a well-respected futurist, the late Dr. Edward B. Lindaman. Dr. Lindaman had an earlier, 22-year-long career as director of program planning for the design and manufacture of the Apollo spacecraft at Rockwell International. In his book, *Thinking in the Future Tense*, Lindaman wrote: "It used to be that the future, like the weather, was something that everybody talked about but that remained totally beyond human control. Today, we not only dream about the future, worry over it, save for it, and invest in it; we also are consciously and unconsciously creating our future. The future may be very different from today. The future will be what we make of it. What a revolutionary idea!"*

Futurists work beyond horizons of 20 or 30 years, where it is a real challenge to imagine the future. Working with futurists and through various leadership exercises, organizations can avoid becoming stale and complacent, thus creating an environment of growth and creativity.

Often we map out a week, a month, or even a year's worth of goals and tasks. The longer the scope of the plan, the more we need to build in contingencies. Often, we evaluate more than one possible scenario and the range of responses to each. This is preparation for change and consciously creating the future.

The construction industry is constantly coping with change and managing expectations—future outcomes. Those who are not prepared, often suffer very expensive consequences.

In my editorial in the Summer 2013 issue of *ASPIRE*,™ "Do Not Let the Perfect Be the Enemy of Good," I proposed some thoughts about dealing with planning and change in our industry.

Then, in the Fall 2013 issue, "You Better Have Teamwork, or You Better Be Perfect," I presented my observations about the need to be a part of a well-functioning team that grows, tests concepts, evaluates ideas, and delivers the best possible product.

So, the latest change for *ASPIRE* became obvious: An extended FOCUS series starting in this issue of *ASPIRE*.

For too long, the pages of *ASPIRE* have overlooked the bridge builder as an integral part of the team! Yes, often project articles have included an author who represented the contractor and much attention was paid to ensure accurate reporting on the contractor participants in each project. But, we have yet to feature a contractor in these pages.

The Editorial Advisory Board and all the supporting associations agreed to alternate the FOCUS series between contractors and consultants. With this issue, *ASPIRE* presents its first contractor company profile. I hope you are as excited as I am about glimpsing inside the minds of concrete bridge builders as they apply new materials and create new techniques to build our nation's infrastructure and deliver the community icons from high-performance concrete.

*Lindaman, Edward B. 1978. *Thinking in the Future Tense* (pp. 15-16). Broadman Press, Nashville, TN. 192 pp.

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Cover
To build 554 bridges as part of Missouri's "Safe & Sound" Bridge Improvement Program, Kiewit teamed with Traylor Bros. Inc. and United Contractors Inc. to build a new bridge every 1.6 working days for 3.5 years. For more information on Missouri's "Safe & Sound" program, see the state article featuring Missouri in the Spring 2013 issue of *ASPIRE*.
Photo: Kiewit.

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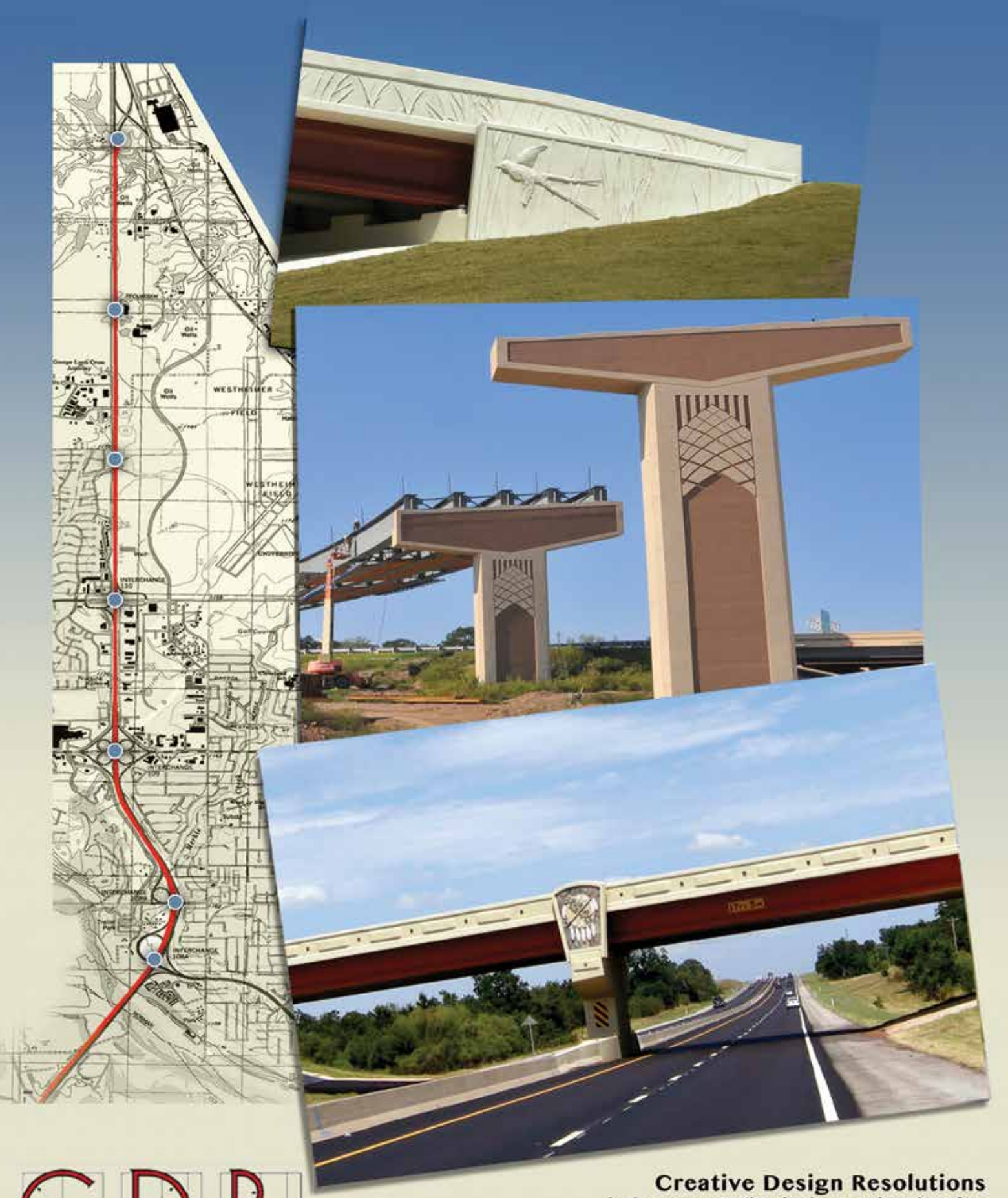

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CONCRETE CALENDAR 2014/2015

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

April 14-15, 2014
ASBI 2014 Grouting Certification Training
J. J. Pickle Research Campus
The Commons Center
Austin, Tex.

April 21-25, 2014
National Bridge Preservation Partnership Conference
Renaissance Orlando at SeaWorld
Orlando, Fla.

April 24-27, 2014
PCI Committee Days and Membership Conference
Hyatt Magnificent Mile
Chicago, Ill.

April 28, 2014
2014 National Accelerated Bridge Construction Conference Call for Papers
http://2014abc.fiu.edu/

May 4-6, 2014
PTI Annual Convention
Norfolk Waterside Marriott
Norfolk, Va.

June 8-12, 2014
International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, Pa.

June 22-26, 2014
2014 AASHTO Subcommittee on Bridges and Structures Meeting
Hyatt Regency
Columbus, Ohio

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
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 15-20, 2015
ACI Spring Convention
Marriott Hotel and Kansas City Convention Center
Kansas City, Mo.

November 8-12, 2015
ACI Fall Convention
Sheraton
Denver, Colo.

Nominations for 2014 PCI Titans Now Being Accepted

PCI is continuing its Titans of the Industry program in 2014. Up to ten more Titans will be honored at the 2014 PCI Convention as we celebrate our 60th anniversary. Nominations for the 2014 Titan award are now open and will be accepted until April 18, 2014. If you would like to nominate a deserving person who qualifies, please send your nomination to PCI President's Office, 200 West Adams St., Suite 2100, Chicago, IL 60606-5230, or email it to presidentsoffice@pci.org

For a list of qualification or more information, visit http://www.pci.org/About_PCI/PCI_Awards_Programs/ or contact Rebecca Coleman at bcoleman@pci.org.

FOCUS

TAKING THE LEAD

Kiewit adapts to new delivery methods, new technologies, and changing requirements to build bridges ranging from the simple to the complex

by Craig A. Shutt

When the state of Missouri Department of Transportation (MoDOT) revamped its entire highway bridge system in 2009, it presented a Kiewit-led, joint-venture, design-build team with a significant challenge: replace 554 bridges in four years while the state refurbished 248 existing bridges simultaneously. The team not only met the goal but finished in 3½ years, completing one bridge every 1.6 working days. To accomplish that feat meant adapting to new delivery methods, creating detailed strategic plans, and thinking in innovative ways. Such capabilities help Kiewit adapt to new challenges every day.

"In general, the more complex, difficult, and technical the project is, the better we compete for the business," says Ralph Salamie, project sponsor (a management position) for Kiewit. "Certainly, we compete and win our share of the smaller, more traditional infrastructure projects. But we're very competitive for the larger, more complex projects."

Missouri's $685-million, design-build Safe & Sound Bridge Improvement Program certainly fits that bill. The state's initial plan called for the winning bidder to design, build, finance, and maintain all 802 bridges for 25 years. But when bids were considerably higher than anticipated, MoDOT removed the bridges that needed rehabilitation and repackaged the remainder as one large design-build project. Kiewit's joint-venture team built 63 of the 554 bridges and managed subcontractors for the rest.

For more details, see the Spring 2013 issue of *ASPIRE*.™

More Delivery Methods

Such unusual delivery methods are becoming more common, Salamie notes. "We still do a lot of rip-and-read work, but more is design-build, which gives us the ability to control the process." They're also seeing construction manager/general contractor (CM/GC) work grow and have been involved in several P3 (Public-Private Partnerships), in which they team with, or even act as, developers to arrange the financing and long-term operations of a project. "We have had to become more engaged in the process of design, project financing, and long-term operation and maintenance of our alternative delivery projects."

The $1.2-billion San Francisco Oakland Bay Bridge Skyway Segment was built by a joint venture led by Kiewit. The 1.2-mile-long, 14-span, twin precast concrete segmental bridges feature 452 precast concrete segments, the largest weighing as much as 750 tons. All Photos: Kiewit.

These new delivery approaches lead owners to look beyond lowest-bid pricing and more heavily weigh other factors. Kiewit has capitalized on the innovative opportunities of alternative delivery projects to increase its win ratio, Salamie says. "More owners want the 'best value' option, which includes cost but also looks at benefits in maintenance and design life."

Evolutions in delivery methods are changing Kiewit's approach to projects, notes Jim Thomsen, who served as project manager for Kiewit's contract with the Missouri Safe & Sound Bridge Improvement Program. "On design-build projects, our construction team is integrated with the design team to ensure constructability and operational efficiency. Design risks and quantity growth are identified, tracked, and mitigated throughout the design process."

The new methods impact the company's personnel and risk-mitigation decisions, notes Salamie. "Given the increase in alternative-delivery methods, we have made changes in the skill sets of our management. We have added designers and design coordinators to our staff to optimize and manage the design process and improve constructability."

That became necessary on design-build projects, as the company was given responsibility for the design process. "No longer is the bridge design a black box for our construction team, where all bidders take the same set of drawings and work up an estimate," he explains. "We now have joint ownership of the design with the designer, where our team's design can be the biggest differentiator in our competitive bid. We expect our construction team to have a working knowledge of the design, and take responsibility for both design and construction."

With the trend towards larger and more diverse infrastructure projects, Kiewit has been able to take advantage of its company structure to bring in the most qualified management and equipment from across the company to pursue and build the work. Notes Salamie, "when it comes to infrastructure work, there is no skill set that we can't provide within our diverse organization."

Environmental Concerns Grow

Environmental concerns also are growing in importance, making projects more complex and impacting bid decisions. "Environmental compliance, safety, and the legal side of overall compliance consume an ever-increasing percentage of our project staff's duties," says Salamie. "In today's world of project management, our staff has to be part designer, part environmental engineer, part safety specialist, and part lawyer.

Maryland's Intercounty Connector (ICC) project shows the requirements needed today. The Kiewit-led MD200 Constructors' $550-million bid for Contract B consisting of 7 miles of the 18.8-mile-long project—said to be the highest monetary contract the state has ever awarded—was won due to its proposed environmental-management program. The bid was slightly higher than others, but "the owners were searching for the team that offered the best value for this high-profile and highly debated, design-build contract," said Gwyon Nelson, the Kiewit sponsor who served as the ICC-B project manager.

The $550-million, 7-mile-long Intercounty Connector Contract B project in Maryland features 10 precast concrete bridges that had to pass over sensitive stream valleys and two local watersheds.

The environmentally sensitive project crosses stream valleys and two local watersheds with specific stream-closure periods. "With no tested designs to fall back on, we had to determine what a project with such ambitious environmental goals would look like," says Nelson. The project included 10 bridges, built using precast concrete components.

Cost control becomes a key aspect of complex projects, notes Salamie. "Material escalation is a consideration for all our project pursuits, especially for steel components on long-duration projects."

Kiewit's 130 Years of Service

Kiewit traces its history to 1884, when two brothers formed a masonry contracting partnership in Omaha, Neb. Now, 130 years later, it's grown into one of the largest construction and mining companies in North America.

The firm entered the heavy and highway construction markets during the Great Depression as building construction disappeared. It also grew during World War II, as it took on a variety of projects for the military, including barracks, airfields, and other facilities throughout the west.

Its government work continued through the Cold War years. Kiewit played a key role in building the interstate highway system, especially some of its most difficult sections.

In the 1980s, Kiewit made significant investments in ventures outside its core businesses, with an emphasis on energy and telecommunications. During the 1990s, it became a leader in design-build and engineer-procure-construct delivery methods.

Today, through its operating companies, Kiewit generates revenues of more than $11 billion and is consistently ranked among the top five contractors by *Engineering News-Record*. It is one of the largest employee-owned businesses in the country.

Kiewit's Bridge to Prosperity

Nine Kiewit employees traveled to Nicaragua in February to put their bridge-building skills to work for the citizens of Cinta Verde near the rural El Limon River. The project, sponsored by Bridges to Prosperity, used concrete footings and anchor blocks along with steel towers and a timber deck, to link the village to schools, medical care, and markets on the other side of the river. It also served as a training exercise to teach the village's 300 people to build more bridges.

Kiewit's construction team faced the challenges of building with primitive materials and tools, overcoming language barriers, and living with no electricity, says Kiewit's Ralph Salamie, project manager. "Kiewit's culture thrives on strong values, and we share our bridge-building talents with people in need."

Bridges to Prosperity has built more than 70 footbridges in 18 countries. Ten bridges are planned for Nicaragua in 2014. The Cinta Verde Bridge took about 10 days to construct.

Kiewit and its partner, International Bridge Technologies (IBT), each contributed $25,000 to design and construct the 115-ft-long suspension footbridge. The volunteers paid their own travel expenses and contributed a week of time, with Kiewit donating a second week for each volunteer. Kiewit employees raised another $2000 to deliver maps, textbooks, sports equipment, and supply kits to the local school.

Mitigating risk also requires picking subcontractors and design partners carefully. "For design-build projects, we look for design teams with proven track records of minimal 'design growth,' maintaining a schedule, and understanding the constructability side of the design," says Salamie. "We involve our experienced builders at bid time to review each element, ensuring we won't have to modify the final design for constructability reasons." Kiewit also includes a second-check design team to mitigate the risk of errors.

Concrete Use Increases

These evolutions have led to specifying concrete materials more often. "My experience on every design-build project has been that our first choice is to go with concrete, due to its speed, cost, and shorter lead times than structural steel," says Thomsen.

The emphasis on service life also has driven this preference, says Oscar Antommattei, senior concrete engineer. "We see a trend among clients wanting a longer service life, so we are pushing concrete to provide more performance," he says. "We look at cementitious materials, durable aggregates, and obtaining a lower water-cementitious materials ratio to achieve this. We evaluate various concrete mix designs, because each region of the country has different materials that create unique challenges to achieve workable mixes that can also meet service life requirements. It can be challenging to get the right mix design."

That's another benefit of the design-build method, he notes. "In design-build, we can look at the entire structure to find ways to combine techniques to protect against corrosion and improve service life." These can include adding post-tensioning and providing alternatives to traditional reinforcement, such as epoxy-coated reinforcement and, more recently, galvanized or stainless steel options.

Kiewit used self-propelled modular transporters to move a cast-in-place, post-tensioned box-beam structure with a curved shape into place in one day on Pecos Street over I-70 in Denver, Colo. During one weekend closure, the existing bridge was demolished, the bridge travel path was constructed with metal plates and fill material, the bridge was moved into place, and the travel path was removed.

Kiewit combined concrete segmental and cable-stayed technology to design and build the Portland-Milwaukie Light-Rail Transit Bridge for TriMet in the Portland, Ore., metro area.

Concrete components also are helping to meet owners' tighter scheduling demands. "Accelerated bridge construction techniques have become a trend throughout the industry," says Thomsen. "Project owners are seeing the value in bridge construction while minimizing the impact to the traveling public. Prefabricating components and delivering standardized pieces have helped achieve those goals."

Adds Antommattei, "Precast concrete can provide significant benefits relating to the schedule. Multiple elements can be fabricated rapidly and in advance of their need: then stored and held until the job requires them. Additionally, precast concrete elements are fabricated under more controlled placement conditions and under strict quality-control measures, which helps ensure that strength and durability requirements are met."

Concrete Capabilities Expand

"Concrete bridge elements are heavier than comparable steel components, but as high-performance concrete pushes the limits to higher and higher strengths, members are getting progressively more slender and lighter, improving the competitive advantage of concrete structures," said Salamie.

Span lengths also are increasing, he adds, which is expanding the market for concrete girders. "Bulb-tee girders made of high-performance concrete let us extend lengths to 200 ft and beyond. That opens up more opportunities for concrete bridges, which we used to cap at about 120 ft."

Those spans are carrying more than vehicles today, with pedestrian bridges growing in use and light-rail applications becoming popular. "We're seeing more transit projects with elevated guideways when there's no space for them at ground level," says Salamie.

One of the most innovative of those projects is being built for TriMet in the Portland, Ore., metro area, which awarded Kiewit a $119-million design-build contract for the Portland-Milwaukie Light Rail Transit Bridge. When completed in 2015, it will be used by light-rail trains, buses, streetcars, bicyclists, and pedestrians. The cast-in-place segmental, cable-stayed bridge was chosen for its minimal environmental impact and aesthetics.

"Combining concrete segmental technology with relatively new cable-stayed technology presented many unique challenges to our design and construction team," says Salamie. Segmental bridge designs are growing in popularity, Salamie says. "Concrete segmental and cable-stay construction can add benefits if there is restrictive access for falsework or erection equipment, such as over water or wide roadways."

Such innovations will keep Kiewit competitive even as new demands and new delivery systems arise. "We're doing more segmental and cable-stayed bridges and other types of unusual designs, but our bread and butter remains the simple span girder bridge," Salamie says. That may be the only thing that's simple about the projects Kiewit builds today.

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

Bridge Information Modeling

Are We There Yet?

by Barbara Day and Shri Bhide, Bentley Systems Inc.

Bridge information modeling (BrIM) has become an important industry tool since it was first introduced to the transportation sector. BrIM is an innovative approach to bridge design, construction, operations, and project delivery. It allows for the creation of an information-rich data model that can be used during the life of the bridge, connecting design, construction, operations, and maintenance.

More than ever, bridge professionals are seeking methods to:

- reduce construction costs with more economical designs,
- improve quantity take-offs,
- model the step-by-step construction process in 4D, and
- realistically visualize projects with imagery and virtual drive-throughs.

The Federal Highway Administration MAP-21 compliance requirements, and the growing popularity of design-build and Public-Private Partnership projects, have set the stage for greater owner expectations for faster and more-efficient methods of constructing our transportation assets. Bridge designers need to be prepared for this shift in workflows.

Information modeling allows more time for evaluating different alternatives, simulating different scenarios, and optimizing your eventual design. All images: Bentley Systems Inc.

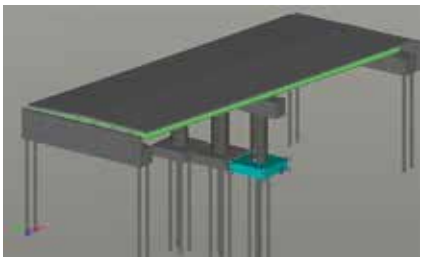
The BrIM design environment has been a headlining discussion at conferences and committee meetings, in articles, and on social media. These discussions are an opportunity for research results and best practices to meet new contractual requirements to select the best solution to design, build, maintain, and operate these assets. While the infrastructure needs increase, new methods to expedite projects, manage funds more wisely, and meet the demands of the public—who want minimal disruption to their traffic patterns—are needed. Current trends indicate that the transportation industry is slow to adopt BrIM workflows and methods. It is unclear whether the industry is waiting for industry standards, if it is uncomfortable with change, or both.

The perceived challenges associated with implementing a BrIM approach are:

- a change in workflow would detract from billable design time, and
- whether it is worth it.

Considering the benefits versus the risks, a traditional workflow can be best described as a fragmented flow of information and it is likely approached from a 'data ownership' perspective. Those responsible for their component of the project own their information and minimal data are sometimes shared.

For example, the highway engineer designs the alignment, profile, and superelevation of the structure based on a typical bridge section. The bridge engineer takes that information and re-enters these data into the structural design software to design the bridge. Following completion of the design, the work is turned over to the detailers who draw the structural sections and reinforcement details based on the engineer's preliminary drawings or even paper sketches.

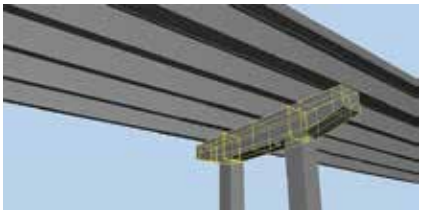


Fully augmented models transfer structural component data directly to field inspection technology.

In this non-automated workflow, any changes or updates to the design are left to the engineers to inform their peers of modifications made. The documented effects of this current workflow translate into project risks, including errors introduced with data re-entry and scattered data across an organization or organizations. Each person only knows where their piece of the workflow is—and the same data may be held in different locations.

BrIM Environment

Working in a BrIM environment eliminates these gaps in shared data. A lot of the information generated during a typical design workflow can easily be adapted into a BrIM workflow with increased productivity and efficiencies. The key components



Interactive inspections allow for collection and reporting of condition data at the component level.

Data re-use and mobility are a necessity.

are already in place; transferring to a BrIM workflow is likely a matter of assessing data mobility and adjusting the gaps. BrIM is a collaborative way of doing business and can be a key component for success in firms of all sizes.

Data re-use and mobility are a necessity for any type of well-designed, constructed, and maintained asset. Having the right version of data, the right format, and the required level of precision available to the right people at the right time is a clear differentiator in this workflow.

Data model standards commonly used for building structures include CIS/2 (CIMSteel Integration Standards), IFC (Industry Foundation Classes), and Bentley's ISM (Integrated Structural Modeling). However, there isn't one currently available for bridges. There are efforts underway at buildingSMART to extend the IFC standard to bridges. A recent research study at the State University of New York at Buffalo found that Bentley's ISM can be used to create data models for the most common concrete and steel bridges. Additional work is necessary in ISM to extend its applicability to complex bridge types and roadway information.

A typical BrIM workflow would involve all stakeholders, from all relevant disciplines, to be involved in developing a fully intelligent, living, cradle-to-grave model. Data sources can include information from the geotechnical, survey, civil, and bridge disciplines. In the design of the bridge, these same data are used to create a global-intelligent, three-dimensional, as-designed physical model. This global model can then be augmented with miscellaneous components such as lighting or signage, thereby becoming the single source of data for the asset.

Publishing this vital as-designed information is more than a plan set. One of the advantages of publishing a BrIM model is the effective and efficient sharing and distribution of information, which can reduce errors, compress the project schedule, and reduce project costs. BrIM models are widely reusable, enabling teams to reference, repurpose, and republish content, including business properties, geometry, graphics, and the respective component relationships. The asset information can be queried or the components linked to construction documents and 2D plan sets. These design data also can be fully utilized by inspection software and seamlessly accessed in the field for collection and reporting of the asset via mobile technology.

In many ways, the bridge industry is ready to embrace BrIM. The potential is there for state-of-the-art deliverables with assurance of accurate results. This year could be the one that BrIM gains traction and places the bridge industry in a position to meet our infrastructure needs, quicker, less expensively, and confidently.

PROJECT

ZILWAUKEE BRIDGE

Bearing replacement need determined after 18 years of service

by Corey E. Rogers, Michigan Department of Transportation

Opened to traffic in 1989, the 325-ft-long approach spans and 393-ft-long river span of the Zilwaukee Bridge rise to 125 ft above the Saginaw River to accommodate marine shipping traffic. The bridge is a 1.5-mile-long twin concrete segmental structure comprised of 1592 precast concrete segments, each weighing an average of 160 tons. It was the largest precast concrete segmental project in the United States at the time. The 25-span northbound structure and 26-span southbound structure carry I-75 traffic over the Saginaw River through the city of Zilwaukee, Mich.

The Zilwaukee Bridge was designed to the 1973-77 *AASHTO Standard Specifications*, with HS-25 live loading and AASHTO Zone 1 seismic loads. The single-cell segments of the superstructure box girder are approximately 73 ft wide at the top flange, 36 ft wide at the bottom flange, and vary in depth from 8 ft at midspan to 20 ft at the piers. Each structure contains eight, in-span, quarter-point hinges to accommodate expansion and rotation from thermal gradients.

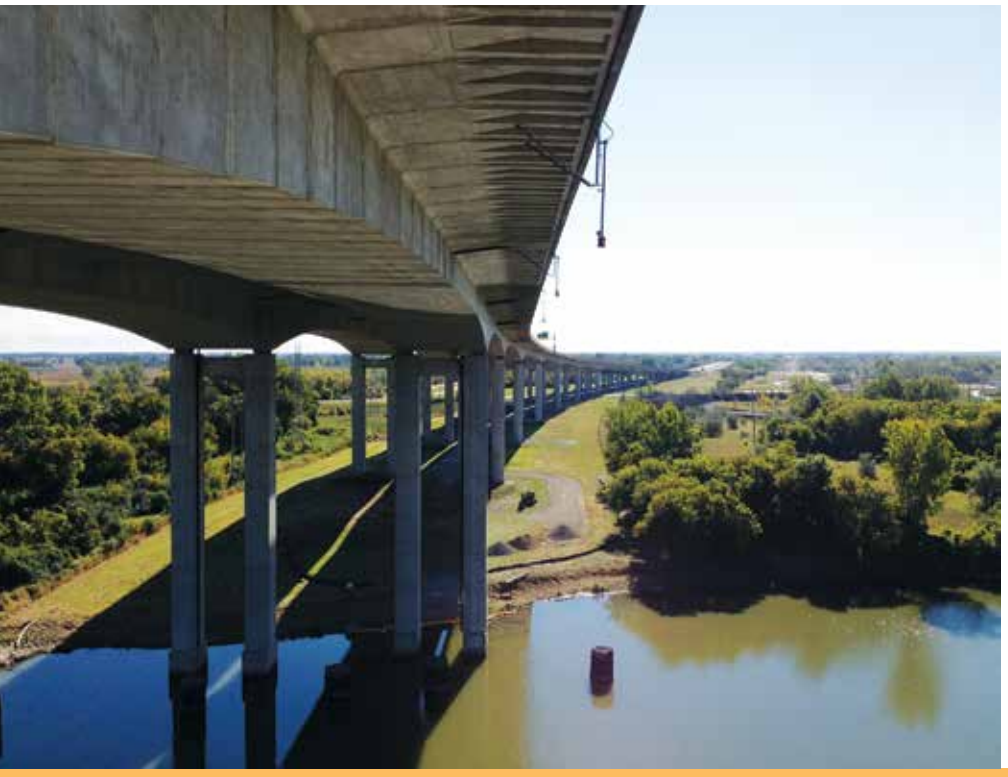
Bearing Problems

Originally, the superstructure rested on high-capacity pot bearings at the piers and expansion joint locations. The pier bearings were mostly fixed with one of the two pier bearings allowing transverse movement. The elastomer pot bearings allowed for 0.04 radians of rotation and accommodated 12 in. of longitudinal and/or transverse movement via the polytetrafluoroethylene (PTFE) sliding surface.

Bearing problems were identified during the first detailed inspection in 1993. Neoprene elastomer was leaking from the sealing ring around the pot piston at the expansion hinge and pier bearing locations. This reduced the rotational capacity of the bearing. There were also indications of wearing in the PTFE sliding surfaces, which was jeopardizing thermal movements of the bridge. At some pier locations, the loss of elastomer resulted in contact between the top sole plate and the bottom masonry plate edge. In 2007, the Michigan Department of Transportation (MDOT) began discussions to replace the 104 pier bearings and 34 expansion joint bearings and upgrade the bearings to current AASHTO service criteria.

Bearing Replacement

The challenges associated with the bearing replacement were clear. Loads approaching 17 million pounds would



The Zilwaukee Bridge, a 1.5-mile-long twin concrete segmental structure, carries I-75 traffic over the Saginaw River. All Photos: Michigan Department of Transportation.

profile

ZILWAUKEE BRIDGE / ZILWAUKEE, MICHIGAN

BRIDGE REPLACEMENT CONSULTANT: T.Y. Lin International, San Francisco, Calif.

QUALITY ASSURANCE ENGINEER: Janssen and Spaans Engineer Inc., Chicago, Ill.

CONSTRUCTION ENGINEER: Corven Engineering Inc., Tallahassee, Fla.

PRIME CONTRACTOR: PCL Construction, Tampa, Fla.

POST-TENSIONING CONTRACTORS: PCL Construction, Tampa, Fla., and Walter Toebe Construction, Wixom, Mich.

have to be jacked from piers with heights up to 130 ft. Then, new, higher capacity bearings would have to be installed into the existing openings with little to no allowable modifications to the structure.

Loads approaching 17 million pounds would have to be jacked from piers with heights up to 130 ft.

The old expansion joint bearings rested on reinforced, cantilevered concrete corbels containing the anchorages for the post-tensioning. Therefore, any modifications to the concrete corbel to gain additional space was limited to the 2 in. of concrete cover above the reinforcing steel. The existing opening housing the expansion joint bearings provided approximately 4 in. of space from corbel to top plate. The top plates were salvaged because they were cast into the upper segment and were in sound condition. This lack of space also meant a higher-capacity and taller pot-style bearing would not be able to be used.

The pier bearings rested directly on top of each pier with a cast-in-place concrete plinth between the top of bearing and bottom of the superstructure. Plinth modifications were made to accommodate various bearing depths. Jacking stresses and load path redistribution were addressed by application of additional external post-tensioning forces via post-tensioning bars and walers to the elements affected. Some of the affected elements required an additional 2.5 million pounds of compression to prevent excess principal tensile stresses during jacking.

Post-tensioned waler configuration, compression collars, and jack layout at pier bearing.

New Contracting Methods

Due to the uniqueness of the bearing replacement project and the associated challenges, MDOT opted to use a construction management/general contractor (CM/GC) contracting method.

This method allowed for greater flexibility during construction.

Erection of pier column work platform.

MICHIGAN DEPARTMENT OF TRANSPORTATION, OWNER

BEARING SUPPLIER: RJ Watson Bridge and Structural Engineered Systems, Alden, N.Y.

PROJECT DESCRIPTION: Pier/abutment bearing replacement, expansion joint bearing replacement, deck patching, barrier wall repairs, epoxy healer/sealer, and lighting upgrades

STRUCTURAL COMPONENTS: 104 pier bearings, 34 expansion bearings, 10 abutment bearings

BRIDGE REPAIR COST: $36 million

Pier column compression collars.

Newly installed pier disk bearing with pressure grouting formwork.

This method allowed for greater flexibility during construction of such a complicated project. An example of this flexibility occurred during the construction management phase and involved the jacking scheme for the pier bearings.

Early designs called for shoring towers that would support the jacked superstructure from the footings. The contractor proposed placing the jacks on top of the pier columns and horizontally compressing the tops of the columns with pier collars to confine them and prevent column edge spalling at jack bearing locations. This method was determined to be feasible and eliminated the need for costly shoring towers.

It was also during the construction management phase that MDOT decided to use disk bearings instead of pot bearings. The disk bearing is simpler in design and thinner than a pot bearing, but requires a larger footprint. A polyurethane disk provides the required rotational capacity and a stainless steel top plate coated in PTFE provides the lateral movements. The disk bearings were able to fit into the 4-in.-deep opening at the expansion joints and provide the needed bearing capacity at pier bearing locations. Upon completion of the design phase, a guaranteed maximum price was negotiated, with the final cost of the project totaling $36 million, and the contract moved into the second, or general contractor, phase.

Checks

Construction began in April 2013 with the closure of the southbound structure. MDOT required the contractor to demonstrate a complete pier and expansion bearing replacement prior to commencing production mode. This allowed MDOT inspectors and construction engineers to become comfortable with the entire replacement operation and work through any design/constructability issues before work began at multiple bearing locations.

The contractor submitted a detailed jacking procedure for MDOT approval. MDOT also created specialized jacking forms for inspection staff to use during all jacking operations. Any deviations from the procedures or forms resulted in an immediate stoppage of work and reevaluation of the procedure.

Ground penetrating radar was used at all proposed coring locations. Chipping was allowed to visually verify the tendon locations. Coring was conducted in the web walls for diaphragm strengthening and in the deck for strongback installation and platform erection.

Platforms weighing approximately 90 tons were designed and constructed by the contractor and hoisted into place at the top of the piers with hydraulic jacks and high tensile rods. Twelve 1¾-in.-diameter post-tensioning rods were installed transversely through the box at most of the pier diaphragm locations and stressed to 210 kips each to support the 12 ft by 25 in. load redistribution walers. The smaller diaphragm locations received modifications by placing reinforced, post-tensioned concrete blocks adjacent to the diaphragm and over the jacking points. The larger diaphragms received no strengthening modifications.

Two 2½-in.-diameter post-tensioning rods held the compression collars and were stressed to 540 kips each. Up to eight 600-ton hydraulic jacks per bearing were used to lift the superstructure from the bearings. Steel rods were anchored into the pier and bottom of the superstructure, and surveys were used to monitor displacement. The existing bearings and concrete plinth were then removed with the use of a wire saw, the new steel reinforcement was anchored with epoxy into the top of the pier and bottom of the superstructure, and the new disk bearings were set into place. Pressure grouting of bearing pedestals with a non-shrink cementitious grout was conducted and allowed to reach a compressive strength of 5 ksi prior to lowering the structure.

The expansion joint bearings were replaced with the use of a strongback system. Overhead and underslung beams spanning the width of the box were supported by twelve 2½-in.-diameter post-tensioning rods stressed to 460 kips each. Four 400-ton hydraulic jacks were used to lift the supported span. The old bearings were then removed and the new disk bearings installed and grouted into place.

Due to the excessive movements associated with the thermal gradient, MDOT decided all jacking and lowering operations be conducted between 7 and 9 a.m., when the structure has the least thermal movement. This provided consistency in the jacking displacements and ensured no new stresses were being introduced into the bridge upon release of the jacks.

Concluding Remarks

The bearing replacement on the southbound structure was successfully completed ahead of schedule in November 2013. Much of the success can be attributed to the group of contractors, subcontractors, consultants, designers, and MDOT staff that continually found solutions when confronted with challenges, and who had a great sense of ownership and pride regarding the project. There was no template for a project like this and many of the procedures were drafted as needed. MDOT was able to gain valuable experience on a complex bridge, built by a previous generation.

Corey E. Rogers is the bridge construction engineer with the Michigan Department of Transportation in Lansing, Mich.

FULL-SPAN PRECASTING OF RAILWAY BRIDGES

by Marco Rosignoli, HDR Inc.

Span stacking on support frames. Photo: Systra.

In recent years, more than 35,000 spans of high-speed railway (HSR) bridges have been built in China and large investments in HSR infrastructure have been made in Europe, Japan, Korea, and Taiwan. Long prestressed concrete (PC) bridges are the typical solution for HSR infrastructure on poor soil. The combination of long bridges and short spans results in a large number of modular spans. This allows for investments in large precasting facilities and special means for beam transportation and erection.

Light-rail transit (LRT) projects also include miles of PC elevated guideways. Many HSR bridges and the first new-generation LRT bridges have been built with precast concrete beams. Precasting offers rapid construction and repetitive casting processes in factory-like conditions. The beams can be erected all year round in almost any weather conditions. This article illustrates the application, transportation, and erection of full-span precast concrete beams for LRT and HSR bridges.

Precasting offers rapid construction and repetitive casting processes in factory-like conditions.

U-beams for LRT Bridges

Dual-track precast concrete segmental box girders have been used intensively for LRT bridges. Single-track, precast concrete U-beams, however, are being used more frequently because of their higher quality and faster erection rate.

Single-track U-beams include two edge girders and a bottom slab that supports the track via ballast or direct fixation. The edge girders keep the train on the bridge in case of derailment, and the top flanges are used as walkways for passenger evacuation. Precast concrete beams offer simple casting operations, rapid and inexpensive erection with ground-based cranes, optimal integration with the urban environment, built-in sound barrier and system functions, and the possibility of lowering the vertical profile by 5 to 6½ ft.[1]

A single-track U-beam is 15 to 18 ft wide, weighs from 340 kips for 82-ft-long spans to 500 kips for 115-ft-long spans, and is typically transported on the ground with trucks and rear steering trolleys. Different proportions of pre- and post-tensioning are possible. Pretensioning simplifies forming and diminishes the cost of prestressing, but requires anchor bulkheads and reaction beams designed for the prestressing force of many strands.

The fabrication process is consistent with the speed of erection. Storage for completion of curing is necessary only when the beams are delivered on the completed deck. Ground transportation and crane erection require two to three days of curing, and the beams can complete curing on the piers. A small storage area may be needed to provide some flexibility in case of delivery delays or defective beams. In typical conditions, the beams are picked up from the

Span transfer to the storage platform with a portal carrier with pivoted tractors. Photo: Marco Rosignoli.

casting bed and loaded onto the truck for just-in-time delivery.

HSR Bridges

The precast concrete beams for HSR bridges are too heavy for ground transportation and need to be delivered on the completed deck and positioned with dedicated machines.[1] The productivity of the precasting facility matches the productivity of the erection lines. The size of the storage area and the number of storage platforms are based on the curing time required prior to delivery, which depends on the type of beam transporter.

The beams are often designed for post-tensioning to facilitate handling of prefabricated cages and to shorten the curing time in the casting bed. Combinations of pre- and post-tensioning are also possible. Partial post-tensioning is applied after 12 to 18 hours of curing to make the beam self-supporting for transfer to the storage area. Parallel casting lines are separated by transportation routes for cage delivery and removal of the beams. Three casting beds may be used in the casting lines for single-track U-beams in combination with an inner form that shuttles back and forth along the casting line.[1] Alternatively, the inner tunnel forms for box girders are more complex to operate and may be stored between two casting beds to serve them. Casting beds and handling equipment for dual-track box girders are more expensive than for single-track U-beams, but the number of units is halved.

Portal cranes on rails or steering wheels are used to move the beams around the precasting facility. Portal cranes with transverse tractors and steering wheels facilitate access to casting beds and storage platforms. Portal cranes with pivoted tractors are also used for beam delivery and placement.

Tire Trolleys

Tire trolleys are used to transport the beams along the access embankment and completed superstructure to the rear end of the launcher. The tire trolleys have 135- to 200-kip capacity and the speed varies significantly from machine to machine. The main beam of the trolley is supported by multiple transverse beams. Each transverse beam has a pivot for 360-degree rotation of two paired wheels controlled by a steering computer. Long transverse beams ensure lateral stability and align the wheels of the trolley with the superstructure webs for direct loading. The load in the wheels is equalized electronically.

An articulated saddle supports the rear end of the beam and rolls along the main beam during beam extraction. Two fixed blocks support the front end of the beam and provide the torsional restraint during transportation.

Span Launchers

The typical configuration of a span launcher includes a rear main frame and a front underbridge. The underbridge is supported at the leading pier of the span to be erected and at the next pier. The front end of the main frame is supported on the underbridge during launching and on the leading pier cap during beam placement. A C-frame supports the rear end of the main frame and allows the precast concrete beam to pass through. The main frame cantilevers out behind the rear C-frame to store two winch trolleys for beam removal from the tire trolley.

Tire trolley for 900-kip, single-track box girders. Photo: BWM.

Telescopic span launcher for 107-ft-long, 2023-kip, dual-track beams. Photo: BWM.

Portal carrier positioned for span lowering. Photo: Marco Rosignoli.

Repositioning of the underbridge. Photo: Marco Rosignoli.

Loading the launcher is relatively simple. The tire trolley is driven under the rear overhang of the main frame, the front winch-trolley picks up the front end of the beam and moves forward, and when the rear support saddle reaches the front end of the tire trolley, the rear winch-trolley picks up the beam to release the tire trolley.

The beam is moved out and lowered to the deck level. Load cells and stainless steel shims are used to adjust the support reactions. Placing the beam takes two to three hours and repositioning the launcher takes another two to three hours, so two to three beams can be placed every day when crossover embankments exist along the delivery route and the precasting facility is designed for such production.

Beam launchers fed by tire trolleys are preferred for very long bridges, as the launcher is not used for beam transportation and the trolleys are stable and fast. Multiple shorter bridges are better handled with portal carriers.

Portal Carriers with Underbridge

A portal carrier comprises two wheeled tractors connected by a box girder that supports two hoists. The tractors have motorized steering wheels controlled by steering computers.[1] In some machines, the tractors rotate by 90 degrees for the lateral movements of the carrier; in other machines the wheels turn by ±90 degrees individually.

To pick up the beam from the casting bed, the carrier is moved alongside the beam and the tractors are rotated by 90 degrees; rotation is not necessary when the carrier has ±90 degree steering wheels. The carrier is driven laterally over the beam, lifts the beam, is driven back to the transportation route, and is realigned with a reverse sequence of operations. The same operations are repeated to release the beam into the storage area and to pick it up for final delivery.

At the leading end of the erection line, the carrier reaches a two-span underbridge. The underbridge is a stiff box girder supported on self-launching pier frames at the two piers of the span to be erected and at the next pier. A motorized saddle rolls along the underbridge and carries vertical support cylinders for the front tractor of the carrier.

The saddle is moved to the rear end of the underbridge, the carrier is driven forward until the front tractor is over the saddle, and the vertical cylinders of the saddle are activated to lift the tractor from the deck. The hydraulic motors of saddle and rear tractor are synchronized, and the carrier is moved along the underbridge until the front tractor is beyond the leading pier.

After reaching the span lowering position, the saddle pushes the underbridge forward to clear the area under the carrier for span lowering. After positioning the beam, the underbridge is moved back to release the front tractor onto the new span for a new placement cycle.[1]

Beam lifting takes one to two hours, placement takes three to four hours, and transportation may take an entire day when the delivery route is long. When the precasting facility has two casting lines, each carrier serves a casting line. Two carriers and two underbridges may be used to erect two bridges simultaneously. Two carriers may also work with a common underbridge to double the erection rate of one bridge when crossover embankments exist along the delivery route.

Portal carriers are the first-choice solution for construction of multiple HSR bridges separated by embankments or tunnels. The carrier picks up the underbridge from the landing embankment and moves it to the next abutment without dismantling. Immediate restart of beam placement minimizes disruption of precasting facilities designed for just-in-time delivery.

Reference

1. Rosignoli, M. 2013. *Bridge Construction Equipment*, 496 pp., ICE Publishing, ISBN: 978-07277-5808-8.

Marco Rosignoli is the bridge technical leader in the Tappan Zee Project Office of HDR Inc. in Tarrytown, N.Y.

EDITOR'S NOTE

This article is an abbreviated version of a paper published in the Spring issue of the PCI Journal. *The full version is available at www.aspirebridge.org and click on Resources.*

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Contact: **Jennifer Peters**, jpeters@pci.org or
Brian Miller, P.E., LEED AP, bmiller@pci.org

PROJECT

FAIRMOUNT LINE BRIDGES

Rehabilitating Boston's commuter rail line

by Aboud Alzaim, Malek Al-Khatib, and Daniel Deng, The Louis Berger Group Inc.

Commuter rail train (inset) passing over one of the new bridges. All photos: The Louis Berger Group Inc.

In 2010, the Massachusetts Bay Transportation Authority (MBTA) determined that two, century-old rail bridges over the Neponset River had reached the end of their fatigue service life. The bridges, which are on the Fairmount commuter line, connect the Fairmount and Readville stations in the Hyde Park neighborhood of Boston.

Both bridges were structurally deficient, with fatigue ratings below statutory limits, but replacing them posed several challenges. There had to be a minimum disruption of traffic, which required a phased construction plan. Work needed to be done quickly under tight constraints at the site, without fouling the adjacent track. The new structures were to require minimal future maintenance, with no fatigue concerns.

Given these constraints and economic considerations, the design engineer proposed a long-span, precast, prestressed concrete New England bulb-tee beam bridge. This type of bridge reduces material costs, future maintenance, and environmental impact, while also improving aesthetics in the surrounding area.

The bulb-tee beam optimizes the strength-to-weight ratio, maximizing the carrying capacity for live loads. At the same time, the wide top flange of the bulb-tee beam eliminated the need for formwork when

profile

FAIRMOUNT LINE BRIDGES / BOSTON, MASSACHUSETTS

BRIDGE DESIGN ENGINEER: The Louis Berger Group Inc., Morristown, N.J.

PRIME CONTRACTOR: S & R Construction Enterprises Inc., Newton, N.H.

GEOTECHNICAL ENGINEER: GEI Consultants Inc., Woburn, Mass.

PRECASTER: Northeast Prestressed Products LLC, Cressona, Penn.—a PCI-certified producer

OTHER MATERIAL SUPPLIERS: High load multi-rotational bridge disc bearings, The D. S. Brown Company, North Baltimore, Ohio

North approach view of the two main tracks looking north on bridge 2 over the Neponset River bridge.

constructing the bridge deck. Additionally, the concrete deck was built immediately after erection of the beams, which shortened the construction duration of the project. Using precast concrete beams with a ballasted deck also prevented construction debris from falling into the river, improving environmental sustainability and protecting recreational users of the river below.

History and Condition of Bridges

The two former bridges dated back to 1906. Bridge 1 was partially reconstructed in 1952 and again in 1974. The bridge was a 56-ft 8-in.-long, single-span steel structure carrying four tracks: two main line tracks and two spur tracks with one owned by the CSX Freight Line. This open deck-type bridge had open steel grates as walkways between the tracks and on cantilevers on both sides of its outer girders. The superstructure consisted of four pairs of steel girders, with each pair of girders supporting one track. The total width was 61 ft 9 in.

Bridge 2 carried two main line tracks. The bridge was an 89-ft 3-in.-long single span steel structure with a 30-degree skew. The out-to-out open deck width was 22 ft 10 in. and used timber planks as a walkway between the tracks. Its superstructure consisted of two pairs of steel riveted built-up girders supporting the main line tracks.

As an alternative to demolishing all the components of the old structures, the design engineer developed a hybrid design. For the main line tracks, two new bridge structures were selected to replace the existing bridges, while only the superstructure was replaced for the spur tracks of bridge 1.

Construction

Staged construction was planned around train operations and other concurrent

Elevation of one of the longest prestressed bulb-tee beams on bridge 2.

Bridge Resiliency

To ensure the bridges' durability and ability to accommodate Cooper E-80 loads, high-performance concrete (HPC) was used to construct the bulb-tee beams, allowing the structure to resist higher loads with a more efficient cross section. The minimum specified 28-day concrete compressive strength was 10 ksi for the prestressed concrete bulb-tee beams, 6 ksi for the rock-socketed drilled shaft foundation, 5 ksi for the bridge deck, and 4.5 ksi for the walkway slab. Due to the weight of the concrete beams, the bridge is less prone to vibration-induced damage than a steel structure. These HPC beams in particular are anticipated to have an operational life span of 75 years.

The project was finished six months ahead of schedule, without any change orders, and is testament to the versatility of precast concrete.

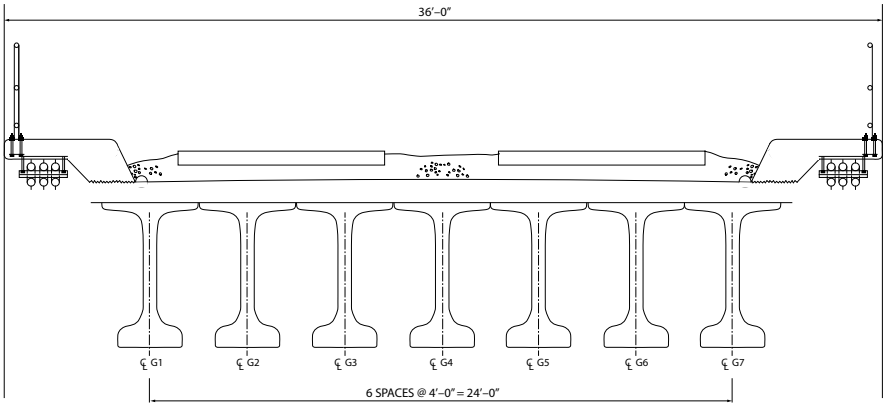
MASSACHUSETTS BAY TRANSPORTATION AUTHORITY, OWNER

PROJECT DESCRIPTION: Replacement of two existing steel railway bridges carrying two main line tracks with two new bridges using New England bulb-tee (NEBT) concrete beams

STRUCTURAL COMPONENTS: Bridge 1: a 71-ft-long, 37-ft-wide, single-span bridge with seven prestressed NEBT 1400 beams. Bridge 2: a 104-ft-long, 36-ft-wide, single-span bridge with seven prestressed NEBT 1800 beams. Both bridges have cast-in-place intermediate and end diaphragms, cast-in-place 10- to 12-in.-thick concrete deck, and 4-ft-wide cantilevered walkways on both sides with six 4-in.-diameter PVC conduits for signal and communication cables suspended from underneath. The substructure for each bridge consists of four, 3-ft-diameter drilled shafts with lengths, including 6-ft-deep rock sockets, ranging from 98 to 117 ft for bridge 1 and 50 to 78 ft for bridge 2.

BRIDGE CONSTRUCTION COST: $8.6 million

AWARDS: PCI 2013 Design Award for Best Non-Highway Bridge



Typical cross section of bridge 2. Drawing: MBTA.

Crane load transfer during beam erection.

construction projects along the Fairmount line. As a result, the bridges were built in two phases: the main line tracks were taken out of service one at a time, allowing the contractor to use the second track on weekends when passenger trains do not run. However, because both spur tracks were needed throughout the week, the spur track superstructure was replaced under accelerated construction techniques during one weekend shutdown.

Precast, prestressed concrete bulb-tee beam structures were determined to be the most economical for the main line bridges. A preliminary design was prepared to estimate the comparative costs of materials; based on this prototype, the cost of steel was estimated at $3,346,000 compared with $1,363,000 for concrete. Additionally, the maintenance cost for a steel bridge would be much higher than that for a concrete one, especially because the bridge is over the river with limited accessibility.

The new bridge abutments were designed as stub abutments supported on four, 3-ft 6-in.-diameter drilled shaft foundations. To minimize outage time, the new substructures were constructed behind the existing abutments. As a result, the span lengths of the new bridges increased to 71 and 104 ft for bridges 1 and 2, respectively.

The bulb-tee beams for bridge 2 have an overall span length of 110 ft, which according to the Precast/Prestressed Concrete Institute, is one of the longest spans for a bridge carrying Cooper E-80 train loads in New England. To achieve the long span, the bulb tees were spaced at 4 ft on center, using four beams connected laterally with concrete diaphragms to support each track during construction.

Precast concrete beams for the Fairmont Bridge Replacement were transported to the site by truck.

A 10- to 12-in.-thick, cast-in-place reinforced concrete deck was placed on the beams. Raised concrete walkways cantilevered beyond the exterior beam to contain the ballast and tracks. The new out-to-out concrete deck widths are 37 and 36 ft for bridges 1 and 2, respectively.

The beams were fabricated in Pennsylvania and transported to the sites. Two cranes located behind opposite abutments were used to lift each beam. One crane lifted the beam and moved it two-thirds of the way over the river. The second crane, on the opposite side, connected the sling on the far end in midair to transfer partial beam load to itself.

Aboud Alzaim is senior vice president in charge of Louis Berger Group Inc.'s northeast transportation division. Malek Al-Khatib serves as associate vice president and Daniel Deng is a structures and facilities engineering manager, both within the northeast transportation division of the Louis Berger Group Inc., in Needham, Mass.

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

SATUS CREEK BRIDGE

Curved, tilted, precast concrete box girders key to replacement project

by Michael Bressan and Paul D. Kinderman, Washington State Department of Transportation

Curved trapezoidal girders were used for the Satus Creek Bridge in south central Washington state. All photos: Washington State Department of Transportation Visual Engineering Resource Group.

Satus Creek Bridge is located 25 miles southwest from Toppenish, Wash., where U.S. 97 crosses Satus Creek. It was constructed as part of a $13.4 million project completed in the first part of 2013. It replaced an old, load-restricted timber bridge built in 1942. Washington State Department of Transportation (WSDOT) designed this new, resilient structure to correct design deficiencies with the old timber bridge including vehicular impact and seismic resistance. Several unique features are implemented in the design including horizontally curved and spliced precast concrete girders.

Structural Design

The Satus Creek Bridge is a 180-ft-long, simple-span bridge. This long, single-span bridge was necessary to satisfy environmental constraints to cross the wide section of the creek. The 7.5-in.-thick bridge deck is comprised of conventional, cast-in-place concrete. The shallow foundation also consists of conventional, cast-in-place concrete that is 18 ft tall.

The superstructure is comprised of three open, precast concrete box girders, which are horizontally curved and tilted to match the 8% cross slope of the bridge. The girders are the WSDOT U78PTG5 series. The "78" indicates the height of the webs in inches and the "5" identifies the width of the bottom flange in feet. Bottom flange and web thicknesses are 6 in. and 10 in., respectively.

To achieve this long, simple span across Satus Creek, each girder line consists of three precast concrete girder segments. Falsework towers were used to temporarily support the segments while the deck was cast and subsequent to assembly of the splice sections. Each web has three post-tensioning tendons comprised of nineteen, 0.6-in.-diameter strands with a total estimated jacking force of 2505 kips per web. After post-tensioning was applied, the temporary falsework towers were removed.

Splicing the segments in the field after the deck was made composite increased the span capability, which eliminated the need for an intermediate pier. This was a great cost savings and it satisfied WSDOT's environmental constraints. Another added benefit of the spliced girders was reduced shipping costs. The precast concrete segments are easier to handle and more shipping routes were available to the precaster due to shorter and lighter components.

Each girder segment was precast with a 1290 ft radius in the horizontal plane. In the bridge special provisions, WSDOT allowed the precaster to chord the girder segments at 20-ft intervals to achieve the prescribed horizontal radius. This construction method would have facilitated the use of conventional, less-expensive, flat formwork panels that are readily available. For this particular project, the precaster was able to build a form to the prescribed radius, achieving a smooth face for each girder segment and a smoother transition between segments at time of assembly.

profile

SATUS CREEK BRIDGE / TOPPENISH, WASHINGTON

BRIDGE DESIGN ENGINEER AND ARCHITECT: Washington State Department of Transportation, Olympia, Wash.

GENERAL CONTRACTOR: Franklin Pacific Construction Company, Seattle, Wash.

PRECASTER: Concrete Technology Corporation, Tacoma, Wash.—a PCI-certified producer

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

Close up of the splice between precast concrete girder segments.

The girders were analyzed as straight segments because:

- the girders are concentric,
- the bearings are not skewed,
- the arc span divided by the girder radius (the central angle) is less than 12 degrees as permitted by AASHTO design requirements, and
- the girder depth is less than the width of the box at mid-depth.

These considerations simplified the analysis of the structure. Three different software packages were used to design the girders: a proprietary software, PG-Splice (developed by WSDOT), and PG-Super (developed by WSDOT). The proprietary software and PG-Splice were both used to verify the validity of each other's results. Both the proprietary software and PG-Splice were utilized to design the main post-tensioning tendons to resist self-weight, superimposed dead loads, live loads, and temperature gradients.

PG-Super was utilized to design the prestressing strands of the individual segments to withstand the stresses induced during the temporary

Falsework towers were used to temporarily support the segments while the deck was cast and subsequent to assembly of the splice sections.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION, OWNER

PROJECT DESCRIPTION: An 180-ft-long, simple-span bridge with horizontally curved, tilted, spliced precast concrete box girders and a 1290-ft-radius horizontal alignment

STRUCTURAL COMPONENTS: WSDOT U78PTG5 precast concrete tub girders with a 28-day design compressive strength of 8.5 ksi and a cast-in-place concrete deck and foundation

BRIDGE CONSTRUCTION COST: $2.49 million

construction stage, which included loads from the deck, diaphragms, and concrete formwork. Additionally, the prestressing strand design was checked to ensure the girders remained within allowable stress limits during shipping and handling of the girder segments prior to assembly.

The post-tensioning tendon paths are parabolic and the post-tensioning losses included:

- friction between the post-tensioning steel and the ducts,
- duct misalignment,
- anchorage slip,
- concrete elastic shortening,
- concrete creep and shrinkage,
- relaxation of post-tensioning steel, and
- stressing sequence.

Earth-tone oxidizing concrete color blends with south-central Washington colors.

Concrete colors and textures complement natural riprap slope protection.

For this particular project, an important aspect in calculating friction losses was the correction for the effects caused by the built-in horizontal curvature. These friction losses introduced by the horizontal curvature were small due to the fairly large radius. Yet the designer could not ignore their effects.

Another interesting design facet for the Satus Creek Bridge is the consideration of out-of-plane and in-plane forces caused by the tendons placed along the webs. These forces are caused by the spreading of the strands within the post-tensioning ducts and by the horizontal and vertical curvatures assumed by the post-tensioning tendons due to the bridge geometry. Small, out-of-plane and in-plane forces may be resisted by the concrete in shear. However, in this project, the addition of stirrups around the post-tensioning ducts along the whole length of the girders provides the necessary resistance to withstand these forces.

Curved trapezoidal girders showing closure concrete placements and diaphragms.

Due to the tremendous forces involved, special attention was given to the end blocks. Two areas of interest were considered: the local zone and the general zone. The local zone is designed to resist the forces introduced by the post-tensioning anchors. The general zone is designed to resist the forces introduced by the jacking forces and the stressing sequence of the post-tensioning tendons. It is not uncommon for end blocks to become fairly large to accommodate the post-tensioning anchors and to provide adequate reinforcement to withstand the forces applied in the general zone.

Architectural Design

This bridge is set in the rural, semi-arid region of south-central Washington state. Except for the creek valley, the area is treeless. Native grasses, sage brush, and basalt rock create colors ranging from golden yellows to reddish browns. The bridge finishes respond to these textures and colors. The abutments and retaining walls are made of cast-in-place concrete with fractured basalt formliners, while the hardened surface is colored with a natural oxidizing agent to blend with the terrain. The barrier and girders are colored and textured for contrast.

The use of curved concrete girders transforms the aesthetic possibilities of precast concrete bridges. Although straight girder sections can be placed on horizontal alignments, there are limits to deck overhangs. These overhangs are invariably changing along the span, creating visual discord. However, with the use of curved girders, the horizontal radius can be less and the deck overhang remains constant.

Lessons Learned

The Satus Creek Bridge is the first horizontally curved, precast, post-tensioned concrete girder bridge to be built in the state of Washington. It is a cost-effective, durable, and resilient structure that is aesthetically pleasing to the eye while satisfying the geometric and environmental constraints of the site.

Satus Creek Bridge was a testing ground for the WSDOT Bridge and Structures Office. The WSDOT team did not encounter significant issues during the design and construction phases of this project. Overall, horizontally curved post-tensioned spliced girders were found to be innovative and cost-effective, while allowing WSDOT to maintain a high level of safety and resiliency in the state's highway bridges.

Michael Bressan is a bridge engineer 4 and Paul D. Kinderman is a bridge architect with the Washington State Department of Transportation in Olympia, Wash.

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

PROJECT

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE

Curved, post-tensioned structure links Seattle campus to downtown

by Claudio Osses and Richard Patterson, Buckland & Taylor, and Orin Brown and Huanzi Wang, AECOM

The Montlake Triangle Pedestrian (MTP) Bridge is a highly-curved, 427-ft-long, cast-in-place (CIP), post-tensioned concrete pedestrian bridge spanning over Montlake Boulevard between the Sound Transit light-rail station and the University of Washington (UW) campus in Seattle, Wash. A number of challenges to bridge design and construction were presented by the unique geometry, curved post-tensioning, dissimilar foundations, and the need to interface with several structures and utilities, both new and existing. It is anticipated that this daring bridge will become a landmark for both the UW and the city of Seattle.

Project Overview

The MTP Bridge was designed and constructed as part of Sound Transit's University Link project to extend light-rail from downtown Seattle to the UW campus. The new station is located on the east side of Montlake Boulevard directly across from the UW Triangle area. This Triangle area is being revitalized by the UW, enhancing the view of Mount Rainer from campus with new landscaping and improving pedestrian and bicycle access. The Headhouse is a building structure that forms the above-ground portion of the

Montlake Triangle Project. Rendering: LMN.

profile

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE / SEATTLE, WASHINGTON

BRIDGE DESIGN ENGINEER: AECOM, Seattle, Wash.

ARCHITECT: LMN, Seattle, Wash.

PRIME CONTRACTOR: Hoffmann Construction, Seattle, Wash.

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

Montlake Triangle Pedestrian Bridge project. Photo: Sound Transit.

new, underground light-rail station. The MTP Bridge provides a direct connection for pedestrians and bicyclists between the Triangle area and the Headhouse.

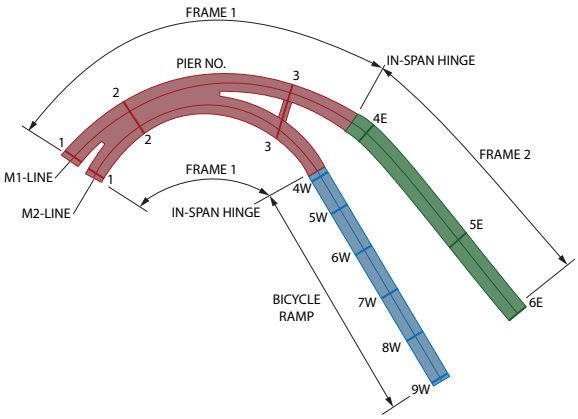
Bridge Layout

The layout of the bridge consists of two horizontally curved alignments:

- The northeast outside curve (M1-line) with a 152-ft radius
- The southwest inside curve (M2-line) with a 94-ft radius

Both alignments begin with pier 1 on the UW Triangle and curve to the right with span 2 of both alignments crossing over Montlake Boulevard. The M1-line has a deck width of 16 ft and consists of five spans with lengths of 55, 131, 76, 100, and 65 ft, ending with a 5-ft cantilever past pier 6E inside the Headhouse. The M2-line has a deck width of 14 ft and consists of eight spans with lengths of 49, 115, 40, 47, 30, 36, 36, and 36 ft, ending at pier 9W as a bicycle access ramp along the east side of Montlake Boulevard. From the middle of span 1 to the middle of span 2, the bridge decks of the two alignments merge into one, making the horizontal geometry resemble a highly curved "X" in plan view, including a forked superstructure at each end of the two spans.

In-span hinges were added to the bridge to divide the bridge into three more-regular bridge segments, which improved the overall static and seismic bridge behavior and simplified the analysis and design. The entire M1-line and the M2-line up to the span 4W hinge are 5-ft-deep, cast-in-place, post-tensioned, concrete single-cell box girders, which become a three cell box in the area where the two lines meet. The M2-line beyond the span 4W hinge is a cast-in-place, reinforced concrete slab girder with a minimum depth of 2 ft and a cross-sectional shape that matches the



Bridge layout. Drawing: AECOM.

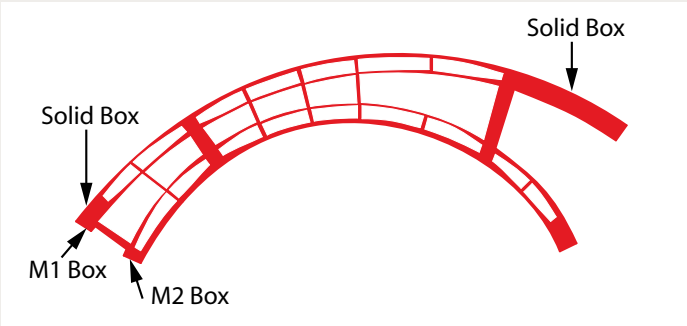
SOUND TRANSIT, OWNER

REINFORCEMENT SUPPLIER: Harris Rebar, Tacoma, Wash.

FORMWORK: Peri Formwork Systems Inc., Woodland, Wash.

PROJECT DESCRIPTION: 427-ft-long by 12- to 35-ft-wide multispan, curved, 5-ft-deep, cast-in-place, post-tensioned concrete box girder bridge founded on drilled shafts, spread footings, and an underground light-rail station

BRIDGE CONSTRUCTION COST: $11.4 million



Framing plan. Drawing: AECOM. Photo: Sound Transit.

overhangs of the box girder. Beyond pier 9W there is a 16-in.-thick approach slab resting on soil sandwiched between two mechanically stabilized earth walls that are about 60 ft long.

Vertical design constraints required the bridge to meet stormwater runoff requirements and match predetermined elevations for three sets of stairs, an escalator, three elevators, temporary and permanent vertical clearances for traffic, and permanent clearances for pedestrians and bicycles. The Headhouse escalator 1 and stair 1 are side-by-side structures that are supported by, and join the end of, the M1-line bridge girder near pier 6E.

Superstructure

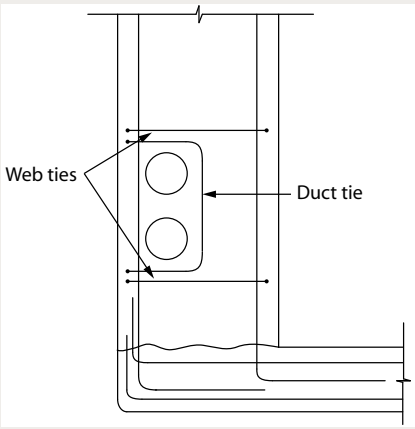
The uneven span arrangement (end-span to main-span length ratio of 0.4) required the use of special design techniques, including the use of a vertical tie rod, a hinge, and mass concrete at selected end-span box cells to control live load uplift reactions at pier and in-span hinge bearings.

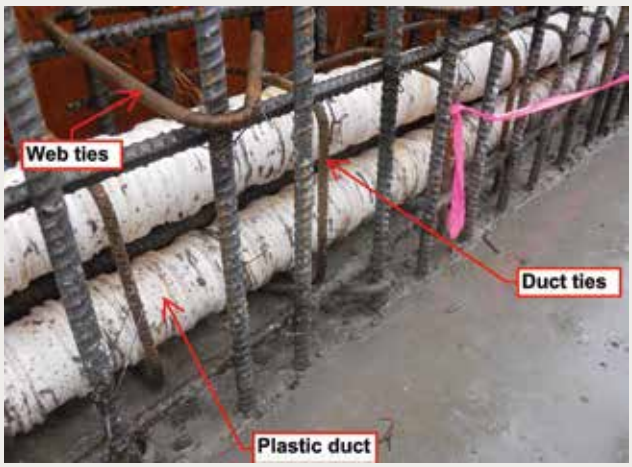
Typically, post-tensioning is avoided in highly curved bridges due to difficulties associated with the large out-of-plane forces induced. However, post-tensioning was chosen for this bridge because it allowed a shallow section that met the vertical clearance requirements and produced a high-level architectural finish without the normal cracking associated with typical reinforced concrete bridges.

In order to better resist the girder torsion due to gravity loads and the lateral bending due to horizontally curved post-tensioning, the two box girder alignments were transversely connected by a soffit slab. This soffit slab is located where the decks merge together and by integral bent cap crossbeams at piers 1 and 3. The soffit slab between the box girders where the decks converge is recessed 9 in. upward from the soffit of the box girders for aesthetic reasons.

With such a complex geometry, simplified straight line models are incapable of capturing important aspects of the structural behavior of the bridge such as the effect of the post-tensioning on the global bridge response and the concrete stress and load distribution across the bridge section. A more sophisticated three-dimensional, structural, finite-element model was used to capture the static and dynamic behavior of the bridge.

The tight horizontal bridge curvature required special post-tensioning analysis, detailing, and construction. Post-tensioning a structure with such a tight horizontal curve produces variable concrete stresses across the bridge section and causes transverse tension in the slabs between the webs and undesirable torsional effects if the tendon forces are not distributed properly. Using prestressing forces at each web that were roughly proportional to the span length of each web minimized these undesirable effects. Additionally, a construction analysis by stages was used to determine the optimal jacking sequence to minimize any undesirable post-tensioning effects.





Duct-tie and web-tie reinforcement.
Drawing and Photo: AECOM.

AESTHETICS COMMENTARY

by Frederick Gottemoeller

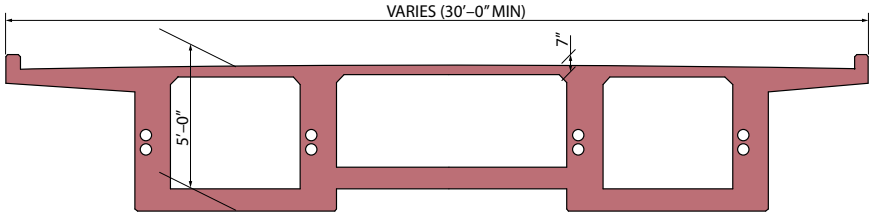
This bridge reminds me of the old television advertisements for Perdue chickens. In those advertisements, Frank Perdue would talk at length about chickens, and then end his spiel with, "It takes a tough man to grow a tender chicken." This bridge demonstrates that it takes excellent engineering to make a complicated bridge look so simple. And that's important because this bridge's aesthetic appeal is based on the simplicity with which its complex geometry is addressed. The bridge is an interesting shape, and it is unencumbered by pier caps, straddle bents, expansion joints, or any of the other details that may be distracting.

The girders are relatively shallow, giving the pedestrian areas under the bridge a feeling of spaciousness. They curve to follow the curve of the deck, creating a generous and constant-width overhang that contributes a consistent shadow line, making the girders seem even thinner. The smooth undersides of the girders provide a clean and light-colored ceiling for this outdoor space; space that pedestrians and bicyclists can occupy without worrying about birds and debris overhead.

The circular piers have no axes or planes that would conflict with the curves of the girders floating above. They also allow the myriad paths of pedestrians and bicycles to flow past them with a minimum of interference. The straightforward railing allows the overall geometry of the bridge to dominate, creating no secondary rhythms or panelization that would distract. The light poles serve their function without attracting the eye away from the bridge itself.

Once the Sound Transit University link is in service, the Montlake Triangle will be filled with the activity of pedestrians, bicyclists, and transit riders. This bridge will provide a dignified and memorable setting for all of them.

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



Typical section at frame 1. Rendering: AECOM.

The girder web stirrups also needed to be designed to resist vertical shear and lateral web bending caused by the horizontally curved post-tensioning. The strut-and-tie method was used to analyze and design the duct-tie and web-tie reinforcement to resist the local out-of-plane lateral post-tensioning forces. Special attention had to be paid to the placement of the duct-tie and web-tie reinforcement during construction, as this reinforcement was critical in resisting the post-tensioning, out-of-plane forces.

Two measures incorporated to enhance the durability of the bridge were the use of epoxy-coated reinforcement in the 7-in.-thick deck, and the use of high-density polyethylene corrugated ducts for the post-tensioning tendons.

Substructure

The girders are integral with 4-ft -diameter columns at piers 2, 3, 4E, and 4W, and with 2-ft 6-in.-diameter columns at piers 5W through 8W. The girders are supported on expansion bearings at piers 1, 5E, 6E, 9W, and at the span 3E and 4W hinges.

Another unique feature of this bridge is that the foundations are dissimilar between piers. Pier 1 is founded on two, 4-ft-diameter drilled shafts, one under the centerline of each box girder alignment. Piers 2 and 3 are founded on two-column combined spread footings 4 ft 6 in. thick. Pier 4E is founded on top of a large roof beam within the underground light-rail station. Piers 5E and 6E are part of the Headhouse building frame. Pier 4W is supported on a single-column spread footing 4 ft 6 in. thick. Piers 5W through 8W (supporting the bicycle ramp) are all founded on single-column spread footings 2 ft 6 in. thick. Pier 9W is an abutment bearing wall with wingwalls, which all bear on a spread footing that is 1 ft 9 in. thick.

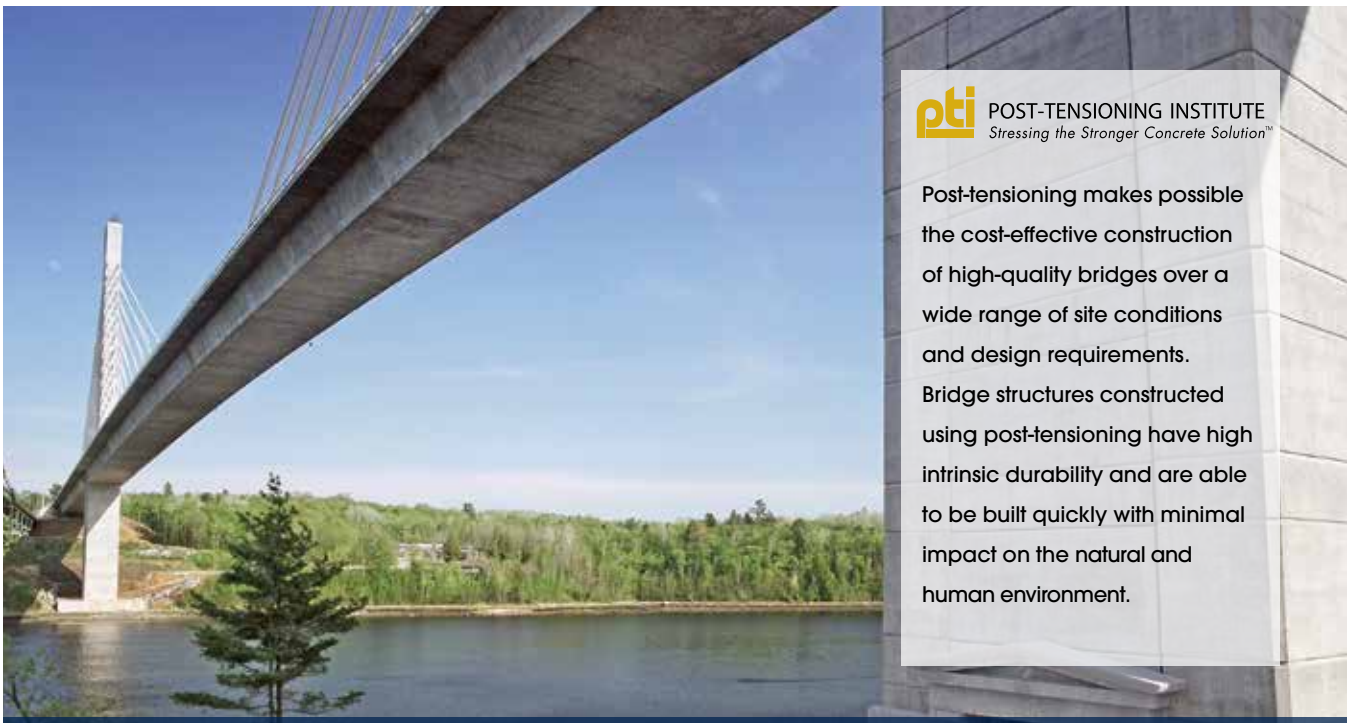
Because piers 4E, 5E, and 6E are all founded on the building frame of either the Headhouse or the station roof, the bridge engineers provided all design loads and displacements to the station designer, and included the Headhouse frame in the bridge analysis model. A special seismic design criterion was developed to satisfy bridge (displacement based) and building (force based) code philosophies for the spans supported by the Headhouse.

Final Remarks

The design of the MTP Bridge has pushed the limits for the use of post-tensioning in highly curved bridges, demonstrating that with the proper analysis and detailing, durable and low maintenance post-tensioned concrete bridges can be used for bridges.

Claudio Osses is a bridge engineer and Richard Patterson is the Washington practice lead with Buckland & Taylor in Seattle, Wash. Both Osses and Patterson were formerly with AECOM. Orin Brown and Huanzi Wang are bridge engineers with AECOM in Sacramento and Oakland, Calif., respectively.

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



MASSENA BRIDGE
LATERAL SLIDE REPLACEMENT

by Ahmad Abu-Hawash and James Nelson, Iowa Department of Transportation

This photo shows the finished Massena Bridge after the lateral slide replacement. All photos: Iowa Department of Transportation.

Improving safety and reducing congestion in the construction zone were two primary factors that motivated the Iowa Department of Transportation (Iowa DOT) to develop a policy for accelerated bridge construction (ABC). Although several ABC projects had been completed in Iowa prior to the policy implementation in 2012, the ABC policy allowed for a systematic approach to selecting ABC projects.

As part of the ABC policy implementation, the Iowa DOT selected bridge sites across the state for the purpose of demonstrating various ABC methods and developing workforce expertise. The Massena Bridge site was identified for a lateral slide. One of the advantages of this method is the use of traditional construction methods.

Massena Design

Constructed in 1930, the original bridge over a small stream in Cass County near Massena, Iowa, had been designated as structurally deficient with a sufficiency rating of 38, load posted for one truck at a time, and was in need of major rehabilitation or replacement. A 120-ft-long by 44-ft-wide prestressed concrete, single-span structure was chosen to replace the existing 40-ft-long by 30-ft-wide steel beam bridge.

With a focus on building internal ABC design expertise, the preliminary and final designs were performed by Iowa DOT engineers. But because this was the first design for a lateral slide in Iowa, a design firm with significant experience in lateral slide was retained to conduct a design-constructability review.

The bridge superstructure consists of six 45-in.-deep, prestressed concrete bulb-tee beams with specified concrete compressive strength of 9.0 ksi at 28 days and an 8-in.-thick, cast-in-place concrete deck. While much of a lateral bridge slide design depends on the means and methods chosen by the contractor, the design team chose to show one feasible slide concept and associated details in the plans. Components for the slide that were anticipated to be permanently incorporated into the final structure included the slide shoe, jacking pockets, bearing pads, and solid end diaphragms.

The solid end diaphragm details were different than those in a traditional design. The end diaphragm had to accommodate jacking pockets, high-strength threaded rods, and anchorages used to push or pull the bridge superstructure.

Laboratory Confirmation

For design of the sliding shoe and bearing pads, the coefficient of friction was needed for the interaction between the pad and specified stainless steel. The Iowa DOT commissioned laboratory testing by Iowa State University (ISU) of a full-scale mock-up of the slide shoe and bearing pads. The tests were performed in both lubricated and non-lubricated conditions with the lubricant being common dish washing soap. Test results indicated that the suggested 10% coefficient of friction for design was reasonable.

Iowa DOT had previous ABC experience and research results with precast concrete abutment footings founded on driven HP10 piling. However, an HP14x117 was selected to meet the design and constructability requirements of this project. Extrapolating the original research data to a pile about twice as large was not felt to be appropriate and so ISU was commissioned to do laboratory testing of the new precast concrete abutment footing to pile pocket detail. The laboratory testing confirmed the design capacity of the new

The lateral bridge slide ABC methodology provided a net savings of about $100,000 versus the traditional construction methodology.

larger connection details.

Bidding and Contracting

With ABC in mind, the construction contract had three phases.

- Phase 1: construction of the replacement bridge superstructure on temporary supports. Constructing off alignment allowed the contractor to work with no working days being charged.
- Phase 2: the ABC period (called the critical closure). The contractor was allowed a maximum of nine days of road closure to remove the old structure, erect the new bridge in its final position, and restore traffic operations. A $10,000 per day incentive/disincentive clause was specified for this phase.
- Phase 3: miscellaneous work performed with no or minimal traffic restrictions. This work included seeding, revetment, and clean-up. A maximum of 15 working days was allowed for this phase.

Four local contractors participated in the April 16, 2013, letting with the bids ranging from $1.3 to $1.6 million. The calculated unit cost of $122/ft^2 of deck area—30% more than typical non-ABC projects for this bridge type in Iowa—is considered very reasonable based on past Iowa ABC projects. Furthermore, this direct construction cost premium is more than offset by the indirect user costs.

User costs for the traditional construction methodology, which would have detoured traffic for the duration of the construction, were estimated at over $400,000. Indirect user costs—such as the value of people's time, safety, and lost local business due to inconvenience—were not included. If the simple user costs are factored into the cost of the project, the lateral bridge slide ABC methodology provided a net savings of about $100,000 versus the traditional construction methodology.

Contractor Modifications

In lieu of the precast concrete abutment footings that were specified in the contract documents, the contractor requested to construct the abutment footings using the traditional cast-in-place concrete method. With the understanding that the contractor is still limited to the same nine-day ABC period, Iowa DOT did not object to the request for change. The contractor utilized a concrete mixture that achieved high early strength with typical insulation. The maturity method was used to verify the concrete strength.

The new bridge superstructure nears completion. A jacking frame has been installed for a test roll.

Preparing the high-strength threaded rods to pull the prefabricated bridge superstructure into position.

The jacking frame for pulling the prefabricated bridge superstructure into position.

The switch to cast-in-place for the abutment footing eliminated the risk of the precast concrete footing pile pockets not fitting over the driven H-pile deep foundation. Pile driving tolerances were 3 in. in any direction from the intended center. Past ABC projects had shown this tolerance to be achievable with the use of a rigid template and contractor care. The contractor also felt that curing of the entire footing was preferable over the curing of just the pile pocket concrete. The larger mass of concrete generates more heat of hydration for faster strength gain versus the smaller mass of concrete of just the pile pockets alone.

The contractor also proposed to change the sliding system from the stainless steel sliding shoe and bearing pads to heavy duty rollers. The contractor had previously rolled a railroad bridge and already owned several rollers. This alternative was anticipated and allowable by the specifications. It required minor plan changes to delete the stainless steel from the sliding shoe and delete the pads from the bearings. A few weeks prior to the bridge slide, a test move was conducted successfully by rolling the bridge in the opposite direction of the actual move to verify the system operation.

Constructing and Opening

The contractor began the critical closure on Friday, September 27, by implementing the roadway detour and beginning demolition of the existing bridge. By the evening of Monday, September 30, the contractor was ready to move the prefabricated bridge superstructure commencing the move at about 7:30 p.m. The move was completed by 2:00 a.m. the next morning, taking about 6½ hours to complete. Gage pressure readings on the jacks were monitored along with the relative distance of travel of both ends of the bridge. The equivalent coefficient of friction typically varied from 2.5 to 5% with a brief period when the gage pressures correlated to an equivalent coefficient of friction of 13% due to binding or racking of the system.

Following the prefabricated concrete bridge superstructure move, there were many additional work items on the critical path including precast concrete wingwall installation, subdrain installation, backfilling, approach pavement placement, longitudinal grooving, painting, and guardrail installation. The contractor completed these activities expeditiously and reopened the roadway to traffic on Sunday, October 6.

This project was considered to be a successful demonstration of a lateral bridge slide. Both the contactor and Iowa DOT achieved the desired critical closure schedule with quality construction. Even in a successful project, there can be lessons to be learned and room for improvement on future projects.

As a standard practice on ABC projects, the Iowa DOT held a post-construction review meeting to gather feedback from both the DOT staff who worked on the project, the contractor, and the contractor's engineer. Notes from the post-construction review can be found on the project website (http://www.iowadot.gov/MassenaBridge/index.html).

Based on the success of the Massena Lateral Slide Bridge Replacement project, the Iowa DOT would not hesitate to use this ABC methodology again where appropriate. Currently, ABC design concepts for several bridge replacement projects in Iowa are being developed with serious considerations given to the lateral slide method.

Lifting the bridge superstructure with pancake jacks to remove the rollers.

Roller in guide channel for rolling the prefabricated bridge superstructure.

Ahmad Abu-Hawash is the chief structural engineer and James Nelson is a design section manager for the Iowa Department of Transportation in Ames, Iowa.

Team members for the Massena Bridge included Iowa Department of Transportation, bridge design engineer, Ames, Iowa; Herberger Construction Co., prime contractor, Indianola, Iowa; and Cretex Concrete Products, a PCI-certified precaster, Iowa Falls, Iowa.

The Long-Term Bridge Performance Program

by Jorge E. Pagán-Ortiz and Hamid Ghasemi, Federal Highway Administration; M. Myint Lwin, formerly with Federal Highway Administration; and Ali Maher, Rutgers: The State University of New Jersey

Various non-destructive evaluation technologies (impact echo, ground-penetrating radar, electrical resistivity, moisture scan, and half-cell potential) were deployed in the first pilot bridge to kick-off the Long-Term Bridge Performance Program. Photo: Federal Highway Administration.

In the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the U.S. Congress directed the Secretary of the U.S. Department of Transportation to establish a 20-year study, develop grants, and enter into cooperative agreements and contracts to

- monitor, material test, and evaluate test bridges;
- analyze the data obtained; and
- prepare products to fulfill study objectives and meet future bridge technology needs.

Accordingly, the Federal Highway Administration (FHWA) initiated a multifaceted research study in 2008 that is strategic in nature with short- and long-term goals. Under this study, referred to as the Long-Term Bridge Performance (LTBP) Program, critical aspects of bridge performance are being examined to better understand the performance of existing and new bridges. The funding for the program has continued through MAP 21-The Moving Ahead for Progress in the 21st Century Act, which is a funding and authorization bill to govern United States federal surface transportation spending.

The Research Team

The LTBP Program's research team consists of a coordinated, collaborative, multi-institutional, and multi-disciplinary group of professionals in government, academia, and industry. FHWA is the lead agency. The primary contractor is Rutgers University, working in partnership with Parsons Brinkerhoff; the Utah State University; the Virginia Center for Transportation Innovation and Research along with the University of Virginia and Virginia Tech; Bridge Diagnostic Inc.; and the technology provider, Advitam.

The research team receives regular input from advisory groups, such as the American Association of State Highway and Transportation Officials, state departments of transportation and the Transportation Research Board, to ensure that the research products are of value to the stakeholders.

Demonstration of the RABIT™ bridge deck assessment tool at the U.S. 15 Bridge over I-66 in Haymarket, Va. Photo: Rutgers University.

Developmental Phase

In the developmental phase, researchers began to synthesize existing information on bridge performance and identified performance issues facing bridge owners in the United States. Based on available resources, researchers developed a short list of high-priority bridge performance topics to be immediately considered for the long-term data collection phase of the LTBP Program. These topics include performance of treated and untreated concrete bridge decks, joints and bearings, coatings for steel superstructure elements, and encapsulated prestressing strand and post-tensioning tendons.

After identifying a prioritized list of questions to be answered, the following steps were taken:

1. Examine the questions to identify the potential for data needs.
2. Design experiments to identify the specific data to be collected.
3. Determine the feasibility and economics of collecting reliable and quantitative data both from legacy sources and from LTBP Program's field monitoring activities.
4. Sort, store, and analyze data through the LTBP Program data portal to address the question from step 1 and close the knowledge creation loop.

Robot components of the RABIT™ bridge deck assessment tool expedites field data collection. Photo: Rutgers University.

Protocols for Data

Protocols for data sampling and collection using inspection techniques and instrumentation, and data quality assurance to carry out these functions were developed to ensure consistent quality. The protocols were documented sufficiently so that any interested party can use them to collect and analyze data. This also allows for proper comparison with data already gathered by the LTBP Program. These protocols are living documents and will be updated frequently.

Sampling Methodology

The LTBP Program's sampling methodology, referred to as the reference bridge/cluster bridges approach, concentrates on small geographic areas and contiguous sections of highways known as corridors. Briefly, this concept involves identifying small groups of similar bridges, or clusters, from FHWA's National Bridge Inventory (NBI) database and studying one or more of the high-priority bridge performance topics using data collected from those bridges. The number of any one cluster will vary, but usually will be about 75 bridges.

Two to four of the bridges within each cluster will be selected as reference bridges and will undergo an optimum periodic inspection and monitoring using visual inspection supplemented with automated bridge deck non-destructive evaluation (NDE), and fiber-optic-based weigh-in-motion systems. The supporting cluster of bridges will only undergo detailed visual inspection and limited NDE or physical testing for reference bridge comparison to ascertain consistency.

Data Management

To manage data collected through the LTBP Program, it was necessary to develop an information technology infrastructure for storing, analyzing, updating, and accessing multiple data models with appropriate security considerations that could be used by a variety of stakeholders. The LTBP Program's Bridge Portal was developed to handle this requirement.

Data Collection Phase

The LTBP Program's long-term data collection phase began in March 2013 in the mid-Atlantic region and will move to other regions of the United States in 2014. The expectation is that up to 1000 bridges will undergo detailed testing, periodic evaluation, and monitoring over the next 20 years. Over 90 test protocols have been developed and are currently being deployed to standardize data collection efforts.

Finally, an automated data collection tool, the RABIT™ bridge deck assessment tool, a product of the LTBP Program, is being deployed to expedite field data collection for the study. The photo on the previous page shows the demonstration of the RABIT™ bridge deck assessment tool for FHWA's administrator, Victor Mendez, on the U.S. 15 Bridge over I-66 in Haymarket, Va.

Moving forward with data collection, researchers will continue to develop refined deterioration and life-cycle cost models and a data-driven bridge condition index. FHWA will continue its outreach efforts to make available a suite of best practices involving bridge design, construction, inspection, maintenance, preservation, and monitoring to assist bridge owners in making better management decisions.

EDITOR'S NOTE

For additional information, please visit FHWA's internet web page at http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/structures/ltbp/.

STATE

HAWAII

Concrete bridges dominate the state's bridge inventory

by Paul Santo, State of Hawaii Department of Transportation

Kahoma Stream Bridge. All photos: KSF Inc.

The first recorded bridge built in Hawaii was constructed in 1840. The first concrete bridges in Hawaii's bridge inventory are recorded as being built in 1900 and are still in service. Since then, concrete has been the predominant construction material for bridges.

More than 85% of the more than 1160 bridges in the state's inventory (including the counties) are constructed with concrete. In the last 50 years, over 95% of all permanent bridges constructed (not including culverts) have been made of concrete. Recent history shows that about nine out of every 10 bridges constructed in Hawaii are made of precast, pretensioned or post-tensioned concrete elements. Concrete bridges have proven to be a durable, cost-effective solution with lower maintenance concerns compared to timber and steel bridges.

Hawaii constructed its first bridges using precast, prestressed concrete girders in 1959. Approximately 30% of the bridges in the state's inventory are constructed using pretensioned or post-tensioned concrete technology. Hawaii's first concrete segmental box girder bridge—constructed by the balanced cantilever method—was the Kipapa Stream Bridge on Interstate Route H-2 on the island of Oahu built in 1975.

Recent History

Over the last few years, a number of bridges with significant innovative applications have been constructed by the State of Hawaii Department of Transportation, Highways Division (HDOT).

North-South Road (Kualakai Parkway) Separation

Completed in 2009, the North-South Road (Kualakai Parkway) Separation supporting Interstate Route H-1 on the island of Oahu provided some innovative developments of high-performance concrete in drilled shafts and bridge decks. The twin, single-span structures are each 165 ft long with integral abutments. Four 5-ft-diameter drilled shafts support each abutment.

Application of drilled shafts for Hawaii highway bridges had historically demonstrated several undesirable concrete properties. The aggregate usually segregated from the concrete matrix during placement resulting in lower density concrete at the top of the drilled shaft. In addition, data indicated extremely high concrete temperatures.

To overcome these difficulties, the project structural engineer designed a cohesive concrete that did not segregate, remained at temperatures below 160°F, and displayed temperature differentials of less than 35°F during hydration. The mixture proportions, which included polycarboxylate plasticizers and stabilizers, also resulted in a flowable concrete with slumps of about 10 in. This flowable characteristic was maintained throughout the casting process.

A low cement content (630 lb/yd^3) reduced the hydration temperature. This was accomplished without much loss of compressive strength because a low water-cement ratio was maintained by using a proprietary, synthetic, air-entraining admixture. Bleed water was almost non-existent.

The deck concrete materials and proportions were selected to minimize drying shrinkage, enhance fatigue endurance, minimize bleeding, and reduce plastic shrinkage compared with previous deck mixtures. The concrete contained a shrinkage-reducing admixture and synthetic air to improve workability, in combination with water-reducing, hydration-stabilizing, corrosion-inhibiting, and viscosity-modifying admixtures. For increased durability of the riding surface, synthetic fibers were added to the deck concrete to address micro- and macro-cracking. As a result of the success from this project, a number of other bridges have subsequently used similar concrete mixture proportions, especially for the deck concrete.

Kealakaha Stream Bridge

The Kealakaha Stream Bridge, located on Hawaii Belt Road (Route 19) on the island of Hawaii, was featured in the Summer 2010 issue of *ASPIRE*.™ It is a 720-ft-long, three-span, continuous concrete bridge on an 1800-ft-radius curve with a maximum span of 360 ft. This bridge utilized Washington State Department of Transportation bulb-tee girders that were spliced and made continuous with post-tensioning.

Kealakaha Stream Bridge with existing bridge in background.

Innovative features associated with this bridge included the use of friction pendulum seismic isolation bearings and a unique launching system for the long-span girders. This bridge is instrumented to monitor its behavior due to seismic loads as well as other loading conditions as part of an HDOT research project being conducted by the University of Hawaii.

Kahoma Stream Bridge

One of the most unique and innovative bridges constructed in Hawaii is the Kahoma Stream Bridge. This bridge is located on the proposed Honoapiilani Highway (Route 30) realignment on the island of Maui. This bridge was designed and constructed as part of a design-build contract. The structure is a 60-ft-wide, 360-ft-long, single span, low-profile, inverted tied concrete arch bridge on a 1200-ft radius curve.

Due to the shape of the structure, the top chord was subjected to tremendous axial forces, bending moments, and torsion. Thus, a considerable amount of reinforcing steel was placed in all top chord components—U-girders, precast concrete panels above the U-girders, deck topping, cast-in-place bent caps that connect the girders, and the top portion of the end block. Concrete for these components also required a higher level of attention in the design, handling of materials, and placement.

For increased durability of the riding surface, the deck concrete included alkali-resistant glass and synthetic fibers to address micro- and macro-cracking. In addition, admixtures were incorporated to enhance fatigue endurance, minimize bleeding, increase workability for proper placement, and reduce plastic shrinkage. At each abutment, two friction pendulum bearings were placed to accommodate rotation, expansion, and contraction of the structure.

After two years of construction at a cost of about $24 million, the bridge was opened to motorists in March 2013. As part of an HDOT research project, the University of Hawaii has instrumented this bridge and will be monitoring its behavior.

Lahainaluna Road Separation and the Kauaula Stream Bridge

Two other bridges on the proposed Honoapiilani Highway realignment on the island of Maui are the Lahainaluna Road Separation and the Kauaula Stream Bridge. Constructed in 2010, the Lahainaluna Road Separation is an elegant, slender, 130-ft-long single-span, cast-in-place post-tensioned concrete, rigid frame bridge with integral abutments that takes advantage of the massive basalt rock formations at each abutment.

The Kauaula Stream Bridge, completed in 2013, is the first geosynthetic reinforced soil (GRS) integrated bridge system (IBS) constructed in Hawaii. The 112-ft-long and 47-ft-wide superstructure is comprised of precast, post-tensioned concrete U-girders; precast, stay-in-place concrete deck panels; and a cast-in-place concrete deck. The abutments are also skewed at 31 degrees.

This system was proposed by the contractor as a value engineering proposal in lieu of an I-girder type superstructure on conventional type abutments on spread footings. The GRS-IBS technology provides a cost-effective, accelerated bridge construction solution.

The GRS abutments have been instrumented for monitoring as part of an HDOT research project being conducted by the University of Hawaii. Funding for the research associated with this project was provided by the Federal Highway Administration's Innovative Bridge Research and Deployment Program.

Current Practice

The majority of new or replacement bridges in Hawaii range in span lengths from about 30 to 130 ft. Common practice in the past has been to use precast, prestressed concrete I-girders with a composite, cast-in-place concrete deck slab. Although still used in appropriate conditions, other structural systems such as adjacent slab beams (or planks), adjacent U-girders, and adjacent tee beams with a composite, cast-in-place, concrete topping are being used to accelerate bridge construction.

Being an island state, a number of Hawaii's highways circle around each island along the coast in flood prone areas. These alternative structural systems, especially the adjacent slab beams or planks, have been effective in providing increased freeboard for replacement bridges over waterways. A recommended upper limit for spans for a precast, prestressed concrete plank system would be about 60 ft partly because of the limitation of the precast stressing beds available in Hawaii. The 80-ft-long, single-span, integral abutment Kii Stream Replacement Bridge built in 2005 on the island of Oahu utilized this system; however, the precast concrete planks were sequentially post-tensioned rather than pretensioned to achieve the prestressing.

HDOT's preference has been to use partial-depth precast concrete deck sections with composite cast-in-place concrete topping. The topping provides a means to correct any differential elevations of the precast concrete elements due to variations in camber from prestressing of adjacent elements, superelevation of roadway, vertical curves, surface imperfections, and combinations thereof. The reinforced structural concrete topping also serves as a tie between the adjacent precast concrete elements, in addition to the grouted keyways, to make the units behave as a more cohesive structural system.

Advances in technology of concrete admixtures have greatly improved the performance and behavior of concrete. Some of the admixtures routinely specified for HDOT bridge deck construction are water-reducing admixtures, shrinkage-reducing admixtures, water-based migrating corrosion-inhibitor admixtures, and polymer-based air-entrainment admixtures.

Other means to enhance concrete performance of deck slabs include more concrete cover for top reinforcing steel, use of synthetic fibers, and specifying maximum shrinkage strains at various ages of concrete. Also, the use of shrinkage-reducing admixtures and corrosion-inhibiting admixtures are usually specified for other bridge elements including walls but not for footings and drilled shafts.

Despite the limited funding available for bridge construction and maintenance, HDOT's goal is to build durable bridges that require minimal maintenance. The use of concrete has been the primary means for HDOT.

Paul Santo is bridge design engineer with the State of Hawaii Department of Transportation, Highways Division, Bridge Design Section in Kapolei, Hawaii.

Rain Rocks Rock Shed

by Mike Van De Pol, California Department of Transportation

South portal of the Rain Rocks Rock Shed. All photos: California Department of Transportation.

The California Department of Transportation (Caltrans) is making improvements to Highway 1 along the Big Sur Coast in Monterey County. The Rain Rocks Rock Shed project will restore highway reliability, decrease maintenance expenditures, and improve safety.

Unstable geology and winter storms cause landslides and rock fall at the site, regularly creating significant hardship for travelers and the coastal communities. Caltrans evaluated structure types and met with other state agencies, local agencies, and local community representatives. Among the alternatives considered were a bypass structure, a tunnel, total Highway 1 relocation, and a rock shed. Multiple rock shed configurations were explored to meet functional needs and the significant aesthetic requirements. An aesthetics advisory committee established goals and guidelines for the structure relating to form, shape, proportions, surface textures, and colors.

The selected structure follows the existing highway alignment and covers the roadway. The roadway section is composed of two 12-ft-wide lanes, 4-ft-wide shoulders, concrete barriers, and steel pipe hand railing. The rock shed is 239.5 ft long and 54.5 ft wide.

The substructure is composed of two, five-span, cast-in-place, post-tensioned concrete arched bent spans. The bent spans are supported on tapered rectangular concrete columns. The columns are founded on steel-case, cast-in-drilled-hole piles with deep rock sockets.

The roof, or superstructure, is composed of precast, prestressed arched, voided rectangular concrete girder sections, which rest on the bent caps. Concrete roof panels are joined together with post-tensioning in the direction of the roadway and are affixed to the bent caps with vertically oriented post-tensioning. The array of roof panels has a cast-in-place concrete overlay.

Internal and external retaining walls span between, and are affixed to, the bent span columns. On each end of the structure, there are variable height headwalls, intended for backfill/cover containment, structure hillside conformance, and visual relief. Tieback anchors are employed between the structure and the hillside and between the headwalls. To absorb rock fall impact loads, a combination of materials is employed on top of the roof panels. The roof cover is composed of sand, expanded polystyrene, coarse aggregate, and a grid system. The grid system is comprised of a continuous layer of welded-wire reinforcement (WWR) with a criss-cross grid of concrete bands that are cast around the WWR in a specific, normal pattern.

For structural design, a geologic history of rock fall was obtained. Employing site contours and computer simulations, rock fall parameters were developed. Structure impact zones were established with impact/force equations to develop rock impact loads on the roof cover. The impact loads were distributed through the roof matrix for structural component design. Multiple staged loadings were evaluated, including temporary static and construction equipment live loads.

Mike Van De Pol is a structures designer for the California Department of Transportation in Sacramento, Calif.

Interior view of the rock shed with roof panels in place, looking south.

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U.S. 90 Bridge over Biloxi Bay, Biloxi and Ocean Springs, MS
Engineer: Parsons Corporation
Photo: Courtesy of Parsons

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ILLINOIS TOLLWAY

Illinois easily transitions from concrete bridge pioneer to state-of-the-art designs

by Paul Kovacs, Illinois Tollway

The Illinois Tollway pioneered the use of prestressed concrete bridge beams during construction of the state's original tollway system in the late 1950s. Concrete bridge beams—both standard and unique designs—continue to be preferred for the tollway's bridge structures. Across its 286-mile system of four interstates in Northern Illinois, the Illinois Tollway favors the durability and constructability of concrete bridges, as well as the engineering advances in the construction techniques for concrete bridges.

In 2007, the Illinois Tollway completed the 12.5-mile expansion of the Veterans Memorial Tollway (I-355) featuring the Des Plaines River Valley Bridge described in the Spring 2008 issue of *ASPIRE*™. This bridge spans 1.3 miles over the Des Plaines River, the Illinois and Michigan Canal, the Sanitary and Ship Canal, several railroad lines, and forest preserve land. This was the first bridge in the state of Illinois to use post-tensioned, precast, prestressed concrete bulb-tee girders.

In 2009, reconstruction of the Reagan Memorial Tollway (I-88) twin bridges over the Fox River was completed. Structural arch members of the twin bridges support a prestressed concrete beam superstructure to reflect the design of the original bridges built in 1958. See *ASPIRE* Summer 2009 for more details.

Today, the Illinois Tollway continues to lead the way with innovative concrete bridge designs as part of its 15-year, $12 billion capital program, Move Illinois: The Illinois Tollway Driving the Future. Move Illinois will:

- address the remaining needs of the existing tollway system,
- rebuild and widen the Jane Addams Memorial Tollway (I-90) as a state-of-the-art, twenty-first century corridor,
- construct a new interchange to connect the Tri-State Tollway (I-294) to I-57,
- build a new, all-electronic Elgin-O'Hare Western Access, and
- fund planning studies for the Illinois Route 53/120 project and the Illiana (Illinois-Indiana) Expressway.

Move Illinois will include the reconstruction of more than 70 mainline and crossroad bridges as part of the I-90 Rebuilding and Widening Project. The Elgin-O'Hare Western Access Project will provide more than 80 new and improved bridge structures. Shallow depth beams are being used on the Illinois Tollway for the first time, and U-shaped girders are being considered for accelerated construction of longer spans.

In addition, as part of Move Illinois, the Illinois Tollway is extending the expected service life of major bridges out to 100 years.

Reconstruction of the Fox River Bridge on the Reagan Memorial Tollway (I-88) was completed in 2009. Photo: Henry G. Russell Inc.

This has prompted the Illinois Tollway to design several of the mainline bridges along the I-90 corridor with stainless steel reinforcement in the concrete bridge decks. This is expected to provide a long-term cost benefit.

Another long-term cost benefit is the incorporation of integral abutments in bridge designs. This design feature minimizes the bridge joints, which have shown to be the weakest link in the tollway's bridge performance chain.

The Illinois Tollway is also adopting the use of a performance-based deck concrete specification to reduce shrinkage cracking that often appears in bridge decks. The Illinois Tollway's approach is not to specify how the mixture proportions are to be developed, but to specify the end-result requirements for the plastic and hardened concrete.

Allowing concrete producers to evaluate the various tools available to reduce deck shrinkage will enable them to choose the approach that coincides with the construction contractors' activities. Options selected by local concrete producers to achieve the specification requirements have included shrinkage-reducing admixtures and lightweight fines to provide internal curing.

From its pioneering roots to the incorporation of state-of-the-art technology, the Illinois Tollway will continue to incorporate concrete bridges into its roadway infrastructure.

Traffic on the Des Plaines River Valley Bridge on the Veterans Memorial Tollway (I-355). Photo: Illinois Tollway.

Paul Kovacs is chief engineer for the Illinois Tollway in Naperville, Ill.

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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.michiganhighways.org/indepth/zilwaukee.html#history
This website contains the history of the Zilwaukee Bridge described on pages 12 to 14.

www.wsdot.gov/projects/us97/satuscreekbridge/
Visit this Washington State Department of Transportation website for additional information about the Satus Creek Bridge discussed on pages 24 to 26.

www.iowadot.gov/MassenaBridge/index.html
Visit this Iowa Department of Transportation website for information about the Massena Bridge lateral bridge slide described on pages 33 to 35. The site includes a photo and video gallery, contract documents, contractor's submittals, and a post-construction review.

www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/structures/ltbp/
This website provides more information about the FHWA Long-Term Bridge Performance Program summarized in the FHWA article on pages 36 and 37.

www.pcine.org/index.cfm/projects/bridges
This PCI Northeast website has additional information and photographs about the Fairmount Bridges described on pages 20 to 22.

Sustainability

www.sustainableinfrastructure.org
Information about Envision,™ a rating system system for sustainable infrastructure, is available at this website.

Bridge Technology

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

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

www.concretebridgeviews.com
This website contains 73 issues of *Concrete Bridge Views* (formerly *HPC Bridge Views*), an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of concrete in bridges.

NEW www.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 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.

NEW 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.

NEW 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.fhwa.dot.gov/research/resources/uhpc.cfm
This FHWA website is the location of considerable information about ultra-high-performance concrete including both research and applications.

www.fhwa.dot.gov/publications/research/infrastructure/structures/hpc/13060
A new 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.

www.abc.fiu.edu/wp-content/uploads/2013/07/ABC-User-Guide-for-posting1.pdf
This Florida International University website contains a users' 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.

Bridge Research

www.trb.org/shrp2/researchreports
Are you looking for a research report from the second Strategic Highway Research Program (SHRP2)? Nearly 90 reports organized by focus area and topic are now available as free downloads from this website.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_733.pdf
NCHRP Report 733, *High-Performance/High-Strength Lightweight Concrete for Bridge Girders and Decks* presents proposed changes to the AASHTO LRFD bridge design and construction specifications to address the use of lightweight concrete in bridge girders and decks.

AASHTO LRFD

2014 Interim Changes Related to Concrete Structures

by Dr. Dennis R. Mertz

The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures (SCOBS) convened their annual meeting in Portland, Ore., this past June. During the meeting hosted by the Oregon Department of Transportation, SCOBS considered and adopted five agenda items specifically related to concrete structures. After several years of development, Technical Committee T-10, Concrete Design, moved Agenda Items 6, 7, 9, 10, and 11 to subcommittee ballot in Portland. These agenda items represent revisions and additions to the *AASHTO LRFD Bridge Design Specifications*. This column reviews the 2013 concrete-structures agenda items, which are integrated into the 2014 seventh edition of the Specifications.

Agenda Item 6 resolves conflicting requirements and terminology regarding the distribution of longitudinal torsion reinforcement in box girders as specified in Articles 5.8.3.6.3 and 5.8.6.4. It clarifies that the calculated value of reinforcement is the total area of reinforcement to be distributed around the outer-most webs and top and bottom slabs of the box girder. The American Segmental Bridge Institute (ASBI) assisted T-10 in developing this ballot item, although the provisions in Article 5.8.3 apply to all cellular concrete cross sections.

The minimum transverse reinforcement requirement for segmentally constructed post-tensioned box girders was unified with that of all other concrete cross sections of Article 5.8.2.5 in **Agenda Item 7**. Based upon new research, this agenda item removes the previous specified exemption for segmental post-tensioned boxes and increases the minimum reinforcement by making it a function of concrete strength.

Agenda Item 9 addresses a desire to increase spacing of shear connectors to facilitate accelerated construction of concrete bridges with precast concrete deck panels. It revises Article 5.8.4.2 by increasing the maximum limit on the spacing of non-welded shear connectors to 48 in. or the depth of the member, whichever is smaller. However, an exception is made for cast-in-place box girders where the original limit of 24 in. is maintained. The revisions are based upon the findings reported in NCHRP Report 584, *Full-Depth Precast Concrete Bridge Deck Panel Systems*.

Article 5.8.6.5, which specifies the shear resistance of segmental concrete bridges, is revised by **Agenda Item 10** to allow Article 5.8.3—Sectional Design Model for shear resistance of concrete members to be applied to segmental concrete bridges. The traditional segmental concrete bridge shear-resistance provisions taken from the *AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges* continue to be an acceptable alternative. This revision increases the permitted load-carrying capacity of some segmental bridges; however the service limit-state check for shear in Article 5.8.5—Principal Stresses in Webs of Segmental Concrete Bridges, is retained as a check on serviceability.

Agenda Item 11 primarily clarifies existing Article 5.10.9.3.4b, regarding crack control behind intermediate post-tensioning anchors through tieback reinforcement, with additional commentary including illustrative figures. Also, the required length of the tie-back reinforcement is shortened.

Interim revisions to the *AASHTO LRFD Bridge Design Specifications* are considered annually by SCOBS. Their next meeting is scheduled for June 22 through 26, 2014, in Columbus, Ohio.

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.

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.*

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