ASPIRE

THE CONCRETE BRIDGE MAGAZINE

FALL 2012

www.aspirebridge.org

Delta Ponds Pedestrian Bridge

Eugene, Oregon

DART TRINITY RIVER BRIDGE
Dallas, Texas

WACKER DRIVE VIADUCT
Chicago, Illinois

MULLICA RIVER BRIDGE
Atlantic and Burlington Counties, New Jersey

RICH STREET BRIDGE
Columbus, Ohio

PEARL HARBOR MEMORIAL BRIDGE
New Haven, Connecticut

BLACK CANYON ROAD BRIDGE
San Diego County, California

FOOTHILLS BRIDGE NO. 2
Blount County, Tennessee

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

Photo: Alfred Benesch and Company.

Photo: Ohio Department of Transportation District 6.

Photo: NV5 Inc.

Features

Departments

Photo: OBEC.

Advertisers Index

Photo: PCI.

Hold It between the Ditches

William Nickas, *Editor-in-Chief*

As I began to pen this editorial, I reflected back on recent conversations I've had with a number of consulting bridge engineers and state bridge engineers.

Past engineering and construction trends are changing and while small intermediate steps are comfortable for some, bold ideas, innovation, and speed of delivery are desirable by others.

ASPIRE™ has and will continue to address both… the tried and true methods and the latest innovations appearing in the marketplace for delivering quality transportation assets.

What is your business culture? What is the culture of the direct and indirect customers you serve? I'm reminded of the old adage… "is this a push or pull technology"? Will your customer push you to change or will you help pull the industry to improve and achieve more durable solutions that can be constructed faster and more economically.

Past—The creators of this publication have provided a unique, high quality platform to publish your professional contributions and outstanding work to a vast and diverse audience. Your efforts and energy do not go unnoticed. Innovations and creative techniques take time to refine and develop into applications embraced by the broader engineering community. Clear and concise communication and strong leadership allow these advancements and game changing creative solutions to enter and benefit transportation system owners and users. The concrete industry continuously supports efforts to improve and implement technological advancements and this publication is one tool to assist in telling your concrete story.

Present—A variety of accelerated construction solutions are gaining traction and we are observing innovative solutions in several states; all with the goal of delivering assets in a timely and economical manner.

There is movement in the research arena suggesting that weight is the critical factor in accelerating bridge construction. Weight is just one factor but not the most important factor in determining a material solution. Longevity, sustainability, site and environmental conditions, and costs likely have a greater effect in determining the appropriate material solution. The turbulence created by the misinformation surrounding the idea that the lightweight structural solution is the best solution is more of a distraction than an accelerated bridge construction methodology.

Owners seek innovative solutions that not only meet the demands of today's users but are timely, sustainable, and supportable within current and projected operational and maintenance budgets.

This Fall 2012 issue of *ASPIRE* once again strives to showcase concrete bridge projects unique to our industry. The new section on ABC projects highlights delivery techniques or technology that can change the way you or someone else goes about developing a specific concrete bridge solution.

Future—As a second-generation engineer, I have picked up a few sayings and habits along the way that will, on occasion, show up in this column. Consider yourself forewarned! My father always told me to try and "Hold it between the ditches," meaning avoid distractions and stay focused on the important things in front of you. In the coming 2013 calendar year, the *ASPIRE* team will continue to highlight the attributes of bridge projects and how these examples best utilize concrete's **resiliency** and **robustness**. Keep sending the team your ideas and creative concrete solutions and remember:

Hold it between the ditches.

Log on NOW at ***www.aspirebridge.org*** and take the *ASPIRE* Reader Survey.

American Segmental Bridge Institute

American Shotcrete Association

Epoxy Interest Group

Expanded Shale Clay and Slate Institute

Portland Cement Association

Precast/Prestressed Concrete Institute

Post-Tensioning Institute

Silica Fume Association

Editor-in-Chief
William Nickas • wnickas@pci.org

Managing Technical Editor
Dr. Henry G. Russell

Managing Editor
Wally Turner • wturner@pci.org

Associate Editors
Emily B. Lorenz
Craig A. Shutt

Editorial Administration
James O. Ahtes Inc.

Art Director
Paul Grigonis

Layout Design
Tressa A. Park

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

Cover
Delta Ponds Pedestrian Bridge, Eugene, Ore., by OBEC, features an asymmetrical, three-span, sable-stayed section with fanned stays.
Photo: OBEC.

Ad Sales
Jim Oestmann
Phone: (847) 838-0500 • Cell: (847) 924-5497
Fax: (847) 838-0555 • joestmann@arlpub.com

Reprints
Paul Grigonis • pgrigonis@pci.org

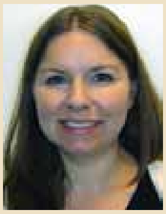
Publisher
Precast/Prestressed Concrete Institute
James G. Toscas, President

Postmaster: Send address changes to *ASPIRE*, 200 W. Adams St., Suite 2100, Chicago, IL 60606. Standard postage paid at Chicago, IL, and additional mailing offices.

ASPIRE (Vol. 6, No. 4), ISSN 1935-2093 is published quarterly by the Precast/Prestressed Concrete Institute.

If you have a project to be considered for *ASPIRE*, send information to *ASPIRE*
200 W. Adams St., Suite 2100 • Chicago, IL 60606
phone: (312) 786-0300 • www.aspirebridge.org • e-mail: info@aspirebridge.org

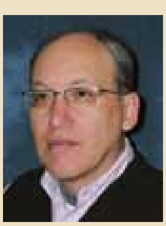
CONTRIBUTING AUTHORS



Gina Ahlstrom is a pavement engineer for the Federal Highway Administration's Office of Pavement Technology. Currently, she is managing the Sustainable Pavements Program, and the Alkali-Silica Reactivity Development and Deployment Program, among others.

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.

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



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

MANAGING TECHNICAL EDITOR

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

Photo: Ted Lacey Photography.

CONCRETE CALENDAR 2012/2013

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

October 20, 2012
ASA 2012 Fall Committee Meetings
Sheraton Centre
Toronto, Ontario, Canada

October 21-25, 2012
ACI Fall Convention
Sheraton Centre
Toronto, Ontario, Canada

October 29-30, 2012
ASBI Annual Convention
Turnberry Isle Hotel & Resort
Miami, Fla.

January 13-17, 2013
92nd Annual Meeting Transportation Research Board
Marriott Wardman Park, Omni Shoreham, and Hilton Washington
Washington, D.C.

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

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

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

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

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

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

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

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

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

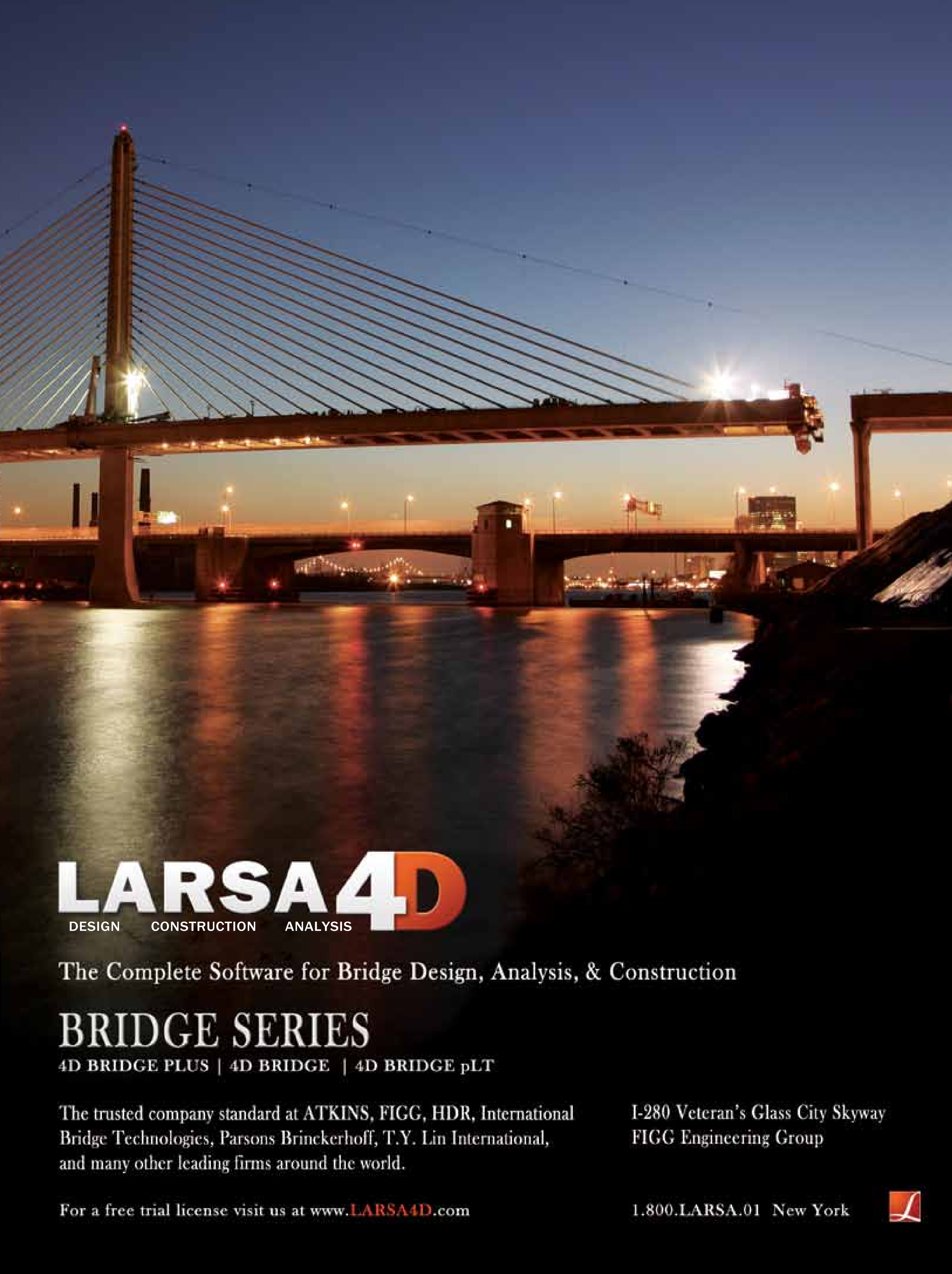
June 16-20, 2013
2013 AASHTO Subcommittee on Bridges and Structures Meeting
Portland Marriott Downtown Waterfront
Portland, Ore.

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

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

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

Correction
In the Summer 2012 issue of *ASPIRE*™, McNary Bergeron & Associates served as the Construction Engineer for both the Route 52 Bridge (p. 16) and the Veteran's Memorial Bridge (p. 32). Our apologies for this oversight.


LARSA 4D
DESIGN CONSTRUCTION ANALYSIS
The Complete Software for Bridge Design, Analysis, & Construction
BRIDGE SERIES
4D BRIDGE PLUS | 4D BRIDGE | 4D BRIDGE pLT
The trusted company standard at ATKINS, FIGG, HDR, International Bridge Technologies, Parsons Brinckerhoff, T.Y. Lin International, and many other leading firms around the world.
I-280 Veteran's Glass City Skyway
FIGG Engineering Group
For a free trial license visit us at www.LARSA4D.com
1.800.LARSA.01 New York

OBEC Focuses on Key Niches

by Craig A. Shutt

Several key areas of expertise—with innovative designs in each—keep OBEC on a successful track

Since it opened in 1966, OBEC Consulting Engineers has been a driving force for evolutions in Oregon's concrete bridge designs. Those efforts continue today, with new concepts for pedestrian bridges, arched bridges, rehabilitation, and high-performance concrete.

"We've done a lot of prestressed concrete slabs and bridges over the years, but we've grown a lot," says Guy Hakanson, vice president of technical services for the Eugene, Ore.-based transportation-engineering consulting firm. "We work on a variety of transportation projects, including many types of concrete bridges, from start to finish. And we've expanded to include roadway and heavy civil projects."

The firm's "concept-to-construction" approach to project creation gives them a unique perspective on constructability and meeting transportation officials' needs, he says. "We pride ourselves on being able to take a project from initial design through completion of construction. And the quality of the product we produce is viewed by a variety of clients as very high."

In recent years, that has meant about 90% of their bridges feature cast-in-place and precast concrete designs, he says. "We try to meet the owners' needs, and many of them prefer concrete bridges for a variety of reasons, including long-term, low maintenance, durability, and competitive initial costs."

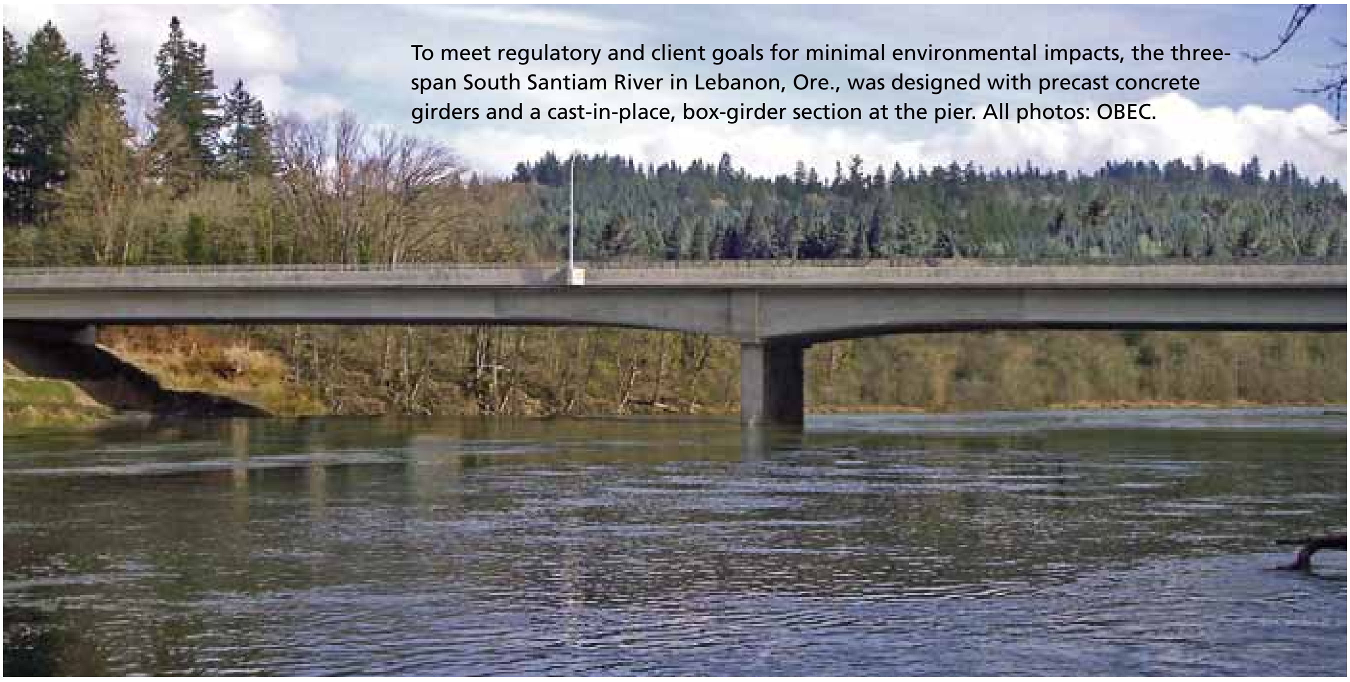
Tradition of Advances

From its earliest days, the company gained a reputation for innovation with its designs for precast concrete, notes Larry Fox, who was named OBEC president last year. That work began with founder Lou Pierce, who produced a variety of designs that advanced the concepts of precast, prestressed concrete bridge design in the late 1960s. The company was the first in the nation to design a segmental, precast, post-tensioned concrete girder bridge, which was used over a county river.

"His goal then, as with many of the designs we do today, was to minimize piers in the river and minimize the use of falsework," explains Fox. "That often leads us to precast concrete designs. We did quite a few early on, and we still do them today." To aid that, the firm helped the Oregon Department of Transportation devise precast concrete girder cross sections that are more efficient than the standard AASHTO girders, he notes.

'His goal...was to minimize piers in the river and minimize the use of falsework.'

An example of their segmental work is the South Santiam River (Grant Street) Bridge in Lebanon, Ore. The three-span, 495-ft-long structure features a combination of precast and cast-in-place concrete sections. It consists of a 55-ft-long precast, prestressed concrete slab approach span and two main spans. The center pier between the main spans supports a variable-depth cast-in-place (CIP) box girder, which extends into both spans. The remainder of each span comprises precast concrete girders that are connected to the box girders with CIP closures and post-tensioning. "The design was created



To meet regulatory and client goals for minimal environmental impacts, the three-span South Santiam River in Lebanon, Ore., was designed with precast concrete girders and a cast-in-place, box-girder section at the pier. All photos: OBEC.

The I-5 twin arch bridges in Eugene, Ore., now under construction, are the largest concrete arch spans to be built in the state.

in part to address regulatory and client goals for minimal impacts at the environmentally sensitive site," says Fox.

Willamette River Bridges

OBEC continues to push the boundaries of concrete bridge design, as seen in its work on the twin I-5 bridges over the Willamette River, now underway. The project features 1759-ft-long and 1985-ft-long structures including main arch spans of 390 and 416 ft cast with 6 ksi concrete. A girder-floor-beam-slab system comprises the superstructure, with one girder in the vertical plane of each arch rib. The project is ODOT's largest to be completed under the Oregon Transportation Investment Act of 2003 and the largest Oregon concrete arch bridge.

The complete project features a combination of bridging techniques including a cast-in-place, post-tensioned, concrete girder span with two, concrete deck arch main spans crossing the Willamette River. In addition, three spans of cast-in-place, constant-depth, post-tensioned, box girders extend over Franklin Boulevard, and three or four spans of cast-in-place, haunched, post-tensioned, box girders are used over railroad tracks, and an exit ramp.

"The desire for a signature bridge that provided very little environmental impact led us to these long concrete arch spans," says Hakanson. "They created an efficient, cost-effective approach that produced a tiny touchdown spot in the river for a very big bridge."

The design builds on another of the company's well-regarded projects, the Maple Avenue Bridge in Redmond, Ore. Design similarities include slender, unbraced ribs, composite crowns for lateral stability, compact support rib intersections, double columns for bearing-free thermal joints, and clean lines with an uncluttered appearance. (For more on the Willamette project, see the Summer 2012 issue of *ASPIRE*™; for more on Maple Avenue, see the Winter 2009 issue.)

Pedestrian Bridges

The company also has made a name for itself with distinctive pedestrian bridges. "Oregon has a reputation for being progressive in its design of multi-modal transportation facilities, and we have worked closely with state and local agencies on many of these," says Fox. "There definitely is an opportunity here for pedestrian bridges."

The company's work dates to the 1990s, when Fox collaborated with California-based consulting engineer Jiri Strasky, who designed one of the first precast concrete, stress-ribbon bridges in the Czech Republic. They met while Fox was employed in California, and he worked with Strasky on the first stress-ribbon bridge built in the United States in Redding, Calif.

The design uses precast concrete deck panels supported on bearing cables and post-tensioned to create long-span bridges. Cables are buried in the deck, creating a slight sag that replicates the look of a rope bridge, he says. "But they're extremely rigid and amazingly solid."

The firm produces a variety of styles of pedestrian bridges, including signature cable-stayed designs. The Delta Ponds Pedestrian Bridge in Eugene, Ore., for instance, is a 760-ft-long concrete bridge with a 340-ft-long, asymmetric,

The 760-ft-long Delta Ponds Pedestrian Bridge in Eugene, Ore., features a 340-ft-long, asymmetrical, three-span, cable-stayed section with fanned stays.

The Maple Avenue Bridge in Redmond, Ore., features cast-in-place concrete arches consisting of two side-by-side ribs fixed at the base while pinned to and continuous across the intermediate footings.

three-span, cable-stayed section with fanned stays. The main span features partial-depth precast concrete deck panels with cast-in-place composite topping for a maximum thickness of 1 ft 2¼ in., post-tensioned with adjacent cast-in-place concrete spans. (For more on this project, see the Spring 2012 issue of *ASPIRE*.)

"We've developed a strong expertise, which leads to more projects," Fox notes. "We've been contacted by officials around the country who have seen reports on our bridges, including those in *ASPIRE*. That's helped spread the word outside Oregon."

Community Gateways

Pedestrian bridges often feature signature styling, he notes, because they serve as gateways to communities or as landmarks for pathways. "Communities don't want just plain appearances for these structures. And the technology is economical." The firm produces many of these designs for under $400/ft^2.

'We often use cable-stayed designs because form should follow function.'

"We often use cable-stayed designs because form should follow function," says Hakanson. "Owners want low profiles and shallow walking surfaces to provide high clearance. So the choices result from a combination of logistics and aesthetics."

This design style can add cost to the structure, he notes, but it pays off with less long-term maintenance and reduced approach-path work. "The bridges aren't as high, so they require fewer mechanically stabilized earth walls, and they're more user-friendly because they're not higher than the surrounding paths, making it more efficient to meet the Americans with Disabilities Act requirements."

In addition to its pedestrian bridges, the firm also has gained renown for its work on bike trails, paths, and covered bridges. Although these bridges typically replicate original timber-covered designs, the foundations usually are cast-in-place concrete, he says.

Arched Bridges Grow

The company has developed a strong expertise in arched construction, too, which often replicates existing designs. "Cast-in-place, concrete-deck arch bridges have definitely become a strong niche for us," says Fox. "They're usually modern versions of traditional styles."

The inventory of such work derives in part from renowned bridge designer Conde McCullough's designs in the 1920s and 1930s, especially along Oregon's coast. "He created a number of beautiful arched bridges that are being preserved today," Fox explains. OBEC's updated approach includes eliminating spandrel columns wherever possible. They also minimize transverse cross bracing between arch ribs by making the arches monolithic with the superstructure at the arch's crown.

The Maple Avenue design featured dramatic cast-in-place arches, consisting of two side-by-side ribs fixed at the footing while pinned to and continuous across the intermediate footings. Each of the three continuous 210-ft-long arch spans has a different parabola to conform to the contours of Dry Canyon, which it spans.

"Our goal is to add modernizing features to create a similar appearance to Oregon's historic arch bridges while enhancing the aesthetics created with our designs," Fox says. "But we also want to provide as few structural columns and braces as possible, because that makes them easier to maintain."

Rehabilitation Work Expands

Easy maintenance has become a watchword with bridge officials today, both engineers agree, as funds must stretch further. For that reason, the firm has found a strong niche in rehabilitation. "We have seen a huge push for funding more rehabilitation, due to the aging of infrastructure and the current funding constraints," says Fox. "We've created a good niche in that area and have helped ODOT with a number of projects."

One recent innovative design repaired the Oregon City Arch Bridge, a Conde McCullough design. The $10.6-million rehabilitation project used creative concrete techniques to rehabilitate the 755-ft-long bridge, which was built with structural steel covered with gunite, cast-in-place concrete, and other coatings. The weakened structure required extensive repairs, including a new concrete deck overlay and replacement of a variety of concrete elements, including floor-beam end and hanger concrete, arch-chamber bottom slabs, sidewalks, railings, and pylons.

Shotcrete replaced the deteriorating gunite. "Finding the proper mix to accurately create the concrete encasements that would stick to the original steel was more challenging than we expected," Fox explains. "But we expect to see a lot more of such unusual work as we deal with our aging infrastructure. We have a responsibility to maintain our historic bridges whenever possible."

'We have a responsibility to maintain our historic bridges whenever possible.'

Concrete Advances

Creating new concrete mixtures offers great potential, Hakanson notes. The firm has been experimenting with various high-performance concrete options, to improve durability rather than strength. "Oregon has a wet climate, along with salt water along the coast, so we're looking at a variety of additives to decrease permeability." Durable deck concrete offers great opportunities, as decks experience the most exposure to weather and therefore need the greatest protection, Fox notes.

For a recent bascule-bridge replacement, the owners required a 5-in.-thick concrete deck and demanded that it be crack-free. "It was a major challenge," Fox says. "But we did extensive research and found a mix design that worked."

The firm also is frequently using a "quaternary" concrete that blends cement, fly ash, silica fume, and slag cement. "The chemistry of the four creates reactions that produce catalysts that create additional reactions. The end result is lower permeability and increased durability," explains Hakanson. "It becomes greater than the sum of the parts."

OBEC also is adding reinforcing fibers to key concrete areas. "We've achieved pretty high-quality results, and we expect to be able to build on that for future designs."

Hakanson also has seen impressive results from increasing the amount of slag cement in concrete. "I look at it from a material properties standpoint and see advantages, while owners and suppliers see it as a green product that reuses waste products," he notes. "It also can decrease costs and improve durability. So there are many good reasons for its use to grow."

Those capabilities will expand as owners stress doing more with less, Fox says. "Transportation dollars are becoming more constrained, so rehabilitation will be used to help spread funds to more locations to keep bridges open. It may not be the ideal approach, but it's practical, and that's the philosophy that will be needed."

OBEC understands the market's realities, too. It has begun expanding its efforts in other fields, such as non-highway transportation projects, including water reservoirs. "We developed that work early on, but recently we have begun to grow that segment to become more diversified and find new ways to help owners," says Fox.

Such new challenges keep the designers excited, Hakanson says. "Owners are developing new requirements, which make each job a new challenge. But that's what keeps us going and drives our work. It's fun to attack new challenges to find the best solutions."

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

A complex rehabilitation project of the Oregon City Arch Bridge used an innovative, custom shotcrete mix specifically designed to adhere to the existing steel.

46 Years of Designs

The Oregon Bridge Engineering Co., Consulting Engineers, was founded in Eugene, Ore., in 1966 by partners Wally Palmateer and Lou Pierce.

The partners split off from Hamilton Construction Co., creating such early designs as the Mary Beckley cast-in-place concrete replacement bridge in Elkton in 1966 and the Seven-Mile Bridge for Weyerhaeuser Co. in Coos Bay in 1967.

The company, which shortened its name to OBEC in 1977, currently has 102 employees in five offices, with most located in the Eugene headquarters. The other offices comprise Salem, Medford, Lake Oswego (which in February moved to a larger location), all in Oregon, and their newest office in Vancouver, Wash.

Uniform Service Life of Bridge Elements through Design and Preservation

Service-life-design plans may be the key

by Bruce V. Johnson, Oregon Department of Transportation

The average age of bridges in the United States is nearing 50 years. This means that agencies are spending a greater proportion of the limited transportation funding maintaining these aging bridges and when necessary, replacing them. The graph shows the number of bridges built during various decades and those remaining in Oregon. This chart shows that there are many bridges in service that are over 40 years old with growing needs. In Oregon the elements that consume the most maintenance resources are

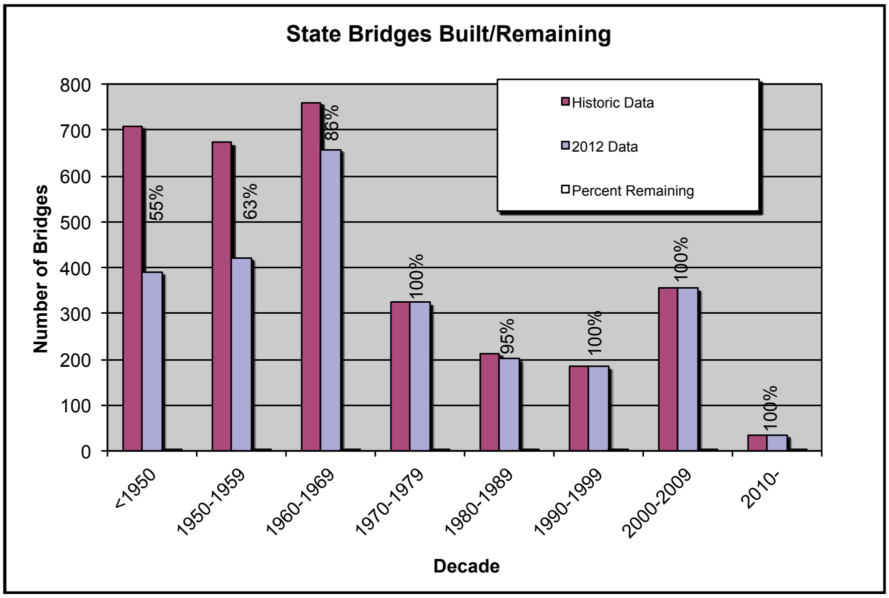
- decks (patching, sealing, and overlays),
- steel girders (painting and fatigue mitigation),
- expansion joints (resealing, patching, and replacements), and
- bearings (cleaning, painting, and replacements).

While only some areas of the country have major issues with corrosion on substructures and scour issues, maintenance crews throughout the nation spend significant resources preserving decks, joints, and steel bridges.

Extending Service Life of New and Existing Bridges

Many questions are raised when considering design lives of bridges:

- Why doesn't a bridge deck or deck joint last as long as most superstructures and substructures and is that a realistic goal?
- Would it be more cost effective to design and construct a deck or expansion joint that would last 100 years without major rehabilitation?
- What would the design specifications for a 100-year deck joint look like?
- Would the stresses need to be limited to some very low value?
- Would you need to design three or more redundant deck sealing systems to avoid corrosion and the constant maintenance needed to maintain cathodic protection systems?
- How can you limit the build up of debris that is the killer of all sealing systems without consistent maintenance actions?
- Should we just be more explicit about the need for scheduled maintenance and preservation actions to achieve the service life we want?



Percent of state-owned bridges still in service in Oregon by decade. Figure: Oregon Department of Transportation.

The aviation and nuclear energy industries have concluded that both service-life design and preservation actions are the only way to ensure desired performance and safety. Is it time for the civil engineering discipline to take a similar structured approach to service life and preservation?

Two very different approaches can be considered to extend service life. One approach is to design and construct using indestructible materials at a greatly increased first cost. Bid prices to construct a 100-year bridge element would likely be higher than one intended for a 50-year life.

The other approach is to design and construct with ordinary materials, and require inspection and maintenance activities at specified intervals to keep the structure safe and in serviceable condition throughout the service life. This practice is consistent with the aviation and nuclear industries, where safety is paramount but indestructible materials sometimes cannot be used due to their cost (or weight).

Several agencies are working to develop a systematic, rational method of designing bridges with elements that have a uniform service life. Bridge designers do this to a certain extent today, but for the most part it is done subjectively. Decisions regarding deck joints, materials such as high-performance concrete, high-performance reinforcement, and bridge type are sometimes justified by seeking longer service life, but normally without developing detailed life-cycle costs over the desired years of acceptable service life. One challenge in taking a more-structured approach to design for service life is that we do not have readily available, easy-to-use tools for analysis.

Deck sealing was completed by Oregon Department of Transportation bridge maintenance crew. Photo: Oregon Department of Transportation.

Nor do we have the substantiated performance metrics of all the different elements used in bridges needed for analysis. In developing these metrics it would be preferable not to be driven entirely by past practices, because the industry is making progress using more durable materials, improving design detailing, and increasing construction quality. That means projections from old data may not provide the best answers for service life estimation. But, it seems clear that complete historic performance data that includes tracking the impact of preservation and maintenance is the best starting place.

Three reports are to be released in the future that may assist with development of this rational, detailed approach:

- SHRP2 Program R-19A, "Bridges for 100-year Service Life" (early 2013)
- SHRP2 Program R-19B, "Bridges for 100-year Service Life—Calibration" (early 2014)
- NCHRP Project 14-23, "Practical Bridge Preservation Actions and Investment Strategies" (early 2015)

Design for service life may include the use of improved materials and structure configurations, or may include a detailed plan for expected preservation actions to extend service life, or some combination of both. Either way, a designer should be able to issue a service-life-design plan with a high expectation that the structure will provide the intended service life, at least with respect to predictable deterioration mechanisms. Extreme events at levels higher than predicted by probabilistic design methods could always threaten the expected service life, but environmental mechanisms such as corrosion and load effects such as live loads or abrasion, would be covered in the service-life-design plan.

This concept is not new because it has long been an integral part of design of mechanical structures used in airplanes and nuclear facilities. We are at a point where rational service-life design is possible and considered worth the effort for major, significant bridges. It may be that owner agencies will choose to use this process only for those bridges, but as the procedures are streamlined and tools are developed and presented that are very easy to use, and have been correlated to achieve results close to actual experience; the process could be extended to routine bridges.

Developing a service-life-design plan can also be extended to existing bridges based on their existing design or in the development of a rehabilitation project. In the case of an existing bridge, elements with a short service life can only be covered by a plan for preservation or maintenance actions. If the service life design is conducted as part of a rehabilitation project, there would be options for increasing the life by use of high-performance materials or a combination of planned actions.

One of the benefits of extending this process to routine bridges is that a preservation program could be developed as a roll up of the planned actions for bridges. A program of preservation developed from actual planned actions could be a very persuasive method for targeting limited budgets for preservation. Defining needs and executing a more systematic program of preventive maintenance and preservation actions for the entire inventory may be the only viable solution for retaining the effectiveness of our highway system.

fib *Approach*

The Model Code for Service Life Design, published by the International Federation for Structural Concrete (fib) in 2006, provides the following four approaches for service life design. These are:

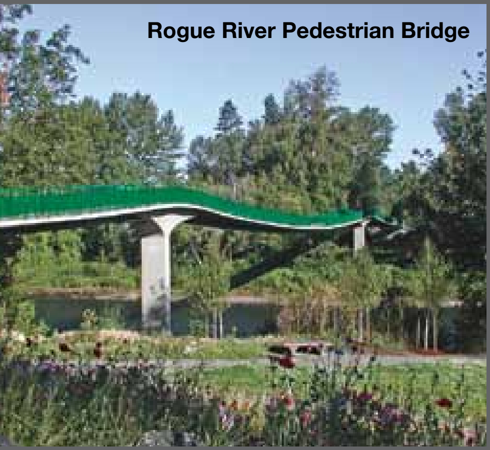
1. full probabilistic design,
2. partial probabilistic design,
3. deemed to satisfy design, and
4. avoidance of deterioration design.

Option 1 is intended for use on exceptional structures. Option 2 is a deterministic approach where material resistance and environmental loads are considered using partial safety factors. Options 3 and 4 are similar to those found in today's standards such as the *AASHTO LRFD Bridge Design and Construction Specifications*.

The fib code is directed more towards European practices. No comparable documentation based on U.S. practices currently exists. For more information about designing concrete bridges for longer service life, the reader is referred to the following American Segmental Bridge Institute (ASBI) publication: *Design and Construction of Segmental Concrete Bridges for Service Life of 100 to 150 years* by Steem Rostam. Available at www.asbi-assoc.org. Click on publications and ASBI Technical Reports and then scroll down to the bottom of the list. The Rostam paper was also reprinted with permission in the Jan.-Feb. 2008 issue of the *PCI Journal.*

Bruce Johnson is a state bridge engineer with the Oregon Department of Transportation in Salem, Ore.


Delta Ponds Pedestrian Bridge
MAKE A
STATEMENT
At OBEC Consulting Engineers, we specialize in the design of signature pedestrian bridges that are constructable, cost-effective, and most importantly — elegant.


Rogue River Pedestrian Bridge


McLoughlin Blvd. Pedestrian Bridge


DeFazio Pedestrian Bridge

Curved, Spliced, U-Girders Gain Momentum

by Craig A. Shutt

Precast concrete spliced U-girders offer key benefits when designing longer spans for continuous structures. Now, curved versions of these girders are expanding the options further—and state departments of transportation (DOTs) are noticing. Officials at the Florida Department of Transportation (FDOT) have put an extensive array of these designs on their website—and they're being used to win bids.

"U-girders represent a relatively new but standardized cross section that has sufficient strength and stability to benefit long-span bridges in many ways," says William Nickas, managing director of transportation services at the Precast/Prestressed Concrete Institute (PCI). "Engineers now are building on those concepts to develop curved sections that expand the use of U-girders, especially in freeway interchange projects."

The girders offer lower fabrication times, faster construction, longer spans, and increased aesthetic appeal due to their ability to provide unified appearance, according to FDOT. Initial work on these designs was done with the Colorado DOT, and now Florida DOT has embraced them as a new option.

The department has devoted a section of its website to the capabilities, showing key requirements, allowances, design criteria, and other data. The site also includes photo slideshows, example drawings created by PCI Zone 6 Producers (SE area), and several presentations, including one showing designs used in Colorado.

The site can be accessed at www.dot.state.fl.us/structures/innovation/UBEAM.shtm or by going to the FDOT site. On the page, click the Offices pull-down menu on the left side, click Structures Design, then click the large green button marked "Invitation to Innovation." Under "Innovative Ideas," click "Curved Precast Spliced U-Girder Bridges." The site is best viewed through Internet Explorer.

Florida is promoting these designs in part due to its decentralized approach and encouragement of design-build delivery methods. "Success in this new era depends on the ability to innovate the products and services that Florida's transportation system provides its users," the site explains. "The Office of Design's mission for innovation will utilize newly developed technology or employ 'outside the box' thinking to generate new and better value for every transportation dollar invested."

The site encourages designers and contractors "to propose one or more of these innovations for project specific solutions with confidence of approval by the District. Many of these innovations have been successfully implemented in other states and countries," it says, noting that not all projects will benefit from these new technologies.

Girders at Boggy Creek

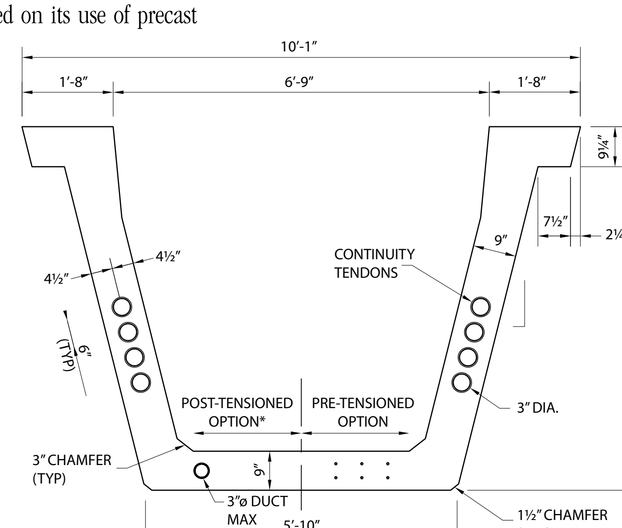
Designers and contractors are responding, too. For example, the Boggy Creek interchange on SR 417 in Orlando, Fla., was recently put out to bid with four alternatives by the Orlando-Orange County Expressway Authority. The $70 million project will revamp the existing interchange to add a flyover and more lanes to help traffic flow more smoothly to the nearby airport and expanding communities. Four options were proposed, and the all-concrete version was the apparent as low bid, based on its use of precast concrete U-girders, including curved segments.

"This project shows that spliced, curved, precast concrete U-girders are more than an innovation to be tested, they are in use and providing benefits to states looking to get the most out of their transportation funding resources, like Colorado and Florida," says Nickas. PCI now is working with at least three other states to provide solutions and design aids customized to their locations.

Construction of the IH-25 Viaduct, located in Trinidad, Colo., includes spliced, curved, precast concrete U-girders. Photo: PCI.

EDITOR'S NOTE

More information can be found at www.gcpci.org/index.cfm/technical/products.



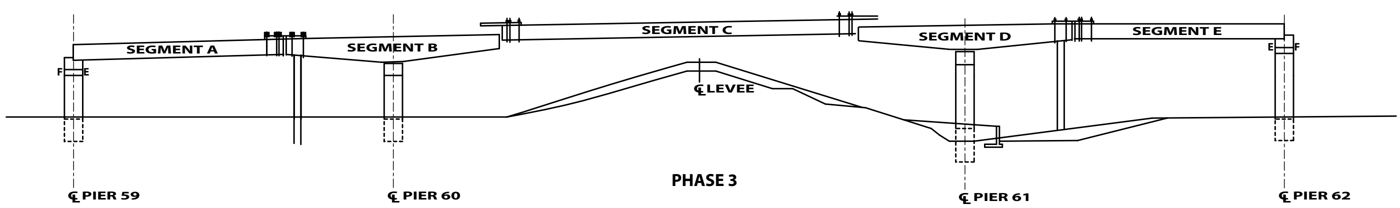
Typical cross section of the U72-3 curved, precast, spliced U-girders was created by PCI Zone 6 Producers (SE area) and is located on the FDOT website. Drawing: PCI Zone 6 Producers (SE area).

PROJECT

DART *Trinity River Bridge*

A Design-Build, Precast Concrete, Spliced-Girder Bridge Solution

by Thomas W. Stelmack, Parsons, and Jonathan Kempfer, Kiewit Infrastructure South Co.



Trinity River Bridge girder layout and erection sequence showing temporary supports. All drawings and photos: Kiewit, Stacy and Witbeck, Reyes, and Parsons, a Joint Venture.

Dallas Area Rapid Transit's (DART's) Irving 1 and Irving 2 segments of the 14-mile Orange Line will extend from Bachman Station in northwest Dallas (on the Green Line) to Belt Line Road at the southern portion of Dallas-Fort Worth International Airport. This will complete 90 miles of DART's rail network by 2014. The 9.3-mile segment includes six stations and eight bridges; one of them is a 7000-ft-long structure over the Trinity River.

The project had its challenges, specifically the design and construction of the Trinity River levee crossing, a three-span, post-tensioned, spliced, precast concrete girder structure. The alignment is vertically constrained by adjacent overhead power lines and a U.S. Army Corps of Engineers (USACE) levee below. These limitations required a structure capable of spanning 260 ft without any temporary supports or placement of heavy equipment on the levee. Through an integrated approach, the design-build team developed a constructable and economical solution.

Alternatives Considered

The completed dual-track structure is a three-span, continuous unit with span lengths of 145, 260, and 145 ft. Each of the six girder lines comprises five girder segments. Girder segments B and D are balanced over the central piers and are stabilized with a temporary support tower beneath the end spans, as shown in the girder layout. The remaining girder segments—A, C, and E—are supported using overhead steel, strong-back beams. The construction sequence, developed in concert with the contractor, during design, ensured that the levee remained undisturbed during construction.

Critical Design Aspects

Because of the tight project schedule and the need to begin construction activities as soon as possible, it was critical for the design of the foundations to be completed before the superstructure design. The foundation for all piers consisted of a single, 108-in.-diameter drilled shaft below each column. This foundation design was rapidly constructed and cost effective. The foundations and substructure were designed, approved by the owner and the USACE, and then constructed well in advance of the girder erection.

Although precast concrete girders are used extensively in Texas, the deepest of the Texas Department of Transportation standard girders was 70 in., which would not be sufficient for the selected structural configuration. The 70-in.-deep standard girder was modified by increasing the web depth by 12 in. and the web thickness from 7 to 8 in. This newly created girder is designated the TX82.

The increased web thickness was used to help with shear capacity and, more importantly, to accommodate the longitudinal post-tensioning tendons located within the web. This girder section is used for segments A, C, and E. The middle segment of the levy span is 160 ft long, and at the time of construction, was the longest precast concrete girder ever erected in Texas. For girder segments B and D, located over the main piers, the standard girders were once more modified by utilizing a variable depth that increased the maximum depth by an additional 4 ft, resulting in a 10 ft 10 in. total girder section depth at the pier.

The transportation, construction, and final configuration of the segments posed a challenge for the prestressing design, requiring a combination of pretensioning and post-tensioning, as well as temporary prestressing. A number of different support methods were used during transportation and erection, requiring a delicate balance of stresses for each of the configurations. Standard (7-wire) precast concrete girder pretensioning

profile

DART TRINITY RIVER BRIDGE / DALLAS, TEXAS

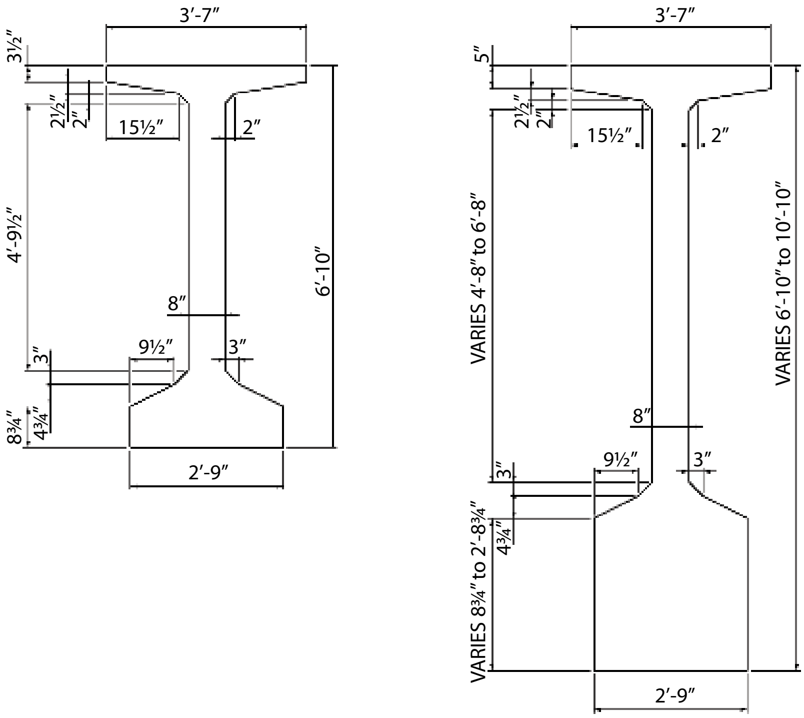
BRIDGE DESIGN ENGINEER: Parsons, Denver, Colo.

PRIME CONTRACTOR: Kiewit, Stacy and Witbeck, Reyes, and Parsons, a Joint Venture (KSWRP); Dallas, Tex.

CAST-IN-PLACE CONCRETE SUPPLIER: Lone Star Ready Mix, Leander, Tex. (batch plant set up on site)

PRECASTER: Bexar Concrete, San Antonio, Tex.

POST-TENSIONING CONTRACTOR: DYWIDAG-Systems International USA Inc. Bolingbrook, Ill.



The Kiewit, Stacy and Witbeck, Reyes, and Parsons, a Joint Venture, developed TX82 cross-section dimensions. Left: Constant-depth girder segments A, C, and E. Right: Variable-depth girder segments B and D.

strand was used in all the prismatic girder segments, providing the compression needed for the handling of the segments before splicing the segments together.

For the variable-depth segments over the piers, permanent post-tensioning was used at the top of the section for the negative moments. This avoided the need to provide pretensioning at the level of the top flange. A single, temporary tendon was required in the bottom of the pier segments to handle positive moments during storage and transport when the support points were located close to the ends of the girders. Similarly, external temporary prestressing was used for C segments to mitigate the negative bending, at the ends, during transport and lifting.

Other critical design aspects requiring close coordination between the design-build team and construction groups included the following:

- Determination of the maximum size of the girder segments
- Location of cranes for critical girder lifts
- Location of the temporary support frames
- Location of the splice points

The construction sequencing, the location of temporary supports, and the location of the girder splice points were an integral part of the analysis model. The layout of the girder segments and the location for the temporary support tower at the side-span end of the variable-depth, pier girder segment required the tower to resist a significant amount of uplift prior to the completion of the girder splicing and post-tensioning.

Tie-down bars from the girders to the top of the tower frame, allowed the uplift to transfer through the steel frame

Girder segments D supported on temporary bent with E-girder segments partially constructed supported by overhead strongbacks.

to the large concrete spread footing. The footing distributed the compression loads in the tower from segments A and E before the drop-in segment C was set. After setting segment C, the footing's weight was used as a deadman to resist the uplift.

Construction of Segment C

Of the five girder segments slated for erection, segment C proved the most challenging. With a girder length slightly longer than 160 ft and weighing more than 214,000 lb, its erection was further complicated by the proximity to underground utilities. Specifically, a 48-in.-diameter water main and 4-in.-diameter, high-pressure gas line, combined with very limited working space.

The first challenge was identifying a crane that could safely make the single-point lift and offer the smallest footprint and ground-bearing pressure.

The selected crane, a CC9600 750-ton Versa Crane, met the performance and small footprint requirements, but concerns about its bearing-pressure and impacts to underground utilities at

DALLAS AREA RAPID TRANSIT (DART), OWNER

BRIDGE DESCRIPTION: A 550-ft-long, three-span, spliced and post-tensioned precast concrete girder bridge carrying dual-track light rail, with single, 108-in.-diameter, drilled-shaft foundations

STRUCTURAL COMPONENTS: 18 constant depth and 12 variable depth precast concrete girders; and cast-in-place deck, bent caps, concrete columns, and drilled shafts

The crane was positioned on a temporary crane pad to protect critical utilities below.

Girder segments A, C and E are supported using overhead strongbacks prior to the cast-in-place concrete closures being cast.

full load required evaluation. The crane would exert a total force of 1.6 million pounds. Compromising the water main would be catastrophic, shutting down water service to large portions of the cities of Dallas and Irving, Tex. The design of the crane pad went through extensive analysis and peer review to ensure the crane would not overload the underground utilities. Further complicating the girder segment lifting operation was the proximity of the 345-kV overhead transmission lines.

The contractor developed a lift plan for the safe rigging and execution of the segment C girders and positioned the crane on-site a week prior to the scheduled set date. The weight and quantity of the individual crane components, combined with the transportation requirements, required 68 truckloads to haul all of the lifting components to the construction site. The transportation and assembly of the crane took five days and a separate 240-ton support crane.

When the crane was fully assembled and readied, the segment C girders were loaded and hauled to the jobsite. Two trucks were modified to transport the girders; meaning only two girders could be delivered every other day. Two, however, would prove challenging enough to get into position, rig, and set within the allotted traffic-closure time frame. All deliveries of the segment C girders followed the same route to the site, with an against-normal, traffic-flow pattern.

The strong-backs rested on the ends of segments B and D girders. The high risk of the pick, given the proximity to the overhead transmission lines, warranted many precautions. Air tuggers, mounted on the crane counterweights and cabled to each end of the girder segment enhanced girder control and placement.

Once each segment-C girder was set into place (so that the strong-backs were supported from segments B and D), the crew installed the tie-down rods and applied the required torque to each rod. After the rods were torqued and independently verified by the design team, segment C was released from the crane.

Once all the C segments were set in place, they were then connected to segments B and D with cast-in-place (CIP) concrete closures. Post-tensioning of the girder segments began after all CIP closures and diaphragms were constructed, curing was completed, and concrete strength achieved. More than 40 miles of post-tensioning strand were installed in the project, and a standard CIP reinforced concrete deck slab completed the structure.

The completed DART Trinity River Bridge over the U.S. Army Corps of Engineers levee.

The Value of Integration

The DART Orange Line project had many key aspects, but none more significant than the design and construction of the Trinity River levee crossing. The difficult horizontal and vertical clearance restrictions due to the levee and the overhead power lines, the limited access available for large girders, and the need to get the structure completed early to allow for rail installation made this bridge a challenging design task and critical to the overall success of the project. Construction also posed many challenges, including site access, night work requirements, a massive crane resting on utilities, and a variety of temporary works. Successfully meeting all of the design and construction challenges required an innovative design and construction approach, effectively integrated through the design-build team delivery process.

Thomas W. Stelmack is principal project manager, Parsons, Denver, Colo., and Jonathan Kempfer is DART Orange Line I-3 project director, Kiewit Infrastructure South Co., Dallas, Tex.

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

Silica Fume Association

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

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

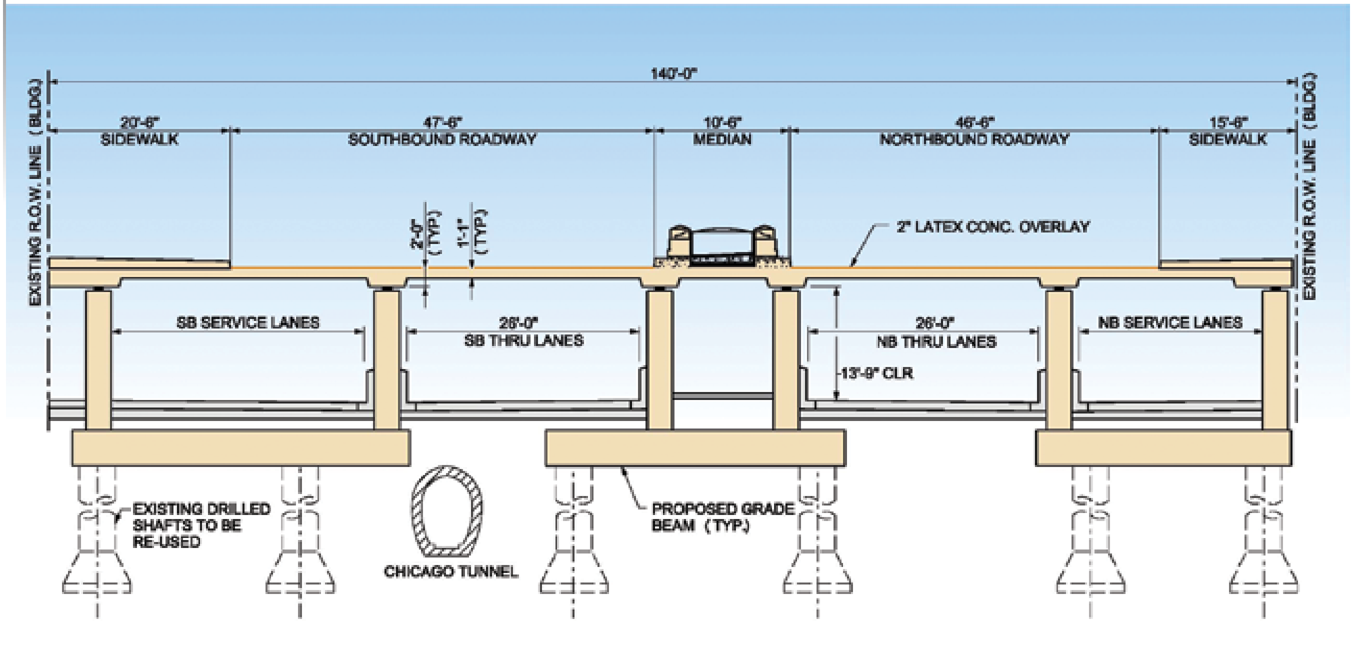
Some of the recent projects completed by the SFA, under a cooperative agreement with the Federal Highway Administration (FHWA), include:

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

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

Reconstructing Chicago's Prized Wacker Drive

by Andrew Keaschall and Hossam Abdou, Alfred Benesch and Company, and Johnny Morcos, Chicago Department of Transportation



Typical cross section through the viaduct. Figure: Chicago Department of Transportation.

A critical downtown artery, Wacker Drive is home to several buildings that define Chicago's iconic skyline. The street is actually a multi-level viaduct structure with upper- and lower-level traffic that jogs along the Chicago River and borders the central business district. The Willis Tower (formerly the Sears Tower), the Civic Opera House, and the Chicago Mercantile Exchange are among those that claim a prestigious Wacker Drive address. An estimated 60,000 vehicles use the drive daily, along with 225,000 pedestrians and vehicles on the associated cross streets.

The north-south leg of the viaduct is being reconstructed to modernize the upper and lower levels, providing a safer, more-efficient roadway for motorists and pedestrians. The reconstructed viaduct is 2900 ft long and 140 ft wide, equaling more than nine acres. This project is an exceptional example of complex urban reconstruction with notable accomplishments in structural engineering, stakeholder communication, maintenance of traffic, and infrastructure security.

Substructure and Geometry Details

The upper deck is supported by individual columns located to accommodate the main travel lanes, service lanes, a median, and numerous building entrances on Lower Wacker Drive. The 3-ft-diameter columns are spaced roughly at 32 ft on center in the longitudinal direction. The transverse spacing varies to accommodate the different constraints as shown in the typical section. The columns at the expansion joints utilize a hammerhead cap in order to support bearing lines for

profile

WACKER DRIVE VIADUCT / RANDOLPH ST. TO MONROE ST.—CHICAGO, ILLINOIS

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

CONSTRUCTION ENGINEER: Parsons Brinckerhoff, Chicago, Ill.

PROGRAM MANAGEMENT ENGINEER: TranSystems Corp, Schaumburg, Ill.

PRIME CONTRACTOR: McHugh Construction, Chicago, Ill.

READY-MIX CONCRETE SUPPLIER: Ozinga Concrete, Mokena, Ill.

POST-TENSIONING CONTRACTOR: DYWIDAG-Systems International USA Inc., Bolingbrook, Ill.

the up-station and down-station deck segments.

New grade beams are typically 5 ft wide by 4 ft deep, but increase to 5 ft by 5 ft at expansion joints to accommodate increased torsional loading from the hammerhead columns. Adjusting the column locations required reconstruction of the existing grade beams, which were supported on belled shafts extending approximately 60 ft below the surface to a hardpan clay layer. The revised column arrangement caused some existing shafts to bear substantial additional loading. In certain locations, pressure-meter testing was conducted to justify increasing the allowable bearing pressure from the 12,000 psf, used in the original design, to upwards of 20,000 psf. All told, 254 of the 264 existing 4-ft-diameter belled shafts were able to be reused, and only eight new shafts drilled.

Another main goal of the reconstruction was to upgrade the alignment of both the upper and lower levels. Re-aligning the Lower Wacker Drive service and travel lanes proved to be the greatest geometric challenge because it affected the locations of the columns previously mentioned. The main geometric modifications to the Upper Wacker Drive Viaduct involved reducing the number of access points between Upper Wacker Drive and Lower Wacker Drive to improve and control the flow of traffic. Another key constraint of the Upper Wacker Drive geometry was that the sidewalks on the edge of the viaduct had to be level with adjacent building plazas. This made for very tight vertical constraints, while still ensuring the viaduct would drain efficiently during a rainstorm.

Bridge Deck Design

The viaduct deck is a cast-in-place concrete slab that is post-tensioned

View from adjacent skyscraper looking down on the existing Madison Street intersection prior to completing deck demolition. Photo: McHugh Construction.

CITY OF CHICAGO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Cast-in-place concrete slab, post-tensioned in both horizontal directions. This portion of the viaduct is 1400 ft long by 140 ft wide and is split into seven segments with 44 spans in the longitudinal direction and five bays in the transverse direction. The average longitudinal span length is about 32 ft. The beam slab is supported on pot bearings that sit on individual columns.

STRUCTURAL COMPONENTS: High-strength, high-performance, 6 ksi concrete, post-tensioned with 0.6-in.-diameter, Grade 270, low-relaxation, post-tensioning strands and 2-in.-thick, latex-modified concrete wearing surface

BRIDGE CONSTRUCTION COST: Total project cost \$300 million; North Viaduct Cost: \$60 million (\$306/ft^2)

Looking south along Wacker Drive with the new columns in place and waiting for the decking. Photo: Alfred Benesch and Company.

Example of the close proximity of the adjacent buildings to the viaduct. Photo: Alfred Benesch and Company.

in both directions. High-strength (6 ksi), high-performance concrete with reduced chloride permeability was specified as another means of ensuring the structure will withstand the harsh Chicago winters. Typically, a 2-ft-deep, 4-ft-wide longitudinal rib runs along each of the six column lines with a 13-in.-thick deck between the ribs.

This design concept required an increased effort to accommodate the post-tensioning tendons along with conventional epoxy-coated reinforcement, while avoiding conflicts. This issue was solved by banding the profiled tendons in ribs in the longitudinal direction with straight tendons in the slab between adjacent ribs. Banding of the profiled tendons allowed for providing uniformly distributed profiled tendons in the transverse direction. In this manner, the deck acts as a one-way slab spanning in the transverse direction, supported by post-tensioned concrete beams formed by the ribs with their banded tendons. At the end of each deck segment is a transverse rib that is also 2 ft deep that accommodates the anchorage blockouts and the expansion joint.

The structural slab was designed for zero tension under all service loads for both the top and bottom surfaces. This design objective was accomplished through the use of three separate post-tensioning systems using 0.6-in.-diameter, Grade 270 low-relaxation strands. The primary system consists of the banded tendons in the longitudinal ribs. Each rib has between five and eight 3-in.-diameter profiled ducts, which contain nine post-tensioning strands. Each tendon was stressed at each end to a force of 370 kips.

The secondary system is in the transverse direction and extends along the entire length of the viaduct with profiled four-strand flat ducts. The ducts are spaced at 1 ft 6 in. or 2 ft on center, depending on geometric variables. These tendons are single-end stressed to 164 kips with a monostrand jack.

The third element of the system consists of non-draped distributed tendons in the longitudinal direction. These are five-strand tendons, single-end stressed, to a force of 205 kips each, and spaced roughly 2 ft on center between the ribs. All ducts were grouted after the stressing operations were complete.

Designing the system to a zero-tension criteria involved quite a few challenges. The geometry and loading were always varying, meaning several different profiles and spacing adjustments had to be made within each system. A nineteenth-century trolley tunnel beneath Washington Street eliminated the possibility of columns for that bay and created an abnormally long span (over 50 ft) between column bents. This was accounted for by using additional tendons in the ribs and modifying the drape to adjust the magnitude of the balance forces.

The Upper Wacker Drive median was also required to support planters requiring a design loading of over 400 psf. The geometric layout of the deck and the congestion created by the post-tensioning ducts, eliminated the ability to provide spare ducts in case field stressing data did not achieve the required results. Designing the post-tensioning tendons to be stressed to 70% of the ultimate strength solved this problem. Once in-place, and after evaluating friction test data, the stressing value could be increased to 75%, if necessary. The additional capacity would also be available if a particular strand was lost. Both of these contingency plans were implemented, on occasion, during construction.

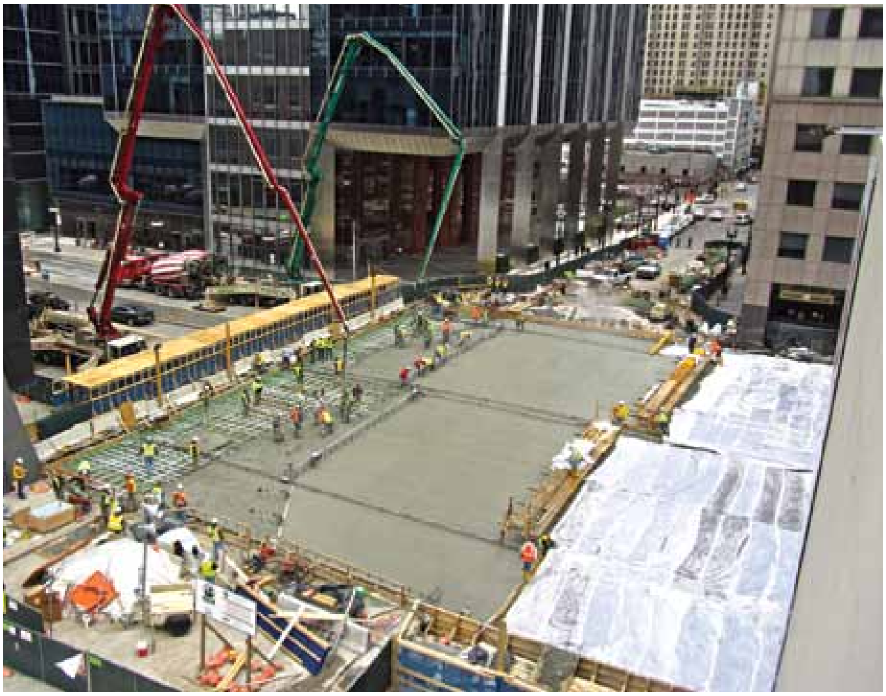
Urban Challenges

The dense urban setting was a fundamental constraint under constant consideration during both design and construction. The viaduct footprint on the east and west is bordered by buildings with the gap between the viaduct and adjacent property set at $^{7}/_{8}$ in. During the design phase, significant effort was required to develop details to allow for transverse stressing at the edge of the viaduct when the facade of a high-rise building may only be inches away. During construction, the contractor preloaded the strands in the transverse ducts prior to installation to avoid threading.

The contractor also had to deal with difficult scheduling. Work activities were limited or restricted during performances at the Chicago Civic Opera, which occupies an entire city block, in the middle of the project. The Madison Street intersection could not be closed until all other side streets were re-opened. This constraint was implemented because the closing of Madison Street diverted 50,000 pedestrians a day that mostly come into the city through Chicago's Union Station and walk across Wacker Drive into the central business district. The contractor was also responsible for maintaining access 24 hours a day to all loading docks and parking garages in the Lower Wacker Drive service drive. Maintaining continuous access for pedestrians to all buildings and businesses was perhaps an even larger challenge.

Overall Project

The overall Wacker Drive Reconstruction project is a remarkable example of a massive urban construction undertaking.



View of first placement of concrete for the deck. Photo: McHugh Construction.

The number of stakeholders and coordination involved becomes much greater when working with skyscrapers lining both sides of a ½-mile-long viaduct.

The north viaduct deck, which consisted of seven deck segments, was completed in December of 2011. The south viaduct contract (Monroe Street to Van Buren Street) includes the remaining eight deck segments of the viaduct and is scheduled for completion by December 1, 2012. The interchange project, which links Wacker Drive to the east-west expressway, is due to be completed in October 2012. As of press time, the remaining contracts are on schedule. The anticipation of a full opening is growing, especially for the hundreds of thousands of people who have been displaced throughout the 2.5-year construction period.

Andrew Keaschall is a project manager and Hossam Abdou is a vice president and structural practice leader, both with Alfred Benesch and Company in Chicago, Ill. Johnny Morcos is the acting chief bridge engineer with the Chicago Department of Transportation.

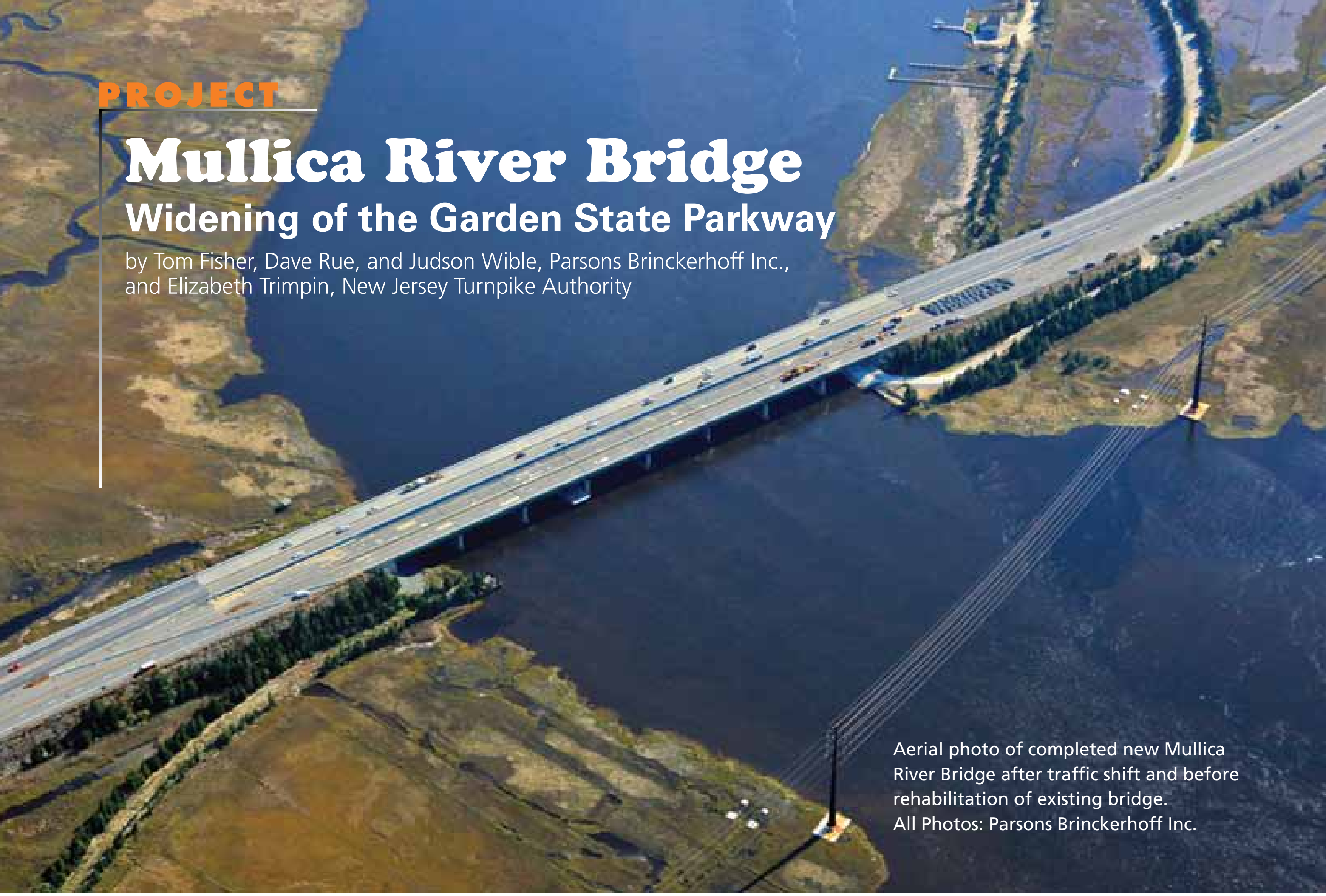
For additional photographs or information on this or other projects, visit www.aspirebridge.org and open Current Issue.

PROJECT

Mullica River Bridge

Widening of the Garden State Parkway

by Tom Fisher, Dave Rue, and Judson Wible, Parsons Brinckerhoff Inc., and Elizabeth Trimpin, New Jersey Turnpike Authority



Aerial photo of completed new Mullica River Bridge after traffic shift and before rehabilitation of existing bridge.
All Photos: Parsons Brinckerhoff Inc.

There's nothing like a 25-mile detour plan to make you realize that the Mullica River Bridge is a critical piece of infrastructure on the Garden State Parkway (GSP). If you're traveling to the Jersey shore (made more popular by the TV show of the same name)—or away from it due to a hurricane—the Mullica River Bridge is the travel crossing located at milepost 49.0 of the GSP.

The New Jersey Turnpike Authority's (NJTA) "Widening of the Garden State Parkway from Interchange 30 to Interchange 80" program consists of planning and design for 50 miles of mainline widening of the GSP from Somers Point, Atlantic County to Toms River, Ocean County, N.J. When completed, the widening program will provide a third travel lane and shoulders for both the northbound and southbound directions.

The widening at the Mullica River crossing will be accomplished with the construction of a new six-span concrete structure to carry northbound traffic, followed by the rehabilitation of the original 1954 eight-span steel structure to carry southbound traffic. The new bridge is designed to handle a four-lane interim traffic pattern, two lanes in each direction, enabling the off-line rehabilitation of the original bridge.

The new structure is 1230 ft long and 56 ft 9 in. wide, providing a final configuration of three 12-ft-wide lanes, a 5-ft-wide inside shoulder, and a 12-ft-wide outside shoulder. The rehabilitated structure is 877 ft 6 in. long, and when finished, will be 61 ft 9 in. wide with three 12-ft-wide lanes, a 10-ft-wide inside shoulder, and a 12-ft-wide outside shoulder. The two tangent parallel bridges are 12 ft apart and the approach embankment is retained by mechanically stabilized

profile

MULLICA RIVER BRIDGE / CITY OF PORT REPUBLIC – ATLANTIC COUNTY AND TOWNSHIP OF BASS RIVER – BURLINGTON COUNTY, NEW JERSEY

BRIDGE DESIGN ENGINEER: Parsons Brinckerhoff Inc., Lawrenceville, N.J.

PRIME CONTRACTOR: Agate Construction Company, Ocean View, N.J.

CONSTRUCTION MANAGER: Parsons Brinckerhoff Inc., Lawrenceville, N.J.

PRECASTER: Precast Systems Inc., Allentown, N.J., a PCI-certified producer

CONCRETE SUPPLIER: Penn Jersey Concrete, Egg Harbor Township, N.J.

POST-TENSIONING CONTRACTOR: Freyssinet Inc., Sterling, Va.

earth (MSE) walls to minimize the environmental impacts.

Substructure

The challenges to successful completion of design and construction of the new bridge included environmental restrictions, drilled-shaft design considerations, scour countermeasures, spliced concrete girder design, and constructability issues. Overcoming all of these issues led to opening the new bridge to traffic in April 2011.

With a six-month permit allowance each year for in-water construction, along with other environmental restrictions, the new bridge design had several major construction obstacles to overcome. Construction scheduling and planning accommodated the environmental constraints and conditions for indigenous species including oyster beds, osprey nests, anadromous fish, winter flounder, and terrapin turtles.

With in-water construction restricted to between July 1 and December 31, the need to reduce the extent and duration of in-water work was paramount for all involved. Fewer longer spans were selected in the design phase to reduce the number of piers that needed to be constructed in the water. In addition, the contractor advanced its work within a temporary steel cofferdam, which created a sealed environment that contained any disturbance of the river bed and allowed installation of the demonstration drilled shaft during the restricted time period. Once the demonstration shaft was satisfactorily tested, the foundation for pier 1 was constructed within the sealed cofferdam.

The Mullica River-area soil can be generally categorized as lowland alluvial deposits overlying marine sediments with locations of tidal marsh soils. The soft soils presented a challenge to developing the foundations for the new bridge. As part of the design, 8-ft-diameter drilled shafts were specified in some areas to extend down to an elevation of -230 ft to satisfy scour, vessel collision, and other design considerations. The foundation design and construction represented a significant item in the total project cost.

Pier 1 segment installation.

A demonstration drilled shaft was included in the project to ensure that the contractor's means and methods were appropriate and confirm the required length of the production shafts. Evaluation and analysis of the demonstration shaft with Osterberg Cell rings and cross-hole sonic logging and tomography, resulted in raising the typical elevation for the bottom of the shaft to an elevation of -180 ft. This change in elevation, from the original foundation design, resulted in a savings of nearly $3 million for the NJTA.

Three, 8-ft-diameter drilled shafts were installed per pier. The three-shaft configuration was selected because of redundancy during an extreme loading event typical of a natural disaster, explosion, or vessel impact. The shafts extended to a height of 18.23 ft above mean high water and are anchored directly into the pier caps. A polymer slurry was used to keep the drilled shaft holes from collapsing during construction and self-consolidating concrete was pumped into the bottom to prevent anomalies in the shaft concrete. The pier caps are 58 ft long, 9 ft wide, and 10 ft thick.

Span segment installation with strong-backs.

NEW JERSEY TURNPIKE AUTHORITY / GARDEN STATE PARKWAY, OWNER

BRIDGE DESCRIPTION: 1230-ft-long continuous, spliced, post-tensioned concrete girder bridge with four 220-ft-long spans and two flanking 175-ft-long spans, supported by 8-ft-diameter drilled shafts anchored into 10-ft-high by 9-ft-wide pier caps, with three 180-ft-long drilled shafts per pier

STRUCTURAL COMPONENTS: Fender system, prestressed concrete piles, mechanically stabilized earth walls, drilled shafts, controlled modulus columns, seismic isolation bearings, articulated concrete block mattresses, and modular expansion joints

BRIDGE CONSTRUCTION COST: $52,524,000

AWARDS: 2012 New Jersey-American Concrete Institute 49th Annual N.J. Concrete Awards—Grand Award; 2012 American Council of Engineering Companies (ACEC)—N.J. Honor Award; 2012 ACEC National Recognition Award; and 2012 Professional Engineering Society of Mercer County Project of the Year

Concrete pumping trucks were used in series to install the self-consolidating concrete in the drilled shafts.

MSE retaining wall and articulated concrete block mattresses were used as an access road.

The new bridge abutments, wingwalls, and MSE walls were all subject to scour and required deep foundations. The abutments and wingwalls were installed on prestressed concrete piles, and the MSE walls were constructed on controlled modulus columns. A controlled modulus column (CMC) is a soil improvement method used to stabilize an area of typically poor soil. An auger forcibly displaces soil and grouts a column of concrete into the ground. The Mullica River Bridge has 2129 CMCs on the project. Additionally, articulated concrete block mattresses were installed to provide scour protection for the existing bridge.

Superstructure

Concrete was selected as the material of choice for the new superstructure to eliminate future painting costs associated with steel bridge sustainment in this coastal area. The new bridge is a 1230-ft-long continuous, spliced, post-tensioned concrete girder bridge with four main spans of 220 ft and two end spans of 175 ft. It is currently one of the longest, continuous, post-tensioned spliced girder units in North America. Modular deck joints are provided only at the abutments. The seven lines of AASHTO Type VI Modified post-tensioned concrete composite girders were spaced at 8 ft 6 in. on centers. The Type VI girders are haunched over the piers and support drop-in segments. The girder depth varies from 78 in. deep at midspan to 108 in. deep at the piers with each pier segment weighing 137,500 lb. Specified concrete compressive strength for the beams was 8 ksi.

The sequence of girder erection consisted of:

- erecting pier segments at five piers,
- installing drop-in segments in the four main spans,
- installing drop-in segments in the two end spans, and
- casting closure joints.

Pretensioning was provided in each of the segments to account for anticipated shipping, handling, and erection stresses. Corrugated plastic ducts were embedded in the beam for the post-tensioning tendons. The design specified four tendons each consisting of twelve, 0.6-in.-diameter, seven-wire strands. Two tendons were tensioned after the girders were erected to achieve continuity. The remaining two tendons were tensioned after the concrete deck slab was placed and cured. Temporary moment connections between the haunched girders and the pier cap were created with vertical post-tensioning. This connection transferred the unbalanced moment during placement of the drop-in girder spans on the pier cap. Strongbacks were designed to support the girder loads.

The high-performance concrete (HPC) deck construction for the Mullica River Bridge went smoothly from start to finish. The specifications detailed important requirements such as a 14-day wet cure burlap application along with Rainhart Profilograph ride quality testing. Two-stage post-tensioning provided residual compression in the deck due to the tensioning of two of the four girder tendons after the composite deck had been placed.

A time-step analysis model was used to evaluate the loading during the girder erection and the post-tensioning phases. Careful consideration and evaluation for temporary unbalanced load conditions on the permanent structure, vertical and horizontal deflections, and loads of both the girders and piers were conducted as each component was constructed. The benefit of this methodology was the elimination of the typical shored construction method using temporary support towers for the superstructure (prior to splicing), resulting in considerable construction cost savings.

Summary

This project presented significant environmental challenges and considerations, restrictive construction windows, unique seismic design applications, and is currently on pace to open, with traffic flowing in both directions and over both structures, by December 2013.

Tom Fisher is the project manager, Dave Rue is the structural lead, and Judson Wible is a structural engineer, all at Parsons Brinkerhoff Inc., Lawrenceville, N.J. Elizabeth Trimpin is a project manager, New Jersey Turnpike Authority, Woodbridge, N.J.

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

PROJECT

Rich Street Bridge Project

The Scioto River gets a ribbon for Columbus's 200th birthday

by C. J. Kiner, Ohio Department of Transportation District 6

Just in time for the Columbus Bicentennial celebration, the Ohio Department of Transportation (ODOT) put a ribbon over the Scioto River, which meanders through the 200-year-old city. A ribbon arch bridge, that is. Technically, the Rich Street Bridge is an engineering marvel, but did pose a few challenges. The bridge design required the use of a three-dimensional model using a finite element method to analyze the structure. The bridge is much more than a link between two points. The Rich Street Bridge is designed to support year-round festivals. Electrical and communication facilities are built into the sidewalks and controlled by master panels located within the columns at each corner of the bridge.

Designed by a Columbus-based design firm, the bridge is a transitional art piece that spans the Scioto River, connecting the past, present, and future.

"The Rich Street Bridge will complete the reconnection of Columbus' very first neighborhood 200 years ago, Franklinton, with our downtown," said Mayor Michael B. Coleman. "The Rich Street Bridge provides a link to jobs and will be a catalyst in the revitalization of Franklinton."

The bridge is adorned with decorative lighting, above and below, and completes the recent reconstruction of the city's Bicentennial Park and the Scioto Mile River Walk and Promenade. The area features light shows, a musical amphitheater, and towering water fountains. The bridge was also center stage when Columbus hosted the famed Red, White, and Boom Fourth of July celebration, the largest fireworks display in the Midwest.

Improving Connectivity

The Rich Street Bridge replaces the historic concrete arch Town Street Bridge which was built in 1917.

The Rich Street Bridge was the perfect back-drop to Columbus's famed Red, White, and Boom Fourth of July celebration. Photo: Burgess & Niple.

profile

RICH STREET BRIDGE / COLUMBUS, OHIO

BRIDGE DESIGN ENGINEER: Burgess and Niple, Columbus, Ohio

CONSTRUCTION ENGINEERING: Finley Engineering Group, Tallahassee, Fla.

PRIME CONTRACTOR: Kokosing Construction Company, Fredericktown, Ohio

CONCRETE SUPPLIER: Anderson Concrete, Columbus, Ohio

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

POST-TENSIONING CONTRACTOR: Kokosing Construction Company, Columbus, Ohio

After the concrete ribbon arch design was selected, the city shifted the eastern abutment to align with Rich Street, resulting in improved connectivity. The Rich Street Bridge was also designed with wider sidewalks to accommodate more pedestrians.

"I am proud of what ODOT and Columbus [were] able to achieve in the planning and design of both the Rich and Main Street bridges," said Robert Taylor, P.E., ODOT District 6 planning engineer. "I think we ended up with something that serves a basic purpose, but is also unique and spectacular for the people of Columbus, and its visitors."

Structural System

The bridge is a precast and post-tensioned, concrete rib arch, on reinforced concrete piers and abutments. With three full arch sections and two half arches at the abutments, it spans 568 ft across the Scioto River with roadway limits of 37 ft from curb to curb. This allows for three travel lanes and 10-ft-wide sidewalks on either side. The piers are supported by "H" pilings with a bearing value of 258 ton per pile.

The four abutments are each supported by four, 66-in.-diameter drilled shafts with 60-in.-diameter shafts into bedrock sockets of varying length, but none less than 67 ft deep. An independent testing agency inspected each completed shaft using the cross-hole sonic log testing method (sound is emitted in the structure, graphed, and analyzed to test for structural integrity).

Construction

Construction began by installing a rock causeway, drilling the shafts and building the piers, and fabricating and erecting eight temporary support towers. These towers were used to piece together and stabilize the precast concrete segments during erection and post-tensioning operations. While the contractor was erecting the support towers, the precast concrete segments were individually, custom fabricated, just miles from the construction site, in Grove City, Ohio. Once the towers were in place, the contractor created the arches by setting the 52 precast concrete segments. The heaviest of these segments weighed 188,000 lb.

Placing the pier cap closures. Photo: Ohio Department of Transportation District 6.

With the arch segments in place, the contractor installed the bearing pads and arch blocks and placed concrete for the lower closure joints using a 7 ksi concrete. Once the closure joints achieved the prescribed compressive strength of 3.5 ksi, the four sets of outer rib tendons were pulled and stressed to 50% of the required 835 kips. The inner rib segments were then post-tensioned percent to 100%.

Following the inner rib tensioning operations, the eight deck segments closest to the abutments were placed on elastomeric bearing pads, and the outer rib segments were then tensioned the remaining 50%. All arch rib ducts were then grouted. The final eight deck segments spanning the middle two piers were then placed and the upper closure joints were cast using the same

Delivery of the precast, prestressed concrete girders. Photo: Ohio Department of Transportation District 6.

Snow flurries did not stop construction of the top segment of the rib arch on the Rich Street Bridge. Photo: Ohio Department of Transportation District 6.

THE OHIO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 568-ft span, precast, post-tensioned concrete rib arch, with reinforced concrete piers and abutments

STRUCTURAL COMPONENTS: 52 precast concrete rib sections and 16 precast and pretensioned concrete beam girders; 10-in. reinforced concrete deck on stay-in-place steel forms with 1 ½ in. micro-silica wearing surface; reinforced concrete abutments on H-piling; reinforced concrete piers on drilled shafts; four sets of reinforced concrete piers each on four 60-in.- and 66-in.-diameter drilled shafts; and elastomeric bearing pads

BRIDGE CONSTRUCTION COST: $20,500,000

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

Placement of the 1½-in.-thick silica fume overlay on the bridge deck. Photo: Ohio Department of Transportation District 6.

7 ksi concrete. After the closure joints were completed, the stay-in-place forms along with the tendon ducts were installed, the reinforcing steel tied, and the deck concrete was placed. When the deck concrete reached 4.5 ksi, the beam tendons were stressed and grouted. More than 240,000 ft of post-tensioning strand was used in the arch and beam segments.

With the beams and arch ribs fully post-tensioned, the temporary support towers were removed. Another 90,000 ft of tendon was used in the deck and stressed to 308 kips. After the post-tensioning operations were complete, the final abutment work was performed, expansion joints were welded and bolted into place, sidewalks and approach slabs were placed, and railings and final lighting were installed.

"The Rich Street Bridge will provide motorists, pedestrians, and bicyclists a safer connection between Franklinton and downtown for many decades to come," said Columbus Department of Public Service Director Mark Kelsey. "This is an investment in the future of Franklinton and the core of Columbus."

Second only to Texas, Ohio has the largest number of bridges. "We build bridges all the time in Ohio," said Ferzan M. Ahmed, ODOT deputy director. "All of them are important, but there is something about this bridge. It carries a roadway and people, connects neighbors and neighborhoods, and is a showpiece for culture and the arts in the Midwest. That makes building the Rich Street Bridge the perfect project."

Aerial photograph after the bridge deck was placed. Photo: Ohio Department of Transportation District 6.

C.J. Kiner is an area engineer with the Ohio Department of Transportation District 6, Columbus, Ohio. Robert Taylor, planning engineer, and Jeff Vance, construction project manager, for the Ohio Department of Transportation District 6, Columbus, Ohio, also contributed to this story.

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

PROJECT

Pearl Harbor Memorial Bridge

SIGNATURE BRIDGE REPLACES ITS AGING NAMESAKE

by Roy Merritt Jr., H.W. Lochner Inc.; Wade S. Bonzon, Figg Bridge Inc.; and John S. Dunham, Connecticut Department of Transportation

When originally constructed in 1958, the existing six-lane Pearl Harbor Memorial Bridge (locally known as the Q-Bridge) was the largest bridge along the Connecticut Turnpike and included the longest plate girder span in the United States. However, the existing bridge currently suffers from structural deficiencies and can no longer accommodate today's high-traffic volumes of over 160,000 vehicles per day, nearly four times the volume of traffic it was originally designed to serve. As a result, a new bridge was needed and planning for its replacement was initiated by the Connecticut Department of Transportation (ConnDOT) in 1990.

The new $635 million, 10-lane Pearl Harbor Memorial Bridge is the focal point of the $2.0 billion I-95 New Haven Harbor Crossing Corridor Improvement Program, one of the largest multi-modal transportation improvement initiatives in Connecticut history. In addition to the new bridge, the program includes operational, safety, and capacity improvements to 7.2 miles of I-95, reconstruction of the adjacent I-91/I-95/Route 34 Interchange, and a new commuter rail station.

A Signature Solution

A context-sensitive design approach focusing on public input was employed, which included an architectural committee of key stakeholders. From this process, a decision was made to replace the existing bridge with a new signature bridge with a 100-year service life expectancy. The new bridge would continue to be named the Pearl Harbor Memorial Bridge, and the design team was tasked with creating a "memorial quality" structure commemorating the veterans of Pearl Harbor. The result was the final selection of a 10-lane extradosed bridge spanning New Haven Harbor.

I-95 northbound traffic traveling over the extradosed cable-stayed main-span bridge, one week after opening. Photo: Walsh/PCL JV II.

Extradosed bridges, while having an appearance similar to traditional cable-stayed bridges, behave differently and have several key distinctions. The extradosed design utilizes shorter towers and a flatter stay-cable inclination than traditional cable-stayed bridges, which results in the deck system being the primary resistance to dead and live loads.

For the New Haven Harbor crossing, the extradosed bridge design allowed for increasing the main span to improve navigation and minimize environmental impacts. The limited tower heights afforded by the extradosed design avoids impacting air traffic from Tweed-New Haven airport located east of the bridge, whereas the taller towers of a traditional cable-stay bridge would have likely infringed on FAA-required flight path clearances. The design was completed with bid packages prepared for two alternatives for the main span; a three-span concrete extradosed prestressed alternative, and steel composite extradosed alternative.

profile

PEARL HARBOR MEMORIAL BRIDGE /NEW HAVEN, CONNECTICUT

PROGRAM MANAGER: Parsons Brinkerhoff Quade & Douglas Inc., Glastonbury, Conn.

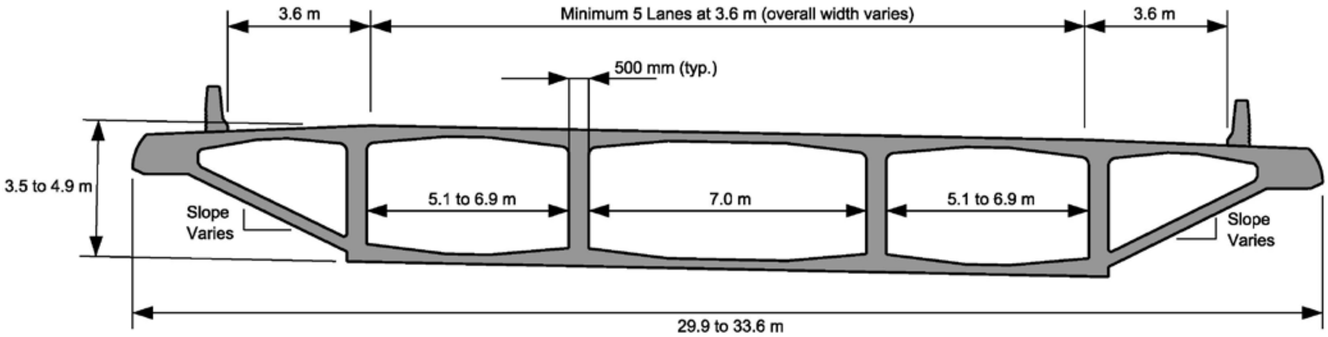
BRIDGE DESIGN ENGINEER: URS, Rocky Hill, Conn., and Tampa, Fla.

CONSTRUCTION ENGINEERING AND INSPECTION: H.W. Lochner Inc., New Haven, Conn. / Figg Bridge Inc., New Haven, Conn.

PRIME CONTRACTOR: Cianbro/Middlesex JV III and Walsh/PCL JV II, New Haven, Conn.

CONTRACTOR CONSTRUCTION ENGINEERING: McNary Bergeron & Associates, Old Saybrook, Conn.

CONCRETE SUPPLIER: The Suzio York Hill Companies, New Haven, Conn.



Typical cross section, cast-in-place segmental main span unit. Drawing: Lochner/FIGG.

The bidding process resulted in construction of the concrete extradosed prestressed concrete alternate, which began in April 2008, with construction of the northbound in-water foundations. The northbound bridge was recently completed and opened to traffic in June 2012. It is the first extradosed bridge constructed in the United States. Construction of the southbound bridge will occur following demolition of the existing bridge and is expected to be open to traffic by November 2016.

The final configuration of the bridge's harbor crossing consists of a 157-m-long (515 ft) main span with adjacent 75.85-m-long (249 ft) approach spans, providing 19.5 m (64 ft) of vertical clearance over the approximately 73-m-wide (240 ft) navigation channel. Beyond the main 308.7-m-long (1013 ft) harbor crossing, approach spans extend 484 m (1588 ft) to the west, and another 624 m (2047 ft) to the east, for an overall bridge length of 1417 m (4649 ft).

Main Span Superstructure

Segmental construction of the main span superstructure was performed utilizing the balanced-cantilever method with cast-in-place concrete segments. Concrete box segments are typically 4.36 m (14.3 ft) long, range from 29.9 to 33.6 m (98 to 110 ft) wide, and have a nominal depth of 3.5 m (11.5 ft) that increases to 5 m (16 ft) at the tower supports. Segments were constructed using high-performance concrete featuring Type III cement for high early strength, a design compressive strength of 41 MPa (6.0 ksi), and 7% silica fume to decrease permeability. The northbound and southbound concrete box-girder segments will each ultimately carry five 3.6-m-wide (12 ft) lanes of traffic, an auxiliary lane varying in width, and two 3.6-m-wide (12 ft) shoulders. During demolition of the existing bridge and construction of the southbound bridge, the northbound segments will temporarily carry three lanes of traffic in both directions.

The initial concrete segments located at the tower piers are referred to as "pier tables," and contain internal diaphragms that transfer the superstructure loads to disk bearings supported on the tower pier strut beams. The pier tables were lengthened to 15.9 m (52 ft) during construction to include the first pair of typical segments, creating additional deck area to ease installation of form travelers on both ends of the pier table. Four travelers were employed, allowing for segment construction to advance simultaneously in both directions from each tower. The 54,500 kN (12,300 kip) bearings beneath the pier tables are the world's largest disk bearings ever installed on a bridge.

Segment post-tensioning consists of longitudinal cantilever tendons, transverse deck tendons, as well as draped transverse external tendons at stay-cable locations that are deflected through the two central vertical webs of the section. ASTM A416M, Grade 1860, low-relaxation strands are utilized throughout. The four longitudinal cantilever tendons anchoring in the top slab of both the backspan and main-span segments were stressed after segments achieved a strength of 28 MPa (4 ksi), and varied in size from 17 to 27 strands. Transverse deck post-tensioning consists of four-strand tendons, typically spaced at 2.18 m (7.2 ft). The 19-strand draped transverse external tendons were provided to transfer superstructure forces to the stay-cables, and were stressed after casting the stay diaphragms and prior to installation of the stay cables.

Stay-Cable System

The northbound and southbound main span superstructures, are each carried by a series of 64 individual stay cables

CONNECTICUT DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A three-span extradosed bridge with span lengths of 249, 515, and 249 ft built using the balanced cantilever method of construction with cast-in-place concrete segments

STRUCTURAL COMPONENTS: Twin structure each consisting of five cell cast-in-place concrete box segments, 14.3 ft long, 98 to 110 ft wide, and 11.5 ft deep supported by 64 stay cables

BRIDGE CONSTRUCTION COST: $635 million

Concrete was placed for the deck of the pier tables from pump trucks stationed on the temporary access trestle below. Photo: Lochner/FIGG.

parallel to each other in a "harp" pattern. The stays anchor in pairs to the edge beams of the cast-in-place concrete segments and to the steel anchor boxes within the tower legs.

Each stay consists of 48 individual 15.2-mm-diameter (0.6 in.), 7-wire, low-relaxation strands up to 66.5 m (218 ft) in length, each greased and encapsulated in a tightly adhered high-

Master Chief Richard Iannucci, U.S. Navy, speaks at the dedication ceremony in front of the architectural lettering at the Anchor Pier. Photo: Lochner/FIGG.

density polyethylene (HDPE) coating for corrosion protection during the strand manufacturing process. These 48 strands are, in turn, encased in a co-extruded HDPE sheathing pipe with an outer diameter of 225 mm (9 in.) that remains ungrouted during its service life.

Stay-cable strand installation was performed using the elongation method to control variations in individual strand force, and then stressed to 60% maximum ultimate tensile strength (MUTS) from within the tower anchor boxes using monostrand jacks. The 60% MUTS limit for the cable strands is higher for the extrodosed bridge design than in conventional cable-stayed bridges, which utilize an upper stress limit of 45% MUTS. Because of the geometric layout of the stay-cables and the relatively large stiffness of the box girder superstructure, the stress range and overall contribution to stay-cable force from live loads is significantly less than that of a typical cable-stayed structure, therefore justifying the use of the higher allowable cable stresses on the new extradosed bridge.

The new northbound extradosed cable-stayed, main-span bridge crosses the Quinnipiac River directly adjacent to the existing Q-Bridge. Photo: Lochner/FIGG.

Strand stressing was typically performed in three steps. First, strands were installed and stressed individually to a force level equivalent to 15% MUTS. This low force level allowed internal "cheeseplate" type strand centering damper assemblies to be slid down the galvanized steel guide pipes near each anchorage and bolted in their final position. The second stage of tensioning was performed to approximately 50% of the final stay-cable force. A final, third stage of strand tensioning was then performed to fine-tune the strand forces to closely match the target stay force value. The adjustable anchorages were then capped and greased.

Tower Piers and Anchor Piers

The main span towers and anchor piers are founded on a series of 2.44-m-diameter (8 ft) drilled shafts and capped by 3.53-m-deep (11.6 ft) rectangular footings. Each pier features three legs with heights up to 45.1 m (148.0 ft), with a horizontal strut beam supported by an intermediate column. The strut beam spans between tower legs to support the superstructure segments. Anchor piers at each end of the main-span unit feature cast-in architectural lettering with gold leaf inlay in a manner consistent with the bridge's monumental aesthetic theme. The vertical tower legs and columns have a hollow, oval shape reminiscent of the smoke stacks of a ship. The main span unit's structural scheme is unique in that stay-cables for both the northbound and southbound superstructures anchor in the shared middle leg of the tower piers.

All portions of the towers were designated as mass concrete, with a 41 MPa (6.0 ksi) mix design employed using slag cement at 75% of the total cementitious materials originally specified in order to control internal curing temperatures. The jump form

AESTHETICS **COMMENTARY**
by Frederick Gottemoeller

It's always exciting when a new (to the United States) bridge type arrives on the scene. The Sunshine Skyway started a period of innovation and experimentation that led, in subsequent decades, to the construction of a number of outstanding cable-stayed bridges in the United States. The Pearl Harbor Memorial Bridge will do the same.

As with the new cable-stayed bridges, a key issue will be the appropriate shape for the towers. However, the girder is also an important feature in extradosed bridges, more so than the deck of a cable-stayed bridge. Designers will have to incorporate the appropriate size and shape of the girder. Striking a good visual balance between the girder and the towers is the key to success.

The first part of the Pearl Harbor Bridge to be constructed, the northbound half, is sandwiched between the old bridge and a massive lift bridge. At this stage, it is hard to evaluate all of the facets of the design, but it is clear already that the designers have achieved a good visual relationship between the visual mass of the towers and the visual mass of the girders. The simple oval cylinders of the towers are visually strong shapes that make clear their central role in the support of the bridge. The sloped outside webs of the girders minimize their visual mass, so that they don't overwhelm the towers. Meanwhile, the slight haunch at the piers makes clear that the girders play a major role in the support of the deck.

There were additional reasons to make the towers strong, simple shapes. The towers need to hold their own against the towers of the adjacent lift bridge, against the tanks and towers of the surrounding industrial landscape, and the sheer width and length of their own bridge deck. The visual strength of their shapes allows them to assert their importance in the scene.

Finally, the exposed stay anchorages along the edges of the girder create a repetitive rhythm of smaller elements and give the bridge some details that relate its scale to its neighbors. They also make clear how the bridge works by drawing the eye to the point where loads are transferred from the girders to the stays and thence to the towers.

Extradosed bridges are now on the drawing boards and a few are under construction. It will be interesting to see how designers address this bridge type's aesthetic challenges.

system was coated with spray-on foam to insulate the surface concrete and maintain internal thermal gradients below the required 20°C (68°F). Internal concrete temperatures were monitored hourly during curing using an automated sensor system that communicated wirelessly with a dedicated internet-accessible computer.

A Grand Opening

On Friday, June 22, 2012, a ribbon cutting ceremony was held to celebrate the completion and opening of the northbound extradosed bridge. The ceremony was highlighted by a Ceremonial Veterans Wreath Dedication with four surviving veterans of the attacks on Pearl Harbor, a ceremonial ribbon cutting, and speeches from local political leaders, FHWA, and the U.S. Navy. Approximately 250 members of the public attended.

Overnight, following the ceremony, work was completed on the approach roadway temporary crossovers and the new northbound bridge opened successfully to traffic, Saturday morning, June 23, 2012.

Tower leg jump-form systems were sprayed with insulating foam to control thermal gradients during mass concrete curing. Photo: Lochner/FIGG.

Roy Merritt Jr., is a senior structural engineer with H.W. Lochner Inc. in New Haven, Conn.; Wade S. Bonzon is an assistant resident engineer with Figg Bridge Inc. in New Haven, Conn.; and John S. Dunham is supervising engineer - Pearl Harbor Memorial Bridge with Connecticut Department of Transportation in Newington, Conn.

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

PROJECT

BLACK CANYON ROAD BRIDGE

by Christopher Krier and Jack Abcarius, NV5 Inc.

Black Canyon Road passes through Cleveland National Forest in San Diego County, Calif., and serves as the main access point between the Mesa Grande Band of Mission Indians Reservation and the unincorporated community of Ramona. The Black Canyon Road Bridge spans a steep canyon over Santa Ysabel Creek downstream of Sutherland Dam and provides an aesthetically pleasing structure.

Geometry

Black Canyon Road Bridge is a two-span, cast-in-place, conventionally reinforced, concrete box girder bridge that carries two lanes of traffic on a tight 150-ft-radius horizontal curve. It is 175 ft long, typically 28 ft wide, and has no sidewalks. The midpoint pier consists of two 4-ft-wide, octagonal columns with a clear height of about 20 ft. The columns are supported by two 8 ft 6 in.-square by 3-ft-thick footings that are formed into the underlying rock layer.

Five, 3-ft-diameter, cast-in, drilled-hole (CIDH) piles support each abutment, and the extension at abutment 1 is supported by an additional four, 3-ft-diameter CIDH piles. The CIDH piles have nine, two-bar bundles of No. 8 longitudinal bars and No. 5

This is a view of Black Canyon Road Bridge from the north. Photo: NV5 Inc.

profile

BLACK CANYON ROAD BRIDGE / SAN DIEGO COUNTY, CALIFORNIA

BRIDGE DESIGN ENGINEER: NV5 Inc., San Diego, Calif.

CIVIL DESIGN ENGINEER: Southern California Soil & Testing Inc., San Diego, Calif.

PRIME CONTRACTOR: Weir Construction Corporation, Escondido, Calif.

CAST-IN PLACE CONCRETE SUPPLIER: Vulcan Materials Company, Chula Vista, Calif.

Looking north at the completed Black Canyon Road Bridge and the original structure. The original structure will be used by non-motorized traffic. Photo: County of San Diego.

From below, shown is the framing between Sutherland Dam Road and Black Canyon Road. Photo: County of San Diego.

hoops at 6 in. on center for transverse reinforcement. The west wingwalls at both abutments are supported by a 2-ft-diameter CIDH pile due to their length, while the east wingwalls are typical cantilever-type wingwalls. The bridge is also located on the sag of a vertical curve and is superelevated with a 2% cross slope.

The 4-ft 9-in.-deep box girder consists of three bays with a maximum center-to-center web spacing of 7 ft. The box girder web thickness is 10 in. typical, and the top slab and soffit slab are 7½ in. and 6 in. thick, respectively. The exterior web on the east edge of the bridge flares to 12 in. where it intersects the dual 12-in.-thick deck extension girders. Concrete for the substructure had a specified compressive strength of 3.6 ksi and the superstructure concrete was specified for 4.0 ksi.

The owner designed the approach roadway using the smallest-allowable cross-sectional width per AASHTO standards to minimize the impact on the environment.

A California Environmental Quality Act clearance with a Mitigated Negative Declaration document was processed and approved. The mitigation required the owner to obtain the necessary U.S. Army Corps and State Fish and Game Permits, and specified certain items for mitigation.

One item in particular was the Visual Impact Assessment recommendation for the use of an open railing design to maintain an unobstructed view of the surroundings. The design team worked with Caltrans reviewers to allow the use of an open rail system using a Type 18 railing with modifications to make the system comply with today's FHWA standards.

Maintaining History

The bridge replaces an existing true three-hinged arch structure that was built in 1913. It is one of only a handful of remaining three-hinged arch structures, so the original bridge is considered to be a local historic landmark. For this reason, the original structure was left in place and can be enjoyed by non-motorized traffic at all times.

The initial replacement design was completed by the County of San Diego in the mid 1990s prior to the establishment of the Caltrans Seismic Design Criteria (SDC). The design plans were set aside until the project was funded. In 2007, when funding was secured, the engineer was tasked to incorporate all requirements of the SDC, while maintaining the layout and configuration of the initial design to the maximum extent possible. This allowed the owner to avoid the preparation of a new environmental document.

In order to maintain the original bridge footprint, engineers were creative in their approach to the design. They worked with the owner and Caltrans to develop special criteria for this rural road because the existing site constraints

Intersection of Black Canyon Road and Sutherland Dam Road. Photo: County of San Diego.

COUNTY OF SAN DIEGO, OWNER

BRIDGE DESCRIPTION: Two-span, 175-ft-long, variable width, three-cell, cast-in-place, conventionally reinforced box girder bridge

STRUCTURAL COMPONENTS: 4-ft 9-in.-deep box girders; 4 ft 0 in. octagonal columns on spread footings; seat type abutments on CIDH piles; and concrete deck extension with two, 1-ft 0-in.-wide by 3-ft 9-in.-deep deck extension girders

BRIDGE CONSTRUCTION COST: $1.672 million ($301/ft^2)

AWARDS: American Society of Civil Engineers San Diego Chapter, 2011 Outstanding Project of the Year Award; American Public Works Association San Diego Chapter, 2011 Honor Award on the proposed geometrics did not allow for the use of the Public Road Standards and Bridge Design Standards. Using the agreed upon layout, the main structure was designed with a 150 ft radius ending at the southern abutment with a 30 ft reversing curve to tie into Sutherland Dam Road.

To minimize the impacts even further, the abutments were placed as close to the channel as possible. Because of this, the abutment piles were designed to be exposed and web walls were proposed and designed to be constructed between the piles. These web walls were doweled into the piles and support the abutment backfill to maintain structural integrity of the abutment systems.

Deck placement using special concrete screed. Photo: County of San Diego.

Challenges

The bridge profile had ample freeboard available so the engineer also recommended the use of a conventionally reinforced concrete, box girder bridge rather than the post-tensioned concrete box girder proposed in the initial design. This revision eliminated potential challenges with post-tensioning on a very tight radius and precluded special detailing of the girders to avoid "bursting" forces during and after post-tensioning.

Engineers also proposed changing bent 2 from a fixed, single column with a massive footing to a two-column bent configuration. This enabled the design of a pinned connection at the base of the columns, which greatly reduced the size of the footings. In turn, this reduced the amount of earthwork in the channel, which was going to be very difficult due to the rocky terrain, and greatly reduced the overall construction cost.

The most interesting design feature was the deck extension at abutment 1. Black Canyon Road intersects Sutherland Dam Road immediately adjacent to that abutment. In order to connect Black Canyon Road and Sutherland Dam Road, abutment 1 and the bridge deck surface had to be extended to the east with a reversing curve. That portion of the bridge deck was designed using two, 3-ft 9-in.-deep, concrete T-girders that extend from the exterior girder of the concrete box to the diaphragm of the extended portion of abutment 1. This deck extension support system prevented a major change in the bridge layout, but in order to meet the design schedule and satisfy all of Caltrans bridge requirements, a unique deck extension design criterion that was agreeable to the design reviewers was created.

A live load trace envelope was used to determine the critical location of the design vehicle on the deck extension. Then, rather than distributing the dead load and live load from the deck extension equally among all four main bridge girders, the special criterion considered a larger proportion of those loads to act on the exterior girder of the bridge. This resulted in a special reinforcement detail for the exterior girder nearest the deck extension.

The radius of the structure also required some extra attention while detailing the longitudinal deck reinforcement and the shear reinforcement for the girders. Because the bridge girders on the interior of the radius are shorter than those on the exterior, a unique reinforcement arrangement was required for each girder. Special reinforcement details were also required for the intersections of the deck extension girders, the abutment diaphragm extension, and the exterior bridge girder.

During construction, the existing rock profile at abutment 1 varied significantly from that expected. This resulted in some piles being much longer or shorter than anticipated. The engineer quickly performed a revised foundation analysis and a rigidity analysis to account for force concentrations in the shorter piles, and then coordinated with the geotechnical engineer to determine new pile demands. The necessary details for the supplemental reinforcement were prepared without delay to the contractor to avoid potential claims.

Other construction issues included challenges caused by the reversing curve at abutment 1. The contractor had to use a special screed during placement of the concrete deck because the setup of the standard mechanical screed machine on rails would not work with the tight radii and varying deck width. The contractor also had to construct special formwork to accommodate the deck extension and the intersection between the deck extension girders and the exterior bridge girder.

All Ends Well

When Caltrans designated the original bridge as structurally deficient with an overall sufficiency rating of 16.5, and the approach roadway geometrics did not meet current design standards, a replacement structure was needed. The new Black Canyon Road Bridge provides a functional solution, and also serves as a focal point in an area known for hiking, bird watching, horse-riding, and other outdoor activities.

Christopher Krier is a senior engineer – Structural Group and Jack Abcarius is an associate, both with NV5 Inc., San Diego, Calif.

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

PROJECT

FOOTHILLS BRIDGE NO. 2

Filling in the "Missing Link"

by John Corven, Corven Engineering Inc.,
in cooperation with the Eastern Federal Lands
Highway Division, Federal Highway Administration

Durability for 100+ Years

Enhanced durability measures used on Foothill Bridge No. 2 included the following:

- Post-tensioning design for no longitudinal or top slab transverse tension under service loads
- Concrete with a high cementitious materials content including fly ash for reduced permeability
- Post-tensioning details and corrosion protection system to enhance durability
- Post-tensioning system installed, stressed, and grouted by certified technicians
- High-performance concrete overlay for an additional layer of protection

The Foothills Parkway was authorized by Congress in 1944 to provide beautiful vistas of the Great Smoky Mountains National Park from the Tennessee side of the park. The *missing link* of the Foothills Parkway is a particularly rugged 1.6-mile stretch of the Foothills Parkway traversing steep mountain-sides that overlook Wears Valley, Tenn.

Foothills Bridge No. 2, is located in Blount County, Tenn., approximately 10 miles west of the north entrance to the Great Smoky Mountains National Park. Construction of this bridge is instrumental to completing the missing link in that it crosses the most difficult terrain and is needed to access the construction of the missing link.

Project Development

The Eastern Federal Lands Highway Division (EFLHD) bridge staff prepared the preliminary design for the Foothills Bridge No. 2. The design envisioned a precast concrete segmental, single-cell, box-girder bridge, built with minimum disruption to the site. The Recovery and Reinvestment Act of 2009 provided needed construction funding for the project, and the National Park Service (NPS), Federal Highway Administration (FHWA), and EFLHD moved to develop the project in a design-build format.

Bridge Layout

The new Foothills Parkway Bridge No. 2 is a 790-ft-long precast concrete segmental bridge built using the balanced cantilever method of construction. Lengths of the five spans of the bridge are 125 ft, three at 180 ft, and 125 ft. The bridge follows an S-shaped alignment with curve radii of 262 and 650 ft. Superelevations vary from 7.8% (right) to 5.8% (left) over the length of the bridge. The vertical profile of the bridge begins at a +6.75% grade and transitions through a vertical curve to a +8.02% grade.

The superstructure of the bridge is a 9-ft-deep single-cell, precast concrete segmental box girder with a top slab width of 36 ft 10 in. The width of the segment bottom slab is 16 ft. The slope of the 1-ft 4-in.-thick webs is one horizontal to three vertical. The thickness of the top slab is 9 in. at the cantilever wing tips and in the middle of the top slab, and 1 ft 6 in. at the faces of the webs. The top slabs of the segments were transversely post-tensioned in the casting yard with two tendons consisting of four 0.6-in.-diameter strands.

profile

FOOTHILLS BRIDGE NO. 2 / BLOUNT COUNTY, TENNESSEE

BRIDGE DESIGN ENGINEER: Corven Engineering Inc., Tallahassee, Fla.

PRIME CONTRACTOR: Bell and Associates Construction, Brentwood, Tenn.

CIVIL AND ENVIRONMENTAL ENGINEER: Palmer Engineering, Winchester, Ky.

GEOTECHNICAL AND FOUNDATION ENGINEERING: Dan Brown and Associates, Sequatchie, Tenn.

PRECASTER: Ross Prestressed Concrete Inc., Knoxville, Tenn., a PCI-certified producer

SEGMENT ERECTION AND POST-TENSIONING CONTRACTOR: VSL, Hanover, Md.

Precast segments were cast using the short-line casting method. All photos: Federal Highway Administration.

The segments were trucked 40 miles from the casting yard to the bridge site.

The typical segment length for the project is 8 ft 8 in. The resulting weight of the typical segments is 45 tons. Pier and abutment segments are 5 ft long. This shorter length along with the added weight of the diaphragm concrete produces a segment weight of 40 tons. A total of 92 segments were required. Special effort was expended to produce a consistently dark tinted concrete color to match the desire of the NPS for the segments to blend into the mountainside.

The piers of the new Foothills Parkway Bridge No. 2 also were comprised of precast concrete segments. The typical cross section of the pier is a 6 ft 6 in. by 10 ft oval. At the top of the piers, the width of the oval increases from 10 to 16 ft to match the width of the bottom slab. The wall thickness of the typical precast concrete column segments is 1 ft. The heights of the column segments vary from 5 to 7 ft. Twenty substructure segments were required.

The precast concrete segmental piers are supported by 5-ft-thick, 20-ft-diameter, circular reinforced concrete footings. The footings of the bridge are elevated and exposed to reduce rock excavation. Sub-footing concrete cast to follow tiered excavation provides a working platform for drilling micropiles and constructing the footings. The exposed faces of the sub-footing and footings are faced with granite matching parkway standards.

The foundations of the proposed bridge consist of $9^{5}/_{8}$-in.-diameter micropiles. Twenty micropiles, each with a capacity of 160 tons, are used to support each pier and are arranged in a circular pattern with a 17 ft diameter. Inclined tie-backs are installed at piers 1 and 2 to resist lateral earth pressures related to potential downslope movement of soils overburdening stable rock.

Two elastomeric bearings are used to support the superstructure at each pier. Disc bearings are used at the abutments.

Bridge Construction

Site access only from the beginning of the bridge and steep terrain along the entire length of the alignment would have suggested progressive segment erection similar to that used on the Linn Cove Viaduct. Unfortunately, this strictly linear approach to construction would not permit the bridge to be completed within the project schedule. A new approach to construction was required that allowed various aspects of construction to be performed concurrently.

The resulting construction methodology incorporated a unique temporary work trestle that provided access along the entire bridge alignment. The work trestle was unique in that it could be reconfigured as work shifted from foundation and pier work to superstructure segment erection.

In the superstructure erection configuration, a specialized segment walker placed segments in balanced cantilever, significantly increasing erection speed over one-direction progressive placement methods.

The supports of the work trestle were rigid frames comprised of two steel pipe columns and a transverse steel girder. Each pipe column was supported by three, 7-in.-diameter micropiles and a precast concrete triangular footing. Longitudinal members of the temporary

NATIONAL PARK SERVICE, OWNER

BRIDGE DESCRIPTION: 790-ft-long, five-span, single-cell, precast concrete segmental bridge built using the balanced cantilever method of construction

STRUCTURAL COMPONENTS: 92 precast superstructure segments, 20 precast substructure segments, cast-in-place footings and micropiles, and cast-in-place concrete deck overlay

The temporary work trestle construction advances from right to left. A secondary crane provides access for foundations and pier construction.

View below the temporary work trestle, as pier 1 footing is formed on top of the sub-footing concrete.

work trestle consisted of two rows of paired steel girders. The transverse spacing of the girder pairs was adjusted depending on the configuration of the work trestle.

During trestle construction, the girder pairs were spaced closer together to support the tracks of the crawler crane that erected the gantry. The spacing of the girder pairs was increased during superstructure segment placement to support the segment walker designed to pass the already constructed portions of the bridge.

Bridge construction began with the building of abutment 1. From there, the trestle erection crane placed drilling equipment at the first work trestle support and micro-piles were installed. The crane then placed the precast concrete footings, support frames, and longitudinal girders. Crane mats were placed over the longitudinal girders to form the deck of the work trestle. The crane then crawled forward, and this sequence was repeated until the 22 spans of the trestle were complete.

When work trestle construction had advanced beyond pier 1, sections of the crane mat over pier 1 were set to the side and a secondary, tire mounted 60-ton crane lowered excavation equipment to make the tiered cut for the sub-footings. When complete, the sub-footing was formed and cast. The secondary crane then lowered the equipment to drill through the sub-footing concrete for the micro-piles that support the pier. Inclined tie-backs, used to provide slope stability were also drilled through the sub-footing. Footing construction followed the installation of the micro-piles and tie-backs.

The secondary crane also placed the pier segments. Individual segments were epoxy-joined and stressed together with four, $1^3/_8$-in.-diameter, 150 ksi post-tensioning bars. All segments of the pier with the exception of the pier cap were erected at this time.

Pier cap placement and balanced cantilever construction began once all typical segments of pier 1 were placed using the segment walker. The segment walker also placed the four-legged cantilever construction stability tower on the footing of pier 1.

Cantilever construction continued until all 20 of the precast concrete segments of the balanced cantilever were erected. The segments were epoxy-joined and stressed to the cantilever with three, 1¼-in.-diameter, 150-ksi post-tensioning bars. Two of the bars were anchored in blisters cast with the segments, and could be removed and reused. The bottom bar was internal and became a part of the permanent post-tensioning system. Once each segment was assembled, the cantilever post-tensioning consisting of two tendons with twelve 0.6-in.-diameter strands each were stressed. Cantilevers at piers 2, 3, and 4 were constructed in similar fashion.

Superstructure continuity was made between cantilevers with cast-in-place concrete closure joints and continuity post-tensioning tendons. Ten tendons with twelve 0.6-in.-diameter strands each (eight bottom and two top tendons) were stressed across each closure joint. End spans were completed by placing three additional typical segments and the abutment segments, casting closure joints, and stressing continuity tendons.

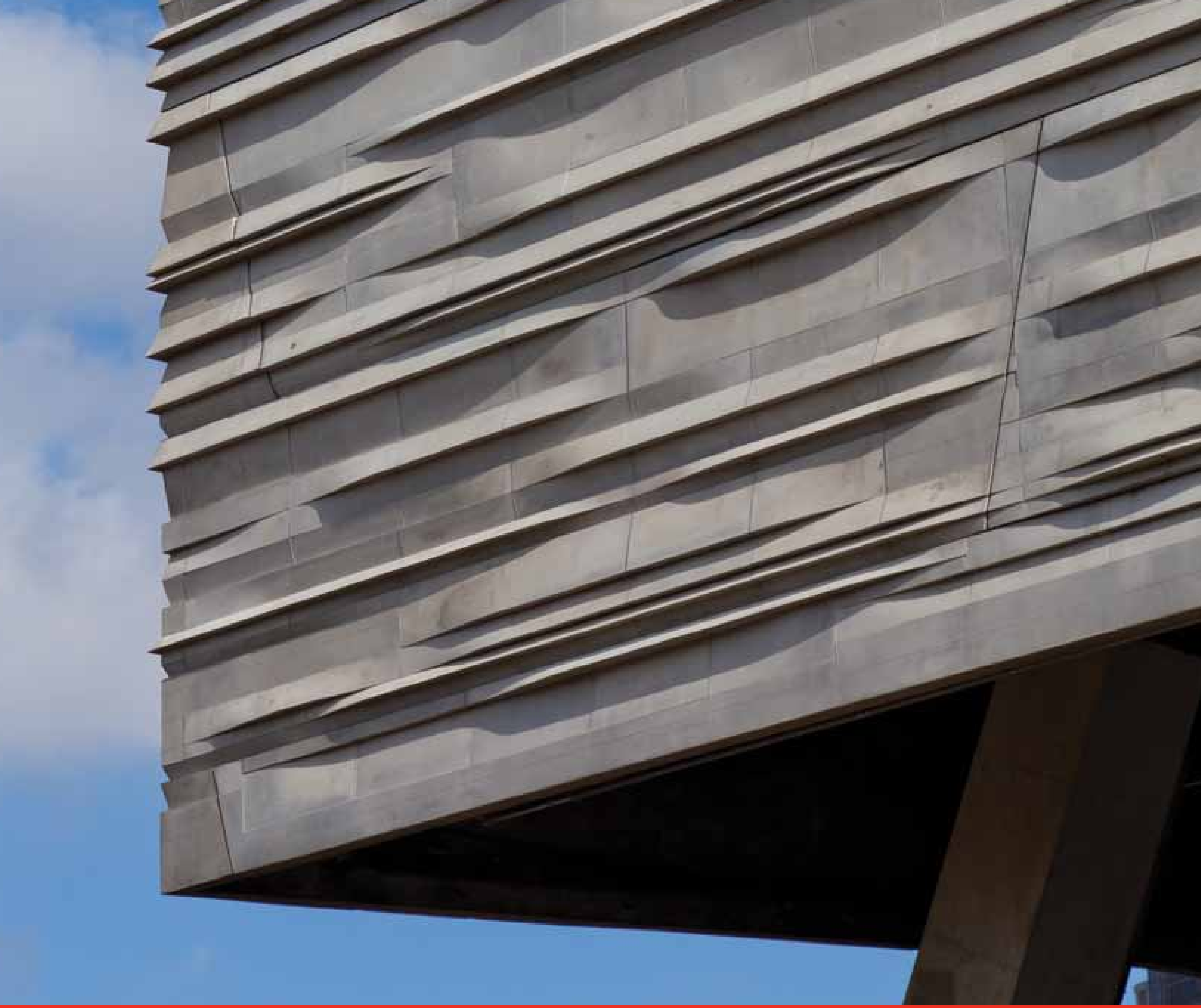
The segment walker places a segment at pier 3.

Completed construction of the major bridge elements.

The innovative design-build approach successfully achieved the goals of the NPS, FHWA, and EFLHD. Environmental impacts were limited to selective tree toppings and minimized disturbance of fragile top soils. Remaining work, including railing and overlay, was completed in September 2012.

John Corven is president and chief bridge engineer at Corven Engineering Inc., Tallahassee, Fla.

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



The Perot Museum of Nature & Science—Dallas, Texas opening early 2013

Segmental Concrete *Solutions*

by Craig A. Shutt

The Victory Bridge in New Jersey was completed more than two months ahead of schedule. Photo: ©FIGG.

Accelerated bridge construction (ABC) is often associated with short bridges or short-span bridges and moving full-span components into place quickly. But ABC techniques also apply to longer-span structures, including segmental concrete bridges. These concepts aid in rapid design and construction of bridges, which save costs and minimize disruption to the travelling public. Here are four examples:

Victory Bridge

ABC techniques have been in development for some years, as can be seen in the Victory Bridge on State Route 35 across the Raritan River between Perth Amboy and Sayreville in New Jersey. The state's first segmental box-girder bridge opened fully to traffic in September 2005—more than two months ahead of schedule.

Even more impressive, the first of the twin structures opened to traffic just 15 months after the notice to proceed was received. The second bridge was completed nine months later, according to a report in the Spring 2006 issue of *HPC Bridge Views*.

The bridge's parallel structures feature main spans of 440 ft, a U.S. record for fully match-cast segments. Two side spans on each bridge are 330 ft, while the approach spans vary in length from 142 to 150 ft. The balanced-cantilever method was used to erect the main and side spans, while the span-by-span approach was used for the approach spans. This helped speed the erection process and hasten delivery.

Other techniques that helped speed delivery included creating bid documents that were significantly more detailed than usual. This allowed the contractor to work directly from the bid documents rather than create shop drawings, saving both time and money.

The bid documents included details of reinforcement bends, segment geometry, and tendon-stressing sequences. They also included electronic files with integrated three-dimensional color drawings for some of the elements. Using this method, the first segment was cast just six weeks after the notice to proceed was issued, getting the project off to a fast start that continued to completion.

Earnest F. Lyons Bridge

The span-by-span approach to segmental designs also can speed construction, as was shown by the Ernest F. Lyons Bridge in Stuart, Fla. The twin, two-lane bridges were completed eight months ahead of schedule.

The 4600-ft-long, bridge features 30 spans at 152 ft plus a first span of 100 ft. Typical segments were 10 ft long, 10 ft deep, and 61 ft wide. A typical span consisted of 15, precast concrete segments, post-tensioned together using ten 19-strand tendons. The spans subsequently were made continuous into six-span units.

Despite a permitting process that took two months longer than anticipated, construction was still completed ahead of schedule. Construction delays and some damage also resulted from Hurricanes Frances and Jeanne passing over the site.

Three casting beds were set up to cast the 501 segments. Two beds cast typical segments, while the third was created to be interchangeable for pier segments and expansion-joint segments. The precaster used high-early strength concrete and transversely post-tensioned the top slab as soon as possible, allowing beds to be stripped every 12 hours. This ensured a new segment was cast each day in each form.

The Earnest F. Lyons Bridge was completed within budget and eight months ahead of schedule. Photo: Jim Schneidermann, PCL.

A top-down method was used to erect the segments due to shallow water depth and strict environmental-permit restrictions for protected seagrass. Components could be delivered only between 9 p.m. and 5 a.m., which allowed about six segments to be trucked in each night. An on-site staging area stored the segments for one complete span, which was erected after all segments for the complete span were delivered.

The self-launching underslung truss worked with a specialized segment lifter to allow crews to consistently erect one span every four shifts. This process, combined with the focus on casting speed and systematic delivery and staging processes, allowed the project to be completed within budget and eight months ahead of schedule.

Route 36 Highlands Bridge

New Jersey's second precast concrete segmental bridge was designed as a total precast concrete project from top to bottom. The goal was to leverage precast concrete's capabilities for early manufacture to reduce construction time on the bridge. It needed to be brought back into service quickly to provide access to key tourist areas around the towns of Sea Bright Borough and Sandy Hook, N.J.

The schedule required the actual bridge construction to be completed in two construction seasons to minimize disruptions between Memorial Day and Labor Day. In the first season, the eastbound bridge was completed, and all traffic was moved onto the new structure. The existing bridge was then demolished to make room for the westbound structure, which was completed in the following construction season.

The nine-span, twin bridges, built with superstructures of precast concrete segments, feature main spans of about 232 ft. Each structure is nearly 1611 ft long with a deck width of about 46 ft. Features that especially aided the ABC approach were the precast concrete footings, piers, and segmental superstructure.

Precast concrete footings, piers, and superstructure segments were used to accelerate construction on the Route 36 Highlands Bridge. Photo: J. H. Reid General Contractor, Unistress Corporation, or DYWIDAG-Systems International USA Inc.

The water-borne footings consist of 12 precast concrete cofferdams, which were cast on the mainland with an architectural finish on their exterior faces. The footings were floated out for placement and suspended on frames in place. The piles were driven through the openings in the soffit of the precast concrete box, after which the boxes were sealed, dewatered, and filled with concrete to create the bridge footings.

Precast concrete pier columns likewise were cast and barged into position. In all, the 18 piers, which varied in height between 12 and 59 ft, required 98 precast concrete segments to construct.

Heavy reinforcement and post-tensioning for these precast concrete components added complexity to the fabrication of the segments. But the column segments for each pier were typically quickly stacked upon arrival, and then post-tensioned with as many as eight U-tendons and grouted over the next several days. The superstructure consists of 384 precast concrete segments that were combined to create 90- to 240-ft-long spans as needed. The contractor used a barge-mounted crane to erect the column and girder segments. The project ultimately met its schedule commitments and provided a durable design that offers aesthetic enhancements to match the surroundings.

St. Anthony Falls Bridge

A high-profile bridge that was completed under intense pressure for early completion, the St. Anthony Falls (I-35W) Bridge spans the Mississippi River in Minneapolis, Minn. The 1219-ft-long twin structures feature 504-ft-long main spans along with three other spans of 219 ft on one side, and 248 and 148 ft on the other.

The sweeping superstructure has an arching parabolic curve, which varies in depth from 25 to 11 ft and seamlessly connects to 70-ft-tall piers. The main span was constructed with precast concrete segments from four on-site, long-line casting beds.

While the precast concrete segments were being cast, the side spans over land were being cast-in-place on falsework. After their completion, the 120 main span segments were erected in only 47 days.

Officials at the Minnesota Department of Transportation (MnDOT) selected the design-build process, as it offered faster project speed, design flexibility, and construction adaptations. The team selected from among seven potential bridge types, proposed geometric solutions, and developed the visual imagery.

The design-build process was expedited so that construction could begin prior to the winter season. Typically, the procurement timeline takes six to twelve months, but this one took only 50 days. Achieving this speed required daily meetings that allowed the design-team to stay up to date on scope changes and get answers immediately.

MnDOT worked closely with regulatory agencies, utilities, and other stakeholders during the procurement process, obtaining all eight of the possible permits prior to letting. They also held public advisory meetings as design work progressed to speed the schedule. Design flexibility was emphasized to ensure any public concerns could be incorporated into the final design.

The 120 segments in the main span of the St. Anthony Falls Bridge were erected in 47 days. Photo: ©FIGG.

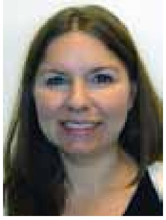
MnDOT offered a $7-million incentive if the project was completed on time by the end of the next construction season, and it included early-completion incentives up to $20 million more if the project was completed 100 days early. The incentives were based on the calculated user costs from having this key bridge out of use.

The bridge opened more than two months ahead of schedule, less than 13 months after the notice to proceed. The design-build process and segmental construction not only brought the bridge into service quickly, but it provided a signature design that will be a proud addition to the community for decades to come.

This is one of a series of articles examining different approaches to accelerated bridge construction and examples featuring those techniques. Details of these projects can be found in the issue archive at www.aspirebridge.org as follows: Earnest F. Lyons Bridge (Winter 2008), Route 36 Highlands Bridge (Summer 2010), and the I-35 W St. Anthony Falls Bridge (Winter and Fall 2008).

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

Dealing with ASR in Concrete Structures



by M. Myint Lwin and Gina Ahlstrom, Federal Highway Administration

Alkali-silica reactivity (ASR) is a durability problem that has resulted in premature deterioration of various types of concrete structures in the United States and throughout the world. Supplementary cementitious materials have been used for more than 50 years for preventing damage to concrete structures by controlling the expansion due to ASR. In recent years, lithium compounds have been used as an additive in concrete mixtures.

ASR-induced damage is caused by the expansion resulting from the chemical reaction between the alkali and silica in the mixture in the presence of moisture. ASR damage in concrete structures is evidenced by the map-like cracking on the surfaces, surface discoloration and gel exudations, and the displacement of components.

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) established funding for further development and deployment of techniques to prevent and mitigate ASR. In response to this act, the Federal Highway Administration (FHWA) initiated an ASR Development and Deployment Program to focus on preventing and mitigating ASR in concrete bridges, pavements, and other highway structures, such as median barriers and retaining walls.

Elements Essential for ASR

Three elements are essential for ASR to occur: reactive silica (from aggregates); alkalis (mainly from portland cement); and moisture (from drainage, leakage and/or high humidity). To effectively combat ASR, one or more of these elements must be controlled or eliminated.

Reactive Silica

The presence of reactive aggregates or another reactive silica source in concrete is necessary for ASR to occur. The term *reactive* refers to aggregates that tend to breakdown under exposure to the highly alkaline pore solution in concrete and subsequently react with the alkalis (sodium and potassium) to form an expansive ASR gel.

Alkali

The presence of sufficient alkalis is another required ingredient for ASR. Portland cement is considered the main contributor of alkalis. Other ingredients that may contribute to additional alkalis are fly ash, slag, silica fume, aggregates, chemical admixtures, seawater, and deicing chemicals.

Moisture

The presence of moisture is necessary to cause the damaging effects of ASR in concrete structures. Concrete mixtures comprised of highly reactive aggregates and high-alkali cements have shown little or no expansion in certain very dry environments. Similarly, portions of the structure exposed to a constant or steady source of moisture have exhibited significant ASR-induced damage, while other portions of the structure that remain essentially dry have shown little or no damage.

Preventing or Mitigating ASR

Several viable methods exist to prevent ASR in new concrete structures, such as

- use of only low- or non-reactive aggregates,
- use of low-alkali cement, or the addition of supplementary cementitious materials such as fly ash, slag, or silica fume, and
- addition of lithium.

Very few methods are available for mitigating further damage in structures already affected by ASR-induced expansion and cracking.

Mitigating ASR in Existing Concrete

Lithium has been shown in limited laboratory studies to have the potential of suppressing the expansion caused by ASR. Field studies have been conducted to introduce lithium into existing concrete:

- Topical treatment—applying lithium to the surface and allowing the lithium to penetrate the concrete
- Electrochemical migration with lithium as electrolyte—using the electrochemical chloride extraction method with lithium as an electrolyte
- Vacuum impregnation—similar to topical treatment, except a vacuum is used to enhance deeper penetration of the lithium into the concrete

However, to-date the field application of lithium has proved to be challenging and in most cases has not proved to be effective in suppressing ASR.

Signs of ASR-induced damage. Photo: Courtesy of Texas Department of Transportation. Copyright © 2002. All rights reserved.

Other methods to mitigate the effects of ASR are being studied in the field, such as the application of sealers or coatings to limit ingress of moisture and reduce the internal humidity of the structure and restraining or confining expansion of the structure elements. Other methods that should be considered for mitigating the effects of ASR are:

- treating existing cracks to minimize future expansion and avoid ingress of moisture, deicing salts, and the like,
- avoiding the use of deicing salts high in alkali content,
- providing proper drainage, and
- sealing leaks.

The FHWA ASR Development and Deployment Program

The FHWA ASR Development and Deployment Program was initiated through SAFETEA-LU funding and addresses the needs of stakeholders. More information was needed on test methods and specifications to control reactive aggregates and ASR in new concrete structures and the methods and techniques to mitigate the effects

Application of Carbon Fiber Reinforcement Polymer (CFRP) wrap to a bridge column. Photo: Federal Highway Administration.

of ASR in existing concrete structures. As a result the program includes a number of initiatives:

- Providing a central location for information pertinent to ASR
- Developing documents to guide practitioners in designing concrete mixtures resistant to ASR and identifying ASR in field structures
- Conducting field trials to further explore methods and techniques to mitigate the effects of ASR in existing structures

More information on the program can be found at: http://www.fhwa.dot.gov/pavement/concrete/asr.cfm.

ASR Reference Center

The ASR Reference Center is a central location that houses numerous documents specifically on ASR. Topics include the basic mechanism of ASR and methods for detection, research reports, ASR specifications from the United States and throughout the world, guidance documents, and a special section on case studies. The case studies highlight various ASR field trials and studies. The ASR Reference Center can be found at: http://www.fhwa.dot.gov/pavement/concrete/asr/reference.cfm.

Application of elastomeric paint to a median barrier. Photo: Federal Highway Administration.

Reports for Additional Support

FHWA put out several publications this summer from the ASR Development and Deployment Program. *The ASR Field Identification Handbook* will assist in the identification of ASR in field structures. The *Alkali Silica Reactivity Surveying and Tracking Guidelines* outlines a process to survey and track structures with ASR. In addition, a report discussing the field trials conducted under the program and suggested methods and techniques to mitigate the effects of ASR is scheduled to be published in the spring of 2013. Reports will be posted on FWHA's web site: http://www.fhwa.dot.gov/pavement/concrete/asr.cfm.

FHWA Publications

Report No. FHWA-HIF-09-001

The title of this report is: *Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction*. This report provides both a performance and a prescriptive-based approach for preventing ASR in new concrete structures. This report is the basis for the AASHTO Provisional Standard PP 65-11 *Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction*.

Report No. FHWA-HIF-09-004

The title of this report is: *Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures*. This report provides information on detecting ASR in the field, confirming the presence of ASR through laboratory tests, and an approach for the quantification of expansion to-date, current expansion rate, and the potential for future expansion. This report also briefly discusses mitigation measures for structures with ASR.

Recommended Actions

New Structures

- Use only low- or non-reactive aggregates
- Use low-alkali cement
- Add supplementary cementitious materials such as, fly ash, slag, or silica fume; or lithium admixtures
- All or combination of the above

Existing Structures

- Test for potential reactivity of aggregates and alkali reactivity of cement-aggregate combinations
- Perform petrographic examination on cores
- Test mitigation strategies in the field to find the most effective remediation methods
- Develop specifications for performing the repair
- Estimate the remaining service life after repair and the cost effectiveness of the proposed repair
- Repair or replace ASR affected components of structures as appropriate

Closing Remarks

ASR is a problem, but several methods are available for preventing and mitigating ASR-induced expansion, including the use of nonreactive aggregates, low-alkali concrete, supplementary cementitious materials, and lithium compounds. In response to the SAFETEA-LU legislation, FHWA, in cooperation and collaboration with AASHTO, NCHRP, and the transportation industry, has been actively developing and implementing research, deployment, and education programs to prevent and mitigate the problems associated with ASR.

EDITOR'S NOTE

More information on the FHWA's guide to identifying ASR can be found in the August 2012 issue of Focus located at www.fhwa.dot.gov/publications/focus/index.cfm and click on Past Issues.

STATE

Spotlight on Georgia's Concrete Bridges

by Paul Liles, Georgia Department of Transportation

Georgia is a mid-level state when it comes to bridge inventory, with 14,661 structures presently listed on the National Bridge Inventory system. Of these structures, approximately 9040 are bridges, with the rest being culverts or other miscellaneous structures. As such, Georgia has a long history in the use of concrete for bridges, with special emphasis taking place over the last 20 to 30 years.

Early Bridges

Georgia's early concrete bridges consisted of reinforced concrete structures and are usually of the T-beam or concrete-arch type of construction. Over 300 of these structures are still in existence dating from the 1900s to the start of World War II. A fine example of an arch bridge from this period is the Dillingham Street Bridge in Columbus, Ga., that dates to 1912 (Fig. 1). This bridge is a Melan Arch that uses small, curved built-up I sections for the arch reinforcement that is embedded in the concrete. All of the pre-World War II structures, listed in the National Bridge Inventory, are still in service and continue to carry traffic daily.

Figure 1. The Dillingham Street Bridge is a Melan Arch, which dates back to 1912. All photos: Georgia Department of Transportation.

Figure 2. The Jonesboro Road Bridge was Georgia's first high-performance concrete bridge.

In the 1950s, Georgia experimented with prestressed concrete when the then-Georgia state bridge engineer helped develop the original AASHTO prestressed concrete beam shapes. These beams were used around the state primarily over the interstate highways. Many of them were removed with interstate widening projects, but approximately 75 still exist in Georgia and carry traffic today.

Beginning in the mid-1970s, Georgia made a concerted effort toward using longer prestressed concrete beam spans along with the use of long-span, post-tensioned concrete box girders. Coupled with extensive research and interaction with the Federal Highway Administration and the concrete industry, this trend continues.

Researching Innovation

Beginning in the mid-1990s, the Georgia Department of Transportation (GDOT) began an extensive bridge research program with the Georgia Institute of Technology (Georgia Tech) to further enhance its bridge and structural program. Beginning with research into high-performance concrete, specifically with the use of Georgia aggregates. Figure 2 shows Georgia's first high-performance concrete bridge built in 2002. This bridge utilized a high-performance concrete superstructure with Type IV AASHTO beams having a span length of 127 ft and a specified concrete strength of 10 ksi.

Georgia Tech's research showed that Georgia aggregates allow high-performance concrete strengths to reach an upper length of around 14 ksi. High-performance concrete is now routinely used for long-span beams for high strength and for coastal prestressed concrete piling to limit chloride intrusion into the concrete.

Research continues in such areas as high-performance lightweight concrete, self-consolidating concrete, and ultra-high-performance concrete. Figure 3 shows Georgia's recent high-performance lightweight concrete bridge built over I-85 south of Atlanta. This bridge used lightweight concrete BT-54 beams with a density of 120 lb/ft^3 and a specified concrete compressive strength of 10 ksi.

Figure 3. The I-85 Ramp over Georgia State Route 54 used prestressed concrete beams with a density of 120 lb/ft^3 and a specified concrete compressive strength of 10.0 ksi.

Current research with Georgia Tech involves investigations into using stainless steel prestressing strand for construction of prestressed concrete piles. These are being developed with the idea of developing a corrosion-free pile for use in Georgia's coastal bridges where the piles are exposed in salt water.

Some other significant Georgia projects involved innovative construction techniques such as precast concrete elements for design-build construction. Georgia's Highways for Life (HfL) project on I-85 near LaGrange used precast concrete bents that were assembled on site (Fig. 4). A major design-build project was the Fifth Street Pedestrian Plaza Bridge over I-75/I-85 in Atlanta (Fig. 5). The Fifth Street Plaza Bridge was previously described in the Winter 2008 issue of *ASPIRE*™ magazine.

Georgia also has two major cable-stayed bridges along the Georgia Coast. These bridges are the Talmadge Memorial Bridge located in Savannah, Ga., and the Sidney Lanier Bridge in Brunswick, Ga. (Fig. 6). Both bridges are cast-in-place, concrete segmental bridges that serve as the gateways to Georgia's two port cities. These structures allow commercial ocean-going ships to enter the ports and provide 185 ft vertical clearance above the waterway with main spans of 1100 ft for Savannah and 1250 ft for Brunswick.

Figure 4. Precast concrete bents were used in Georgia's Highways for Life program.

Figure 5. Fifth Street Bridge over I-75/I-85 provides a user-friendly environment.

Figure 6. The Sidney Lanier Bridge has a main span of 1250 ft.

Summary

This article summarizes some of the trends and highlights Georgia's concrete bridges. Developments over the past 20 years greatly influenced the design of concrete bridges in the state. The use of high-performance concrete, with increases in concrete strength and concrete durability, increased beam lengths by almost 100%. Backed by research, we expect this trend to continue into the future.

Paul Liles is the assistant division director of engineering, Georgia Department of Transportation, Atlanta, Ga.

For more information about Georgia's bridges visit www.dot.state.ga.us/doingbusiness/PoliciesManuals/bridge/

CONCRETE BRIDGES for Grand Junction, Colorado

by Trent Prall, Grand Junction, Colo.

The $110-million Riverside Parkway project (shown here during the 2008 Grand Opening) required three bridges at the U.S. Highway 50 crossing. Two carry the parkway over the Union Pacific Railroad tracks and the third bridge connects the on/off ramps to U.S. Highway 50. All photos: Grand Junction, Colo.

Girders for the 29 Road Bridge were placed at night to limit disruption to daytime traffic on I-70B.

Construction on the D Road Bridge over the Redlands Water and Power Canal took place during the winter to prevent interruption to irrigation water. Prestressed concrete girders were used on this bridge as well.

Grand Junction, Colo., is a city of 58,000 people located on the western slope of the Continental Divide, 25 miles east of the Utah state line, at the junction of the Colorado and Gunnison Rivers. There are several large drainages that are subject to occasional flash floods, four major canal systems providing water to farmers and ranchers, and the Union Pacific railroad tracks running throughout the valley. All of these physical barriers require multiple crossings to connect adjacent communities.

The Public Works Department maintains 38 major bridge structures with spans greater than 20 ft and over 68 minor structures with spans less than 20 ft throughout the city. Major structures include 700-ft-long spans of the Colorado River.

Funding for the city's capital improvement program comes primarily from a 0.75% sales tax approved in the late 1980s that generates about $12 million annually. Many of the capital dollars in the late 1990s and 2000s were invested in transportation network improvements. Major development of the southern and eastern legs of the Riverside Parkway beltway around the city included four bridge structures that were completed with precast, prestressed concrete girders.

The Riverside Parkway project also included a prestressed concrete bridge over the Union Pacific Railroad at 25 Road.

Three of these structures use the Colorado BT54 precast, prestressed concrete girder. Two structures cross over railroad tracks and have three spans each with span lengths varying from 67 to 90 ft. The third bridge is over U.S. Highway 50 and has two spans with lengths of 70 and 94 ft.

The fourth bridge is the 25 Road Bridge over the Union Pacific Railroad (UPRR). It is a five-span concrete bridge with a total length of 595 ft. The shortest span is 97 ft and the longest is 141 ft. This bridge utilizes Colorado BT72 precast, prestressed concrete girders.

The 29 Road/I-70B interchange and overpass over Union Pacific Railroad (UPRR) was completed in 2011 for $34.0 million and was jointly funded between the city of Grand Junction and Mesa County. Three spans (135, 138, and 157 ft) over the UPRR right-of-way were designed as precast, pretensioned and post-tensioned spliced girders. For more details, see *ASPIRE*™ Spring 2012.

In 2009, the city of Grand Junction and Mesa County reconstructed the Monument Road Bridge, a 50-ft crossing of Redlands Water and Power Canal. The following year, the city replaced the D Road Bridge, a 60-ft span crossing of No Thoroughfare Wash. Both of these concrete bridges utilized 20-in.-deep precast, prestressed concrete, side-by-side, slab beams topped with a 6-in.-thick cast-in-place concrete deck slab.

The use of precast concrete girders benefit the city because no falsework is required and given the restrictive construction windows associated with working over the canals, they are the perfect solution. Construction needs to be completed during the fall and winter season, when water is drained from the canals, and completed before spring irrigation when water is needed.

Most of the structures utilized precast concrete deck panels, also speeding construction schedules. The city also seals all of its new structures with a thin, bonded, epoxy overlay to improve skid resistance and seal the concrete surfaces.

Trent Prall is engineering manager for the city of Grand Junction, Colo.

2013 Call for Papers

Abstracts due JANUARY 31, 2013!

PCI Convention and National Bridge Conference

September 21–24, 2013 • Grapevine, Texas

PCI is accepting abstracts for technical papers to be presented at the 2013 PCI Convention and National Bridge Conference in Grapevine, Texas. Next year's theme is "Discover High Performance" and will focus on the high performance attributes of precast concrete. While abstracts may be submitted on any relevant topic to the precast concrete industry, abstracts that support the event theme will be given preference. Abstracts and papers will be peer-reviewed and accepted papers will be published in the proceedings.

The PCI Convention and National Bridge Conference is the premier national venue for the exchange of ideas and state-of-the-art information on precast concrete design, fabrication, and construction. The event attracts an average of 1,000 participants each year and provides an outstanding opportunity for networking, education, and sharing of ideas. Don't miss out on this excellent opportunity to share your knowledge– submit your abstract today!

Submission Requirements

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

The 2013 Call for Papers submission site will open November 12, 2012.

Contact:
Transportation:
William Nickas, P.E.
wnickas@pci.org
Buildings:
Brian Miller, P.E., LEED AP
bmiller@pci.org

PCI™ Precast/Prestressed Concrete Institute
200 West Adams Street | Suite 2100 | Chicago, IL 60606-5230
Phone: 312-786-0300 | Fax: 312-621-1114 | www.pci.org

New Specifications for Grouting

by Theodore L. Neff, Post-Tensioning Institute

Proper grouting is essential to ensure the performance and durability of post-tensioned (PT) concrete structures. Cementitious grout provides an alkaline environment that passivates the steel and serves as a physical barrier that helps keep water, oxygen, and corrosion-causing contaminants (such as chloride) away from the prestressing steel. Thus, the grout is providing corrosion protection. In bonded, post-tensioning applications, the grout also bonds the steel and duct to the surrounding concrete so that the structural element performs integrally as a unit.

Prior to 2001, most grouts used in PT construction were a simple mixture of cement and water. Generally these grouts performed satisfactorily. However starting in the 1990s, corrosion problems were observed on several projects in Florida and around the world. These durability issues were primarily attributed to a combination of the use of high-bleed grouts and improper workmanship.

In 2001, the Post-Tensioning Institute (PTI) released *Specifications for Grouting of Post-Tensioned Structures*, which introduced many new requirements to minimize bleed water and improve grouting practices. This led to widespread use of engineered, low-bleed grout materials that were prepackaged by manufacturers. While these prepackaged grouts have been effective in minimizing the formation of voids due to bleeding, new problems related to high chloride content and segregation have recently been reported.

PTI's 3rd edition of the *Specifications for Grouting of Post-Tensioned Structures* is intended to address concerns related to high-chloride content and segregation as well as strengthen the provisions to minimize bleed water and to ensure proper construction.

Control of Chlorides

Previously, the specification limited the chloride content in new grout to 0.08% by weight of cement. However for prepackaged grouts, chloride was only tested during the initial qualification testing. In the latest version, chloride must be tested more frequently: first during the qualification testing, then once per 40,000 lb of grout, with a minimum of at least once per project. In addition, the manufacturer must certify the chloride content of all constituents.

Grout Segregation or Instability

Grout segregation was observed in Europe in early 1990s. In response, research by The Technical Department for Transport, Roads and Bridges Engineering and Road Safety (SETRA), a department within the French Ministry of Transport and Infrastructure, found the inclined tube test (see sidebar for more information) and a modified wick-induced-bleed test to be very effective in checking the stability of grouts under conditions representative of field conditions. The tests were adopted as part of the French specification in 1996 and have subsequently been incorporated into European standards for grouting. The new edition of the PTI grout specification also includes these tests to identify grouts that are susceptible to bleed and segregation.

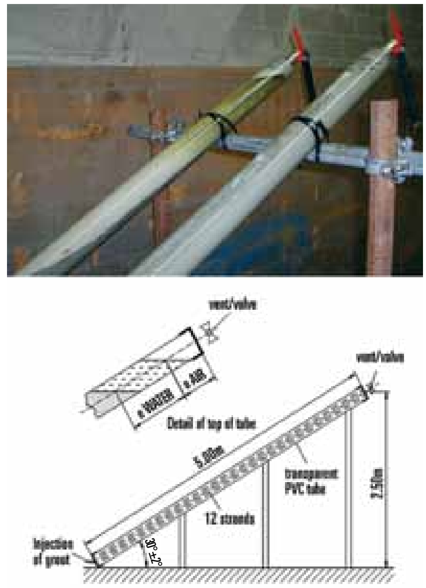


Photo (above) and schematic (below) of Inclined Tube Test set-up. Note: the difference in bleed between the high-bleed grout on the left and the low-bleed grout on the right. Graphic: VSL.

High pumping rates and pressures also were determined to contribute to the segregation of grout. Pumping rate must be slow enough to avoid air entrapment and segregation; and is required by the specification to be between 5 and 15 m per minute (16 and 49 ft per minute). Pumping pressures are listed in the PTI specification, and the new specification also eliminates the procedure of holding pressure for one minute after grouting.

Construction Quality

Several revisions have been made to the PTI specification to improve quality of grouting operations. Of particular significance, flushing of ducts is no longer permitted whether to clean the ducts prior to grouting or to remove grout in the event of a problem.

Inclined Tube Test

The inclusion of the inclined tube test is a key improvement in the qualification testing of post-tensioning grouts.

Advantages of this test are that it:

- includes the effects of both pressure and the strand, and
- is sized to be representative of a real environment in a duct.

The test was studied and validated by the French agency SETRA, and found to be a good indicator of a grout's susceptibility to bleeding and segregation.

The test is based on a standard procedure set forth in Euronorm EN 445—"*Grout for prestressing tendons—Test methods.*" Set-up includes two clear tubes that are 5 m (16 ft) in length and 80 mm (3.1 in.) in diameter. Each contains 12 prestressing strands and is inclined 30 degrees to the horizontal. (See figure.)

Grout is injected into both tubes. When filled, the outlets are closed; after 30 minutes, the valves of the second specimen are reopened and the pump re-started until grout flows out the outlet again.

Air, water, and segregation that accumulate at the top are recorded after 30 min., and 1, 3, and 24 hr.

Because worker training and ability greatly affects grouting quality, this version of the specification requires that the work be performed and supervised by qualified personnel. The specification recommends that grouting operators, supervisors, and inspectors be certified under American Segmental Bridge Institute's Grouting and PTI's Bonded PT certification programs.

Summary

These are only a few of the enhancements that have been included in the third edition of the PTI *Specifications for Grouting of Post-Tensioned Structures*. For more information, contact PTI or visit www.post-tensioning.org.

Theodore L. Neff is the executive director of the Post-Tensioning Institute.

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

http://cce.oregonstate.edu/about/history/mac/index.htm
The Focus article on pages 6 to 9 mentions Conde B. McCullough, a former Oregon state bridge engineer. More information about Conde McCullough and the bridges he has designed is available at this website.

www.i95newhaven.com
The complete story of the new I-95 New Haven Harbor Crossing Corridor Improvement Program, including the Pearl Harbor Memorial Bridge described on pages 30 to 33, is available at this website.

www.wackerdrive.net
This Chicago Department of Transportation and Illinois Department of Transportation website provides additional information about five projects related to the Wacker Drive replacement project described on pages 18 to 21.

http://www.efl.fhwa.dot.gov/technology/Bridge-VS/Foothills/foot-hills-bridge2.aspx
Visit this FHWA Eastern Federal Lands Highwood Division website for visualization of the Foothills Bridge No. 2 described on pages 38 to 40.

www.dot.state.fl.us/structures/Innovation/Ubeam.shtm
This Florida Department of Transporation website contains information about curved precast concrete spliced U-girder bridges described in the Creative Concrete Construction article on page 13. Links are provided to concept drawings and presentations about Colorado precast concrete girders, development of precast concrete spliced U-beam construction, and PCI Zone 6 standards.

www.fhwa.dot.gov/publications/focus/12aug/12aug02.cfm
This FHWA website contains an article from the August 2012 issue of FOCUS. Links are provided to the FHWA report No. FHWA-HIF-09-004, the ASR Field Identification Handbook, and the ASR Reference Center mentioned on page 46.

Environmental

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

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

Sustainability

http://sustainablehighways.org
The Federal Highway Administration has launched an internet-based resource designed to help state and local transportation agencies incorporate sustainability best practices into highway and other roadway projects. The Sustainable Highways Self-Evaluation Tool, currently available in beta form, is a collection of best practices that agencies can use to self-evaluate the performance of their projects and programs to determine a sustainability score in three categories: system planning, project development, and operations and maintenance.

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

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

Bridge Technology

www.aspirebridge.org
Previous issues of *ASPIRE*™ are available as pdf files and may be downloaded as a full issue or individual articles. Information is available about subscriptions, advertising, and sponsors. You may also complete a reader survey to provide us with your impressions about *ASPIRE*. It takes less than five minutes to complete.

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

www.hpcbridgeviews.org
This website contains 68 issues of *HPC Bridge Views*, an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of high-performance concrete in bridges.

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

Bridge Research

NEW www.dot.state.mn.us/metro/projects/35estpaul/maryland.html
Visit this website to watch the Minnesota Department of Transportation use self-propelled modular transporters to move a finished concrete bridge into position. Click on time-lapse video to see the 12-hour process in just over a minute.

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

BUYERS GUIDE

The companies listed on these pages have supported *ASPIRE*™ magazine during 2012. Each produces a high-quality product or service targeted to the bridge industry and is worthy of your consideration. In choosing *ASPIRE* as the way to communicate with you, they show enormous confidence in us.

These companies share in the significant success achieved by *ASPIRE*. Advertisers put their money where their mouths are, and they can rightfully be proud of *ASPIRE*'s success and our ambitious plans for 2013. They enable us to move ahead with confidence to better serve our readers.

Just as important, the advertisers create valuable messages for our readers. Their announcements and product information supplement our own presentations to keep readers current with new ideas.

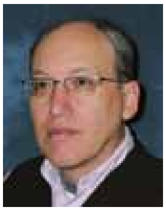
Whenever an opportunity arises, please contact an *ASPIRE* advertiser, ask them for more information, and thank them for their investment in the bridge community. For an easy way to make a contact, go to **www.aspirebridge.org** and select "Advertisers." Clicking on any listing will take you to their home page.

We appreciate their support, and yours, for making *ASPIRE* the most read and talked about bridge magazine!

	DESCRIPTION	ADDRESS/PHONE
ww.aecom.com	**Aecom** provides professional technical and management support services to the transportation industry. We provide a blend of global reach, local knowledge, innovation and technical excellence in delivering solutions that create, enhance and sustain the world's built, natural, and social environments.	4840 Cox Road Glen Allen, VA 23060 804.290.2460
www.bentley.com/BrIM	**Bentley** offers comprehensive bridge software solutions for design, analysis, and construction engineering: LEAP Bridge and RM Bridge.	685 Stockton Dr. Exton, PA 19341 800.BENTLEY
www.bridgescape.net	**Bridgescape, LLC.** Principal, Frederick Gottemoeller, is considered America's most distinguished bridge architect. His award-winning Woodrow Wilson Bridge in Washington, D.C., has received universal acclaim. His book Bridgescape is a 'bible' for bridge designers.	5425 Vantage Point Road Columbia, MD 21044 301.490.6088
www.caba-bridges.org	**Central Atlantic Bridge Associates.** Promoting the benefits, advantages, and performance of prestressed concrete bridges in the Central Atlantic region.	1042 North 38th St. Allentown, PA 18104 610.395.2338
www.cmeengineering.com	**CME Associates** is a multi-disciplinary civil engineering consulting firm that specializes in bridge engineering and accelerated bridge construction technologies.	333 East River Drive, Ste. 400 East Hartford, CT 06108 860.290.4100
www.corveneng.com	**Corven Engineering** specializes in the design, construction engineering, and inspection of complex prestressed concrete bridges, with an emphasis on precast and cast-in-place segmental concrete bridges.	2882 Remington Green Circle Tallahassee, FL 32308 850.386.6800
www.dsbrown.com	Founded in 1890, The **D.S. Brown Company** is a leading worldwide designer, supplier and manufacturer of engineered products for the bridge, airport and highway industries. D.S. Brown's home office and manufacturing facilities are located in North Baltimore, Ohio.	300 East Cherry Street North Baltimore, OH 45872 419.257.3561
www.dywidag-systems.com	**DYWIDAG-Systems International USA**. Experts in the design, manufacture, supply, and installation of THREADBAR®, multistrand, and cable-stay post-tensioning systems.	320 Marmon Dr. Bolingbrook, IL 60440 630.739.1100
www.earthcam.net	**EarthCam** is the global leader in providing webcam content, technology and services to business and government agencies. EarthCam provides time-lapse megapixel cameras, live streaming video and complete managed services to monitor, document and archive the world's most important projects and events.	84 Kennedy Street Hackensack, NJ 07601 201.488.1111
www.figgbridge.com	**FIGG** specializes exclusively in the design and construction engineering of American bridge landmarks.	424 North Calhoun Street Tallahassee, FL 32301 850.224.7400
www.flatironcorp.com	Founded in 1947, **Flatiron** is one of the leading providers of transportation construction and civil engineering in North America. Its core competencies include major bridge, highway, and rail projects.	10188 E. I-25 Frontage Rd. Firestone, CO 80504 303.485.4050
www.pile.com/grl	**GRL Engineers** services range from investigating unknown foundations to monitoring and analysis of hundreds of test piles. GRL's seven offices allow it to maintain a quick, cost-effective responsiveness to client needs throughout the world.	30725 Aurora Road Cleveland, OH 44139 216.831.6131
www.hansonstructuralprecast.com	**Hanson Structural Precast** is a leading supplier of precast products to much of the upper Midwest and Western United States through facilities in Idaho, Minnesota, and Utah. We've been delivering customized solutions since 1960.	9060 Zachary Lane, #101 Maple Grove, MN 55369 763.425.5555
www.flyash.com	**Headwaters Resources** manages and markets CCPs, including fly ash. Fly ash use improves concrete performance and creates significant benefits for our environment.	10653 S. River Front Parkway, Ste. 300 South Jordan, UT 84095 888.236.6236
www.helser.com	**Helser Industries** designs and manufactures steel forms for producing precast and prestressed concrete components for numerous commercial applications.	10750 SW Tualatin Rd, P.O. Box 1569 Tualatin, OR 97062 503.692.6909

	DESCRIPTION	ADDRESS/PHONE
www.holcim.us	**Holcim** is one of the world's leading suppliers of cementitious materials including our eco-efficient Envirocore products delivering innovation and greener building solutions to your customers.	201 Jones Road Waltham, MA 02451 888.646.5246
www.larsa4d.com	**LARSA Inc.'s** software for bridge analysis and design addresses specialized needs of a variety of bridge structures, including cable, segmental, curved, box, and other types, and is a standard in leading U.S. firms.	Melville Corporate Center 105 Maxess Rd., Ste. 115N Melville, NY 11747 800.LARSA.01
www.mcnarybergeron.com	At **McNary Bergeron** we believe in Engineered Construction.® Through extensive practical experience and knowledge, we provide constructible cost-effective solutions to meet the technical challenges of building today's sophisticated bridges.	US Highway 301 Tampa, FL 33619 813.248.194
www.meadowburke.com	**Meadow Burke** is a premier manufacturer and distributor for the concrete construction industry serving architects, engineers, and contractors with a superior line of concrete reinforcing products, concrete forming accessories, road and bridge products, and products for precast construction.	565 Burbank Street, Suite A Broomfield, CO 80020 303.450.6900
www.mi-jack.com	**Mi-Jack Products Inc.** is recognized as an industry leader and innovator in Travelift® and Translift™ rubber tire gantry crane manufacturing, sales, service, and support	3111 W. 167th Street Hazel Crest, IL 60429 708.596.5200
www.obec.com	**OBEC Consulting Engineers** is a full-service engineering firm based in the Northwest, offering a wide range of high-quality design, survey, permitting, and construction engineering solutions since 1966.	920 Country Club Road, Suite 100B Eugene, OR 97401 541.683.6090
www.olsonengineering.com	**Olson Engineering Inc.** has provided state-of-the-art structural and infrastructure NDT condition assessment services since 1985. The staff of Olson Engineering has been carefully assembled to have world class expertise in NDT&E consulting services.	12401 W. 49th Ave. Wheat Ridge, CO 80033 303.423.1212
www.pbworld.com	**PB** is a leader in infrastructure development around the world, dedicated to meeting the needs of clients and communities.	One Penn Plaza New York, NY 10119 212.465.5000
www.poseidonbarge.com	**Poseidon Barge Corporation** manufactures, sells, and rents Portable Sectional Barges to the Heavy Highway and Marine Construction Industry. We have distribution in Indiana, Arkansas, Florida, California, and Massachusetts.	3101 New Haven Ave. Fort Wayne, IN 46803 866.992.2743
www.reinforcedearth.com	**The Reinforced Earth Company** has forty years of experience designing and supplying materials to contractors for retaining walls, sound walls, and precast arches used in civil engineering applications.	8614 Westwood Center Dr., Ste. 1100 Vienna, VA 22182 800.446.5700
www.safway.com	With more than 85 branches across North America, **Safway Services** specializes in providing scaffolding and innovative access solutions. Our unique, patented QuikDeck® Suspended Access System is a versatile modular platform solution designed for safe, easy installation and reduced labor costs.	N19 W24200 Riverwood Dr. Waukesha, WI 53188 800.558.4772
www.schwagerdavis.com	**Schwager Davis, Inc.** is committed to providing quality and innovative solutions to your post-tension and bridge erection needs. As a post-tensioning system supplier and installation contractor, SDI has both the technical proficiency and practical know-how to support your design or contracting team.	198 Hillsdale Avenue San Jose, CA 95136 409.281.9300
www.standardconcrete.net	**Standard Concrete Products,** producer of prestressed/precast concrete products has plants in Tampa, Savannah, Atlanta, and Mobile.	PO Box 1360 Columbus, GA 31902 706.322.3274
www.transpo.com	**Transpo Industries Inc** is a manufacturer of roadway safety products–breakaway supports and specialty polymer concrete materials for the rehabilitation, maintenance and preservation of bridge and concrete structures—since 1968.	20 Jones Street New Rochelle, NY 10801 800.321.7870
www.tylin.com	**T.Y. Lin International** is a full-service infrastructure consulting firm recognized worldwide for its long-span and signature bridge design services, as well as seismic analysis and retrofit expertise.	Two Harrison St., Ste. 500 San Francisco, CA 94105 415.291.3700
www.vector-corrosion.com	Innovative solutions for corrosion of conventionally reinforced and precast/post-tensioned concrete including Galvanic and Impressed Current Corrosion Protection, Electrochemical Treatments and Specialty Corrosion Services.	3822 Turman Loop, Ste 102 Wesley Chapel, FL 33544 813.830.7566
www.williamsform.com	**Williams Form Engineering Corporation** has been offering ground anchors, concrete anchors, post-tensioning systems, and concrete forming hardware to the construction industry for over 85 years.	8165 Graphic Dr. Belmont, MI 49306 616.866.0815

Longitudinal Reinforcement to Resist Shear



by Dr. Dennis R. Mertz

With the acknowledgement of the modified compression-field theory as a sectional resistance model for concrete members, it was realized that a certain amount of longitudinal reinforcement is required to develop the shear resistance. Article 5.8.3.5—Longitudinal Reinforcement of the *AASHTO LRFD Bridge Design Specifications* requires sufficient longitudinal reinforcement on the tension side of the member to preserve equilibrium as shown schematically in Fig. C5.8.3.5-1 of the commentary.

Any reinforcement on the tension side of the member may be considered to resist this longitudinal tension force: prestressed or nonprestressed reinforcement as suggested in Eq. 5.8.3.5-1 of the LRFD Specifications, which is reproduced here:

$$A_{ps}f_{ps} + A_s f_y \geq \frac{|M_u|}{d_v \phi_f} + 0.5\frac{N_u}{\phi_c} + \left(\left|\frac{V_u}{\phi_v} - V_p\right| - 0.5V_s\right)\cot\theta$$

Equation 5.8.3.5-1 is derived taking a free-body diagram of the diagonally cracked section and summing moments about the resultant of the concrete compression force as shown in Fig. C5.8.3.5-1 of the LRFD Specifications.

Thus, the amount of longitudinal prestressed and nonprestressed reinforcement required ($A_{ps} + A_s$) is a function of the applied moment (M_u), applied axial load (N_u), and applied shear (V_u) force effects. The amount of steel required is also a function of the nominal shear resistance provided by transverse reinforcement (V_s) and the angle of inclination of the compressive stresses (θ) from the shear resistance determination. The required longitudinal reinforcement increases as the angle of inclination of the compressive stresses (θ) decreases and as the nominal shear resistance provided by tensile stresses in the concrete (V_c) increases. For a more complete explanation of the terms of the equation, see Article 5.8.3.5 of the LRFD Specifications.

This provision does not necessarily require additional reinforcement above that typically included to resist the other force effects. In cases where more reinforcement is provided than absolutely necessary—for example, where strands are added to yield a symmetrical strand pattern—the requirement may be easily satisfied. Also, as previously stated, all reinforcement on the tension side of the member can be counted upon for this resistance. Therefore, in prestressed concrete members, nonprestressed reinforcement not typically included in the moment resistance (such as steel used to form the reinforcement cage), can be considered for this provision, if necessary. However, the longitudinal reinforcement must be developed fully to consider it fully. If not, the tensile resistance must be reduced by assuming a linear variation over the development length for nonprestressed reinforcement or a bi-linear variation over the transfer and development length for prestressing steel. This situation is more likely to occur at the inside edge of the bearing area.

If the longitudinal reinforcement requirement of Eq. 5.8.3.5-1 cannot be satisfied by the developed steel on the tension side of the member, either additional transverse reinforcement or additional longitudinal reinforcement must be provided.

For load and resistance factor rating, Article 6A.5.8, Evaluation for Shear, of the *AASHTO Manual for Bridge Evaluation* specifies that sufficient longitudinal reinforcement must be present or some of the calculated nominal shear resistance must be discounted. A

Annual Survey

Each year, the AASHTO Highway Subcommittee on Bridges and Structures conducts a survey of the state bridge engineers to collect information on their bridge-engineering practices. Originally conceived to collect LRFD implementation information, the survey has evolved into more general topics and issues. Take a look at the latest survey and those over the past years at http://bridges.transportation.org/Pages/FAQ.aspx.

This year's questions identified the number of states that accept electronic submittals of shop drawings; have identified complex bridges; use Load and Resistance Factored Rating method for new bridges, existing bridges, and the overweight permit process; use elastomeric bearings; use different axle loads for design of concrete decks on longitudinal girders; and use life-cycle cost analysis.

EDITOR'S NOTE

More information on the FHWA's guide to identifying ASR can be found in the August 2012 issue of Focus located at www.fhwa.dot.gov/publications/focus/index.cfm and click on Past Issues.


D.S. Brown Bridges the World with Leading Infrastructure Solutions
Quality Engineered Products Available Worldwide for Bridge Construction and Rehabilitation
D.S. BROWN
A GIBRALTAR INDUSTRIES COMPANY
Cableguard™
Cable Corrosion Protection
Versiflex™
Bearing Assemblies
Deckguard™
Spray-Applied Waterproofing Membrane
Steelflex®
Expansion Joint Systems
D.S. Brown manufactures innovative products for bridge, pavement, concrete repair and architectural applications.
www.dsbrown.com