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THE CONCRETE BRIDGE MAGAZINE

SUMMER 2013

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Photo: Alfred Benesch & Co.

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Photo: PCI

Do Not Let the Perfect Be the Enemy of Good

William Nickas, *Editor-in-Chief*

When an engineer tries something new, there is a series of questions that will be asked by others involved (and sometimes those not involved) in the project.

- Is this change really going to simplify things?
- Will this change really save that much money?
- Is this procedural change going to add value to the final project?
- Why change if the current approach has worked for years?

In September 2011, as the retiring Tennessee state bridge engineer, Ed Wasserman presented a paper titled "Reflections or Fiction and Fact from Ed's Almanac." The main thrust of his reflection was the many opportunities he enjoyed through learning and sharing with others about changes in bridge technologies (see the *ASPIRE*TM website, under Resources/Papers, for a copy of Wasserman's paper). He goes on to say, bridge engineers should be brave but must also be smart. He reminds us all to never become just a number checker, and to always step back and evaluate the new concept for fundamental- and advanced-stage flaws.

My goal with this editorial is to keep his advice in the forefront. When evaluating new concepts and technologies, we all need to ask ourselves:

- Is this change an appropriate risk?
- What is the consequence of exceeding the limits?
- Does there need to be redundancy (multiple levels of protection) in the member's durability?
- If this change has a flaw, will it always meet the belt-and-suspenders strength limit state?
- Will the transient overloading from a superload cause an exceedance affecting the serviceability of this new detail?

- Is there adequate redundancy in the load path?
- Or, is there enough excess capacity above all factored loads?

Voltaire was the pen name of a French philosopher named François-Marie Arouet who lived from 1694 to 1778. According to Wikipedia, "the phrase *'The perfect is the enemy of good'* is an aphorism or proverb meaning that insisting on perfection often results in no improvement at all." The phrase is commonly attributed to Voltaire's moral poem, *La Béguéule*.

Judiciously taking design codes and applying these design principles is always an engineer's professional responsibility. But how the engineer sequences the construction and selects details is how the concrete bridge industry advances every day. New equipment and new materials are changing the tools available to engineers to deliver every infrastructure project.

During my career as a state bridge engineer, I had the chance to look at in-service bridge problems and major construction challenges. In every case, it took multiple issues to cause the problem. There was never a single root cause for the challenge.

Recently, I attended a meeting of the AASHTO T-10 committee on Concrete Design where committee members were working to ballot additions and changes to the 2014 (and beyond) *AASHTO LRFD Bridge Design Specifications*. These specification changes will certainly offer more high-performance concrete choices to industry suppliers, designers, contractors, and owners. Today, bridge engineers have dramatically more choices to address our nation's bridge inventory. Please, *do not let the perfect be the enemy of good.* 



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The Paducah & Louisville Railway Bridge

J23.3 near Fort Knox, Ky.

Photo: Alfred Benesch & Co.

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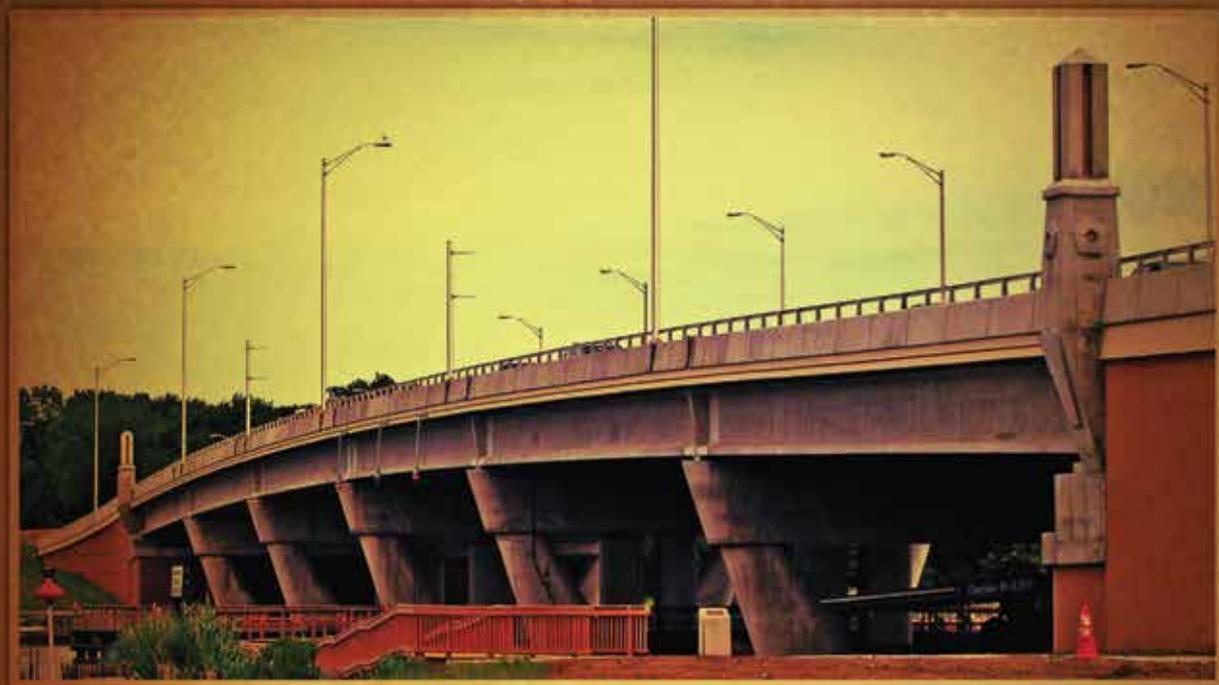


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Dr. Dennis R. Mertz is professor of civil engineering at the University of Delaware. Formerly with Modjeski and Masters Inc. when the *LRFD Specifications* were first written, he has continued to be actively involved in their development.



Ananth Prasad was named secretary of the Florida Department of Transportation (FDOT) in April 2011 by Governor Rick Scott. Prasad has a total of 22 years of experience in transportation; 20 years with FDOT where he previously held the positions of the assistant secretary for engineering and operations, chief engineer, and director of construction.

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 2013/2014

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

August 16-18, 2013
UDOT Bridge Replacement Showcase
Park City Marriott
Park City, Utah

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

September 4-6, 2013
Western Bridge Engineers' Seminar
Hyatt Regency
Bellevue, Wash.

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

September 30-October 2, 2013
ACAA 2013 Fall Meeting
Pinehurst Resort
Pinehurst, N.C.

October 2-4, 2013
PTI 2013 Committee Days
Austin Marriott North
Round Rock, Tex.

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

October 20-24, 2013
ACI Fall Convention
Hyatt Regency & Phoenix Convention Center
Phoenix, Ariz.

October 28-29, 2013
ASBI 25th Annual Convention
Portland Marriott Downtown Waterfront
Portland, Ore.

January 12-16, 2014
93rd Annual Meeting
Transportation Research Board
Marriott Wardman Park, Omni Shoreman, and Hilton Washington
Washington, D.C.

January 20, 2014
ASA World of Concrete 2014 Committee Meetings
Las Vegas Convention Center
Las Vegas, Nev.

January 20-24, 2014
World of Concrete 2014
Las Vegas Convention Center
Las Vegas, Nev.

March 22, 2014
ASA Spring 2014 Committee Meetings
Grand Sierra Resort
Reno, Nev.

March 23-27, 2014
ACI Spring Convention
Grand Sierra Resort
Reno, Nev.

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

September 6-9, 2014
PCI Annual Convention and Exhibition and National Bridge Conference
Gaylord National Resort and Convention Center
Washington D.C.

October 25, 2014
ASA Fall 2014 Committee Meetings
Hilton Washington
Washington D.C.

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

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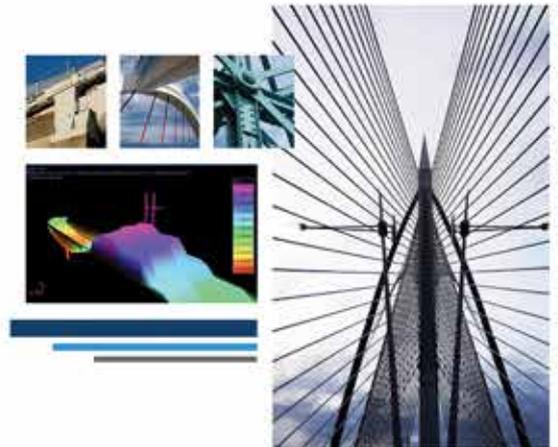
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Photo by Brooke Duthie, courtesy of T.Y. Lin International

READER RESPONSE



Editor,
Could you please send me a new copy of the Spring 2013 issue of ASPIRE™? I lent my first copy to students. ASPIRE is an excellent magazine. I regularly share my copy with my students.

John R. Sladek
Saint Martin's University Civil Engineering
Lacey, Wash.



Editor,
In the Fall 2012 issue of ASPIRE, there was an article on the curved, spliced, U-girders in Florida. I thought you might be interested in recent developments.

The June 6, 2013, issuance of Structures Design Bulletin 13-07 (SDB 13-07) by the Florida Department of Transportation (FDOT), with approval from the Federal Highway Administration (FHWA), shows the commitment of these organizations to bring the innovative technology of straight and curved, spliced pretensioned/post-tensioned U-girder bridges to Florida. In addition, the Orlando-Orange County Expressway Authority (OOCEA) has shown tremendous leadership by commencing

the final design for several spliced, pretensioned/post-tensioned U-girder bridge projects. SDB 13-07 gives definitive design recommendations, complimented by the PCI's Zone 6 standards and "Curved Precast Concrete Bridges State-of-the Art Report," and opens the door for a new structure type in Florida.

I would like to acknowledge the foresight of FDOT, OOCEA, and FHWA, the cooperation of Colorado DOT and industry professionals in Colorado for their assistance in sharing U-Beam technology, sponsorship by PCI, and the efforts of numerous individuals who have been forerunners and also guided the development of the spliced U-Beam concept.

In an era, now more than ever, where structural performance goes hand-in-hand with economy, spliced, pretensioned/post-tensioned U-girder bridges importantly provide design flexibility and will encourage and promote healthy industry competition.

Robert B. Anderson
URS
Tampa, Fla. 

Happy 30th Birthday, IBC!

June 2-5, 2013, bridge-industry professionals converged in Pittsburgh, Pa., for the 30th International Bridge Conference. ASPIRE staff and contributors thank IBC for a great show. Congratulations also go to Massachusetts, the featured state, for a great exhibit.



The Massachusetts Department of Transportation highlighted its accelerated bridge program with a theatre-themed booth at the International Bridge Conference. Photo: Massachusetts Department of Transportation.

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Market Diversity Keeps Benesch Flourishing

A range of projects, including railroad and pedestrian bridges, deepens firm's expertise

by Craig A. Shutt

Ever since Alfred Benesch & Company opened its doors in 1946, the firm has looked to grow its structural and civil engineering services. Its first major expansion in the early 1950s added bridge design projects as well as construction management. That work has led the firm to design a wide spectrum of bridges, including railroad and pedestrian bridges, as well as those with spans ranging from stream crossings to high-profile arch bridges. It has now embarked on a planned program of growth that will expand its client list and expertise in new directions.

"We've been designing bridges for nearly 65 years, and we've done pretty much every type there is," says John Carrato, president and CEO of the Chicago-based firm. "Our engineers are proficient in the study and design of continuous, complex structures, including tied-arch, segmental box girder, and cable-stayed bridges."

The firm also specializes in high-order, finite-element analysis associated with nonlinear and buckling behavior. "We are relentless in the pursuit of industry advancements, and we pride ourselves on implementing innovative solutions," he says. That pursuit led Benesch to design one of the first segmental concrete box girder bridges in the United States and the first in Illinois. The Kishwaukee River Bridge near Rockford was bid in 1976.

The Paducah & Louisville Railway Bridge J23.3 near Fort Knox, Ky., features 95-ft-long precast concrete AASHTO girders with a cast-in-place concrete deck. The bridge was built offline and the alignment was switched once the bridge was completed.

All photos: Alfred Benesch & Co.

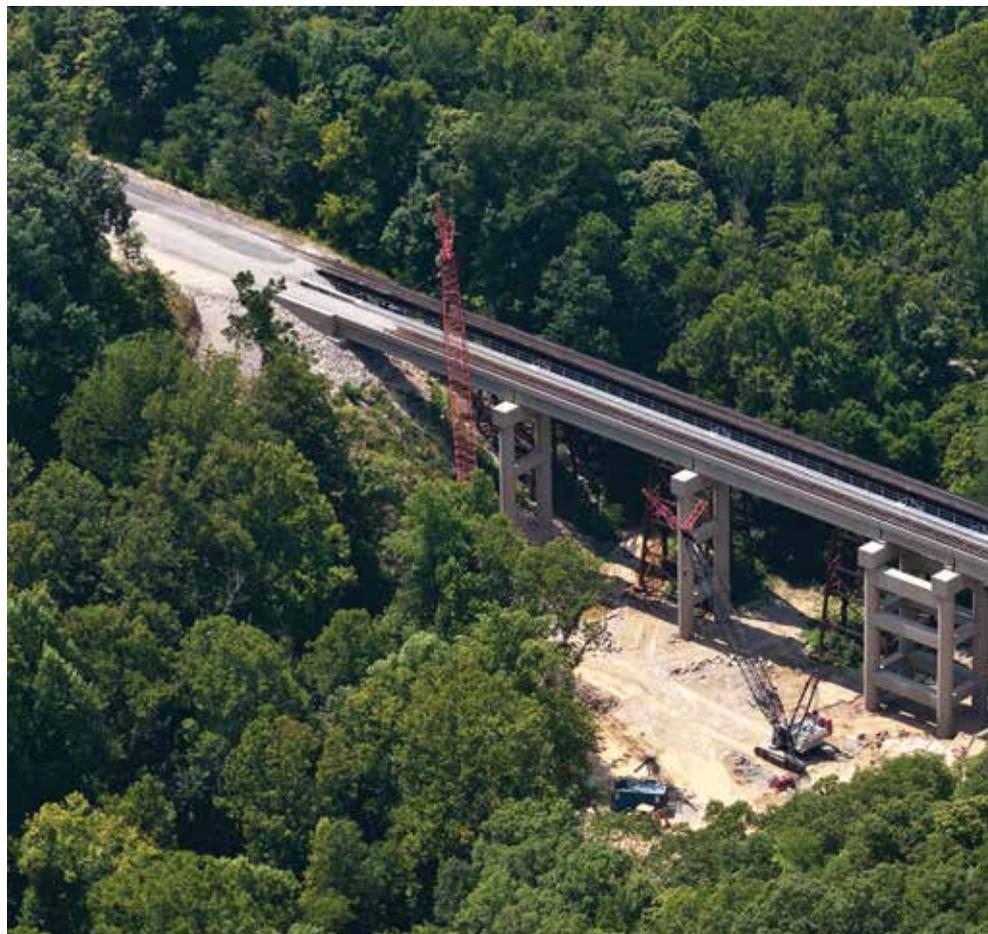
Value Engineering Techniques

The company emphasizes the importance of its study and evaluation of bridge conditions prior to design. For each project, it performs a type-size-location study to determine the best solution, bringing in a variety of perspectives to consider for every concept. "Our design philosophy is to marry conventional engineering with value engineering," he says. "We often use value engineering techniques to plan and design our projects."

Workshops for each project aid that approach. They bring together the

project's senior people, including the owner when possible. The meetings last one to five days, depending on the complexity of the project. "It's a short but formal way to ensure we look at all of the needs, desires, and constraints of the owners, users, and stakeholders," Carrato explains. "It allows us to look at the challenges through their eyes." The workshops, held for more than 30 years, "are ingrained in our culture now."

The firm also uses an online technical blog to keep employees abreast of new ideas and to facilitate communication. Ongoing communication and planning has created such close relationships



that about 95% of the firm's business comes from repeat customers, including departments of transportation, toll authorities, cities, counties, and other types of municipalities.

Value engineering also plays into providing tighter estimates, which owners are demanding, Carrato notes. "They want to know how every change impacts the budget and how it will affect user costs, for which they've gained a great appreciation. It's not only about the lowest cost but also the most value for the money spent."

Railroad Designs Thrive

Benesch offers particular expertise in railroad bridges. "Railroad bridges are unique because we can't stage traffic or create detours," Carrato explains. "They have to be constructed quickly with small work windows, typically a few hours."

In many cases, the railroad bridges are constructed of concrete, regardless of the original bridge's construction, adds David Morrill, senior vice president



The three-span, 268-ft-long Mayor Mike Peters Pedestrian Bridge in Hartford, Conn., has prestressed bulb-tee girders with a composite precast concrete deck slab. It features two colors of stamped concrete to create a brick-like pattern.

and structural group manager for Illinois. "The use of concrete has been increasing dramatically in railroad bridges," he says. "Where we used to design with steel, we're now using concrete for more superstructures." That's especially true for replacement of shorter timber-trestle bridges in the 20- to 40-ft range.

'The use of concrete has been increasing dramatically in railroad bridges.'

Typically, the designs prove more economical in the short and long term. "Concrete segments can be heavier, so bigger cranes and a larger substructure may be needed," says Morrill. "But those costs are more than offset by precasting pieces and moving them into place quickly and by reducing long-term maintenance needs."

A recent railroad project involved the Paducah & Louisville Railway Bridge J23.3 near the Fort Knox Army Base in Kentucky. Designers used 95-ft-long precast concrete AASHTO girders with a cast-in-place concrete deck for the project, which replaced a steel-tower viaduct bridge from the late 1800s. The bridge was built off line and the alignment was changed to connect to it rather than replacing the steel bridge

in line. "Constructing the bridge in line would have been a tremendous challenge," Carrato says. "We often build off line and slide the bridge into place, but this project proved most effective by changing the alignment."

Pedestrian Bridges Growing

Benesch also has become proficient at designing pedestrian bridges, which are becoming more popular. "The new urbanism and focus on transit options are leading to a desire for better pedestrian access while minimizing vehicle use," says Jim Fuda, Connecticut division manager. "Cities want to connect neighborhoods in better ways."

Those projects feature different, but no fewer, challenges, he notes. "With pedestrian bridges, owners are more sensitive to aesthetics and function. Since pedestrians' perspectives are at a walking pace, they experience more details, ornamentation, and the bridge's walking surface." That can often lead designers to use concrete. "From a pedestrian's perspective, concrete offers a more integrated appearance, from deck to railings to substructure," he says. "It can create nice lines that allow pedestrians to see the aesthetic elements working together."

The Mayor Mike Peters Pedestrian Bridge in Hartford, Conn., is an example. The 268-ft-long bridge, connecting the Connecticut Convention



Center with the Connecticut Science Center, is a three-span, precast concrete bridge consisting of prestressed bulb-tee girders with a composite precast concrete deck slab. The design provided the best overall economy, durability, and maintenance costs while offering accelerated bridge construction (ABC), minimizing disruptions to the highway ramps below. More details about this bridge are provided in the Winter 2012 issue of *ASPIRE*.™

The speed with which precast concrete allowed the bridge to be constructed, by fabricating components off site and bringing them together with minimal disruptions, was a key attribute. "We are seeing much more emphasis on doing work quicker, with less impact on traffic, and more searching for accelerated bridge concepts," says Morrill. "Accelerated bridge concepts are more prevalent and desirable today."

Expanding ABC Techniques

The firm is well versed in ABC techniques from its railroad work, says Carrato. "We've had no choice there, and many of those concepts can transfer to highway bridges." The firm has used sliding techniques on many railroad bridges as well as on several highway bridges recently. It also has experience with self-propelled modular transporters (SPMTs). "SPMTs show that even with massive components, these bridges can be moved readily."

Precast concrete helps speed up projects, especially with its ability to integrate its components. "In the past, precast concrete was used mostly for beams, but now it's expanding its uses to include pier caps, columns, and combinations of pieces that can be put together like an erector set," Morrill says. "We're seeing more of a drive in that direction now."

Benesch has even patented a precast concrete retaining wall to aid in simplifying designs. "Our goal with precast concrete projects is to simplify details and repeat them to reduce fabrication efforts, creating more efficiencies of every kind," Morrill explains. More details about this retaining wall system are provided in the Spring 2013 issue of *ASPIRE*.

An example of the speed that concrete designs can provide is the State Route 222 Bridge in Lehigh County, Pa. A 5.5-mile-long, boulevard-style bypass, required to alleviate congestion, included a new three-span bridge over the Pennsylvania Turnpike. This 358-ft-long bridge features precast, prestressed concrete AASHTO I-beams and spread box beams in a splayed arrangement to accommodate the loop-ramp geometry, with span lengths up to 158 ft. Estimates showed that the precast concrete design saved about 20% compared to the steel design.



Nighttime turnpike closures of no more than 15 minutes each were allowed to set the center-span beams, which had pick weights in excess of 110 tons, explains John Eagan, vice president and assistant division manager in the Pottsville, Pa., office. "We coordinated with the Turnpike Commission to swing the beams into place quickly and get the turnpike open again as fast as possible each night," Eagan says.

Aesthetics Gain Attention

As owners become more concerned about aesthetics, designers are incorporating ornamentation using formliners, curving forms, and interesting geometries. "We're doing shapes and amenities that we previously would not have done," says Fuda. "It's great, because we can create a nice ambience. Bridges are very visible structures, so attention to aesthetics pays off."

'Bridges are very visible structures, so attention to aesthetics pays off.'

An example of functional aesthetics can be seen in the firm's work on the University Avenue Bridge over I-74 in Peoria, Ill. The central supporting pier on the bridge, made with precast concrete, came down alongside the Dry Run Creek Flume. To avoid disrupting this waterway, designers created a concrete tied-arch pier that straddles the flume. This design was repeated on another bridge further down the highway.

As that project shows, sites are becoming more challenging. "It can be difficult to shoehorn a new bridge into the existing space," says Fuda. More projects replace existing bridges, where restrictions have increased since the original construction. For that reason, many bridges are being rehabilitated, and include the reuse of piers and foundations.

A type-size-location study for the State Route 222 Bridge in Lehigh County, Pa., led to a precast concrete design using AASHTO I-beams and spread box beams for the 358-ft-long, three-span bridge over the Pennsylvania Turnpike.



University Bridge on I-74 in Peoria, Ill., features a concrete tied-arch support pier that straddles the Dry Run Creek Flume. The design for the project, which features precast concrete girders, creates an aesthetically pleasing, functional support design.



The rebuilt two-level Wacker Drive viaduct in Chicago replaced the existing 1400-ft-long structure but retained many of the existing caissons. To help attain a 100-year service life, the deck slab was post-tensioned in both directions and included epoxy-coated reinforcement.

Retaining caissons on the Wacker Drive upgrade in Chicago, Ill., for instance, saved considerable time and money, but it created challenges, says Morrill. Benesch's portion of the project required replacing the 1400-ft-long, two-level viaduct and repairing fixed spans of the adjacent bascule bridge. The design, covering 44 spans that were five bays wide, featured a cast-in-place, post-tensioned concrete slab. Existing caissons were kept, but grade beams had to be placed over some of the existing caissons to support new

columns placed in different locations. See *ASPIRE* Fall 2012 for more details about the Wacker Drive project.

Durability has become more prominent in the owner's concerns, says Eagan. "Owners always want longer life and less maintenance," he says. Key ways to achieve that are to minimize deck joints and stretch precast concrete beams to eliminate piers. That's being helped by higher concrete strengths, he notes. "We used to work with 5 ksi concrete, but today we get 10 ksi routinely." More seismic control is being added to designs both as zones become more stringent and to add overall resilience, adds Morrill.

Sustainable Designs Sought

Longer life, more durable structures, and reuse of existing materials are key sustainable-design concepts that owners appreciate, Morrill notes. "Owners want more green structures, both to be sustainable and because reuse saves funds," he says. "Based just on environmental and economic factors, rehabilitation is definitely a higher priority today. The luxury of simply replacing a deficient bridge is over. We get more questions today about what can be reused."

Benesch has positioned itself to meet the demands of both new and existing bridges by expanding its business in recent years. In the past three years, it has made four acquisitions.

Its expansion isn't finished, says Carrato. "We have a long-term plan to grow and diversify geographically." Acquisitions now are focused on bolstering Midwest offices and expanding in the Southeast, where Benesch gained a foothold with its 2011 merger (see sidebar for more information).

"We don't want to become a mega-company, but we do want to have diversity, because not all markets are in the same shape at the same time," he explains. "We also know that more offices create more opportunities for our employees to grow."

The acquisitions add expertise and diversity as the firm deals with evolving needs, such as an emphasis by states

Benesch's Beginnings

Alfred Benesch founded his structural and civil engineering firm in Chicago in 1946. The next year, he hired his first employee, Harold R. Sandberg. Today, the firm has approximately 460 employees operating in 19 offices.

In the early 1950s, the firm expanded its expertise to include railroad and highway bridges and construction management. It also evolved from a partnership into a corporation and did work especially on the Illinois and Indiana toll-road system. It added value engineering in 1975, first internally and then expanding it into a separate service.

In recent years, it has experienced significant growth through mergers and acquisitions. In 2010, it merged with HWS Consulting Group in Lincoln, Neb., adding offices in three Midwestern states. In 2011, it merged with Clinard Engineering Associates LLC in Brentwood, Tenn., opening its first Southeast office.

In 2012, it added to its Colorado and Illinois offices by merging with LONCO. It also added offices in Connecticut and Massachusetts by merging with Purcell Associates Inc.

Benesch consistently ranks among the Top 500 Design Firms in the country as ranked by *Engineering News Record*. It recently received recognition for the fifth year in a row as one of the nation's Top 50 "Go-To" bridge-design firms by *Roads & Bridges* magazine.

on design-build and public-private partnerships (P3). "P3 projects are one reason we want to grow," he says. "We want to compete in that arena. We see where owners are going with their projects, and we want to be part of that activity and be a leader in that market with innovative, cost-effective designs."



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

Providing New Transportation Opportunities in Florida

Express lanes, dynamic tolling critical to Florida's managed-lane strategy

by Ananth Prasad, Florida Department of Transportation



As part of the Florida Department of Transportation's interconnected network of express lanes, the 95 Express project in Miami-Dade County has created momentum to continue planned extensions. All photos and diagrams: Florida Department of Transportation.

In 2011, the Florida Department of Transportation (FDOT), under the leadership of Governor Rick Scott and the Secretary of the Florida Department of Transportation, created the Florida Transportation Vision for the 21st Century. This vision establishes a bold roadmap for advancing the most innovative transportation system in the country. Many strategies and innovative tools are part of this vision, expanding choices for users and making our transportation system more efficient. The availability of express lanes on our most congested corridors is one of these important tools.

In an effort to get the most capacity out of our existing highways, states throughout the nation have employed a wide variety of "managed-lane" strategies. As part of these strategies, designated special lanes within a highway facility, or sometimes all lanes of an entire facility, are managed in response to changing conditions. These strategies may include controlling accessibility to these lanes, vehicle eligibility, pricing, or a combination of these tools. Examples of managed lanes include high-occupancy vehicle (HOV) lanes, high-occupancy toll (HOT) lanes,

truck-only lanes, bus rapid-transit lanes, reversible lanes, and express lanes.

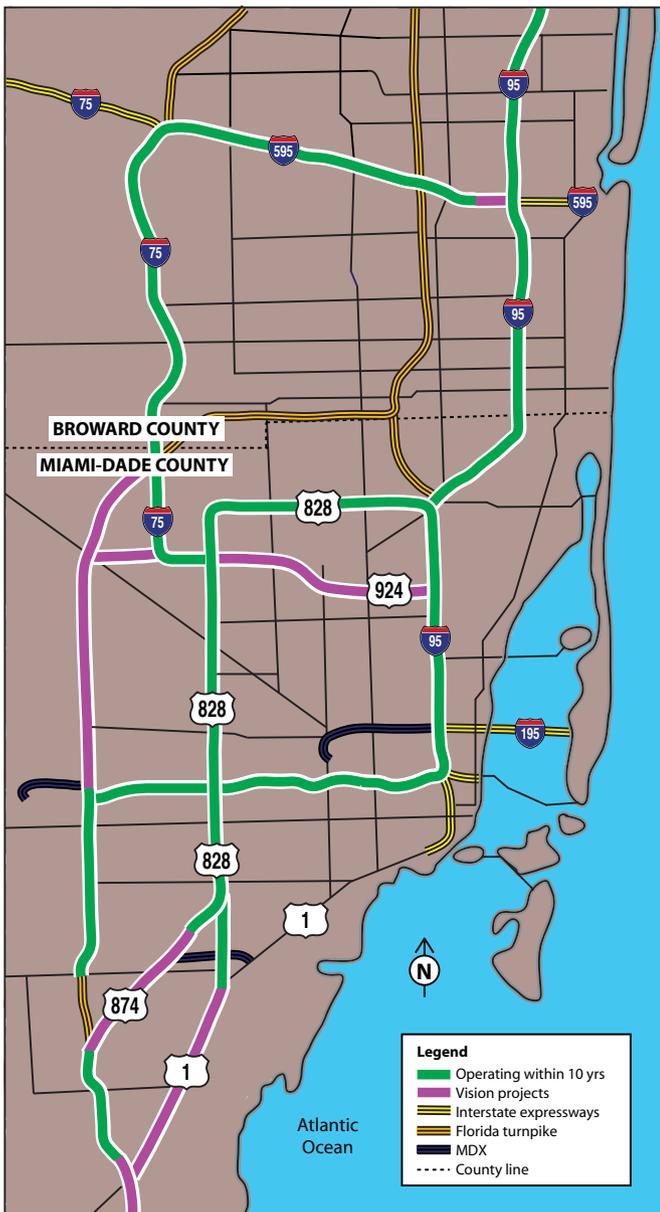
"Express lanes" is the term used in Florida to describe the state's approach to implementing managed lanes strategies. These barrier-separated tolled lanes within an existing highway allow congestion to be managed by limiting the number of access points to the special lanes, and by charging variable toll rates throughout the day, depending on congestion levels. Tolled express lanes have proven to be successful on highly congested facilities, providing individuals a choice of paying a toll to bypass congestion and experience more reliable travel times. Express lanes will be a necessary solution for many Florida urban areas, with plans for express lanes in southeast Florida, Tampa, Jacksonville, and Orlando.

Implementation of express lanes in Florida is made possible by recent federal and state laws that allow tolling of new capacity on existing facilities. This new capability is critically important to addressing Florida's long-term transportation needs. In traditional freeway capacity expansion projects, non-tolled, general-purpose

lanes are built, and may provide only 20 years of acceptable level of service. A dynamically tolled express lane, however, can adapt to future conditions using technology that adjusts toll rates, and provides individuals with the ability to make travel choices based on real-time traffic information. The driver can compare the estimated tolled and non-tolled travel times, and decide whether the current toll rate is worth the travel time savings and reliability of the express lanes.

At the heart of the system is dynamic tolling. When sensors detect the express lanes are beginning to reach capacity, the price increases incrementally, thereby reducing the number of drivers that choose the express lane option, and maintaining reliable travel speeds on the tolled lanes. As the express lanes begin to stabilize, the price is adjusted downward accordingly, enticing more drivers to choose the express lanes. This constant balancing process is repeated continually throughout the day. Dynamic pricing on the express lanes even benefits those who choose never to use the lanes, because when drivers divert to the express lanes, they free up more capacity in the general-purpose lanes.

As Florida advances its new transportation vision, FDOT is beginning to form an interconnected network of express lanes. The success of the 95 Express project in Miami-Dade County has created momentum to continue planned extensions along I-95 in Broward and Palm Beach counties. Expansion of the express-lane concept encompasses other facilities in the southeast Florida region, including I-595, I-75, and the Palmetto Expressway, creating a need to develop a Regional Concept of Operations for the Southeast Florida Express Lane Network (ELN). Successful implementation of a regional network requires a high degree of coordination among all regional stakeholders and agreement on a framework for policy



Future network of express lanes in Southeast Florida.

decisions on how the network will function and operate. The framework must define roles and responsibilities for all involved.

The Florida Department of Transportation, in partnership with expressway authorities, Florida's Turnpike Enterprise, and others, is building on its successes in southeast Florida by developing statewide policy guidance for all types of managed lanes. This guidance will provide a structure to coordinate plans and encourage consistent business rules, including these guiding principles:

- Express lanes have the purpose of managing congestion and creating

additional transportation options for drivers.

- Additional capacity on limited-access facilities on the state highway system will be dynamically tolled while maintaining the same number of non-tolled lanes.
- Toll revenue may be used for the operations and maintenance of express bus service routes operating within the express lanes.
- Multi-axle vehicles (vehicles with three or more axles) will not be permitted to use express lanes.
- Except where toll exemptions are granted by law, exemptions will not be provided on express lane facilities.

- Express lanes will use only electronic toll collection via Florida's SUNPASS.

The Florida Transportation Vision for the 21st Century lays the foundation for a future that maximizes existing infrastructure including our many concrete bridges. It is a future that uses evolving technologies to create a more advanced and efficient transportation system for Florida residents and visitors. Express lanes and other advanced strategies are important tools helping to fuel this transformation, and providing a new set of flexible choices to enhance the quality of life for transportation users in the Sunshine State. 

Funding Expansion

Governor Rick Scott and the Florida Legislature recognize that good transportation infrastructure is a key ingredient for a thriving economy. Governor Scott recently signed the FY 2013-14 General Appropriations Act into law which provides \$9.4 billion for transportation in Florida.

Florida Transportation Budget

- **FY 2013-14: \$9.4 billion**
- **FY 2012-13: \$8.2 billion**
- **FY 2011-12: \$7.9 billion**
- **FY 2010-11: \$6.9 billion**
- **FY 2009-10: \$6.5 billion**

More information can be found in Governor Scott's May 20, 2013, press release on the transportation budget located at <http://www.flgov.com/governor-scott-florida-families-first-budget-makes-strategic-transportation-improvements/>

NORTHEAST REGION

Interstates 95 & 295: Jacksonville Area

CENTRAL REGION

Interstate 4: Orlando Area

Interstates 4, 27, & 275: Tampa Bay Area

SOUTHEAST REGION

Interstate 95: Broward & Palm Beach Counties

Interstate 595: Broward County

Interstate 75: Broward & Miami-Dade County

826: Palmetto Expressway in Miami-Dade County

Future location of express lanes in Florida.

PROJECT

Maynard H. Jackson Jr. International Terminal Elevated Roadway System

Extensive use of precast concrete enables rapid and cost-effective construction of multi-level bridge and roadway structure at the Atlanta International Airport

by Barry L. Brown, Atkins



The Maynard Holbrook Jackson Jr. International Terminal at Hartsfield-Jackson Atlanta International Airport in Georgia is a major expansion at one of the world's busiest airports. The 40-gate, \$1.4 billion, 1.2 million-ft² international terminal is an efficient, state-of-the-art gateway for international passengers traveling through the United States via Atlanta.

But creating the passenger terminal was only one part of the airport expansion project.

A sophisticated transportation system was needed to give terminal access to travelers and terminal employees. So while the new terminal was being built, Maynard Holbrook Jackson Jr. Boulevard was also undergoing a \$100-million reconstruction to smoothly connect Interstate 75 to the new terminal. The project involved designing and managing the construction of the 1-mile-long, elevated concrete roadway structure that gives direct access to the terminal and terminal parking.

The elevated roadway system that serves the Maynard H. Jackson Jr. International Terminal of the Hartsfield-Jackson Atlanta International Airport incorporates a mile-long, multi-level, prestressed concrete beam bridge that features 14 horizontal curves and 12 grade changes. All photos: Max Anton Birnkammer.

profile

MAYNARD H. JACKSON JR. INTERNATIONAL TERMINAL ELEVATED ROADWAY SYSTEM / ATLANTA, GA.

BRIDGE DESIGN ENGINEER: Atkins, Atlanta, Ga., an Ascend Joint Venture partner

GENERAL CONTRACTOR: Holder, Manhattan, Moody, Hunt, a Joint Venture, Hapeville, Ga.

BRIDGE CONTRACTOR: Matthews/Thrasher, a Joint Venture, College Park, Ga.

CONCRETE SUPPLIER: Argos USA, Alpharetta, Ga.

PRECASTER: Gulf Coast Pre-Stress Inc., Jonesboro, Ga., a PCI-certified producer

ERECTOR: Thrasher Contracting, Atlanta, Ga.

OTHER SUB-CONSULTANTS: Prime Engineering Inc., Atlanta, Ga., Delon Hampton & Associates Inc., Atlanta, Ga., and Street Smarts Inc., Duluth, Ga., all Ascend Joint Venture partners; and Brindley Pieters & Associates Inc., Atlanta, Ga.



To enhance the durability and appearance of the elevated roadway, a protective coating was applied to all exposed vertical faces of the bridge superstructure, the exterior faces of the beams and parapets, and the pier caps and columns.

Constructed from 100,000 yd³ of precast, prestressed concrete, the 70-span, elevated roadway system incorporates a multi-level beam bridge with 14 horizontal curves and 12 grade changes. The structure supports large, protective passenger canopies; provides multiple access points for vehicles and pedestrians; and is designed to enable future expansion with minimal traffic disruption.

Overcoming “Foundational” Challenges

The busy airport couldn’t stop operating while a new terminal was being built, which meant that constructing the elevated roadway system required complex coordination. One of the biggest challenges was that the construction site for the elevated roadway was the former airport access road that served the Delta Airlines Technical Operations Center, a Gate

Gourmet food-service facility, and the airport’s control tower.

The need to preserve and protect existing utilities created unique challenges—especially when designing the foundations of the elevated roadway. For example, the headwaters of the 344-mile-long Flint River flow beneath the airport runways—and the construction site—through an 18-ft-diameter concrete culvert. To avoid culvert damage and possible river pollution, a set of cantilevered pier caps and dual-level piers were used.

The bridge footings also had to span the airport’s 42-in.-diameter main sanitary sewer. This was achieved with a footing that straddles the sewer line, which helped reduce costs and enabled the airport to maintain restroom service throughout construction.

Another challenge engineers had to overcome was Delta Airlines’ use of vibration-sensitive equipment in the adjacent aircraft maintenance facility. An investigation revealed that vibration from a normal pile-driving operation would force Delta technicians to continuously and laboriously recalibrate highly sensitive equipment—which would have meant significant aircraft maintenance slowdowns and potential flight delays. Instead, auger-cast concrete piles—which had never been used on a bridge of this size in Georgia—were used. The auger-cast piles were an outstanding success, enabling aircraft maintenance to proceed unhindered and saving Delta millions of dollars in equipment-calibration and work-delay costs.

The complex geometry of the bridge presented an entirely different set of design challenges. The precast concrete beam manufacturer was able to produce prestressed concrete beams with beveled ends—often varying within a single span—to match the many different bends and skews required by the complicated bridge geometry. The manufacturer also incorporated multiple sleeves into the precast concrete beams to serve as conduits for lighting, security, and communication systems.

Drainage was also an issue. With three roadway levels (service on the bottom, passenger arrival in the middle, and passenger departure on top), draining the structure with conventional scuppers was not possible. In addition, the roadway’s varying geometry—including long stretches of bridge with 0% profile grade—rendered a typical deck-drain system unworkable and impractical. The solution was to install trench drains along the gutter line at the departure and arrival levels—another first in Georgia for a bridge of this scale.

CITY OF ATLANTA, DEPARTMENT OF AVIATION, OWNER

BRIDGE DESCRIPTION: Bridge features 14 horizontal curves (radii from 115 to 382 ft), 12 grade changes (up to 6%), deck widths between 27 and 115 ft, and span lengths ranging from 40 to 90 ft.

STRUCTURAL COMPONENTS: 578 AASHTO Type III I-beams and 36 prestressed concrete box beams with an 8-in.-thick, cast-in-place concrete deck and single- and dual-level concrete piers with spread footings and auger-cast concrete piles

BRIDGE CONSTRUCTION COST: \$35,100,000 (\$117/ft²)

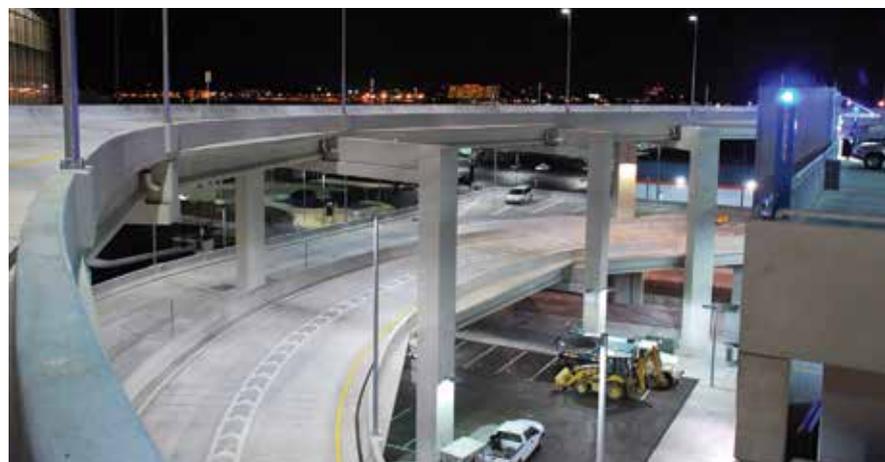
AWARDS: Precast/Prestressed Concrete Institute (PCI): *2012 Design Award* (Best Bridge with Spans 76 to 150 Feet); American Concrete Institute (ACI) Georgia Chapter: *2012 First Place Award* (Public Works Other than Buildings); American Council of Engineering Companies (ACEC) of Georgia: *2013 Grand Award for Engineering Excellence*; ACEC of Georgia: *2013 People’s Choice Award* (combination of elevated roadway structure and I-75 access roadway)



A forest of cast-in-place, reinforced concrete piers rises from the former site of a key Atlanta airport service road. Each pier is supported by spread footings and auger-cast concrete piles.



All three levels of the roadway are visible in this view. The ground level is for service access, the second level is for arrivals, and the top level is for departures.



The 8-in.-thick, cast-in-place, reinforced concrete deck is supported by prestressed concrete box beams that sit on cast-in-place concrete piers and spread footings with auger-cast concrete piles.

Improving Efficiency, Boosting Productivity

Using concrete for both substructure and superstructure enabled the contractor to meet an aggressive project completion schedule. By slightly increasing the concrete strength and using multiple early-break cylinders, the contractor was able to remove formwork and place construction loads on concrete members earlier in the schedule, which helped reduce overall construction time.

Because the pier caps for both levels could support construction loads, prestressed concrete beams could be placed on either or both levels, which enabled multiple decking crews to work simultaneously.

The girder erector was able to further accelerate the construction at the widest sections of the bridge by using a gantry system to install girders on the bridge's upper level. Using the gantry enabled the lower level deck to be constructed with a single concrete placement and eliminated a longitudinal construction joint. The bridge is comprised of 614 girders; during their most productive week, crews were able to erect 200 of them.

Increasing Durability, Reducing Maintenance

Materials and construction methods were selected to not only satisfy the project's requirements in a cost-conscious manner, but also with longer-term needs in mind—such as durability and maintenance. In addition to the

artful installation of trench drains, the bridge incorporates a number of other maintenance-reducing features, including:

- Minimizing permeability by paying careful attention to the concrete
- Using as few expansion joints as possible—some as far as 500 ft apart
- Protecting and enhancing the appearance of the concrete by applying a highly durable water-based coating to all exposed vertical faces of the bridge superstructure, the exterior faces of the beams and parapets, and the pier caps and columns

"We certainly encountered a wide range of engineering challenges in this project," said Atkins project manager Stephen Kahle; "not the least of which was designing a multi-level roadway in a tightly confined area—while at the same time maintaining public access and utility service to numerous mission-critical, pre-existing businesses and facilities. I'm pleased to say that our structural engineering team was able to employ a number of innovative, 'first-in-Georgia' design and construction techniques that helped minimize costs and keep the project on schedule."

New Gateway to the World

With 80% of U.S. residents within two hours' flying time from Atlanta, Hartsfield-Jackson Atlanta International Airport is a vital part of North America's transportation infrastructure. Now international travelers are using the elevated roadway system to gain convenient access to both the arrival and departure levels of the international terminal.

The new elevated roadway structure enables the Maynard H. Jackson Jr. International Terminal to serve as an efficient and attractive gateway to world travel. 

Barry L. Brown is an assistant vice president and senior transportation group manager for Atkins in Atlanta, Ga.

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

AESTHETICS COMMENTARY

by Frederick Gottemoeller



Airport-terminal roadways are hybrids; they are not quite buildings, but they are not quite bridges either. Design speeds for these structures are low, permitted curvatures are sharp, and long spans are not required to cross ramps below. The pier spacing for these structures mimics the bay sizes of the terminal itself. In fact, for reasons of architectural or functional harmony, it may well be necessary for the two dimensions to match.

Like a building, the terminal roadway is seen close-up by pedestrians. For those on the lower arrival level, the space below the terminal roadway becomes an extension of the arrivals hall, which is often filled with people. The terminal roadway defines the boundaries and creates the ceiling of this huge outdoor space. If done well, the roadway structure can make the arrival experience more welcoming.

This is an immense challenge. The curves of the roadway and the need to clear undercrossing ramps necessitates multiple pier configurations and straddle bents. The key to success in this situation is to use simple, attractive details, which are consistently repeated.

The Maynard H. Jackson Jr. International Terminal Elevated Roadway System does this very well. The piers always use “inverted T” pier caps supported by simple square columns. The pier caps always end with rectangular blocks, terminating the cap and at the same time disguising the “T” cross section. At the straddle bents, the rectangular end blocks are always simple extensions of the columns. The differing planes of the webs and flanges of the precast concrete I-girders create panels of shade and shadow that add to the visual interest. With a highway bridge, these characteristics are seen from such a distance and at such high speed that they are barely noticed. Here, they become valuable contributors to the overall impression.

The fact that there are no decorative architectural features adds to the effect of simplicity and calm. Adding such features would have added only visual distraction and complication.

The simplicity and calm extends to the roadway lighting and the way it is supported by the structure. Finally, the light-colored coating evens out the color and texture of the concrete elements and makes it possible to appreciate the piers as simple shapes. It also reflects light within this huge arrival hall, making it brighter in daylight and easier to light at night.

For any airport terminal seen from the landside, the terminal roadway structure is more important in determining the architectural impression of the terminal than the terminal building itself. Many airports miss this fact, spending much time and energy on the architecture of the building and not enough on the appearance of the terminal roadway. By constructing a terminal roadway of this high visual quality, Atlanta has avoided this trap.



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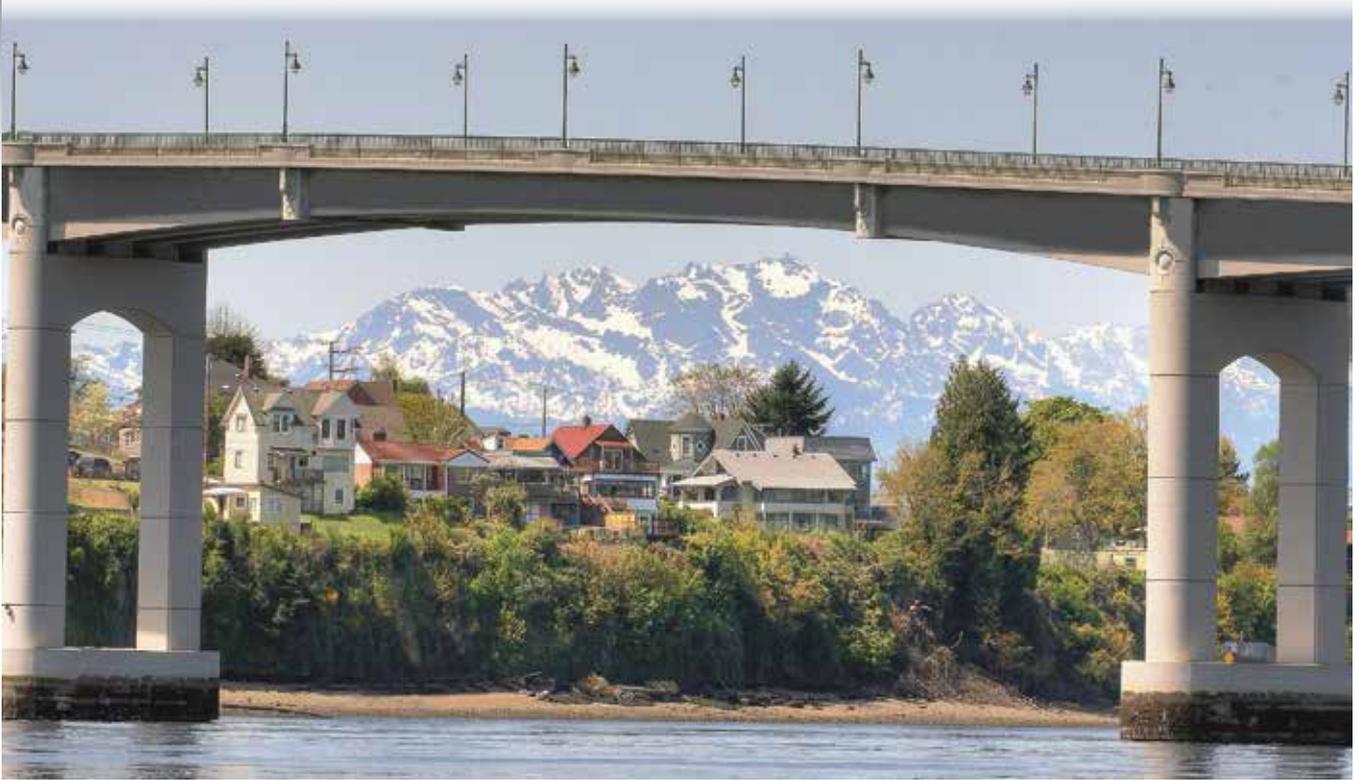


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PROJECT

SR 303 Manette Bridge Replacement Project

A collaborative, interdisciplinary bridge design approach encourages community input
by Paul Kinderman and Eric Ferluga, Washington State Department of Transportation



Complete bridge with Olympic Mountains in the background. All photos: Washington State Department of Transportation.

The SR 303 Manette Bridge Replacement Project was built in the Naval Shipyard town of Bremerton, Wash. The project team took part in a collaborative, interdisciplinary design approach that involved all stakeholders and resulted in a new modern bridge that preserves and enhances the scenic and historic community.

This project replaced an 80-year-old bridge that was important to the city and neighborhoods in terms of transportation of goods and services and civic pride. Some of the greater

challenges that needed to be addressed by the project team included the following:

- The existing bridge was to remain open during construction of the new bridge.
- The new bridge needed to be architecturally interesting and unique to satisfy the local community, yet economical to fit within the budget.
- The bridge foundation had to resist high seismic forces coupled with swift currents and large scour potential.
- The new bridge was to be constructed within 3 ft of the existing bridge to facilitate tie-in with existing roads.
- The bridge is not part of the state highway system, but state law had dictated that the state was responsible for the bridge's replacement.

Existing Bridge History

The Manette Bridge was originally built in 1930 across the Port Washington Narrows connecting the neighborhood of Manette with the rest of the city of

profile

SR 303 MANETTE BRIDGE REPLACEMENT / BREMERTON, WASH.

BRIDGE DESIGN ENGINEER: Washington State Department of Transportation Bridge and Structures Office, Tumwater, Wash.

GENERAL CONTRACTOR: Manson–Mowat, a Joint Venture, Seattle, Wash.

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

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

READY-MIX CONCRETE SUPPLIER: Kitsap Ready Mix, Poulsbo, Wash.

Bremerton. The main spans consisted of five steel trusses (four deck trusses and one thru truss) with approaches constructed of timber. In 1949, the timber approaches were replaced with steel girders.

Foundations supporting the truss spans were a combination of concrete seals and timber piles, and the approaches were founded on spread footings. The existing bridge was 1573 ft in length, with a 24-ft-wide roadway. The roadway width for the thru-truss span was 18 ft 4 in.

Originally, the existing bridge was part of the state highway system. However, state law (RCW 17.17.960 effective in 1991) decrees the following: "Although not part of the state highway system, the [Manette Bridge] shall remain the continuing responsibility of the Washington State Department of Transportation. Continuing responsibility includes all structural maintenance, repair, and replacement of the substructure, superstructure, and roadway deck. Local agencies are responsible for snow and ice control, sweeping, striping, lane marking, and channelization."

This law required state and city officials to coordinate closely with the project team during the planning, design, and construction phases.

The greatest structural issue with the existing bridge was the condition of the main span concrete piers. Testing of cores taken from the foundation starting in 1976 determined that the main cause of the deterioration in the concrete was due to alkali-silica reaction. Repairs to the bridge were completed in 1949, 1991, and 1996. These repairs attempted to encase the deterioration, but did not restore the capacity of the foundations.

Aerial view of the complete bridge.

The bridge was added to the replacement priority list in 1993 with a priority of 25, and had been waiting since then for funding. In 2007, the bridge had risen to a priority of 3, and funding of the \$65 million was provided. In 2008, the bridge required posting below legal limits due to rusting and section loss in the floor stringers.

The Replacement Bridge

The replacement bridge is 1550 ft long, carrying two traffic lanes, two 5-ft-wide shoulders, and a 10.5-ft-wide bicycle/pedestrian path.

The new bridge is a seven-span, continuous, prestressed, post-tensioned spliced girder design, supported by two-column bents founded on drilled shafts. The superstructure consists of five 250-ft-long spans, with end spans of 140 and 160 ft.

The new bridge was constructed approximately 3 ft from the existing bridge while the existing bridge was kept open to traffic. The exception was on the west end, where the new bridge needed to overlap the existing bridge to facilitate tie-in with the existing road. This overlap meant the existing bridge had to be closed to traffic for a short duration before the new bridge was opened. This was accomplished with partial demolition of the existing bridge and creative construction of the new bridge. The Washington State



Hammerhead precast, prestressed concrete girders.

Department of Transportation (WSDOT) made a commitment to the public that the closure duration would not be greater than 4.5 months.

Substructure

The bridge piers consist of an arched cross beam supported by two architectural columns that are founded on 12-ft-diameter drilled shafts. The column-shaft connection occurs at the water line and is encased in a shaft cap. The shaft cap consists of a precast concrete shell with reinforced concrete infill.

The precast concrete shell acted as a stay-in-place form that was sealed against water intrusion to facilitate placement of the infill concrete during varying tide conditions. At high tide, only a few feet of the shaft cap is visible. At low tide, the shaft cap is entirely out of the water by a few feet.



WASHINGTON STATE DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: The bridge is 1550 ft long and 42 ft wide and consists of five 250-ft-long spans and two end spans of 160 and 140 ft. Pretensioned, precast, post-tensioned, parabolically haunched, spliced I-girders are supported by twin column bents on deep foundations.

STRUCTURAL COMPONENTS: Cast-in-place concrete deck; 52 precast, prestressed, variable-depth concrete I-girders including 24 hammerhead segments and 28 drop-in span segments; 8 by 10 ft cast-in-place architectural columns supported by pier tables; and 12-ft-diameter drilled shafts

BRIDGE CONSTRUCTION COST: \$60 million



Structurally complete bridge with construction barges.

The construction contract contained two options for cross beam and column construction: a conventional cast-in-place option and an innovative precast concrete option. The contractor, who won the bid, elected to go with the cast-in-place concrete option.

The bridge is located in an area of high seismicity with close proximity to the Seattle Fault. In addition to the seismic forces, the bridge resists currents of 3.5 knots and a potential scour depth up to 20 ft. In order to resist these factors with only two shafts per pier, the superstructure was isolated from the substructure in the longitudinal direction with large elastomeric bearings.

Superstructure

The superstructure design utilizes a typical framing plan for continuous spliced girder bridges; hammerhead segments at the intermediate piers, drop-in segments spanning between the hammerhead segments, and drop in segments spanning between the end abutments and adjacent hammerhead segments. The bridge has four lines of girders spaced at 11 ft 7 in., except at the west end where the girders splayed to accommodate a right turn lane. The girders are spaced at 12 ft 5 in. at the west abutment.

Typically, continuous spliced girder bridges are post-tensioned several spans at a time or from expansion joint to expansion joint. This bridge was stressed span-by-span with unique opposing tendon anchorages centered over the

piers in the hammerhead segments. This detail allowed most of the new bridge to be constructed while keeping the existing bridge open. Only the west abutment and first span of the new bridge needed to be constructed during the 4.5-month closure period.

Due to the architectural desire for a parabolic shape, custom I-girder sections that included a truly parabolic (not chorded) haunch were developed for both the hammerhead and drop-in segments. The custom segments, weighing up to 306,000 lb, varied in depth from 6 to 12.5 ft. At the time of construction, the precast concrete hammerhead segments were the heaviest ever produced by the precaster. The precast concrete girder segments were transported by barge from the fabricator along the Tacoma waterway to the bridge site in Bremerton.

The deck is mildly reinforced and placed after the girders are post-tensioned. The west end of the bridge contains an additional lane to facilitate right hand turns. This wider deck is supported by splayed girders and has a large overhang supported by a diaphragm, which extends beyond the exterior face of the girders. The deck contains overlooks at the piers and corbels at luminaire locations. All deck reinforcement is epoxy coated per WSDOT standards.

Specified minimum concrete compressive strengths for the superstructure girder segments were

6.0 ksi at release and 8.0 ksi at post-tensioning. The closure concrete (between girder segments) had a specified minimum compressive strength of 6.0 ksi at the time of post-tensioning.

Architecture

The bridge is set in a small town with an historic United States Naval shipyard. The look of the new bridge was driven by architectural details provided after lengthy public input. The main architectural feature is the parabolically haunched girders that make up the bridge superstructure.

Other details include compass rose motifs on the piers, which reference seafaring navigation. The deep green colored railing is chosen to recall the old replaced steel truss. The columns are classic forms rising outboard of the superstructure to embrace pedestrian overlooks. Girder closures are highly detailed with nautical themes and traditional looking brackets.

Bridge aesthetics were important for this bridge because the surrounding neighborhood had a strong sense that the existing bridge defined their community. They were adamant they did not want a typical highway bridge and strongly resisted chorded haunches like a nearby bridge. The budget for the replacement bridge did not allow for a truly signature bridge. The spliced, parabolically haunched precast concrete girders provided an aesthetically pleasing structure for a reasonable cost.

WSDOT practices the Federal Highway Administration's context-sensitive design process. In this project, the team took part in a collaborative, interdisciplinary approach that involved all stakeholders. In this approach, the community's desires are integrated early in the process leading to efficient project delivery. **A**

Paul Kinderman is the state bridge and structures architect and Eric Ferluga is the senior bridge engineer, Washington State Department of Transportation in Olympia, Wash.

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

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The PCI State-of-the-Art Practice Report on **Precast/Prestressed Adjacent Box Beam Bridges**

This report (SOP-02-2012) presents the state-of-the-art practice on adjacent precast, pretensioned adjacent box-beam bridges. This report is relevant for Accelerated Bridge Construction, new bridge construction, or superstructure replacement projects.

The PCI State-of-the-Art Report on **Full-Depth Precast Concrete Bridge Deck Panels**

The *PCI State-of-the-Art Report on Full-Depth Precast Concrete Bridge Deck Panels* (SOA-01-1911) is a report and guide for selecting, designing, detailing, and constructing precast concrete full-depth deck panels for bridge construction. This report is relevant for new bridge construction or bridge-deck replacement.

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

This report details the application of curved precast concrete bridge design, fabrication, construction techniques, and considerations through the study of 12 related projects. The document was written and intended to provide bridge owners, designers, fabricators, and engineers an up-to-date reference in developing precast concrete bridge solutions for curved geometric situations.

www.pci.org/epubs

PROJECT

The Bronco Arch Bridge

Design and construction of the replacement for the I-25 Bridge over the South Platte River

by Gregg A. Reese, Summit Engineering Group Inc.



The new Bronco Arch Bridge spans the South Platte River near Mile High Stadium in Denver, Colo. All Photos: Summit Engineering Group Inc.

The I-25 Bridge over the South Platte River has been a Denver landmark structure since its initial construction in 1951. The steel arches, supporting the bridge superstructure, became known as the Bronco Arches after the Denver Broncos began playing football in the adjacent Mile High Stadium in 1960.

Today the bridge carries over 200,000 vehicles per day. After many years of service the bridge deck, superstructure, and supporting arches became seriously deteriorated resulting in the bridge having one of the lowest sufficiency ratings in Colorado.

A new replacement bridge, designed by the Colorado Department of Transportation (CDOT), was bid in March 2011. The new bridge is 371 ft long and 197 ft wide to accommodate four through lanes of traffic in each direction as well as acceleration lanes and on and off ramps. The superstructure consists of three spans with eight parallel girder lines with skewed abutments at each end.

Value Engineering Proposal

The contractor requested that CDOT consider a number of value-engineering proposals that would enhance the design of the bridge, reduce the

number of stages of construction, shorten the schedule, and greatly reduce the impact on existing traffic. CDOT recognized that the value-engineering proposals suggested by the contractor would result in less disruption and a shorter schedule and allowed them to proceed.

Because the project was bid prior to performing any preliminary value engineering, the designs had to be accomplished within the overall project construction schedule to avoid delays. To accomplish this, a design schedule was established with priorities driven by the construction schedule.

profile

BRONCO ARCH BRIDGE / DENVER, COLO.

BRIDGE DESIGN AND CONSTRUCTION ENGINEER: Summit Engineering Group Inc., Littleton, Colo.

PRIME CONTRACTOR: Lawrence Construction Co., Littleton, Colo.

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

POST-TENSIONING CONTRACTOR: VSL, Denver, Colo.



The piers are arched to simulate the look of the original arch bridge.

Structural Concept

The new design retained the original number of girder lines, girder spacing, cross section, and the full-depth precast concrete deck system. Heights and locations of all retaining walls remained the same.

The new bridge structure was designed as a rigid frame with integral connections between the substructure and superstructure and assuming flexible foundations. All permanent bearings were eliminated. The revised superstructure framing consisted of a transversely pretensioned and longitudinal post-tensioned, precast concrete deck slab supported on continuous, post-tensioned girder lines during construction. The use of a rigid frame enhanced the structural efficiency and stiffness of the system while optimizing the use of precast, prestressed concrete elements.

Design and Casting of Interior Piers

The most distinctive architectural features of the Bronco Arch Bridge are the interior piers. Concrete piers simulate the look of the arches they replaced. Each of the 16 precast,

reinforced concrete piers consists of a pair of slender, arched shafts that converge into a square base. The pier shafts are connected with a concrete strut at mid-height. The piers connect to the drilled shaft foundation with a cast-in-place, reinforced concrete pedestal. A capital at the top of each pier shaft supports the precast, prestressed concrete girders.

Concrete piers simulate the look of the arches they replaced.

As cast, the piers were 34 ft tall and 33 ft across at the top with 54-in.-wide shafts that varied in thickness from 24 in. at the base to 30 in. at the capitals. The base section was 54 in. square. The addition of the strut reduced bending moments in the pier shafts by 60%. This, in turn, resulted in a more slender design that reduced the overall weight of the piers to 100 kips, which made precasting, handling, and erection possible.

All the precast, reinforced concrete piers are identical. They were cast in the contractor's yard adjacent to the bridge site. The piers were cast on their side in a simple casting bed consisting of conventional curved wall forms on a smooth finished concrete mud slab. Casting of the piers commenced during construction of the walls and abutments.

Interior Pier Construction

Each pier foundation consists of a single, 54-in.-diameter drilled shaft. This foundation provides the necessary strength to resist all design loads while providing the flexibility to accommodate longitudinal movements.

The pier foundations were designed for a minimum concrete compressive strength of 4 ksi and approximately 1.5% vertical reinforcement, which extends 4 ft into



Precasting the interior piers.



The precast concrete interior piers were cast and stored horizontally.



The piers were cast horizontally, rotated, and threaded into the shoring towers.

COLORADO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 371-ft-long, three-span, rigid frame consisting of precast concrete deck panels; spliced precast, pretensioned and post-tensioned U-girders; precast concrete curved piers; and integral abutments

STRUCTURAL COMPONENTS: Sixteen precast, reinforced concrete piers; 24 precast, prestressed concrete, 72-in.-deep, U-girders with lengths of 95, 136.5, and 133.5 ft; and 8-in.-thick, precast, full-depth, concrete deck panels, pretensioned transversely and post-tensioned longitudinally

BRIDGE CONSTRUCTION COST: \$14.2 million

the column pedestal above. Drilled-shaft penetrations into the siltstone bedrock, approximately 30 ft below existing grade, varied from 14 to 18 ft.

A square footing cast on top of each drilled shaft supported a temporary shoring tower that was used to support the precast concrete piers during erection. Once the foundations were complete, the precast concrete piers were loaded in the storage area on to conventional trailers that were retrofitted with transverse support beams. Two cranes lifted the piers at locations at the top of the cross strut and at lifting loops embedded in the end of the pier base.

Erection required the piers to be rotated from a horizontal to vertical position and threaded into the shoring towers. A special head frame at the top of each shoring tower supported the pier. Jacks on the head frame were used to adjust the piers into their final alignment.

After the piers were secured on the shoring towers, the reinforcement and forms for the support pedestal were set in place and the pedestals were cast. Pedestal concrete had a minimum design compressive strength of 4.5 ksi. Superstructure girders were erected 8 to 14 days following erection of the precast concrete piers.

Superstructure Design

The superstructure framing consists of eight continuous girder lines supporting a composite precast concrete deck slab and an integral connection to the substructure. The girders are standard CDOT U72 precast concrete girders with a depth of 72 in. and 5- and 7½-in.-thick webs. The girders were cast with self-consolidating concrete with a design compressive strength of 8.5 ksi.

Each girder line consists of three precast concrete U72 girders cast in lengths of 95.0, 136.5, and 133.5 ft. Girder weights varied from 170 to 210 kips. Span lengths are 84, 148, and 134 ft. When erected, the girders are spliced with concrete between adjacent girder ends and connected to the piers and abutments with cast-in-place concrete diaphragms.



The simple-span girders were spliced and post-tensioned together and connected to the piers and abutments.

Unique prestressing patterns were developed for each of the three different girders using a combination of straight, draped, and debonded strands. Once the girders were spliced and connected to the substructure, they were post-tensioned with twelve 0.6-in.-diameter, 270 ksi strand tendons in each of the girder top flanges over each interior pier. The design creates a combination of pretensioning and post-tensioning that resulted in a fully prestressed, continuous girder line prior to setting the bridge deck panels.

The deck slab consists of full-depth, transversely pretensioned, 8-in.-thick, precast concrete deck panels with a concrete design strength of 7.4 ksi. Once erected, the deck panels are made composite with the precast concrete girders with a continuous haunch placement and a series of transverse closure placements. Once the haunch and closure concrete reached design strength, the deck panels were post-tensioned longitudinally. The deck post-tensioning consisted of four 0.6-in.-diameter strand tendons spaced at 2 ft 6 in. and located at the mid-depth of the precast concrete panels.

Accelerated Construction

The construction of the Bronco Arch Bridge was completed within budget and ahead of schedule. More importantly, construction was accomplished with minimal disruption to existing traffic considering it was a full replacement of a busy section of interstate highway over a waterway in a downtown urban area with a high volume of daily traffic.

To minimize the impact on traffic, the contractor built all retaining walls and abutments before commencing the first stage of demolition and bridge construction. Precast concrete piers, girders, and deck panels were all fabricated well in advance of the time they were needed. An efficient set of operations was repetitively executed minimizing the time necessary for each stage of construction.

Summary

The design and construction of the Bronco Arch Bridge is an excellent example of accelerated bridge construction. A signature structure was built within budget and schedule. New and innovative technologies and construction methods were developed and successfully executed and all of this was accomplished with a minimum amount of inconvenience to the citizens of Colorado.

The success of the Bronco Arch Bridge was largely due to the close cooperation that existed between CDOT, the contractor, the engineer, and all the various subcontractors and suppliers who worked on the project. An open, cooperative environment that encourages innovation has resulted in a number of nationally recognized bridges, and the Bronco Arch Bridge is another example. 

Gregg A. Reese is president of Summit Engineering Group Inc. in Littleton, Colo.

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Rail Transit Bridges

Overcoming challenges with cost-effective, low-maintenance, segmental concrete solutions

by William R. Cox, American Segmental Bridge Institute



The first precast concrete, segmental, post-tensioned rail transit bridges in the United States were built for the Metropolitan Atlanta Rapid Transit Authority in 1985. Photo: FIGG.

Rail transit projects have become more prevalent over the years as municipalities look to encourage rail transport to alleviate congestion. In a growing number of cases, segmental concrete bridges are creating the optimum solution for cost-effective, quickly constructed, and aesthetically pleasing structures.

Today, 35 major metropolitan areas have passenger rail systems, with many of them elevated above surface streets and highways. These systems are often challenging to construct, with limited right of ways, obstructions to span, and small radius curves. They also are highly visible to the public, requiring more attention to detail, especially on the substructures and the underside of the superstructures that are more apparent to pedestrians and drivers.

Segmental concrete bridges offer a variety of benefits that overcome these

design and construction challenges. They provide an optimum span length of 100 to 150 ft but can extend to 350 ft or more when required.

Segmental construction can be used in a variety of difficult site conditions. Piers can be set in tight footprints, and superstructures can go over and around community landmarks and roads. The segments also can be set from above, alleviating ground congestion and disruptions. Segmental designs allow tight radii for curved spans. Precasting, using shortline casting methods, allows segments to be cast and erected with speed and accuracy.

Generally, no specialized transport equipment is needed to deliver segments to the site, where they can be picked and placed immediately, allowing faster on-site handling. Power supplies and other rail service requirements can be located inside the box girders

leaving an uncluttered outside concrete appearance.

The designs offer aesthetic versatility by allowing concrete to be cast into sleek geometric shapes from piers to superstructure and railings. Designs also can use formliners to create textures that fit with an existing neighborhood.

Transit projects have been using segmental concrete construction since the early to mid-1980s, and they continue to grow in number and diversity, as the following examples show.

Atlanta's MARTA

Completed between 1983 and 1985, two precast concrete, segmental, post-tensioned structures for the Metropolitan Atlanta Rapid Transit Authority (MARTA) were the first of their kind for a railway bridge in the United States. They showed transportation officials nationwide that segmental techniques could economically solve bridge construction needs in heavily congested urban areas.

The project's original plan for using cast-in-place concrete box girders was value-engineered to a precast concrete segmental design erected using span-by-span construction with external post-tensioning tendons. The tendons were located within the box-girder void but external to the concrete.

The first segmental structure is 5230 ft long and 30.35 ft wide, and was designed to carry two tracks. It consists of simple spans ranging from 70 to 100 ft in length. The box-girder superstructure segments are 10 ft long, 7 ft deep, and weighed approximately 30 tons.

The second structure, which is 1900 ft long, has span lengths from 75 to 143 ft. It includes a four-span continuous unit. Continuity was accomplished by



The 8.7-mile-long concrete segmental guideway at JFK International Airport features precast concrete segmental box girders that were erected with four erection trusses working simultaneously using the span-by-span method. Photo: FIGG.

modifying the post-tensioning pattern of the pier segments where the tendons are anchored. The outside concrete dimensions are the same as those for the first structure, allowing the same side forms to be used.

For erection, identical triangular trusses on each side of the box section were used to support the box girders under their wings. To accommodate the variety of span lengths, the truss was adapted with the addition of 40-ft, 8-ft 10-in., or 5-ft-long sections. This was the first application of the triangular truss system for span-by-span construction in the United States and proved successful.

New York's JFK Airtrain

This 8.7-mile-long concrete segmental guideway links the terminals at JFK International Airport with New York City's mass transit systems. The structure spans parking lots and active roads, and runs along an expressway right-of-way. The segmental structures were built while maintaining traffic of 160,000 vehicles per day.

Two types of concrete boxes were precast to create the 5195 segments needed, all of which were barged from Virginia to Camden, N.J., and then trucked to the site for delivery.

Seattle's Sound Transit project in 2008 features twin, 26-ft 6-in.-wide precast concrete box girders. Typical span lengths of 120 ft were used, with spans of 220 to 350 ft to traverse ground obstructions.

Photo: Hatch Mott MacDonald.

The Type I box, with a width of 19 ft, was designed for a single track. The Type II box, with a width of 31 ft, was designed for dual track. Both types are 7 ft deep and vary in length from 8 to 9.5 ft in 6-in. increments. These variations accommodate the varying span lengths in the congested urban setting.

The segments were erected using span-by-span methods, with four erection trusses working simultaneously in different parts of the project. Twelve segments were fabricated each day using 14 casting machines. Twin triangular erection trusses were used to erect one span (with epoxy joints) in 1½ days, with



an average of 800 ft of bridge erected each week. The structure has 460 spans and was completed in 2001 two months ahead of schedule.

Seattle's Sound Transit

Engineers designing the Seattle Sound Transit rail system, which was completed in 2008, used a similar design to the one they had recently completed in Vancouver, B.C., Canada. The restricted right-of-ways on both projects were a key reason for using a segmental design, which features 26-ft 6-in.-wide, 7-ft-deep precast concrete box girders.

The 4.2-mile-long elevated project used 2207 segments and 160 concrete piers to carry twin tracks with continuously welded rails on top of the superstructure. Typical span lengths are 120 ft, with spans of 220 to 350 ft used where the bridge spans I-5, the BNSF rail tracks, and the Duwamish River.

The box girders feature a unique triangular-shaped cross section. The width of the bottom slab was sized to satisfy the box-girder bending stresses. Lateral stability at the piers is provided by external diaphragms, which are integrated with the pier shapes. This creates a sleek, narrow section that significantly reduced material quantities.

Speed of construction was a key benefit, as the project represented the last section of the rail system.



The Miami Intermodal Center—Earlington Heights Connector features three types of concrete spans, including precast, post-tensioned segmental concrete box girders. Thirteen single-cell, constant- and variable-depth box girder units were erected using the balanced cantilever method. Photo: Rizzani de Eccher USA.

The superstructure was erected using an overhead travelling gantry. The segmental design cut the estimated schedule by more than nine months, as site work was performed while segments were cast. The winning bid also came in more than 10% below original estimates.

Miami's Intermodal

The Miami Intermodal Center—Earlington Heights Connector provides a light rail connection between the new Miami Intermodal Center Metrorail station and the existing Earlington Heights Metrorail station. The 2.4-mile-long elevated guideway carries both single and double tracks.

The concrete box-girder portions feature 13 units over 1.1 miles with constant- and variable-depth, single-cell precast concrete box girders. The single-track box girders have a constant depth of 7 ft 8 in., while the dual-track box girders have a variable depth ranging from 8 ft at midspan to 14 ft at intermediate piers.

The segments were erected using the balanced-cantilever method. Cantilever stability was achieved with frames around columns supported on

The Dulles Corridor Metrorail Project used segmental construction to handle heavy congestion in the work site. More than 2700 precast concrete match-cast segments were erected using overhead trusses. Photo: Chuck Samuelson, Dulles Corridor Metrorail Project.

permanent foundations and stability towers on one or both sides of the piers on temporary foundation pads.

Because the guideway corridor is located along some of the most heavily traveled highways in south Florida, construction was designed to keep traffic flowing. The segment-lifting system consisted of the lifting frame, overhead traveling truss, lifting beam, and a secondary spreader beam. The project opened for use in 2012.

WMATA/Dulles Corridor

The Dulles Corridor Metrorail Project is a two-phase, 23-mile extension of the existing rail system for the Washington (D.C.) Metropolitan Area Transit Authority (WMATA). Heavy congestion in the work site led to the use of segmental construction for two sections of the 3

miles of elevated concrete guideway. The guideways used more than 2700 precast concrete, match-cast segments approximately 7 ft 6 in. wide by 8 ft deep, with a top flange approximately 16 ft wide for typical guideway segments. The box sizes change to 7 ft wide by 5 ft deep with a 16-ft-wide top flange through the stations, where the spans are about 50% shorter. The webs and slabs are 9 in. thick in the guideway spans and 10 in. thick in the station spans.

Segments were trucked in individually and hoisted into place by a truss erector, where their match-cast faces were coated with epoxy, joined together, and aligned. Segments were approximately 10 ft long, depending on the radius of the alignment at that location. Span lengths generally were dictated by the availability of ground space to locate the concrete piers, which are mostly located in the medians of heavily travelled thoroughfares. Where support was required in the roadway, straddle bents were constructed.

Bridge construction was not allowed over active roadways, so much of the work was done at night. The guideways were completed in May 2012, and the first new riders will board the trains in late 2013.

Portland's Willamette River Bridge

A sleek, 1720-ft-long cable-stayed bridge across the Willamette River will serve as the centerpiece for the Portland-Milwaukie Light Rail Transit project that is currently under construction. The





Now under construction, the 1720-ft-long cable-stayed bridge across the Willamette River features three spans of 390, 780, and 390 ft with constant-depth, open-edge segmental girder sections erected using the balanced cantilever method. Rendering: T.Y. Lin International.



The Honolulu High-Capacity Transit Corridor Project for the Honolulu Authority for Rapid Transportation, currently under construction, features single-cell trapezoidal box girders to carry a dual track. This rendering shows the Kamehameha Highway section of the project. Photo: FIGG.

bridge will connect a planned campus for Oregon Health & Sciences University with the Oregon Museum of Science & Industry. It will carry the rail trains as well as buses, bicycles, and pedestrians. It also is planned to accommodate the Portland Streetcar in the future.

The bridge's three spans of 390, 780, and 390 ft, use constant-depth, open-edge girder sections and are being constructed using the balanced cantilever method. Each bridge is being built from its tower outward, followed by installation of cable supports. The cable is threaded through the towers

to the deck sections as each section is added. The bridge's main span will connect above the middle of the river with a center closure placement and then to the landside-span portion on both banks.

Construction has been designed to minimize impacts to river users and disturbances to habitat and wildlife, especially protected fish species. Because in-water construction can take place only during a four-month window from July 1 through October 31, two temporary work bridges and two cofferdams were placed in the river to

create barriers between the river and pier construction sites.

The bridge is expected to be completed in 2014, but it will not become functional until lighting is installed and the rail service begins in 2015.

Honolulu's HART

The Honolulu High-Capacity Transit Corridor Project for the Honolulu Authority for Rapid Transportation (HART), which began construction in 2011, consists of 20.5 miles of railway connecting 21 stations and is divided into four sections. Two of the sections, the 7-mile-long Farrington section and the 4-mile-long Kamehameha section, are being completed under design-build delivery systems, while the other two are using design-bid-build delivery. The design features single-cell, trapezoidal box girders to support a dual track.

The Farrington section has 268 spans, while the Kamehameha section has 165 spans, all with typical span lengths of 125 ft. Each span comprises 12 constant-depth segments, which are 11 ft long, 30 ft wide, and 7 ft 2 in. deep. The majority support two tracks per box, although a few have a single track.

This approach is being used because of the need to construct the bridge down a narrow median of a busy major artery. Handling the existing utility infrastructure also will be easier with concrete segmental bridges. The project is expected to be completed in 2019.

Summary

These projects give an idea of the range of challenges that segmental construction can help overcome on transit projects of all types. Concrete segmental construction is a strong choice to create long-lasting, quickly erected, aesthetically pleasing, and cost-effective solutions for America's infrastructure needs. 

William R. Cox is the manager of the American Segmental Bridge Institute in Buda, Tex.

A list of segmental concrete projects can be found at www.aspirebridge.org and click on "Resources."

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Sliding and Rolling Bridge Solutions—Part 3

by Craig A. Shutt



Construction of falsework for the new bridge begins on the right side. All photos: Hilman Rollers.



Construction of widened substructure begins on the left side.



The deck is ready for casting concrete.



The old bridge has been removed and the new bridge is ready to be moved into place.



The new bridge is in its final location.

Sliding and rolling bridges into place offers key benefits to owners, designers, and contractors. As a result, more bridges are being designed and built using these techniques. This series of articles looks at some of the key considerations when using these approaches to construct bridges.

The first two parts of this series examined key design considerations that impact construction. This part addresses construction considerations.

Pads

Pads are a simple, low-cost solution. They offer significant directional flexibility, as the direction of movement is not tied to the orientation of the pads. Pads also allow the use of an unguided system that will not bind if ends of the bridge move at different rates.

Normally, the superstructure is lifted prior to the slide, to allow the skid shoes and bearings to be cleaned and to apply a non-petroleum-based synthetic grease onto the sliding surface. Continuous lubrication of the pads is critical during the slide, especially to overcome the initial inertia and achieve the breakaway force.

Fortunately, many types of inexpensive lubrication can be used. A variety of biodegradable lubricants are available that won't damage the pads. A popular option is dish soap, readily available from any mass-merchant store, but it dries quickly if left for any time. One contractor uses bananas as lubricant. Whatever is readily available, inexpensive, and has been found to be effective can be put into service for this need.

Skid shoes should be braced during construction to maintain a level slide surface. Normally, the sliding surface of the shoe consists of polished stainless steel. There are many ways to construct skid shoes. One method uses concrete-filled steel shapes using steel as thin as $\frac{1}{4}$ in. Other methods use steel box or I-sections with the base plate at least $\frac{3}{4}$ in. thick. Thinner shoes can deflect or warp during construction, creating an uneven sliding surface. Beveled ends should be used to ease sliding over the pads and limit friction.

Rollers

Rollers are more costly than pads but have a longer service life. They are often used on bridge projects with larger load requirements. When properly sized, the slide resistance is more predictable and requires less force to start and stop the bridge. Undersized rollers can dimple the slide surface, which can significantly increase the starting force.

Rollers are almost always guided with troughs or channels that align the rollers during the move. Roller-guide surfaces can be flush or approximately 2 to 3 in. wider than the rollers to allow room as the jacks push or pull the bridge. These channels must be kept clean and clear at all times to ensure no obstructions for the rollers.



Rollers were used between the end diaphragms and the temporary substructure on the I-205 Redland Road overpass in Oregon.

Contractors using rollers must fully understand the tolerance issues, know the requirements to achieve the breakaway force, and monitor when to reduce the force once the bridge begins moving. These calculations must be precise, as any deviation can bind up the system and require time-consuming adjustment.

Push-Pull Options

The decision to use jacks to pull or push the bridge will depend on a variety of specific factors, including terrain, bridge design, and contractor preference. Typically, the deciding factor is the contractor's preference given the specifics of the bridge under construction.

When pushing a bridge, temporary abutments are used with self-setting jacks. When pulling the bridge, the mechanism relies on cables attached to an electric drum, strand, or



This before and after view shows how the abutment was changed once the bridge was moved into place. Note the channel guide rail and tension rods.

threaded bars. Anchor points are needed to secure the jacks. Often, the jacks are anchored to the existing bridge beyond the replacement bridge being pulled into place.

In either format, it is critical that the movement is monitored to ensure the jacks move at the same rate. Uneven movement often occurs due to differences in friction regardless of how careful the system is designed. Early correction of uneven movement minimizes the potential for binding or final misalignment.

Monitoring is especially important on bridges moved without guides. Without guides, the structure will move back and forth as rams will most likely be hydraulically connected and not using a displacement-based control. Achieving a final alignment within the specified tolerance can be time consuming, especially when inadequate monitoring allows significant racking or rotation to occur.

Jacks

When pushing the bridge, restroke jacks are used, with no stroke length greater than 30 in. Longer strokes take too long



Tension rods are anchored at the abutment to create a reaction point. Note the bracket to accommodate the skew of the bridge.

and can create bending in the jack piston. A push range of 6 to 18 in. is recommended.

Typically, the jack features a home rail with pins, with the piston pushing to advance the bridge, after which the pins are advanced (or a second set of pins are inserted) at about 6-in. increments. Double-acting rams can retract quickly, moving the bridge at a faster rate. Pressure in the system may not always be proportional to the jacking force because of friction in the jack.

A trial-and-error approach, along with the use of a measuring stick along the rails, will best determine how far the bridge can be moved at once. If one side moves farther, however, adjustments must be made quickly. Workers should be assigned to each corner to watch the longitudinal and lateral movement carefully.



A simple measuring system is needed to monitor bridge movement at both abutments.

Terrain

It is best to move the bridge on a horizontal surface, irrespective of any slope in the terrain. A complete evaluation of soil conditions is critical to ensure adequate support during the move, especially under the launching rails.

Typically, it is more advantageous to move the bridge uphill if a level surface cannot be provided, as it makes it easier to control movement. Moving downhill requires a launch mechanism that includes heavy-duty brakes or a restraining system to restrain movement when gravity tries to take over.

In all cases, a test run will help assess any concerns. This should include actually moving the bridge, even if only by a few inches.

Key Stages

The initial lifting of the structure to place the slide system can be the controlling load case for the shoring system. Next, the initial movement creates the largest horizontal force demand and the maximum transverse force in the shoring system. During the slide, transitioning from the temporary support to the final support can cause differential deflections between the supports. This stage maximizes the vertical-load demand on the connection element. The final stage places the bridge on the permanent bearings.

Typically, permanent bearings are thicker than pads and shorter than rollers. After the bridge is aligned in its final position, it is jacked up, the slide system is removed, and permanent bearings are placed. Shim plates can be used to correct any elevation discrepancies in the bearing surface on the permanent abutment or variation in the bottom of the substructure elevations.

Other Considerations

Integral diaphragms and shoes provide a robust section and minimize differential deflection between girder lines. Normal cross-frames provide a more flexible system and can reduce the impacts of differential deflection in the slide supports.

Use of two slide supports increases the load per support but minimizes the variation in load due to an uneven slide surface. Three or more slide supports reduce the average load per support, but it also can concentrate the load onto a single support if the system is stiff and the slide surface has a high point.

Often, pads are reused in a slide as the bridge transitions over them. At the final move into the bridge's permanent position, new pads are placed and left in place. They are locked in with shear keys after the bridge is positioned. Detailing gaps between the skid shoes can allow temporary and final bearings to be switched during the final push.

Deck cracking due to lateral moves is rare. The deck is vulnerable during the initial or final jacking, but the loads are similar to those encountered in a normal bearing-replacement project. The deck can also be stressed when a high point is encountered by the rollers or slide shoes during the move. Bridges using a flexible cross-bracing system are more vulnerable.

No matter how well thought out the process and how high the quality, these projects should always have contingency plans. These plans typically include backup power for the rams, backup rams themselves, additional bearings, redundant load paths, and other accessory parts.

As contractors and engineers become more experienced with this type of construction, some of these requirements will become second nature. That will not reduce their importance. A strategy must be developed to ensure the owner receives an acceptable as-built bridge. The contractor's team must be diligent about every aspect of the project to ensure its success. 

This is the third in a series of articles examining approaches to accelerated bridge construction as it applies to slide-in bridge construction. This report was produced from interviews with Hugh Boyle, chief engineer at H. Boyle Engineering; Mike Dobry, principal structures engineer, Larry Reasch, vice president and manager of the structures department, and Derek Stonebraker, structures engineer, at Horrock Engineers; R. Craig Finley Jr., founder and managing partner at Finley Engineering Group; and Steve Hague, formerly chief bridge engineer at Burns & McDonnell.

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

MAP-21 and Bridge Life-Cycle Cost Analysis

by Nathaniel Coley and M. Myint Lwin, Federal Highway Administration



The Moving Ahead for Progress in the 21st Century Act (MAP-21) continues the support of bridge life-cycle cost analysis (BLCCA). The law defines life-cycle cost analysis (LCCA) as “a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.”

The practice of applying LCCA to transportation decision-making has a long history in the United States. It was first called for in federal law dating back to the late 1950s. Areas of current federal law of particular interest to bridge engineers included by MAP-21 are listed in sections that relate to the development and implementation of a state asset management plan (AMP) for the National Highway System (NHS) in 23 USC section 119, requirements for federally funded bridge projects over \$40 million discussed in 23 USC section 106, and bridge performance reporting called for in 23 USC section 150.

In general, a state is to develop a risk-based AMP for the NHS to improve or preserve the condition of the assets and the performance of the system. LCCA and risk management analysis are minimum requirements to be included in a state’s AMP. On a project level, states are to perform LCCA as part of the value-engineering study for all NHS bridge projects receiving federal assistance with an estimated total cost of \$40 million or more. On a network level, MAP-21 established a National Highway Performance Program that requires states to establish performance targets and report on progress toward achieving those targets. Rulemaking processes for AMP and transportation performance management are currently underway.

This article provides and discusses the BLCCA process in meeting the requirements of MAP-21.

The bridge life-cycle cost analysis includes impact to traffic resulting from work zones.

Photo: Federal Highway Administration.

The BLCCA Process

Including BLCCA in the overall decision-making process helps bridge engineers plot a course for bridge performance under budgetary constraints. The BLCCA process involves five basic steps and draws on an understanding of how effective investments in the life cycle of bridges support the achievement of long-term performance goals.

Step 1: Define Alternatives

The first step in the BLCCA process focuses on identifying available alternatives that support the level of service needed. A scenario that includes completing the immediate repairs and maintaining the bridge represents the base case against which proposed alternatives are compared. Alternatives to the base case could include replacing the bridge or replacing the deteriorated components with more-durable products. Another alternative could include accelerated bridge construction techniques such as prefabricated bridge elements and systems discussed in the Federal Highway

Administration’s (FHWA) Every Day Counts initiative (see <http://www.fhwa.dot.gov/bridge/abc/prefab.cfm>).

Step 2: Forecast Performance

Each alternative will provide performance over an expected time horizon; therefore, an understanding of expected performance is needed. The forecasted performance plays an important role in identifying the stream of costs expected over the time horizon of the analysis.

Forecasting future performance is not a science, and many bridge engineers struggle with understanding how to do it. Nevertheless, numerous examples of viable processes exist. Some agencies use past performance trends to provide insights into the future. Others have developed sophisticated algorithms and software tools to assist in this process. One reference is the FHWA’s *Bridge Preservation Guide*, which offers guidance on how to apply various proactive measures to postpone advanced deterioration (see <http://www.fhwa.dot.gov/bridge/preservation/guide/>).



Many engineers new to BLCCA perceive that there is a challenge to make 75 years' worth of investment decisions today. The goal of forecasting performance to identify probable future costs is not to mandate future expenditures. It is simply a process for making a reasonable investment today based of knowledge, experience, and available technology about expectations of the future.

Most bridge owners have experience with how their bridges perform and can be relied on to provide good guidance on future bridge performance. Complex bridge deterioration algorithms have been proven to serve as good resources as well. The forecasting of performance in the BLCCA provides ample opportunity for capturing new products and technologies in the future that serve to reduce life-cycle costs.

A significant aspect of the BLCCA process is analyzing the impacts to traffic resulting from work zones. This step focuses on estimating the number and demographics of roadway users in the affected traffic streams during construction work zones. This information, typically readily available from state traffic engineering offices, will be used to quantify the impacts on roadway users from the alternative approaches being considered.

Traffic engineers commission specific traffic counts of the numbers and types of vehicles, as well as surveys of vehicle drivers and passengers, to provide insight for use in estimating these impacts. The FHWA offers a guide called *Work Zone Road User Costs - Concepts and Applications*, available at <http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/index.htm>, that provides guidance on calculating work-zone user costs. Bridge engineers can decide if analyzing the expected impacts to traffic streams can help rationalize the comparative advantages of each investment candidate to identify those that most efficiently provide support for reducing costs to users.

Step 3: Estimate Life-Cycle Costs

Estimating the direct costs to the agency as well as work-zone user costs, involves applying the relevant unit costs to the current and future activities. The costs estimated over the analysis period are discounted to calculate a net present value for each alternative. These amounts can be compared to select the alternative with the lowest life-cycle cost discussed in Step 5.

Step 4: Analyze Impact of Uncertainties/Risks

The analysis is based on many assumptions about the future. Examining the impact of the inherent uncertainties, or risks, on the inputs into the analysis is important. Forecasts of

traffic, timing of activities, and impacts on users are not expected to be 100% accurate. Identifying and estimating the variances in those inputs and incorporating the variances into the analysis provide opportunities to make decisions based on statistical outcomes.

This fourth step is crucial in light of past estimates that have left taxpayers questioning why specific estimates were so far beyond planned expenditures. Being able to make investment decisions on the "most likely" outcome leads to better investment decisions. In addition, communicating to key decision makers and the public is more effective with statements such as "Based on our best estimates, this project could result in a 20% cost reduction or as much as a 45% reduction." These ranges of potential outcomes provide more credibility to decisions.

Step 5: Recommend Alternative

The final step involves recommending an alternative that meets the mission of the agency at the lowest life-cycle cost with an understanding of the work-zone user costs that will occur from that alternative.

After engineers have identified projects that best meet individual objectives at the lowest cost, the BLCCA outputs can assist in developing a plan, such as an AMP, or program that supports long-term network goals based on expected

The Bridge Life-Cycle Cost Analysis Process

1. Define alternatives
2. Forecast performances
3. Estimate life-cycle costs
4. Analyze impact of uncertainties/risks
5. Recommend an alternative

funding levels. Specifically, examining the amount of costs of each project provides critical insight in developing a program that maximizes the use of limited funds.

Closing Remarks

Performing an LCCA can enhance the selection of cost-effective solutions for bridge projects. A follow-up article in the Fall issue will provide information on the use of BLCCA tools.



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WISCONSIN

Innovative research produces concrete results

by Aaron Bonk, Wisconsin Department of Transportation



Concrete bridges are an integral part of the nearly 14,000 state and local bridges along Wisconsin's transportation system. Approximately 70% of these state and locally owned structures are concrete and consist of concrete slabs, prestressed I-girder or box girder structures, culverts, and arches. Through research and the evolution of concrete technology, concrete has proven to be a durable and economical material for initial construction, as well as providing low life-cycle costs.

The Past

Wisconsin has a long history of concrete use for transportation structures. Many of the prestressed concrete girder structures remaining in service today were originally constructed in the 1950s. Wisconsin was one of the first states to use the American Association of State Highway and Transportation Officials (AASHTO) I-girder shapes in bridge construction. Precast, prestressed concrete AASHTO I-girders were used exclusively through the 1990s for new, prestressed concrete I-girder type structures. The shallower AASHTO shapes, such as the 28- and 36-in.-deep versions (Types I and II), are still used for new structures in Wisconsin today. However, current policy states that the deeper, traditional AASHTO prestressed concrete I-girder shapes are to be used only for rehabilitation projects.

Precast, prestressed concrete box beams, called box girders in Wisconsin were used concurrently with the AASHTO I-girders in the 1960s, 1970s, and 1980s on many state- and locally owned projects throughout the state. Due to performance and maintenance concerns, mainly related to reflective cracking of the bridge decks between adjacent box beams, use of this beam type on state-owned projects has been limited since that time. However, the relative ease of construction has proven to be a reason why prestressed concrete box beam structures are still being used for locally-owned structures today.

The Present

Beginning in the mid-1990s, the Wisconsin Department of Transportation (WisDOT) began investigating the possibility of introducing more-efficient, prestressed concrete, wide-flange I-girders to replace the deeper AASHTO I-girder shapes for use on new structures. WisDOT, along with the



Accelerated bridge construction demonstrated with a geosynthetic reinforced soil-integrated bridge systems structure. All photos: Wisconsin Department of Transportation.

precast, prestressed concrete suppliers and national technical experts, conducted research to produce and adopt more-efficient girder sections that could be used for longer spans. One alternative studied was the use of higher strength concrete.

WisDOT adopted the use of 8 ksi concrete with the wide-flange I-girders, whereas 6 ksi concrete had been used with the traditional AASHTO I-girders. Concretes with strengths higher than 8 ksi were evaluated, but were not ultimately used due to the longer curing times associated with the higher strengths. Another design change increased the size of the bottom flange of the girders, which maximized girder efficiency through the number of strands able to be housed in the flange. The Wisconsin version of the prestressed concrete, wide-flange I-girders has been used extensively since the early 2000s.

WisDOT has also investigated improving the design details and fabrication techniques used with the wide-flange I-girders. In the early 2000s, as implementation of the wide-flange I-girders got underway, WisDOT inspection and maintenance engineers identified the frequent occurrence of end cracking of the girders immediately after production. Three types of cracks were noted: horizontal web cracking, inclined or diagonal

cracking near the top of the girder web, and Y-shaped cracks near the bottom flange.

While the structural efficiency of the wide-flange girders was an improvement from the AASHTO shapes, the girder cracking introduced a significant maintenance concern. WisDOT's bridges are exposed to highly corrosive environments due to the widespread use of deicing chemicals on roadways in the winter months. Although it is WisDOT's policy to coat the exposed ends of girders, the development of these end cracks was a concern given the location with respect to the potential leaking expansion joints on the bridge deck.

Through research conducted by the Wisconsin Highway Research Program (WHRP), in conjunction with WisDOT and the University of Wisconsin, it was determined that the cracks were generated due to the high concentration of prestressing strands located in the girder ends and the large forces induced during fabrication. Researchers used finite element modeling in addition to measurements made at prestressing facilities to analyze the cracking issue and create recommendations for updates to the WisDOT girder designs. Cracking of the wide-flange girder shapes was especially prevalent in the



Accelerated bridge construction demonstrated with a precast concrete abutment.



Accelerated bridge construction demonstrated with a precast concrete pier cap.

heavily prestressed (54-, 72-, and 82-in.-deep) girders. The WHP study of prestressed girder cracking provided design alternatives geared to reduce each of the three types of cracking. For horizontal web cracking, increasing the size of the vertical end zone reinforcement bars nearest the girder end helped to reduce the concrete tensile strains by nearly 50%. Regarding inclined or diagonal cracks, the best remediation approach was optimization of the number and spacing of draped strands. Finally, it was determined that the Y-shaped cracks near the bottom flange could only be prevented in heavily prestressed girders by methodically debonding the bottom strands. Debonded strands are currently not allowed in WisDOT prestressed concrete girders due to

continuing concerns over long-term durability and corrosion resistance of the strands. This study may lead to an in-depth review of the current policy.

In addition to continuously working to improve the design of WisDOT's prestressed concrete, wide-flange I-girders, WisDOT is also involved with multiple studies to improve the performance of prestressed concrete box beam structures. Recently, a local WHP study was initiated to review past applications of box beams; conduct a survey of professional experts to identify the extent and consistency of the reflective cracking problem with the Wisconsin box section; and to make recommendations for improved WisDOT design, detailing, specifications, and construction inspection policies. Along with the state-level WHP study, WisDOT's chief development engineer is involved with a National Cooperative Highway Research Program (NCHRP) study related to connection details used with adjacent precast concrete box beam bridges.

The objective of this NCHRP research is to develop guidelines for the design of connection details to eliminate cracking and leakage in the longitudinal joints between adjacent boxes. Ultimately, WisDOT views these research opportunities as highly beneficial to the future use of box beam structures in Wisconsin, especially as they relate to accelerated bridge construction (ABC) projects.

The Future

As part of the Federal Highway Administration's (FHWA) Every Day Counts Initiative, WisDOT has successfully deployed numerous types of ABC projects and will expand their use in the future. One bridge in northern Wisconsin was constructed using geosynthetic reinforced soil-integrated bridge systems (GRS-IBS) technology. This project was constructed with the assistance of FHWA's Innovative Bridge Research Deployment program, which provided the opportunity for WisDOT to implement new ABC technology while incorporating cast-in-place superstructure technology. In addition, several bridges have been constructed using precast concrete substructure elements, multiple bridges have been placed using lateral slides, and one bridge was placed using self-propelled modular transporters (SPMTs).

WisDOT has for many years studied practical field applications for bridge structures. WisDOT views the research pertaining to adjacent box beam structures as something that could be extremely beneficial to GRS-IBS type structures. The GRS-IBS bridge that was completed in Wisconsin used a cast-in-place concrete slab span. The project proved to be highly efficient in regards to construction time; nevertheless, WisDOT views adjacent box beams as being an option that could decrease the roadway closures to an even greater extent.

WisDOT has also successfully employed the use of precast bridge elements and systems (PBES) as an ABC technology. Two projects, specifically using PBES substructures, were deployed using research conducted through a previously completed FHWA Innovative Bridge Research and Construction study. The first implementation of PBES used precast concrete abutments for a bridge carrying U.S. 63. This project was the first of its kind in the state and significantly reduced the abutment construction time from two weeks for conventional abutments to less than two days.

A subsequent project using PBES employed precast concrete pier caps at a nearby project site along WIS 25. This second project used lessons learned from the first PBES project to improve construction techniques and the overall efficiency of ABC technology. Specifically, the sizes and subsequent weights of the precast concrete elements were reduced in order to reduce the demand on construction equipment required for the project. It is anticipated that lessons learned from previously completed PBES projects will continue to reduce construction costs and timelines, along with lower life-cycle costs for these structures.

As structures continue to age and funding resources become increasingly limited, WisDOT will continue to emphasize the importance of research and applying it towards innovative methods using concrete. The practical application of this research, which is aimed at maximizing the durability and cost efficiency of our concrete structures, will become increasingly essential. WisDOT will continue to study and make improvements to concrete technology and its use in enduring structures. **A**

Aaron Bonk is the lead structures development engineer in the Automation, Policy, and Standards Unit of the Bureau of Structures at the Wisconsin Department of Transportation in Madison, Wis.

EDITOR'S NOTE

For more information about Wisconsin's bridges, visit www.dot.wisconsin.gov/projects/bridges.

To see a video of the bridge in northern Wisconsin that used geosynthetic reinforced soil-integrated bridge systems (GRS-IBS) technology, see <http://www.youtube.com/watch?v=frxx9J7qiWU>.

Innovations in Buchanan County, Iowa

by Brian Keierleber, Buchanan County, Iowa



Ultra-high-performance concrete was used in the Pi-shaped girders of the center span of the Jakway Park Bridge. Photo: Iowa Department of Transportation.

Like much of the nation, Buchanan County, Iowa, has many old bridges. For some perspective, Buchanan County has replaced bridges built in 1870, 1872, and 1875. As a reminder, General Custer fought in the Battle of Little Bighorn June 25, 1876. Buchanan County has been aggressively replacing these older bridges, yet it still has pin-connected truss bridges from the late 1800s or early 1900s.

In rural Buchanan County, economics drive replacement methods. Economics consider life-cycle costs, so greater first costs are acceptable in exchange for long-term performance. Most of the county's 257 bridges are less than 60-ft-long, so simple spans are preferred. Currently, precast concrete slabs seem the most economical for spans less than 50 ft. This system is popular in the region.

Buchanan County is the location of the Jakway Park Bridge—one the first bridges in the United States to use ultra-high-performance concrete (UHPC). The UHPC is used in the Pi-shaped girders of the 51-ft 4-in.-long center span of this three-span bridge. (See *ASPIRE* Winter 2010)

Recently, a cast-on-site slab bridge was constructed on geosynthetic reinforced soil (GRS) abutments. The goal was to construct the bridge without a crane. The plan was to construct the concrete slabs on site and pull them into place with a wrecker. This was an

aggressive concept because the slabs were 6 ft wide, 2 ft thick, and 52 ft long. Placing the slabs with the wrecker led to safety concerns. In an effort to expedite the opening of the bridge, a large crane was brought in to place the slabs.

The county incorporated a number of new technologies on this project, such as internal curing of the concrete using prewetted lightweight aggregate. Test results showed that the concrete's 28-day compressive strength was increased by 19%, flexural strength was increased by 9%, shrinkage was reduced, and charge-passing coulombs (per rapid chloride permeability test [ASTM C1202]) was reduced by 13.7%. This information correlated very closely with an article in the January/February 2013 issue of *Concrete Bridge Views*.

In addition to the internally cured concrete and cast-on-site concrete slabs, this project also incorporated GRS abutments, designed and constructed with layers of backfill wrapped in fabric, and stacked on a one-to-one slope and faced with a roller-compacted concrete. Slopes of 2:1 were used parallel to the road. Placement and compaction was accomplished utilizing a vibratory compactor on a hydraulic excavator.



Brian Keierleber is county engineer, Buchanan County, Independence, Iowa.



Cast-on-site concrete slabs. Photo: Buchanan County.



Compacted concrete on geosynthetic reinforced soil abutments on Jakway Park Bridge. Photo: Buchanan County.

EDITOR'S NOTE

More information about internal curing of concrete using lightweight aggregate is available in a new American Concrete Institute publication titled "Report on Internally Cured Concrete using Prewetted Absorptive Lightweight Aggregate," ACI (308-213)R-13.

More information about GRS is available on the FHWA website: www.fhwa.dot.gov/everydaycounts/technology/grs_ibsl.

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Twyckenham Drive over St. Joseph River, South Bend, Ind.

by **Leslie Benson, American Structurepoint**

When the Twyckenham Drive Bridge was constructed over the St. Joseph River in 1929, it was conceived as more than part of the transportation system. The beautiful concrete open spandrel arch was also intended to honor those who gave their lives in World War I, represented by decorative pylons along the bridge. The bridge originally had 16 deck expansion joints and inadequate drainage that caused significant damage as water leaked through to the substructure. When it came time for repairs, the St. Joseph County Board of Commissioners turned to the project team to restore the structure to its original condition.

By analyzing the bridge using finite element analysis, the number of expansion joints was reduced to one joint at each end of the bridge. The reduced number of joints and improved drainage sys-



The spandrel arch bridge was restored to its original appearance using modern materials. Photo: American Structurepoint.

tems are intended to keep roadway salts away from the concrete, increasing the bridge's service life. To protect the bridge from future deterioration, zinc galvanic protection was placed at the interface of the new and original concrete throughout the bridge.

Additional structural improvements for the deteriorating bridge included repair of concrete elements and replacement of non-original aluminum railings with concrete ones that closely resemble the original. While some key portions of the bridge had to be replaced, one of the project's goals was retaining as much of the existing structure as possible in order to retain the aesthetically pleasing look of the historic bridge. This also resulted in a savings of time and money for the county.

Unique features of the bridge are its plaza areas. These were constructed to allow pedestrians a place to rest and enjoy the view of the river from the bridge. The historic plazas at the four corners of the bridge were restored by placing new sidewalk and concrete railing and lighting for night-time safety. A newspaper photograph from the opening of the original bridge was used to match the standards and lanterns along the roadway. Eight ornamental streetlights and 36 ornamental lanterns were installed across the bridge and plazas.

The design scope also addressed removing and replacing all transverse beams and spandrel columns under the existing expansion joints, as roadway salts had saturated these. In addition, the existing concrete deck and sidewalk were removed and replaced with concrete deck panels, a 6-in.-thick concrete sidewalk, and a 12-in.-thick concrete curb. A coating was applied to all concrete sections of the bridge.

This project honored the structure's original engineers by restoring the monument to last well into its second century. American Structurepoint used the lessons learned and new materials developed over the last century to produce a tighter, more durable bridge. Since its completion, the Twyckenham Drive Bridge has been recognized with the 2011 Award for Outstanding Achievement in Concrete in the Special Structures—Concrete Restoration from the American Concrete Institute, Indiana Chapter, as well as the 2012 Concrete Bridge Award from the Portland Cement Association. 

Leslie Benson is a public relations specialist with American Structurepoint, Indianapolis, Ind.



The concrete open spandrel arches of the Twyckenham Drive Bridge. Photo: Susan Fleck Photography.

Getting Connected: Dearborn Island Bridge

Salvaged beams reused to link island to mainland

by Karl Wieseke, Oregon Department of Transportation

When the Oregon Department of Transportation (ODOT) built a temporary Interstate 5 detour bridge over the Willamette River in 2004, the design was permitted for only 10 years. In 2009, construction would begin on a permanent replacement, the Whilamut Passage Bridge, erected as part of the Oregon Transportation Investment Act (OTIA III) State Bridge Delivery Program.

Yet the materials used to construct the temporary bridge—in particular, more than 200 concrete beams, 93 to 115 ft long—were well able to safely serve motorists for decades to come. As part of its environmental stewardship, ODOT was prepared to offer the beams at a minimal price to keep them in circulation, salvaged to their highest use.

“ODOT’s primary motivation was to get the beams reused, so we essentially cut the price to what it would cost to move and store them,” said Bert Hartman, ODOT Bridge Unit manager. “For end users, it was a really good deal: A new beam would cost more than \$17,000, yet buyers paid just \$2,500 for beams that are good for at least another 50 years.”

In September 2011, crews prepared to dismantle the temporary bridge to make room for the replacement. Meanwhile, the near-



With the new bridge in place, larger vehicles such as delivery trucks and emergency equipment can directly serve the island’s 14 residences.

by Dearborn Water District was looking for a way to replace the sole aging bridge that connected Dearborn Island’s 14 residences to the mainland beyond the surrounding McKenzie River.

For more than two years, only residents’ cars had been allowed access to the island. The original truss bridge connecting it with Oregon 126 had been saddled with a 3-ton weight limit because of structural deficiencies. No emergency vehicles, cable company trucks, maintenance equipment, or other vehicles weighing more than 6000 lb could get to the island.

Gayle Harley, executive vice president of OBEC Consulting Engineers, connected the beams looking for a home with the island looking for some beams. Harley, now retired, knew the salvaged beams would be available because his firm had designed the new I-5 bridge. OBEC had also performed the inspection on the Dearborn Island Bridge that identified safety concerns. As soon as the salvaged beams were available, Harley laid claim to four 48-in.-deep by 48-in.-wide by 115-ft-long box beams to cut the cost of rebuilding the Dearborn Island Bridge. To replace their bridge, island residents had themselves raised \$400,000 to cover all design, permitting, and construction costs.

“The original bridge was 125 ft long,” said Harley. “We shortened the new bridge span length so that the 115-ft-long beams from the Willamette River Bridge’s temporary structure would fit perfectly and not need to be reshaped.”

OBEC has designed customized bridge abutments to accommodate salvaged beams for other agencies in Oregon, including Lincoln, Jackson, and Lane counties. The project team replaced the bridge in one week, limiting inconvenience to the island’s residents. Because of the salvaged beams, the new bridge will safely and economically carry traffic for at least a half century.



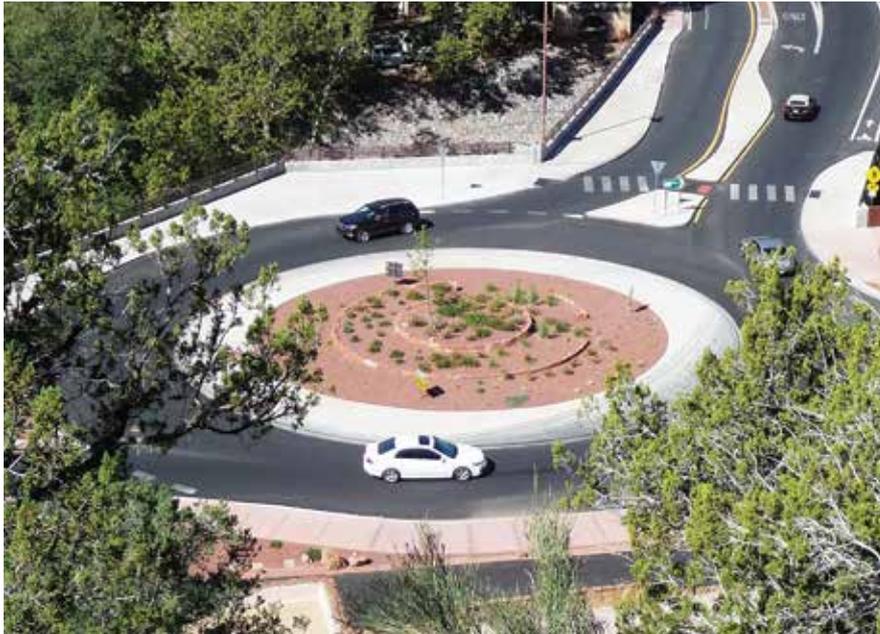
Karl Wieseke is the Willamette River Bridge project manager for the Oregon Department of Transportation in Springfield, Ore.



Four 115-ft-long beams from a temporary freeway detour bridge were salvaged to replace a severely load-limited bridge over Oregon’s McKenzie River. All photos: Oregon Department of Transportation.

Unconventional Loadings on the SR 179 Oak Creek Bridge

by Christopher A. Labye, AECOM



Completed SR 179 Oak Creek vehicular bridge. Photo: Steve Boschen.

State Route (SR) 179, in Sedona, Ariz., traverses a uniquely scenic area visited by hundreds of thousands of tourists each year. As the main route connecting the business and residential communities of greater Sedona, SR 179 is also an important intercity link for residents, commuters, and commercial traffic of the Sedona/Verde Valley region.

To address anticipated traffic volumes, improvements to SR 179 included the enhancement of the roadway by improving traffic, pedestrian, and bicycle movements. Part of the overall enhancement of the corridor included the replacement of an existing bridge over the perennial Oak Creek. Because of tight right-of-way constraints, the new bridge needed to incorporate a large portion of a new roadway roundabout within the first span of the three-span, precast, prestressed, concrete box girder structure.

Unusual Design of Girders

The 178-ft-long bridge is comprised of three spans with lengths of approximately 62, 57, and 55 ft. Placing the roundabout in span 1 adjacent to the more-conventional roadway configuration in spans 2 and 3 introduced several design challenges.

To address the structural load disparities, an

expansion joint was placed at the first pier to mitigate structural incompatibilities that would have been introduced with continuity. Because the deck in span 1 varies in width from 146 ft at abutment 1 to 126 ft at pier 1, the first eight (of 24 total) BIII-48 box beams are splayed.

The unique superstructure configuration of splayed box beams with variable skews at pier 1 was complicated further by live load configurations. The roundabout in span 1 requires traffic to traverse the span in both longitudinal and transverse directions—potentially allowing several heavier axles of trucks to align along the box beams in a way that could not be accounted for using traditional AASHTO distribution factors. The splayed box beams, therefore, were analyzed using two distinct sets of live load considerations:

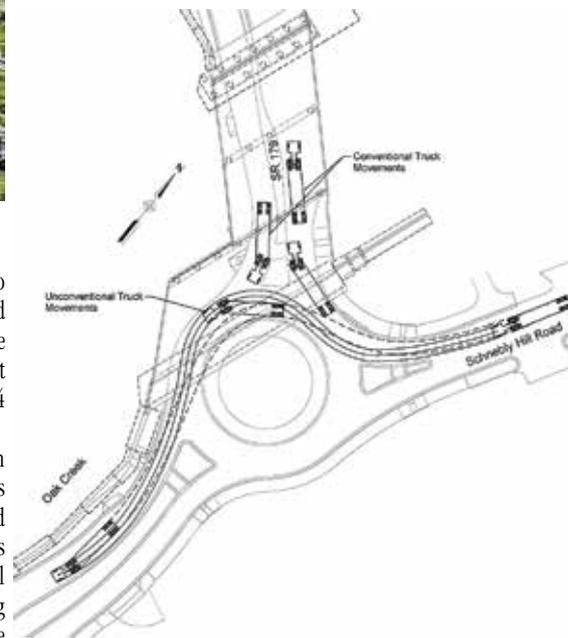
- Traditional analysis using AASHTO-prescribed distribution factors
- Tailored live load vehicle that simulated the presence of live load configurations traversing the bridge in a transverse direction

To simulate the loads in the transverse direction, truck patterns across the bridge were modeled with AutoTURN to ascertain potential locations of point loads. CONSPAN was then used to simulate behavior using these point loads with

wheel loads conservatively acting on the box beams that were traversed.

Ultimately, the traditional load from the HS-20 truck governed; however, this unusual bridge superstructure configuration does highlight the need for load considerations for bridge structures that accommodate unusual geometry not necessarily covered by the AASHTO design specifications. **A**

Christopher A. Labye is a senior bridge engineer/geotechnical engineer with AECOM, in Phoenix, Ariz.



Unconventional live load configurations are shown. Figure: AECOM.

EDITOR'S NOTE

A more detailed description of this bridge is available at www.aspirebridge.org. Click on "Resources."

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Composite Girder Connections for Precast Concrete Decks

by Michael Oliva, University of Wisconsin, and Pinar Okumus, SUNY-Buffalo



Installed precast concrete deck panels with pockets and beams with shear connectors. Photo: Purcell Associates.

The shear connection between precast composite concrete bridge decks and girders is receiving renewed attention as precast concrete deck panels have become an alternative to cast-in-place decks in accelerated bridge construction. Shear connections are commonly made in precast concrete deck panels by using steel connectors, such as studs or bars. The steel connectors extend from the top of the girder into blockouts in the panel, which are then grouted. However, the maximum connector spacing limit of 24 in., defined in the *AASHTO LRFD Design Specifications*, poses a dilemma for precast concrete deck design. There are two important reasons why closely spaced blockouts are undesirable in precast concrete deck panels. First, each blockout requires special labor for grouting. Second, a precast concrete deck panel manufactured with blockouts spaced at 24 in. may have a definite plane of weakness through the blockout openings. Special care must be taken to reinforce this weak section, particularly for effects of moving and handling to avoid cracking. In both cases, minimizing the number of connectors and blockouts is preferred.

The original sources of the current maximum connector spacing of 24 in. are unclear. An investigation described in *NCHRP Report 584*,¹ on full-depth precast concrete deck panels, attributes that limit to a “rule of thumb” in design suggested in 1943 by Newmark and Siess.² The 24-in. limit first appeared in the 4th edition of the *AASHTO Standard Specifications for Highway Bridges* in 1944.

These connections using studs were the focus

of a push-off investigation by Issa³ in which clusters of studs in a pocket were found to have less capacity than the sum of individual studs. The AASHTO Q_n capacity value for studs in Article 6.10.10.4 of the *2012 AASHTO LRFD Specifications*, however, matched Issa’s measured capacity for two stud clusters in a single pocket. The test data showed a 15 to 25% capacity reduction when the number of studs was increased or the number of pockets increased. AASHTO does not specifically change capacity with the number of studs in a cluster, but taking the capacity as 85% or less of AASHTO’s value when more than two studs are clustered in a pocket is recommended based on Issa’s work.



Three threaded-rod shear connectors extending from the girder will be grouted into the blockout in the Texas Department of Transportation deck panel. Photo: TxDOT.

A series of recent research activities has re-examined the needs of composite deck connections. Testing of panels connected to 84-ft-long steel girders with both 24-in. and 48-in. connector spacing was conducted at the University of Wisconsin and found no reduction in composite action stiffness or strength with the wider spacing, even after 2 million cycles of repeated service loading. On testing to the theoretical ultimate capacity, no deck uplift was detected and the 48-in. connector spacing provided an actual ultimate load capacity higher than predicted using AASHTO procedures, even though no capacity reduction was taken for multiple studs per pocket.

Additional work described in the *NCHRP Report 584* resulted in suggested guidelines for designing deck panels with wider connection

spacings. These research activities were followed by the construction of two bridges using 48-in. spacing for the connectors.

The Live Oak Creek Bridge built by the Texas Department of Transportation (TxDOT) in 2008 used 8-ft-wide by 32-ft-long precast concrete, 8-in.-thick deck panels on precast concrete I-girders. The shear connections were spaced at 48 in. and used three 1¼-in.-diameter steel rods, in a group, extending from the girder into blockouts of the deck panels. This bridge has been reported by TxDOT as performing very well.

Wisconsin also used precast concrete deck panels with 48-in. connector spacing in the widening and redecking of a heavily traveled bridge on Interstate 39/90. The panels were 8-in. thick with rectangular blockouts into which clusters of 6- to 10⁷/₈-in.-diameter headed studs from the steel girders were embedded and grouted. No capacity reduction was used for the large stud clusters. The Wisconsin bridge was built in 2006 and averages 60,000 vehicles per day. Inspections have found that the precast concrete deck, on one of a pair of bridges, appears to be performing better than the cast-in-place concrete deck on the twin bridge.



Interstate I-39/90 deck with studs in pockets at 48-in. spacing. Photo: University of Wisconsin.

A wider spacing than 24 in. for the composite connections between precast concrete deck panels and bridge girders appears appropriate. Forty-eight-inch spacings were successfully implemented in these recent research and construction projects. Recent research has not, however, examined the behavior of composite decks with shallow beams. As the beam becomes



Wisconsin laboratory test beam for fatigue cycling. Photo: University of Wisconsin.

shallow relative to the deck, the system with 48-in. spacing acts less like a composite beam and more like a Vierendeel truss. With shallow beams we suggest that the composite connector spacing be limited to a maximum distance equal to the beam depth.

At its 2013 annual meeting, the AASHTO Highway Subcommittee on Bridges and Structures approved a change to Article 5.8.4.2 of the *LRFD Bridge Design Specifications* to permit a longitudinal spacing up to 48 in. but not greater than the beam depth. This change will become effective with the 2014 Interim Revisions.

Care should be taken, however, when large clusters of studs are used, as required by wider

spacings. Confinement from reinforcement should be provided around the stud pockets and spacings greater than 48 in. are not suggested. A stud capacity reduction of 25% may be reasonable for design, with multiple studs per pocket, based on the work of Issa. **A**

Michael Oliva is a professor at the University of Wisconsin in Madison and Pinar Okumus is an assistant professor at the SUNY-Buffalo in Buffalo, N.Y.

References

1. Badei, S., and M. Tadros. 2007. "Full Depth Precast Concrete Bridge Deck Panel Systems." NCHRP Report 584, Transportation Research Board, Washington D.C. (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_548.pdf).
 2. Newmark, N. M., and C. P. Siess. 1943. "Design of Slab and Stringer Highway Bridges." Public Roads, FHWA, Washington, D.C. Vol. 23, No. 1.
 3. Issa, M.A., T. Patton, H. Abdalla, A. Yousif, and M. Issa. 2003. "Composite Behavior of Shear Connectors in Full-Depth Precast Concrete Bridge Deck Panels on Steel Stringers." PCI Journal, PCI, Chicago, Ill. Vol. 48, No. 5 (Sept.-Oct.).
- Carter, J., F. Hubbard, M. Oliva, T. Pilgrim, and T. Poehnel. 2007. "Wisconsin's Use of Full-Depth Precast Concrete Deck Panels Keeps Interstate 90 Open to Traffic." PCI Journal, PCI, Chicago, Ill. Vol. 52, No. 1 (Jan.-Feb.).
 - Markowski, S.M., et al. 2005. "Full Depth Precast Prestressed Bridge Deck Panel System for Bridge Construction in Wisconsin," Proceedings from the PCI National Bridge Conference, PCI, Chicago, Ill.
 - PCI Committee on Bridges. State-of-the-Art Report on Full Depth Precast Concrete Bridge Deck Panels, PCI, Chicago, Ill. SOA-01-1911.

EDITOR'S NOTE

More information about composite girder connection for precast decks is available as follows:

- Carter, J., F. Hubbard, M. Oliva, T. Pilgrim, and T. Poehnel. 2007. "Wisconsin's Use of Full-Depth Precast Concrete Deck Panels Keeps Interstate 90 Open to Traffic." PCI Journal, PCI, Chicago, Ill. Vol. 52, No. 1 (Jan.-Feb.).
- Markowski, S.M., et al. 2005. "Full Depth Precast Prestressed Bridge Deck Panel System for Bridge Construction in Wisconsin," Proceedings from the PCI National Bridge Conference, PCI, Chicago, Ill.
- PCI Committee on Bridges. State-of-the-Art Report on Full Depth Precast Concrete Bridge Deck Panels, PCI, Chicago, Ill. SOA-01-1911.

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CONCRETE CONNECTIONS

Concrete Connections is an annotated list of websites where information is available about concrete bridges. Fast links to the websites are provided at www.aspirebridge.org.

IN THIS ISSUE

www.wsdot.wa.gov/Projects/SR303/ManetteBridgeReplacement/

This Washington State Department of Transportation website contains information about the Manette Bridge replacement described on pages 18 to 20. A link is provided to project photographs.

www.dullesmetro.com

Visit this website for more details on the Washington, D.C. to Dulles Airport Metrorail project described on page 28. Click on Construction for a series of photographs.

<http://trimet.org/pm/construction/bridge.htm>

For more information about the Portland-Milwaukie Light Rail Bridge described on page 28, visit this website. Two live webcams show the current stage of construction. Time lapse videos show the construction sequence.

<http://honolulutransit.org>

This Honolulu Rail Transit website contains general information about the new transit system mentioned on page 29. Click on Videos & Photos for photographs of the initial construction.

www.fhwa.dot.gov/everydaycounts/technology/grs_ibs/multimedia.cfm

Visit this Federal Highway Administration website for a presentation by Brian Keierleber of Buchanan County, Iowa, about the county's use of geosynthetic reinforced soil integrated bridge technology as described on page 38.

www.dot.state.fl.us/structures/innovation/UBEAM.shtm

This Florida Department of Transportation website provides information about the design of curved, precast, spliced, pretensioned/post-tensioned U-girder bridges, which are now included in their Structures Design Guidelines. See Reader Response on page 6.

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.

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 Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) is a collection of best practices to help transportation agencies integrate sustainability into their programs and projects. INVEST has three modules: system planning, project development, and operations and maintenance.

www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf

The FHWA *Bridge Preservation Guide: Maintaining a State of Good Repair Using Cost-Effective Investment Strategies* may be downloaded from this website.

www.fhwa.dot.gov/bridge/preservation/

This website provides a toolbox containing bridge-related links on bridge preservation.

NEW www.sustainableinfrastructure.org

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

Bridge Technology

www.aspirebridge.org

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

www.nationalconcretebridge.org

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

www.concretebridgeviews.com

This website contains 70 issues of *Concrete Bridge Views* (formerly *HPC Bridge Views*), an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of concrete in bridges.

NEW www.trb.org/Publications/Blurbs/168757.aspx

This Transportation Research Board website contains a new National Cooperative Highway Research Program Synthesis titled *High Performance Concrete Specifications and Practices for Bridges*.

NEW [http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07\(217\)_FR.pdf](http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07(217)_FR.pdf)

This Transportation Research Board website contains a report titled *Verification and Implementation of Strut-and-Tie Model in LRFD Bridge Design Specifications*, prepared for the AASHTO Highway Subcommittee on Bridges and Structures.

Bridge Research

NEW http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_733.pdf

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

NEW www.trb.org/main/blurbs/168046.aspx and www.trb.org/main/blurbs/167693.aspx

These two websites contain the Strategic Highway Research Program 2 reports titled *Innovative Bridge Designs for Rapid Renewal*. The first website has the 870 page prepublication draft. The second website contains the associated ABC Toolkit.

Dual Bridges Keep Historic Integrity in Lebanon, Pennsylvania

by Ben J. Wadsworth, formerly with Dewberry Engineers Inc.



Shown is the 9th Street Bridge overall elevation. Five precast concrete architectural fascia panels per span were suspended from the exterior beams to mimic the look of an historic arch structure. Photo: Troy Jenkins, Northeast Prestressed Products LLC.

For many years, Lebanon, Pa., has been inconvenienced due to the railway-system traffic that passes frequently through the city each day. After many public meetings, it was agreed that bridges should be constructed on the 9th and 10th Street routes, which would provide both northbound and southbound passage over the railroad. Considering that these structures would influence the aesthetics and feel of the city, architectural finishes were chosen for this design that mimicked original brick patterns and colors found throughout the historic town of Lebanon.

Architectural finishes were chosen for this design that mimicked original brick patterns and colors found throughout the historic town of Lebanon.

The precast concrete fascia panels were designed so that, once in place, they would form



Trains freely pass through the city, inconveniencing residents no more. Photo: Ben Wadsworth, formerly of Dewberry Engineers Inc.

a series of arches along each side of the bridge. A formliner and concrete stain were used to give the fascia panels the texture and color to complement the look of the historic surrounding community.

The exterior beams, produced by Northeast Prestressed Products, were specially designed with pockets to provide a recessed support area for the precast concrete architectural fascia panels. In order for the exterior beams to carry the load of the fascia panels safely, the beams had to act compositely with the deck prior to the fascia panel installation. To accomplish this,

the construction of the deck took place in two phases. First, the deck concrete was placed only to the center of the exterior beams, and cured for seven days. Next, the fascia panels were installed. Finally, the remainder of the deck was cast.

The vertical support for the fascia panels consisted of studded, stainless steel plates embedded into the recessed beam pockets. Two studded, stainless-steel structural tubes were cast into each fascia panel. These structural tubes were designed to withstand all vertical loads resulting from the panel's self weight.

To keep the fascia panels plumb and resistant to wind loading, horizontal supports were designed. The horizontal support for the fascia panels consisted of threaded inserts cast into the beam. Slotted inserts, with vertical adjustments, were cast into the fascia panels. The threaded and slotted inserts were connected by stainless steel bolts and bent plates. Due to anticipated

need for field adjustments, the bent plates were designed with horizontal slotted holes to allow for greater construction tolerances.

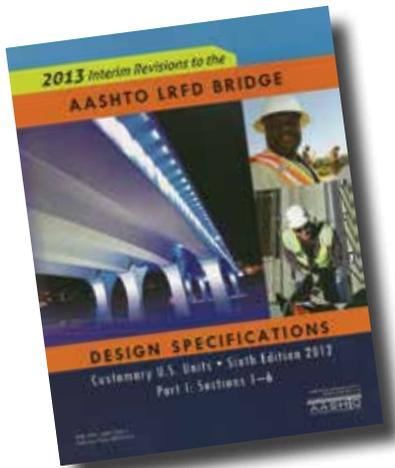
The 9th and 10th Street Bridges were successfully designed to alleviate the major traffic congestion throughout the city of Lebanon, while still preserving the historic community. ▲

Ben J. Wadsworth, formerly with Dewberry Engineers Inc., Fairfax, Va., was structural designer for the project.

2013 Interim Changes Related to Concrete Structures



by Dr. Dennis R. Mertz



The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures considered and adopted five agenda items specifically related to concrete structures at their annual meeting hosted in July 2012 by the Texas Department of Transportation in Austin, Tex. Technical Committee T-10, Concrete Design, developed Agenda Items 35 through 39 over the past several years and moved them to the subcommittee ballot for consideration in Austin. The agenda items represent revisions and additions to the *AASHTO LRFD Bridge Design Specifications*. This column reviews the 2012 concrete-structures agenda items, which have become the 2013 Interim Revisions.

Article 5.8.2.8 of the general shear provisions and Article 5.8.6.2 of the segmentally constructed bridge shear provisions required that the effects of inclined flexural compression or tension to be considered. Many times, the effect may be beneficial rather than detrimental. To simplify design, **Agenda Item 35** revises both of these articles to require their effect be considered where it is “detrimental (increase in shear load) but may be ignored if the effect is beneficial (decrease in shear load).”

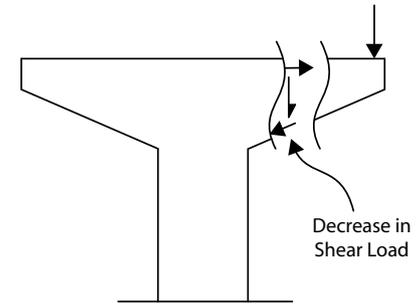
In the design of segmentally constructed bridges, Article 5.8.6.2 of the Specifications was not clear how much of the web depth an inclined tendon had to traverse in order for the vertical component of prestressing to effectively reduce the applied shear. **Agenda Item 36** clarifies this by inserting modified language from the *AASHTO Guide*

Specifications for Design and Construction of Segmental Concrete Bridges. The revised article states that the vertical component of inclined tendons shall only be considered to reduce the applied shear where the tendons extend through the web depth, engage both the flexural compression and flexural tension zones and are anchored or fully developed by anchorage, deviators, or internal ducts located in the top or bottom 1/3 of the webs.

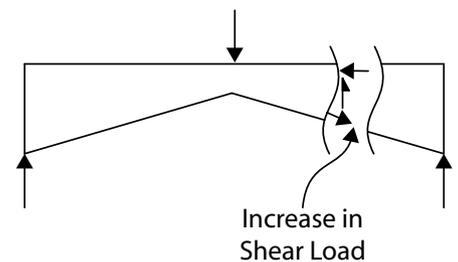
Agenda Item 37 extends the provisions for development of prestressing strand in Article 5.11.4 to “normal-weight concrete with specified concrete compressive strengths up to 10.0 ksi at transfer (f_{ci}) and up to 15.0 ksi for design (f_c).” This extension is based upon research reported by Ramirez and Russell in the National Cooperative Highway Research Program (NCHRP) Report 603, *Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete*.

Agenda Item 38 results from NCHRP Report 679, *Design of Concrete Structures Using High-Strength Steel Reinforcement* by Shahrooz et al., which concludes that reinforcing steel with specified minimum yield strengths of up to 100 ksi can be successfully used in nonseismic bridge applications for both increased corrosion resistance and higher yield strength. A value of yield strength, f_y , not exceeding 100 ksi was found to be permissible without requiring significant changes to the LRFD specifications or, more critically, to the design philosophy and methodology prescribed therein. Some limitations to this increase were identified. This agenda item extends the minimum yield strength for use in design to 100 ksi for most nonseismic applications. Where higher yield strengths are not permitted by the specifications, the yield strength defaults to the existing values. Appendix D5 defines the articles where a minimum yield strength up to 100 ksi is permitted.

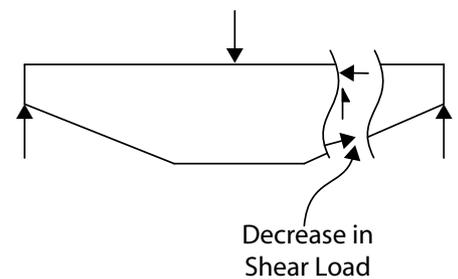
NCHRP Report 603, cited in the discussion of **Agenda Item 37** above, also addresses development of deformed reinforcement. Based on the research, **Agenda Item 39** revises Articles 5.11.2 and 5.11.5 to allow these provisions to apply to development and splice lengths of deformed reinforcement



Hammerhead Pier



Beam



Beam

Article 35: Conditions that decrease and increase shear load. Figure: PCI.

in tension for normal weight concrete with specified concrete compressive strengths up to 15.0 ksi provided that minimum transverse reinforcement is provided along the development and splice lengths. 

EDITOR'S NOTE

If you would like to have a specific provision of the AASHTO LRFD Bridge Design Specifications explained in this series of articles, please contact us at www.aspirebridge.org.

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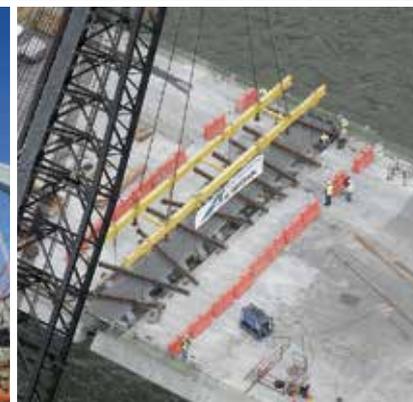
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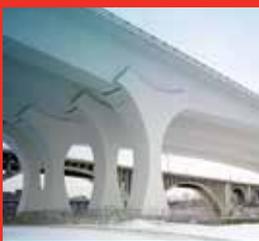
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