# ASPIRE™

THE CONCRETE BRIDGE MAGAZINE

Winter 2010

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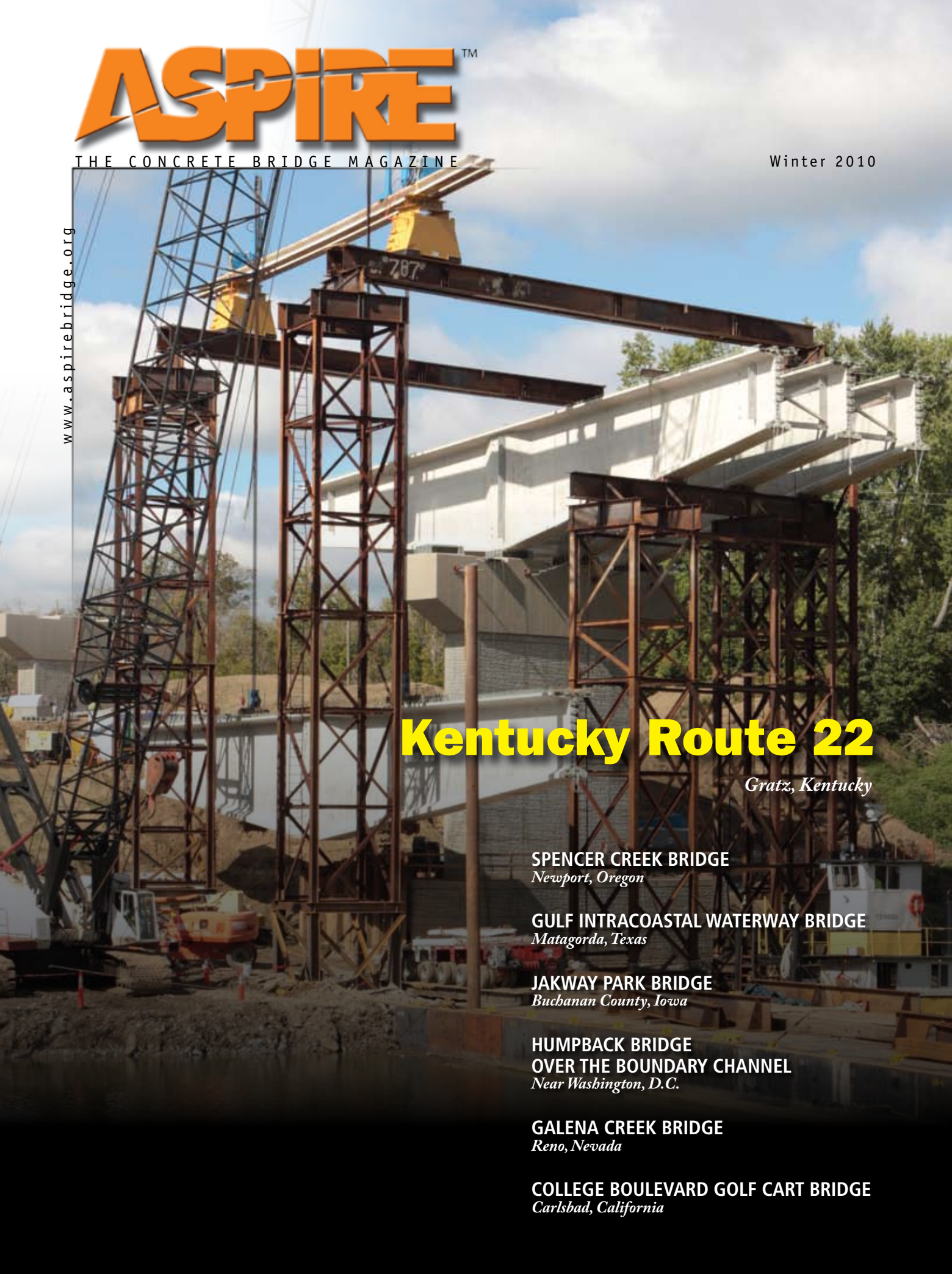

## Kentucky Route 22

*Gratz, Kentucky*

**SPENCER CREEK BRIDGE**
*Newport, Oregon*

**GULF INTRACOASTAL WATERWAY BRIDGE**
*Matagorda, Texas*

**JAKWAY PARK BRIDGE**
*Buchanan County, Iowa*

**HUMPBACK BRIDGE OVER THE BOUNDARY CHANNEL**
*Near Washington, D.C.*

**GALENA CREEK BRIDGE**
*Reno, Nevada*

**COLLEGE BOULEVARD GOLF CART BRIDGE**
*Carlsbad, California*

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*Photo: Prestress Services LLC.*


*Photo: Cianbro Corp.*


*Rendering: CH2M Hill.*

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*Photo: Prestress Services LLC.*

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# EDITORIAL

*Photo: Ted Lacey Photography.*

## Sustainability and the Art of Concrete Bridge Design

John S. Dick, *Executive Editor*

With this issue, *ASPIRE*™ begins its third year of exploring sustainable solutions. We find the subject more pervasive—in a most positive way—with each passing year. Both Myint Lwin and Scott Snelling address the topic in their articles. Myint, who is director, Office of Bridge Technology at the Federal Highway Administration, provides transcribed comments made during a presentation last November at the American Segmental Bridge Institute's annual convention in Minneapolis. Scott is a senior engineer with Hardesty & Hanover in New York City and serves on the American Society of Civil Engineers' Task Committee for Sustainable Design. From his background, he suggests what a new national standard for sustainable bridge design could look like, based on existing sustainability standards for buildings.

*ASPIRE* has highlighted many arch bridge projects over the years including three in this issue, and there is yet another waiting in the wings for the Spring issue. The three projects in this issue are:

- Spencer Creek Bridge, Newport, Ore.,
- Humpback Bridge over the Boundary Channel on the George Washington Parkway near Washington, D.C. in Virginia.
- Galena Creek Bridge on the I-580 Freeway Extension, near Reno, Nev., and

The arch is structurally and aesthetically well-suited for creating highway bridges. Fred Gottemoeller, in his popular book titled, *Bridgescape: the Art of Designing Bridges,* says about evaluating bridge types, "…if it is desirable for the structure to frame an important view, than a structural type with a curved, arched soffit will be an effective choice...Arches continue to have strong visual appeal because of their shape…Arch bridges look best where the surroundings 'contain' the visual thrust of the arch."

Each highlighted project uses the arch in a unique way. Each draws on context sensitivity and uses concrete for interesting solutions. These projects also illustrate different techniques for building concrete arches. We believe you, too, will find these projects innovative and useful in the future consideration of such designs.

Janssen & Spaans Engineering (JSE) has played an important role in concrete bridge design for nearly 30 years. They have been involved in two record bridge spans in recent years. Since 1960, the two parallel Oneida Lake Bridges in Brewerton, N.Y., were the world's longest precast, prestressed concrete bridge spans at 320 ft. But, in 2000, a JSE design for the Moore Haven Bridge over the Okeechobee Waterway in Florida resulted in a three-span unit with a 320-ft-long main span, tying the record. The Kentucky Route 22 project, shown on the cover and mentioned in the FOCUS on JSE, when completed, will be the new world record holder, with a main span of 325 ft. Along the way, techniques pioneered by JSE and used in the design and construction of spliced girder bridges have become commonplace. We are proud to feature them in this issue.

The Jakway Park Bridge in Iowa not only uses ultra-high-performance concrete at a design compressive strength of 21,500 psi but employs a special new shape called the Pi girder (owing to its cross-section's resemblance to the Greek letter). Created by the Massachusetts Institute of Technology and the Federal Highway Administration, the shape takes advantage of the material's unique properties.

The Pennsylvania Department of Transportation is this issue's featured state. The concrete industry acknowledges Pennsylvania as home to the nation's first modern precast, prestressed concrete bridge; a cutting edge solution for the time. Today, PennDOT continues its state-of-the-art applications of concrete technology.

Each article serves as a testament to wise decisions by designers and good investments by owners on behalf of the traveling public. As always, we hope you enjoy and benefit from their presentation.




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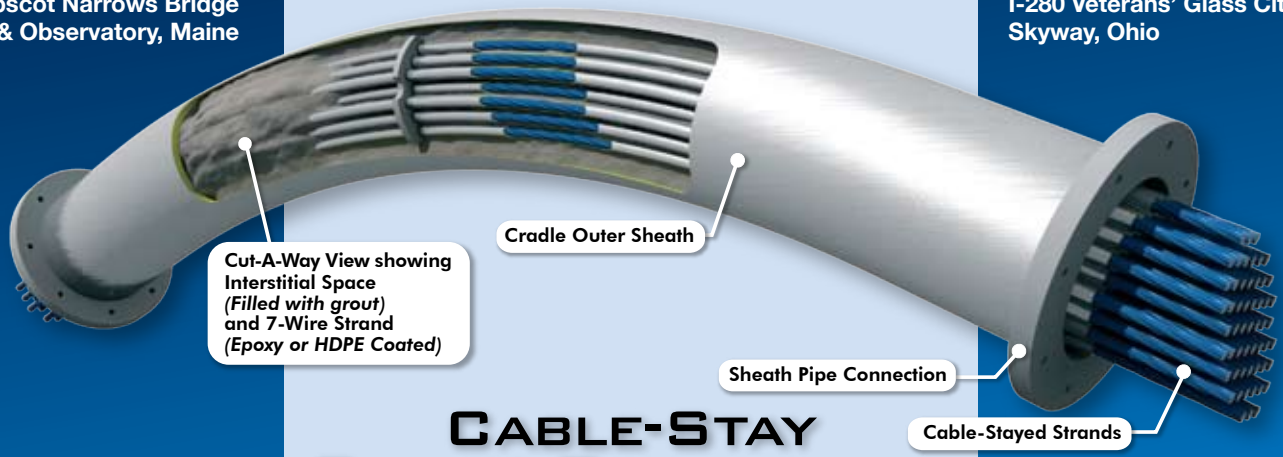
**Cover:**
Kentucky Route 22, Gratz, Ky.
Photo: Prestress Services LLC.

**Penobscot Narrows Bridge & Observatory, Maine**

**I-280 Veterans' Glass City Skyway, Ohio**




# Cable-Stay Bridge Technology

The FIGG Cable-Stay Cradle System™ Invention – first used in the I-280 Veterans' Glass City Skyway, Ohio & Penobscot Narrows Bridge & Observatory, Maine – was designed to revolutionize cable-stay bridges. The cradle is one unit that goes through the pylon. Among the cradle's many benefits are that it allows for unlimited stay sizes and makes it possible to remove, inspect and replace individual stay strands. Awards include: the 2007 ASCE Charles Pankow Award for Innovation, the NOVA Award from the Construction Innovation Forum, the 2006 NSPE New Product Award and the 2006 Modern Marvels Invent Now Top 25 Inventions (selected from 4000 entries)

OWNER: **Maine Department of Transportation**
DESIGNER: **FIGG**
CONTRACTOR: **Cianbro/Reed & Reed, JV**

The world's tallest public bridge observatory at the top of the 420' western pylon provides 360 degree vistas of Maine for visitors from May through October. The cable-stay bridge features a 1,161' main span and was opened to traffic on December 30, 2006. Aesthetics selected by the community center around a bridge theme of "Granite, Simple and Elegant". This bridge has received numerous awards, including the George S. Richardson medal from the International Bridge Conference and the ASBI Bridge Award of Excellence.

OWNER: **Ohio Department Of Transportation**
DESIGNER: **FIGG**
CONTRACTOR: **Bilfinger Berger Civil Inc.**

Toledo's landmark cable-stay bridge features 612.5' spans on either side of a single pylon and incorporates stainless steel cable casings and a pylon with four sides of glass on the top 196'. The custom glass reflects the community's vision and honors their heritage in the glass industry. At night, LED lights behind the glass create dramatic lighting celebrating seasons and holidays. This bridge opened to traffic in June 2007 and has received numerous awards including the NCSEA Outstanding Project Award and the ASBI Bridge Award of Excellence.

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*Editor,*
*I commend you on a beautiful, up-to-date, relevant, and educational magazine. Therefore I was surprised to see in the FHWA article on the American Recovery and Reinvestment Act [see ASPIRE™ Fall 2009, p. 42] a background photograph of a person marking up a bridge technical design drawing using a fountain pen and a hand compass. While I still am partial to the beautiful nuance of using varying line weights on older, hand-drawn technical drawings and bemoan the poor penmanship of younger engineers who never took a manual drafting class, the last time I was required to use a fountain pen was in the fourth grade (40 years ago) and for a hand compass it was in college (over 25 years ago). While the photograph accompanying the FHWA article was nostalgic, it doesn't at all represent the computer drafting and complex 4D modeling used by today's engineer, or ARRA projects.*

Roger Haight
Parsons Brinckerhoff
New York, NY

[Editor's Reply]
Roger…
Thank you for the compliments. It is always encouraging to hear that we are achieving our goals to bring relevant technical information to bridge designers in an attractive and appreciated package. I have to admit that I too pondered the use of instruments from a bygone era shown in the background of this feature. I wondered if others would take notice. It appears that I am older than you! I used an ink compass, LeRoy lettering instruments, and a set of Koh-I-Noor Rapidograph ink pens to create what I think were very attractive standard drawings for the Wyoming Highway Department in 1965 and '66. The use of this background contrasts greatly with the exceptionally contemporary program we know as the ARRA. Maybe that's the irony.

*[Roger Haight's Response]*
*Yes, it was good to hear you reminisce about the good old days—you are much older than I am!!*

## EDITOR'S NOTE

Additional copies of *ASPIRE* may be purchased for a nominal price by writing to the Editor through "Contact Us" at the *ASPIRE* website, www.aspirebridge.org. A free subscription can be arranged there using the "Subscribe" tab.

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

**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.

**Scott Snelling** is a mechanical and structural engineer with Hardesty & Hanover LLP in New York City. He serves on the American Society of Civil Engineers Task Committee for Sustainable Design and the Structural Engineering Institute's sustainability committee. He has served in the field with Engineers Without Borders and Bridges to Prosperity.

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

## MANAGING TECHNICAL EDITOR

*Photo: Ted Lacey Photography.*

**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.

## CONCRETE CALENDAR 2010

*For links to websites, email addresses, or telephone numbers for these events, go to www.aspirebridge.org.*

**February 2–5, 2010**
***World of Concrete***
Las Vegas Convention Center, Las Vegas, Nev.

**February 17-18, 2010**
***2010 ASBI Seminar on Design and Construction of Segmental & Cable-Supported Concrete Bridges***
Mariott Hotel, Denver, Colo.

**February 24-26, 2010**
***NCBC Concrete Bridge Conference***
Hyatt Regency, Phoenix, Ariz.

**March 21-25, 2010**
***ACI Spring Convention***
Sheraton Hotel, Chicago, Ill.

**April 8-9, 2010**
***2010 FHWA Bridge Engineering Conference: Highways for LIFE and Accelerated Bridge Construction***
Hyatt Regency Grand Cypress, Orlando, Fla.

**April 12-13, 2010**
***2010 ASBI Grouting Certification Training***
J.J. Pickle Research Campus, The Commons Center, Austin, Tex.

**May 23-27, 2010**
***AASHTO Subcommittee on Bridges and Structures Annual Meeting***
Sacramento, Calif.

**May 29 – June 2, 2010**
***Third International CEB-fib Congress and Exhibition***
***PCI Annual Convention***
***PCI-FHWA National Bridge Conference***
Gaylord National Resort & Convention Center, National Harbor, Md.

**June 6-9, 2010**
***International Bridge Conference***
David L. Lawrence Convention Center, Pittsburgh, Pa.

**September 23-26, 2010**
***PCI Committee Days***
Chicago, Ill.

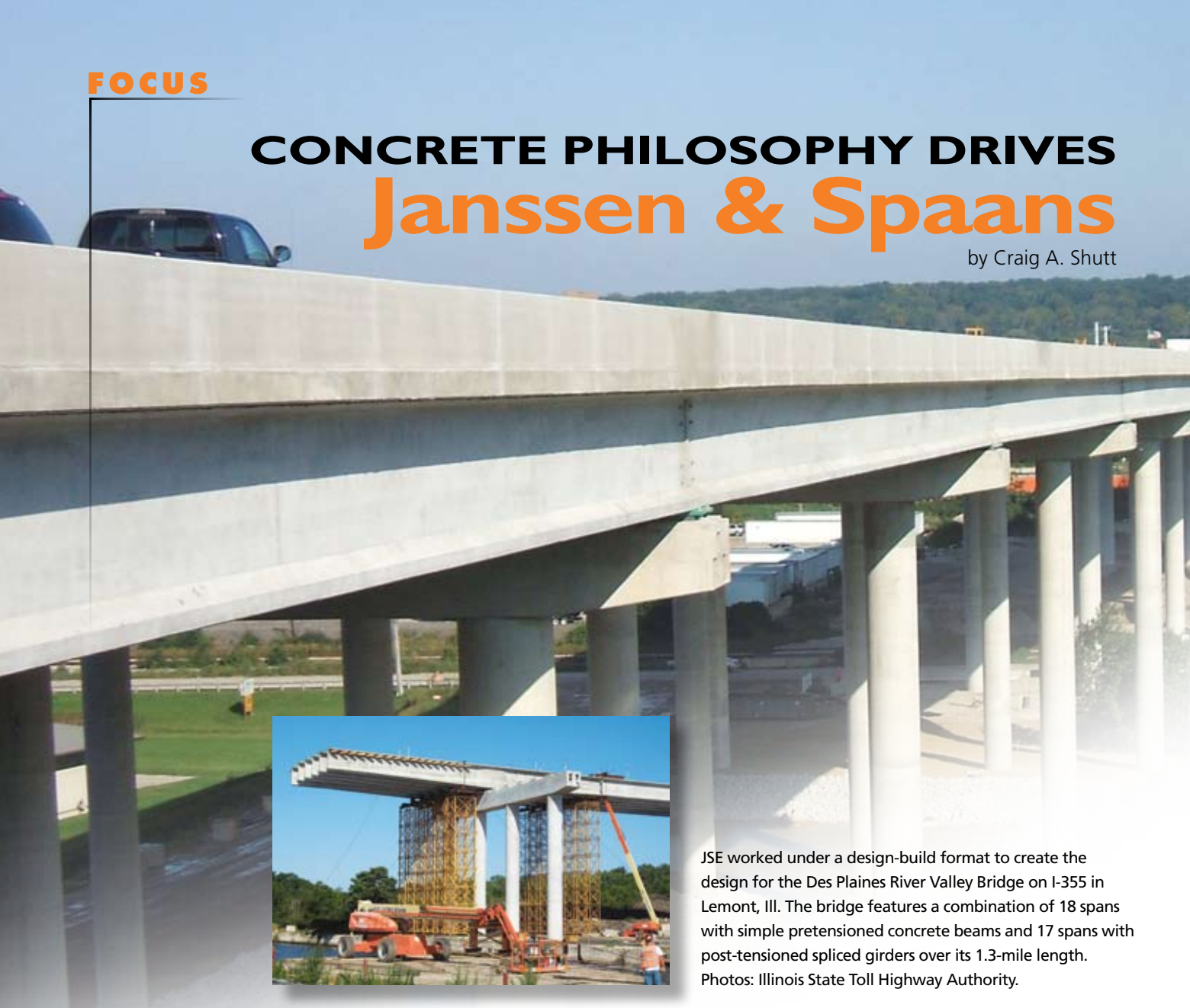
**October 11-12, 2010**
***2010 ASBI 22nd Annual Convention***
The Westin Bayshore, Vancouver, British Columbia

**October 24-28, 2010**
***ACI Fall Convention***
The Westin Convention Center, Pittsburgh, Pa.

FOCUS

# CONCRETE PHILOSOPHY DRIVES Janssen & Spaans

by Craig A. Shutt



JSE worked under a design-build format to create the design for the Des Plaines River Valley Bridge on I-355 in Lemont, Ill. The bridge features a combination of 18 spans with simple pretensioned concrete beams and 17 spans with post-tensioned spliced girders over its 1.3-mile length. Photos: Illinois State Toll Highway Authority.

**Whether bread-and-butter bridges or long, complex structures and projects, concrete designs offer the best alternative**

In its nearly 30 years of operation, Janssen & Spaans Engineering Inc. (JSE) has created designs for a multitude of bridges, including some highly complex ones that have become its forte. Throughout that history, it has found one maxim to be true: Properly designed, a concrete bridge will outlast, outperform, and underbid any alternative.

"Every time we perform cost-alternate studies or work on design-build projects with contractors estimating construction costs, we find that concrete superstructures are consistently more economical than the corresponding steel superstructure alternates." says Leo Spaans, founder and co-owner of Indianapolis-based JSE. "In addition to the upfront construction cost savings of concrete over steel, we have witnessed continued cost savings throughout the life of these structures. These savings result from lower maintenance requirements of concrete structures and better long-term durability."

Over the years, this conclusion has been confirmed by a number of projects in which alternative designs were prepared. An example is the preparatory work completed for the Des Plaines River Valley Bridge on I-355 in Lemont, Ill. Created under a performance-based specification, the structure features 18 spans with simple precast, pretensioned concrete beams and 17 spans with post-tensioned spliced girders over its 1.3-mile length. The $125-million project, which includes 612 girders using three different depths, needed this combined approach to efficiently place piers in a complex terrain. (For more on this project, see the Spring 2008 issue of *ASPIRE*.™)

JSE created this option along with a steel-plate girder alternative, using two design teams that each presented their approach to the contractor, Walsh Construction Group in Chicago. "Walsh did the calculations and added up all the costs and chose the concrete design," Spaans says. "They made the choice based on the bottom line."

## Close Relations with Contractors

JSE works closely with contractors, especially when they are using their preferred delivery method, design-build. "We love the design-build system," he says. "It helps create a level of freedom that permits us to be as efficient as possible. We like working closely with contractors. They're only interested in being efficient and in constructing the best design possible."

A recent example is the U.S. Route 460 Connector project in Buchanan County, Va., for which JSE provided design-build engineering services. The 1733-ft-long, six-span twin segmental box-girder bridge features two main spans of 489 ft with the box varying from 31 ft to 12 ft 6 in. in depth. The bridge is supported by H-shaped concrete columns with a maximum pier height of 220 ft, the tallest bridge piers in the state. The construction cost for JSE's design beat the next closest option by $3 million, on top of being the most responsive bid, based on the bids being weighted for technical proposal scores.

JSE designers relish the discussions that hone the final creation to make it as efficient as the talents of both sides will allow. "The contractors take our ideas, directly translate them into reality and give us feedback," he says. "It's a very interactive process with good give and take." Typically, weekly meetings are held as the project gets underway, to learn how smoothly the two groups will work and how close their visions of the final design are.

The effectiveness that this process provides when compared to the typical design-bid-build process can be striking, he adds. "When we are designing without having any idea who the contractor will be, we need to create engineering drawings that everyone can bid on. That lack of interaction keeps it from being as effective as possible and playing to the individual contractor's own skills." Value-engineering processes can follow, but those steps occur after the bidding and add time. "Design-build speeds up the process greatly."

## Speed is Key Goal

The need for speed is a major ingredient in owners' goals today, he notes. Owners want projects completed faster to bring them online quicker and to have construction disrupt events for a shorter period, reducing user costs and increasing worker safety. The firm's work on the I-70 project in Indianapolis, Ind., shows the dramatic improvements that can be made in construction speed with a design-build process.

The $175-million project replaced all roadways and upgraded 23 bridges along a 6-mile stretch of highway. Two new bridges were constructed with precast, prestressed concrete I-beams—a design, he notes, that "is almost impossible to beat." The entire project took only 10 months, compared to an estimated 2-year process for a traditional design-bid-build project. JSE took 3 months to create the drawings and then dealt with construction issues for the remaining 7 months. "This approach saved a tremendous amount of time."

The success of this approach can be seen in the company's own projects in Indiana. JSE has a 70% success rate in winning projects that it proposes with a design-build delivery method, he says. "We've been extremely successful with it in Indiana, because it saves a tremendous amount of time."

**'We find that concrete superstructures are consistently more economical than the corresponding steel superstructure alternates.'**

The $175-million "Super 70" bridge project in Indianapolis involves revamping 6 miles of I-70, comprising all roadway and 23 bridges. In addition, two new bridges were constructed with precast, prestressed concrete I-beams. The design-build project was completed in only 10 months. Photo: © 1800TOPSITE.com.

**'Spliced bulb-tee girders are going to drive concrete strengths higher.'**

## New Partnerships Forming

The company also has been gaining success with public-private partnerships, which it sees growing as government agencies want to gain additional funding and private entities gain benefits from operating the roadway. One such project is currently underway in one of Canada's western provinces, where the roadway and 35 bridges (90% of them proposed to be constructed with prestressed concrete I-beams) are being improved. The $1-billion project is being funded by a private group, which will build and then maintain the highway.

"The owners are demanding anything possible to prolong life, because they are responsible for maintenance," he says. "These private entities understand that to keep the project profitable, the owner must look long term and account for all expenses throughout the structure's service life."

One way to lower maintenance and increase durability is using a concrete mix containing fly ash and a high-range, water-reducing admixture. These mixtures achieve high compressive strengths and have a low permeability. Additionally for deck protection, some owners are specifying an overlay of silica fume concrete, further increasing the long-term durability of the deck.

## Durability a Requirement

Durability is a key concern as owners look to extend service life to 100 years or more. Concrete bridges can provide that attribute, Spaans says, by focusing more attention on bearings and expansion joints. "The use of integral abutments to eliminate or reduce the number of bearings, and the use of elastomeric bearings, can aid durability greatly," he says. Denser concrete, especially through adding fly ash and other admixtures, also offers potential for extending service life. "The more rigid the structure, the less vibration will be created and the better opportunities to avoid cracking."

But Spaans doesn't believe a 100-year service life will achieve the goals that bridge owners are hoping it will. "The bigger problem over that period is the functionality of the roadway and the bridges," he explains. As usage grows and codes change, bridges will need to be upgraded or replaced to handle traffic and satisfy new criteria rather than be replaced because they have worn out. "The bridges may still have life, but they will be functionally obsolete 100 years from now," he argues. "Current standards provide bridges with enough service life to last 75 years, and that durability will be enough."

High-performance concrete that focuses on improving concrete strengths, however, is offering new opportunities, especially for spliced-girder bridges. "Spliced bulb-tee girders are going to drive concrete strengths higher," he says. "Ten years ago, if we had said we wanted concrete of 7000 psi or higher, people wouldn't have known what to do with it. That has changed. The biggest trend in bridge design is the new properties we're able to achieve with concrete. We can gain higher strength and more durability, which aids design creativity and functionality."

## Sand-Lightweight Concrete Grows

Sand-lightweight (SLW) concrete also is being used more often, he notes. "It can greatly reduce the weight for transporting and erecting larger beams for new projects." Unless there is significant widening involved, there is less need to use SLW concrete when replacing only superstructures in rehabilitation projects, he notes. "Foundations and substructures typically are robust enough that it does not create a problem to replace the superstructure with new materials."

An example of JSE's use of SLW concrete is the Kentucky Route 22 project currently underway in Gratz, Ky. Designed as a steel plate girder bridge, the precaster joined with JSE to propose a 900-ft-long, four-span (175, 200, 325, and 200 ft) spliced bulb-tee girder design. This design yielded a savings of more than $800,000 when compared to the as-bid steel design.

The main span features a 325-ft-long spliced bulb-tee girder, the longest in the country to feature this type of construction.

### Janssen & Spaans' Long Prestressed Concrete History

Janssen & Spaans opened its doors in the early 1980s, but founders Hubert Janssen and Leo Spaans had many years of experience with concrete bridge designs before that. The two previously had worked together in the Netherlands for the engineering firm BVN. That company had a long history with prestressed concrete designs, as one of its own founders had been a student of Eugene Freyssinet of France, acknowledged as the inventor of prestressed concrete.

Spaans came to America in 1977 as part of a BVN team that worked with the Indiana-based engineering firm STS. Shortly after, the two companies merged to create BVN-STS, which later was purchased by HDR. Janssen and Spaans broke off on their own a few years later, focusing at first on segmental bridge designs. The company soon expanded its expertise beyond segmental bridges to all types and ultimately to pavement and roadwork projects as well.

Today, JSE's 65 employees work on more roadwork projects than bridges—but they also create more bridges than at any time in the past, an indication of the growth it has experienced.

The Kentucky Route 22 project in Gratz, Ky., was redesigned by JSE from a steel-plate girder bridge to a four-span, 909-ft-long spliced bulb-tee girder design that saved about $800,000 from the previous design. The 325-ft main span provides a record length for construction of this type. Photos: Janssen & Spaans Engineering.

SLW concrete was used to reduce its weight for handling purposes. The haunched pier segments are 16 ft deep, while the 9-ft-deep drop-in girders have a maximum length of 185 ft. The bridge will be completed in the summer for the Kentucky Transportation Cabinet.

## Equipment Capabilities Expand

Aiding these projects are the improvements that precasters and erectors have made in their equipment, including special trucks for transporting large components, creativity in barging girders to the site, and larger and more adept cranes to pick and place pieces rapidly and efficiently. "There have been significant improvements in the past 10 years to aid transport and handling. Ten years ago, if we'd said we were going to create spliced bulb-tee girders for a span of 325 ft, they'd have said they couldn't get the pieces to the site. But today we can do it."

An example of the creativity that can be achieved with designs is the Fulton Road bridge replacement project in Cleveland, Ohio, for which JSE performed construction engineering services. The 1573-ft-long bridge features 35 spans of AASHTO Type III precast, prestressed concrete girders supported on five approach spans and six 210-ft-long precast, post-tensioned concrete arch spans with cast-in-place concrete piers, spandrel columns, and transverse cap beams. The bridge spans a park, the city zoo, a creek, and two active railroad lines.

The arch spans have a parabolic profile and a 41 ft 8 in. rise, consisting of three precast concrete sections, comprising two identical end segments and a crown segment. The owner's design specified cable stays for the erection of the arch pieces for two of the spans. JSE was able to develop an alternate erection scheme for the contractor that eliminated the cable stays by using conventional falsework, greatly speeding up the erection time while lowering erection costs. During erection, arch struts were installed between arch lines by bolting them to the face of the arches. The project was completed in the fall of 2009. (For more on this project, see the Spring 2009 issue of *ASPIRE*.)

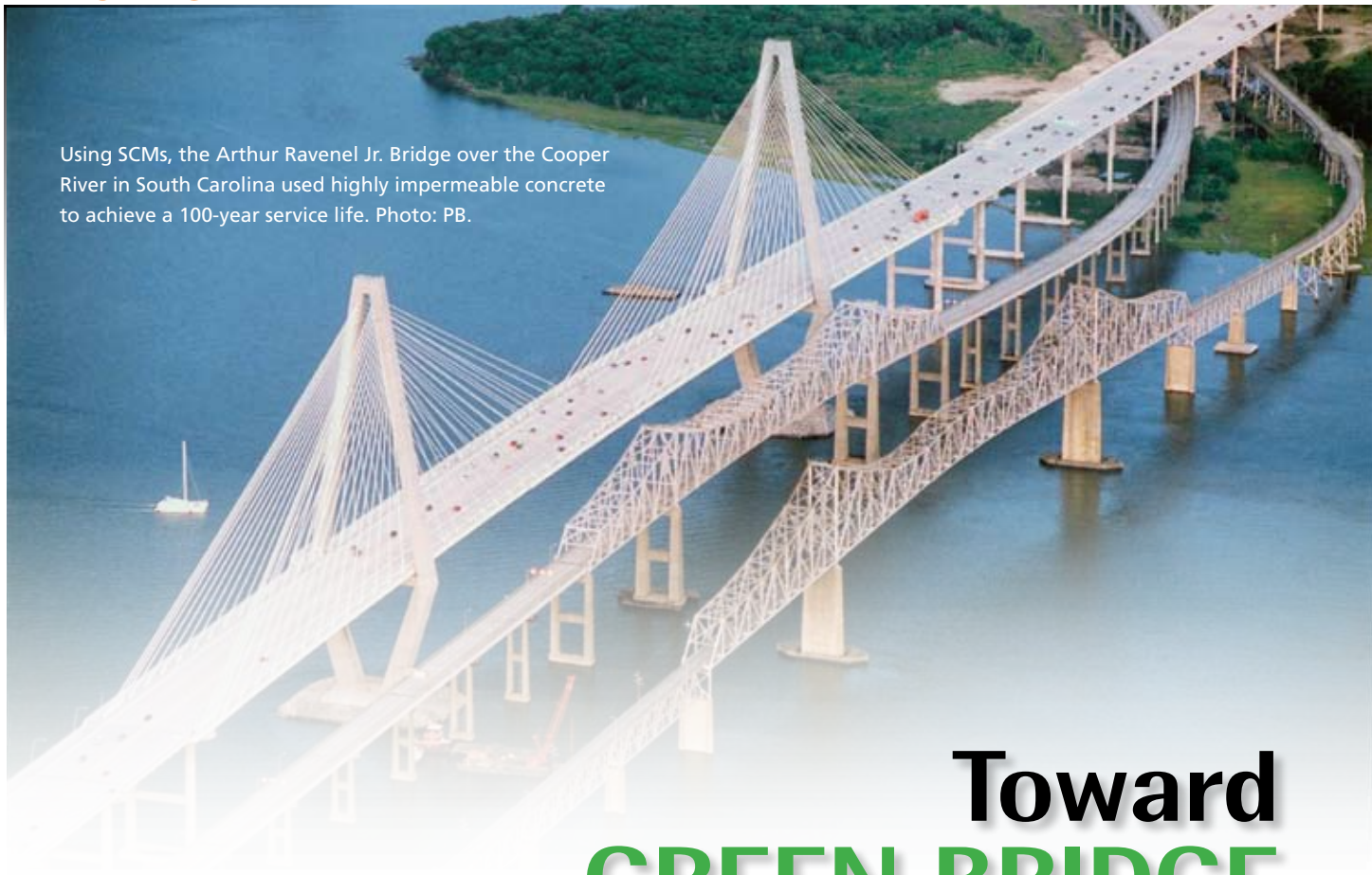
Rehabilitation of existing bridges also is becoming a bigger part of JSE's business. The firm has an agreement with the state of Indiana to inspect and recommend action for bridges. One of the firm's groups is devoted exclusively to inspecting bridges, creating reports to recommend improvements, and following through with design plans if the state requires them. These recommendations can range from modest repairs through total replacement.

As the needs for repairs and replacement bridges grow in coming years, Spaans anticipates more improvements in concrete engineering and handling, making it even more the dominant material. "If you design properly, it's almost impossible to create a better bridge using steel," he says. That philosophy is helping the company produce economical designs and grow during the current recessionary times.

"Despite the economy, we are expanding and pursuing work in new areas of the country, as well as internationally." Those proposals include ones in Alberta, Canada, as well as the Middle East and Libya. In all of those projects, no doubt, Janssen & Spaans will build an efficient, attractive, and cost-effective structure—and it more than likely will be made with concrete.

**For more information on this or other projects, visit www.aspirebridge.org.**

The Fulton Road bridge replacement project in Cleveland, Ohio, features 35 spans of AASHTO Type III precast concrete girders supported on five approach spans and six 210-ft-long precast concrete, post-tensioned arch spans with cast-in-place concrete piers, spandrel columns, and transverse cap beams. The bridge spans a park, the city zoo, a creek, and two active railroad lines.



Using SCMs, the Arthur Ravenel Jr. Bridge over the Cooper River in South Carolina used highly impermeable concrete to achieve a 100-year service life. Photo: PB.

# Toward GREEN BRIDGE Standards

*The following article presents the opinions of the author and not necessarily those of the publishers of ASPIRE.™ Readers are encouraged to respond with their opinions or ideas about this subject.*

by Scott Snelling,
Hardesty & Hanover LLP

Sustainable or "green" design has entered the public consciousness and the mainstream media. Taxpayers, voters, politicians, and policymakers want assurance that public funds are being used to build environmentally sensitive infrastructure. The American Society of Civil Engineers (ASCE) recently launched an initiative to create a standard for defining and certifying green infrastructure projects and design professionals. While it is not yet clear when ASCE will be ready to introduce such a standard or if another organization will become pre-eminent, it is clear that sooner than later, a green standard will be incorporated into the bridge industry in the United States. In the concluding section of this article, the framework of a future green bridge standard is proposed from a review of the existing green standards that have been put into practice in other segments of the construction industry.

## Existing Green Standards

These standards include LEED, SPiRiT, and Greenroads. LEED is the acronym for Leadership in Energy & Environmental Design; this standard certifies green building and neighborhoods. LEED is administered by the United States Green Building Council, a non-profit organization founded in 1993. SPiRiT is the Sustainable Project Rating Tool developed by the U.S. Army for their facilities. Since 2000, all new army facilities have been required to be built to LEED or SPiRiT standards. Greenroads was introduced in 2009 to certify roadway and pavement projects. This standard was developed at the University of Washington with funding from the United States Department of Transportation and several state departments of transportation. Greenroads' documentation states, "A future system focused on structures [i.e., bridges, tunnels, and walls] could be incorporated into Greenroads, but none currently exists."

## Evaluating Infrastructure Projects

Engineers can calculate the energy required to construct and maintain competing proposed design alternatives for specific projects by performing life-cycle assessments (LCA). One tool that enables LCA was developed by the Carnegie Mellon University Green Design Institute, (2008), titled, *Economic Input-Output Life Cycle Assessment (EIO-LCA)*, US 2002 Industry Benchmark model. It is available from: www.eiolca.net. LCA published by Horvath (1998), Dennison (2004), and Struble (2004) indicate that embodied energy and greenhouse gas emissions tend to be lower for portland cement concrete bridges when compared with structural steel bridges. Concrete bridges using high percentages of supplemental cementitious materials (SCMs) and recycled materials further widen the gap.

## Concrete Bridges

Concrete bridges significantly save on maintenance resources by eliminating the need for painting. Bojidar Yanev of the New York City DOT, in his book, *Bridge Management*, writes, "Empirical evidence therefore suggests that annual maintenance level amounting to 1% of the replacement cost is a threshold below which deterioration accelerates." Of these maintenance costs, 66% is attributed to repainting and spot painting for steel bridges.

Concrete can be crushed and recycled—downcycled—as aggregate or fill, but has no scrap value. By-products, such as mine tailings, can be used instead of virgin aggregate. However, the most significant environmental impacts of concrete are associated with cement production. The amount of energy consumed and greenhouse gas emitted when concrete is produced varies drastically depending on the cements used.

Most pozzolanic admixtures or SCMs are by-products of industrial processes. These include materials such as fly ash, silica fume, and blast furnace slag. On projects that use design-bid-build procurement, designers often specify portland cement-based mixes as a matter of standard practice. Typical bridge specifications call for 15% SCMs and 85% portland cement. Meanwhile, the majority of potential industrial by-product SCMs is sent to landfills. There is substantial opportunity for bridge engineers to economically specify higher percentages of SCMs in concrete.

The Roslyn Viaduct Bridge on Route 25A over Hempstead Harbor, Long Island, N.Y., designed by Hardesty & Hanover, New York, N.Y., is a context sensitive design created in concert with the community and uses both high strength and high performance concrete to ensure a 75-year service life. Rendering: Hardesty & Hanover LLP.

Recent design-build projects have seen the successful use of concretes with high percentages of SCMs such as ground granulated blast-furnace slag—up to 85%—because they have proven to be the lowest-priced concrete meeting the required physical properties. The reductions in energy use, greenhouse gas emissions, and landfill volume have been regarded as beneficial side-effects. Such concretes may take hours longer to set, but once cured, can result in higher strength and lower permeability. For example, the Arthur Ravenel Jr. Bridge over the Cooper River in Charleston, S.C., was designed to meet its 100-year service life using uncoated reinforcement and low permeability, high SCM content concrete. Meanwhile, the new St. Anthony Falls Bridge in Minneapolis, Minn., received positive coverage in the media for its use of environmentally friendly, high-performance concrete. In the piers, 85% of the cementitious materials were SCMs. In California, the San Francisco-Oakland Bay Bridge consisted of four distinct construction projects. From the beginning, specifications required a minimum 25% fly ash concrete, principally to mitigate alkali-silica reactivity. In one case, the contractor was permitted to use 50% ground granulated blast-furnace slag in lieu of fly ash. In areas needing thermal curing controls, mixtures of cements containing up to 50% fly ash mixes were used. In 2006, the Environmental Protection Agency recognized Caltrans as a leader in the construction use of waste products.

The Roslyn Viaduct Bridge on Route 25A over Hempstead Harbor, Long Island, N.Y. Photo: Rich Lorenzen.

The San Francisco-Oakland Bay Bridge incorporated up to 50% SCMs in portions of its construction.

## Proposed Green Bridge Standard

The following proposal is intended as a starting point for the development of a standard for the certification of green bridges. Ultimately, the formulation of such a standard would be through a committee of bridge professionals.

This proposed green bridge standard has a total of six prerequisites and 39 possible credits grouped into seven categories. The seven categories are materials and resources; alternative transportation; project delivery process; construction activity; maintenance and access; environment and water; and energy.

These categories of criteria would be used to award credits to a bridge project. A designated minimum point value—say, 15 credits, for example—would be required before a bridge project could be certified as green. All the prerequisites would have to be met.

### Materials and Resources

*SIX CREDITS: Use materials that are recycled, recyclable, and industrial by-products. One credit is earned for recycled material content of 20%. Additional credits would be earned for 40%, 60%, 80%, and 90% recycled material content. Use "regionally" extracted and manufactured materials to reduce the effects of shipping. Regional is defined as an 800-km (500-mile) radius from the project site.*

### Alternative Transportation

*FIVE CREDITS: Encourage transportation alternatives to single occupancy motor vehicles. Provide pathways for pedestrians and cyclists. Provide designated lanes for buses, light-rail transit, car pools, and low-emission vehicles.*

### Project Delivery Process

ONE PREREQUISITE:

Perform bridge life-cycle cost analysis in accordance with NCHRP Report 483. Perform life-cycle assessments to compare the environmental impacts of competing bridge proposals.

*SEVEN CREDITS:*

*Use design charettes to develop context-sensitive solutions. Consider future uses, demolition cost, and salvage value of the bridge. Use innovative designs. Include green design accredited professionals.*

### Construction Activity

THREE PREREQUISITES:

- Divert 75% of the on-site construction and demolition waste from landfills for reuse or recycling (refer to the online Construction Waste Management Database developed by the National Institute of Building Science).
- Control erosion and storm water runoff.
- Prepare a construction noise mitigation plan.

*SIX CREDITS:*

*Account for water and electricity use. Provide on-site environmental awareness training. Reduce fossil fuel use and emissions of construction equipment.*

### Maintenance and Access

*TWO CREDITS:*

*Produce a maintenance manual at the time of design, including estimated maintenance activities, frequencies, and costs. Provide safe and productive maintenance access.*

### Environment and Water

ONE PREREQUISITE:

Comply with the applicable environmental laws.

*NINE CREDITS:*

*Minimize destruction to the local ecology around the bridge construction site. Minimize erosion; storm water sedimentation; construction dust; and particulate, noise, and light pollution. Minimize the heat island effect. Prefer the redevelopment of brown field or urban sites instead of developing agricultural or wetland sites. Use native vegetation with no irrigation.*

### Energy

ONE PREREQUISITE:

Monitor the bridge electrical systems after construction to verify that the actual energy used conforms to the design values.

*FOUR CREDITS:*

*Sign a multiyear contract to procure grid-source green electricity. Minimize the life-cycle costs of the bridge electrical equipment and lighting.*

## The Future

Green building has grown from minor influence to a major market impact with tens of billions of dollars worth of projects constructed each year. State DOTs have built hundreds of green buildings and are beginning to apply the relevant lessons learned to their infrastructure projects. A green bridge standard will reward innovation and encourage existing best practices to be used more widely, while reducing life-cycle costs. Now is the time for bridge engineers to adopt a green bridge standard.

## References


Dennison, Glen and Maddox, B., 2002, *The Role of Steel in Building a Better Environment*, International Association for Bridge and Structural Engineering, Symposium Report Volume 86, Towards a Better Built Environment—Innovation, Sustainability, Information Technology, Melbourne, Australia, September.

Hawk, Hugh, 2003, *Bridge Life-Cycle Cost Analysis*, NCHRP Report 483, Transportation Research Board, Washington, D.C., 106 pp.

Horvath, Arpad and Hendrickson, Chris, 1998, *Steel Versus Steel-Reinforced Concrete Bridges: Environmental Assessment*, Journal of Infrastructure Systems, American Society of Civil Engineers, Vol. 4, No. 3, September, pp. 111-117.

Struble, L. and Godfrey, J., 2004, *How Sustainable is Concrete?* International Workshop on Sustainable Development and Concrete Technology, Beijing, China, May 2004, proceedings published by Center for Transportation Research and Education, Iowa State University, Ames, Iowa, pp. 201-211.

Yanev, Bojidar, 2007, *Bridge Management*, John Wiley & Sons, January, 672 pp.

PROJECT

# CREATING AN AESTHETIC GATEWAY

by Tanarat Potisuk, H.W. Lochner Inc. and
Keith Kaufman, Knife River Corp.

At the top of the arch, the No. 14 reinforcing bars were spliced together to make the arch segments continuous. Then the arches were connected through the crown cross beam.

## Spencer Creek Bridge on Oregon's scenic Coastal Highway 101 suits its setting

Officials agreed that replacing the existing 1940s-era reinforced concrete, deck-girder bridge on Highway 101 in Newport, Ore., required sensitivity due to its popular and scenic context. But the suggested precast concrete, post-tensioned deck-arch replacement had to overcome a series of constraints that included poor soil conditions with potential liquefaction during an earthquake. To accomplish the goals, a unique foundation system was created that resists horizontal reactions from the arch ribs.

The original three-span bridge had suffered from severe deterioration, corrosion, and age. Replacing it with a durable design that was aesthetically pleasing was required because of its location adjacent to the Beverly Beach State Park, one of the most popular state parks in Oregon. The highway also serves as the major north-south route along the Oregon Coast and has been designated as a National Scenic Byway and an All-American Road. Aesthetics, functionality, and durability had to blend seamlessly on this high-profile project.

After several years of studies by the Oregon Department of Transportation (ODOT) to consider alternative routes and bridge appearances, a concrete deck-arch bridge was selected as the best way to provide an aesthetic gateway from the park to the beach. This required shifting

## profile

**SPENCER CREEK BRIDGE** / NEWPORT, OREGON

**STRUCTURAL ENGINEER:** H.W. Lochner Inc., Salem, Ore.

**ROADWAY, HYDRAULICS, AND ENVIRONMENTAL ENGINEER:** Oregon Department of Transportation

**GEOTECHNICAL ENGINEER:** Shannon & Wilson Inc., Lake Oswego, Ore.

**PRIME CONTRACTOR:** Slayden Construction Group, Stayton, Ore.

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

The new Spencer Creek Bridge features six continuous spans supported by three concrete arch ribs. The bridge replaced a 1940s bridge and had to blend with the scenic landscape surrounding it.

**A precast concrete design was selected due to the sensitive environment at the bridge site.**

part of the highway about 50 ft to the east to accommodate the new bridge. The majority of the roadway shift was located at the south end of the bridge. The bridge span over the creek was lengthened to move the bridge foundation further away from the creek.

## Precast Concrete Selected

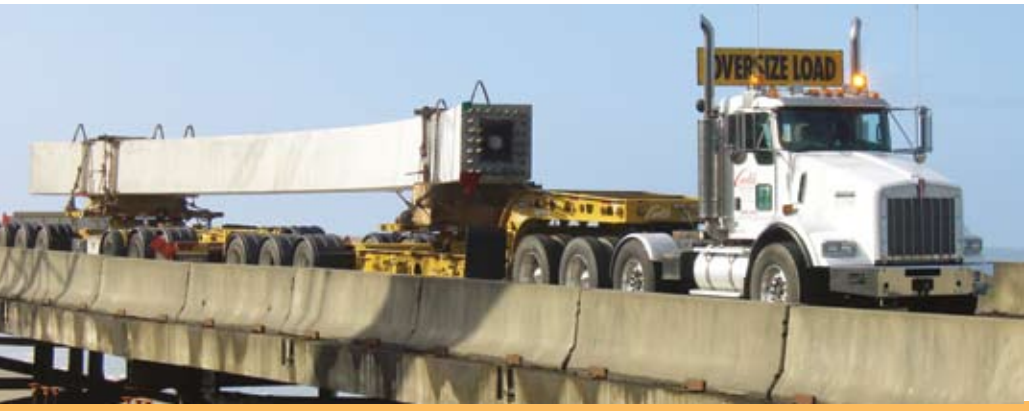
The new Spencer Creek Bridge is 210 ft long and 51.3 ft wide. The superstructure consists of 35-ft-long spans. Four spans are supported on columns over the arch. The two end spans fit between the bent columns over the arch support and the abutments. The arch spans 140 ft and consists of three parallel ribs with a constant width of 3.5 ft and a depth that varies from 4.5 ft to 3.25 ft.

Due to the sensitive environment at the bridge site, precast concrete was chosen for the main structural members, including the arches and beams for the superstructure. That approach allowed the amount of falsework and formwork to be reduced, minimizing the environmental impact. The precast concrete fabricators in the area also were considered to be able to provide better quality products for this coastal region than could be achieved with cast-in-place concrete construction.

Each of the three arch ribs consists of two precast concrete arch rib segments cast at a plant in Harrisburg, Ore. They were delivered to the construction site and connected at the crown with a crossbeam closure pour. Each arch segment was 70 ft long, weighed 160 kips, and contained 28 No. 14 longitudinal reinforcing bars. In addition, the arch segments were post-tensioned to prevent cracking during the shipment as well as to control cracking in service.

## Stainless Steel Reinforcement Used

In accordance with the ODOT Bridge Design and Drafting Manual (BDDM), all concrete was required to be high-performance concrete, while stainless-steel reinforcement was required in the concrete decks and crossbeams for bridges in the coastal area. This included all reinforcing bars extending into the concrete deck. As a result, stainless steel was specified for stirrups in the precast slabs. These bars met the Unified Numbering System (UNS) designation S31803, AISI Type 2205, Grade 75. Isolation between different alloys (stainless and black steel) was performed according to ODOT specifications.




Rather than transport upright as originally planned, the precast concrete arches were delivered in their casting position to avoid difficulty in transporting them through some of the sharp turns on the highway.

SIX-SPAN BRIDGE ON A PRECAST CONCRETE ARCH / OREGON DEPARTMENT OF TRANSPORTATION, OWNER

**POST-TENSIONING CONTRACTOR:** AVAR Construction Systems Inc., Fremont, Calif.

**REINFORCING BAR SUPPLIER:** Dixon Steel & Supply Company, Roseburg, Ore.

**BRIDGE DESCRIPTION:** Six-span bridge (including two approach spans) 210 ft long, 51.3 ft wide with continuous spans supported by three precast concrete arch ribs. Each span is 35 ft long and comprises 12 precast, prestressed concrete slabs with a composite cast-in-place concrete deck.

**BRIDGE CONSTRUCTION COST:** $19.5 million

(Photos 1-3) Upon arrival at the site, the precast concrete arches were rolled into lifting position on precast concrete blocks that used the half-arches' center of gravity to provide the rotating force.

The precaster's recommendations during preliminary design included limiting the arch rib's weight of each segment to 140 kips. However, due to the amount of reinforcement required in the arch segments the weight reached 160 kips. To handle the arch-rib segments in the plant, the arch casting form was strategically positioned so two travel lifts could nest and lift in tandem.

The precaster also worked with the reinforcing bar supplier to provide longer than typical length bars. This avoided the need to splice bars within the arch segments, which would have added time and complexity. Rather than the typical 60-ft-long bars, the supplier fabricated 70-ft-long pieces.

Securing the longitudinal No. 14 reinforcement within the complex steel cage of reinforcing bars also posed a challenge. Typically, the stirrups would be tied into position and the No. 14 bars threaded through by hand. But the grid was too tight to allow that to be accomplished safely and efficiently. Instead, a woven tube that constricts as it's pulled was placed over the end of each bar and then pulled through to the opposite end with a winch. This approach worked efficiently and provided better safety than working with the bars by hand.

## Arches Needed Special Handling

The arch segments were cast on their side. They were originally planned to be shipped on their bottom edge—in their final resting position. But the precaster determined that this position would make the arch segments difficult to transport through some of the sharp turns along the highway. Instead, the arch segments were redesigned to be shipped flat in the as-cast position. This required special equipment to handle the segments, necessitating special lifts that were built into the sides of the arch segments for maneuvering at the site.

Upon arrival at the bridge site, the arch segments had to be rolled from their shipping position into the proper alignment for erection. To avoid site-lifting expenses and time, a stack of precast concrete blocks was created at the site to serve as a base for rotating the arch segments. The half-arches' roll axis was offset from the center of gravity, so the arch segments could be picked horizontally from the truck and set with the center of the arch on the blocks. As the weight of the arch segment was transferred to the block support, they would roll into the proper position for final lifting and setting. Sand bags were set over the entire top of the blocks to protect the components as they rolled.

Connecting the two segments of the arch segments also posed challenges. The bottom portions were set in a 3 ½-in.-deep socket, after which it was enclosed by a 3.5-ft-deep cast-in-place, reinforced concrete block. To make the arch segments continuous, the No. 14 reinforcing bars extending from the top end of each segment were connected using metal-filled mechanical splices before placing concrete. The splices provided tolerance for adjusting the longitudinal rebar alignments while retaining the necessary strength.

Precast, prestressed concrete voided slabs made continuous for live load were designed for the bridge superstructure. Prestressing strands extending from the precast slab ends were hooked at bents to provide continuity between the slabs. The cross-members connecting the three arch crowns also served as supports for the precast concrete slabs.

## Soil Creates Challenges

Soil in the area consisted of alluvium deposits of silty-sand, clayey-silt, and organic debris. These are generally not suitable for laterally supporting an arch bridge. In addition, there were challenges with anticipated extreme scour and the sensitive environment surrounding Spencer Creek that had to be addressed.

A foundation system was designed using grouped, 6-ft-diameter drilled shafts embedded in bedrock to support the arches and the mechanically stabilized earth (MSE) walls for the approach embankments. Both provide good performance during seismic events.

A unique feature was added to the foundation system by attaching horizontal deadman anchors and struts to the drilled shaft caps. The anchors and struts were buried beneath the 40-ft-high MSE wall backfill. The deadman-anchor system was jacked into the MSE wall fill, using the developing passive earth resistance as the lateral support for the arches. This strengthening method allowed the arches to be set on the weak soil while providing the drilled shafts with additional resistance to withstand the horizontal forces.

The high-performance precast concrete and stainless steel reinforcement were specified to increase life expectancy of the new Spencer Creek Bridge. The design minimized impact to the environmentally sensitive creek and provided an aesthetically pleasing structure. The bridge has been well-received by the community. During construction, many local citizens would watch the arches being created and comment to the construction team on the bridge's pleasing appearance.

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*Tanarat Potisuk is a structural design engineer at H.W. Lochner Inc. in Salem, Ore., and Keith Kaufman is the chief engineer at Knife River Corp. in Harrisburg, Ore.*

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# The Gulf Intracoastal Waterway Bridge
## AT MATAGORDA, TEXAS

by Dean Van Landuyt, Texas Department of Transportation

### Combining superstructure types provides economical solution

Cattle drive across the previous floating swing bridge at Matagorda, Tex. Photo: Keith Dornak, TxDOT.

The Matagorda Peninsula in Texas is a largely undeveloped, 60-mile-long stretch of barrier islands known for its fishing, beautiful beaches, and cattle ranching. Only one of the two islands comprising the peninsula is accessible by vehicle. Formerly, that access was by a single, floating swing bridge across the Gulf Intracoastal Waterway at Matagorda. The bridge is used by vacationers and a few year-round inhabitants. Interestingly, ranchers owning property on both the mainland and island, also use it to drive their herds to the island for winter grazing.

The swing bridge was a retrofitted barge that opened using a cable and pivot to allow both commercial and recreational vessels to pass. It required frequent maintenance and operators on duty around the clock. After considering the operating costs of approximately $350,000 per year and time delays for inhabitants and emergency vehicles, a decision was made to replace the bridge with a tall, fixed structure.

A new, visually unique bridge replaced the floating swing bridge. The new bridge was required to provide 73 ft of vertical

**A new, visually unique bridge replaced the floating swing bridge.**

A three-span segmental box girder bridge was used at the waterway. Photo: Dean Van Landuyt, TxDOT.

## profile

**GULF INTRACOASTAL WATERWAY BRIDGE** / MATAGORDA, TEXAS

**ENGINEER:** Texas Department of Transportation Bridge Division, Austin, Tex.

**CONSTRUCTION ENGINEERS:** Summit Engineering Group Inc., Littleton, Colo., and Frank W. Neal & Associates, Ft. Worth, Tex.

**PRIME CONTRACTOR:** Midwest Foundation Corporation, Tremont, Ill.

**CONCRETE SUPPLIER:** Alamo Concrete Products Ltd., Bay City, Tex.

**PRECASTER:** Texas Concrete Company, Victoria, Tex.

**SEGMENTAL FORMWORK SUPPLIER:** Mexpresa, Mexico City, Mexico

clearance for shipping. A long span was also needed in order to locate piers on land and away from possible vessel impact. Appearance was important. The new bridge would be the most imposing structure in this town of just 1400 people and would visually convey the community's mind-set toward visitors and the environment.

A haunched section and tapered V-hull soffit were used at the piers. Photo: Dean Van Landuyt, TxDOT.

## The Segmental Concrete Spans

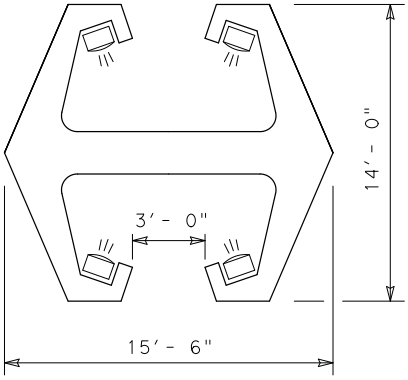
Cast-in-place concrete segmental spans were selected early in the design process for the center portion of the 3387-ft-long bridge. This type of structure was chosen because it can span the required 320 ft and is durable and aesthetically pleasing. With adjacent side spans of 180 ft, the 46-ft-wide segmental concrete box girder unit has a total length of 680 ft.

The large scale and tremendous force demands on the bridge, particularly during construction, required non-standard formwork. This gave the designer freedom to create unique shapes. Two primary artistic concerns were visually integrating the substructure and superstructure so they appear as a single unified element—something all-too-frequently absent from slab and beam bridges—and creating a column shape that could serve as an architectural beacon.

The idea began by altering the typical segmental box shape. The typical flat-bottom shape gradually gives way to a V-hull shape as the girder approaches the columns. The bevel is then carried directly into the columns with the same 3:7 bevel to form a perfectly mitered corner.

The main piers have a unique double-anchor shape that continues the heavily chamfered appearance of the superstructure. The tips of the anchors curl around to protect and hide light fixtures that illuminate an internal web. A 3-ft-wide opening between the tips is just wide enough for a man-lift to enter to allow for the installation and maintenance of the lighting system. With an overall longitudinal dimension of 15 ft 6 in. and with thick flanges, the pier had a large enough moment of inertia to meet the severe flexural demands of the unshored, balanced cantilever construction. The tips also provide enough area at the extreme lateral edges for the column to withstand 100 mph design winds in the transverse direction.

The superstructure details and construction method are, by contrast, rather conventional by segmental standards. A 27-ft 6-in.-long pier table segment with twin diaphragm walls crowns each of the main piers. Then, 15-ft-long segments, constructed one-half segment out of balance, were added until the ends of the cantilevers were within one full segment apart. Four top slab tendons are anchored in each segment to handle the cantilever stresses. Each tendon consists of fourteen 0.6-in.-diameter strands. Once the cantilevers were joined to form a continuous girder, bottom slab tendons




Cross section of the main piers in the segmental unit. Illustration: Dean Van Landuyt, TxDOT.

THREE-SPAN, CAST-IN-PLACE CONCRETE SEGMENTAL UNIT AND 19 APPROACH SPANS WITH PRECAST, PRESTRESSED CONCRETE I-GIRDERS / TXDOT, OWNER

**MAIN PIER FORMS:** DOKA USA, Tomball, Tex.

**POST-TENSIONING MATERIALS:** VSL, Grand Prairie, Tex.

**REINFORCEMENT SUPPLIER:** Katy Steel, Katy, Tex.

**BRIDGE DESCRIPTION:** 3387-ft-long and 46-ft-wide bridge consisting of a three-span 680-ft-long variable-depth, variable-soffit, cast-in-place box girder with a 320-ft-long main span and 19 spans of either 141-ft- or 145-ft-long, precast, prestressed concrete AASHTO Type VI girders

**BRIDGE CONSTRUCTION COST:** $16.0 million ($212/ft$^2$ for segmental box-girder spans and $75/ft$^2$ for I-girder spans)

Cross section of the pier segment.
Photo: Dean Van Landuyt, TxDOT.

**The approaches were quite long, resulting in 125,000 ft² of bridge deck area.**

consisting of eleven 0.6-in.-diameter strands were stressed to overcome future tensile stresses resulting from railing loads, live loads, and redistributed cantilever moments.

One unusual aspect of construction was the bottom soffit form. Flexible, rotatable "wings" mounted on a central spine allowed for a continuously changing bevel to be cast. In fact, the entire system was designed so that it could be warped. The back portion of the form was clamped to the underside of the previous segment while the leading edge, located 15 ft ahead, was opened to a wider angle.

## The Approach Spans

One of the difficult decisions that owners must face when planning segmental bridges that span navigable waterways on flat landscapes is the structure type used for the approaches. Obviously, large spans are not necessary and therefore more economical short-span, multigirder superstructures can be utilized. Since the change in roadway elevation from the abutment to the segmental portion is approximately 75 ft, the approaches were quite long—19 spans—resulting in 125,000 ft² of bridge deck area. In Texas, the differential costs between a segmental superstructure and a precast, prestressed girder superstructure is about $135/ft². Therefore the overall bridge cost could be reduced from $33 million to $16 million. The downside to this approach is aesthetics.

The transition from a segmental to a multigirder superstructure presents obvious visual discontinuity when viewed from below. Aside from placing ear walls on the bent cap to block the view of dark, cavernous openings between beams, little can be done to resolve the issue of dissimilar superstructure cross-sections. However, it was possible to improve another common architectural misstep—an abrupt section depth change to a shallow approach span. The overall slab and AASHTO Type VI girder depth for the 141-ft and 145-ft-long approach spans is 6 ft 9 in. Optimal depth for the thinnest portion of the segmental superstructure is about 8 ft; however, the Texas Department of Transportation (TxDOT) engineers were able to reduce the section to just 7 ft to make the depths appear nearly equal when viewed in profile.

## The Arrival of Hurricane Ike

Hurricane Ike entered the Gulf of Mexico after the construction of the first set of cantilevers, but before the back span closure segment was cast,. Then, 3 days before landfall, with Matagorda directly in line

Night-time lighting of the main piers.
Photo: Dean Van Landuyt, TxDOT.

The transition pier showing the ear walls to hide the ends of the precast, prestressed concrete beams.
Photo: Dean Van Landuyt, TxDOT.

with the projected path, the channel-side travelers were inadvertently removed. While somewhat mitigating the wind effects, it further unbalanced the longitudinal moment on the main pier. The bridge was left with a 160-ft-long cantilever supporting a 100-kip traveler and a 152.5-ft-long cantilever with no traveler. Immediately upon discovery, the channel-side cantilever was counter-weighted with timber mats and concrete blocks.

While the longitudinal moment was brought back within design limits, a larger issue remained. The first severe hurricane in 50 years was heading toward Matagorda and the bridge was in full cantilever, supported only by a column with minimal torsional strength. While meeting the *AASHTO LRFD Bridge Design Specifications* requirements for wind, engineers were concerned that an absence of unbalanced wind loading requirements in the specifications left the structure vulnerable.

An analysis of the structure based on eccentric wind loading conditions established by ASCE 7 revealed that the pier could experience torsional moments equal to about twice the cracking moment. A cable guying plan was enacted that would reduce torsion to nearly half the cracking moment. The end of the side span cantilever was secured to the ear walls cast on to the transition bent. Fortunately for the bridge, the hurricane turned north shortly before landfall, leaving the bridge on the "good side" of the storm. The maximum sustained 1 minute wind speeds were only 58 mph and the bridge suffered no damage.

## AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

"Having an attitude" is usually considered a negative. But, if designers want to accomplish something worthwhile, they have to "have an attitude" toward the features of their bridge. It's another way for saying that they have to have a vision of what they want to accomplish, not just for the technical features, but for the aesthetic features as well.

For girder bridges, and particularly for concrete box girder bridges, a key decision is the relationship of the pier to the girder. Does the designer want them to be seen as separate elements, with the girder floating above the pier? Or does the designer want them to be seen as a single monolithic shape, with the pier blending into the girder?

Actually, that decision should be made not on visual grounds, but on structural grounds. If the bridge is designed with bearings at the piers, then that fact should be evident, and the pier top should be attenuated to demonstrate the presence and role of the bearings. If the bridge is designed for the girder to act monolithically with the piers, the girder and piers should physically blend together. An excellent aesthetic result can be accomplished with either approach. Designs that fail aesthetically often do so because of an attempt to make one approach look like the other.

The box girder bridge at Matagorda is an excellent example of blending girder and piers together. The girder and pier are shaped similarly in a simple but sophisticated way. The planes of the girder soffit turn and become the planes of the pier shaft. The obvious similarities between the girder and the pier ensure that the bridge is perceived as a single integrated entity. At the same time the recess between the pier halves, perceived as a dark vertical line in the daytime and as a lighted vertical line at night, punctuate the bridge and give it an additional level of interest. All of this is accomplished with the shapes and sizes of the structural elements themselves, the elements that have to be there anyway. Nothing (except the lighting) is added solely for aesthetic effect.

## Lighting

Engineers wanted to produce a sliver of blue light on either side of the channel to make the bridge unique to Matagorda and recognizable by those using the waterway. After much consideration, including photometric studies, a series of individual induction florescent fixtures was located up the sides of each of the four openings. These fixtures were chosen because of their long life (more than 20 years) and light intensity. Unfortunately, they can only produce white light. There was a fear that because the lights were so bright and only located 4 ft from the center web, the light would reflect mostly white hot. However, this was not the case, helped in part by the shade of blue paint chosen.

The plans required that four large test panels of varying shades of blue temporarily be affixed before painting. A dark color was chosen for its ability to reflect a variegated light-blue/white fusion. The 46 fixtures and accompanying electrical materials cost $75,000—a small percentage of the $20 million project cost.

The bridge was opened to traffic in the summer of 2009 and the old swing bridge dismantled shortly thereafter. The frequent traffic stops that provided for the passage of barges and pleasure craft are now a thing of the past. The future of the town and peninsula will undoubtedly be influenced by the improved accessibility and distinctive architecture of the segmental bridge.

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*Dean Van Landuyt is a senior design engineer for the Bridge Division of the Texas Department of Transportation, Austin, Tex.*

**For more information on this or other projects, visit www.aspirebridge.org.**

The Jakway Park Bridge in Buchanan County, Iowa, features the second generation of the Pi-girder cross section made with ultra-high-performance concrete, shown here in the precaster's yard. At the bottom of the beam webs were 7-in.-deep by 1-ft-wide flanges. Each flange contained nine 0.6-in.-diameter strands tensioned to 72.6% of ultimate. Photos: Iowa Department of Transportation.

# FHWA, Iowa Optimize Pi Girder

by Brian Keierleber, Buchanan County, Dean Bierwagen, Iowa Department of Transportation, Terry Wipf, Iowa State University, and Ahmad Abu-Hawash, Iowa Department of Transportation

## Buchanan County constructs a bridge using ultra-high-performance concrete girders

The UHPC component was used in the center span.

The new Jakway Park Bridge in Buchanan County, Iowa, offers great potential for expanding the use of ultra-high-performance concrete (UHPC) in bridge girders and specifically in the new Pi (as in the Greek letter π) girder. By understanding the process used to create the second generation of this girder and leveraging its full capabilities, designers can take better advantage of the properties of this unique material and help reduce costs in future projects.

Officials in Buchanan County were granted funding through the TEA-21 Innovative Bridge Research and Construction Program (IBRC), managed by the Federal Highway Administration, to construct a highway bridge using an optimized Pi-girder section with UHPC. The design, using the second generation of the Pi-girder section, provides the first application of the Pi section for a highway bridge in the United States. The girders are pretensioned longitudinally and tied together transversely with mild reinforcing steel and steel diaphragms.

Developed in France during the 1990s, UHPC has seen limited use in North America. UHPC consists of fine sand, cement and silica fume, and quartz flour in a dense, low water-cementitious materials ratio (0.15) mix. Compressive cylinder strengths of 18,000 psi to 30,000 psi can be achieved, depending on the mixing and curing regimen. The material has extremely low permeability and high durability. To improve ductility, steel or fiberglass fibers (approximately 2% by volume) are added, replacing mild reinforcing steel. For this project, the patented mix Ductal,® developed by Lafarge North America, was used with steel fibers.

Iowa was first introduced to UHPC with a bridge project in Wapello County, which was completed in 2006. Wapello County was also granted funding through IBRC for that project. The UHPC mix was used in four Iowa bulb-tee beams that were modified to better utilize the mix. Beam performance was verified by flexure and shear tests on a 71-ft-long

## profile

**JAKWAY PARK BRIDGE** / BUCHANAN COUNTY, IOWA

**ENGINEER:** Iowa Department of Transportation, Ames, Iowa

**CONSULTING ENGINEERS:** Buchanan County Department of Engineering, Independence, Iowa; IIW Engineers & Surveyors P.C., Dubuque, Iowa; and Iowa State University Bridge Engineering Center, Ames, Iowa

***AWARDS:*** *Co-winner of PCI's 2009 Design Award for Best Bridge Project (up to 75 ft span); 2009 Iowa Quality Initiative Structures Research Merit Award from the Associated General Contractors of Iowa and the Iowa Department of Transportation*

prestressed bulb-tee beam tested by the Bridge Engineering Center at Iowa State University. Three 110-ft-long prestressed concrete bulb-tee beams were then used in a single-span, integral-abutment bridge-replacement project near Ottumwa, Iowa. (For more information on this project, see the Summer 2007 issue of *ASPIRE*.™)

## Five Beams Produced

Buchanan County and Iowa Department of Transportation (DOT) were given the opportunity to build on that UHPC experience with this project. The same UHPC mix was used to fabricate five optimized Pi girders: two 25-ft-long girders reserved for testing at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, Va., and three 51-ft-long girders used for the bridge construction.

The replacement bridge, 115 ft 4 in. long by 24 ft 9 in. wide, is located on a county road in a northeast section of Buchanan County over the east branch of Buffalo Creek. The UHPC component is the center span, 51 ft 2 in. from center-to-center of the pier caps. The 50-ft-long simple-span Pi sections are supported on plain neoprene bearing pads. The beam ends are encased in cast-in-place diaphragms with 3500 psi compressive strength concrete. End spans consist of traditionally reinforced cast-in-place concrete slabs with integral abutments supported on steel HP10x42 piles. The pier caps are supported on steel piles encased in concrete.

As a starting direction, the design team used the initial optimized (first generation) Pi shape, which was developed by the TFHRC and the Massachusetts Institute of Technology. It was created to optimize the UHPC mix by minimizing the cross section and taking advantage of the material properties for the bridge deck. Testing of the section by TFHRC had revealed overstresses in the transverse capacity of the deck and a low transverse live load distribution between adjacent Pi sections. These two issues were the biggest design challenges for the project and suggested that improvements to the initial Pi-girder section would need to be made.

## Testing Leads to Improvements

Load testing at TFHRC showed that the 3-in.-thick deck under service load did not have the strength to meet the design specifications for a 12.5-kip tandem or single 16-kip wheel load with 33% impact included. Improvements to the section were investigated by the Iowa DOT and Iowa State University and included finite element analysis of the different modifications. Improvements to the first-generation Pi section were initially investigated, with the intention of reusing or modifying the existing forms.

Several design options were considered for strengthening the deck. These included increasing the deck thickness with or without reinforcement, adding ribs under the deck with or without mild reinforcement or post-tensioning, and thickening the deck with or without reinforcement. After review, it was decided to use a uniform 4-in.-thick deck with transverse post-tensioning. This kept the changes as simple as possible and attempted to keep the cost of modifying the beam forms within budget limits.

The connection detail that was used in the initial test consisted of a grouted keyway with horizontal tie bolts provided at 3-ft spacing. To improve load distribution and help stiffen the section, two adjustments were made. Steel diaphragms were added at the quarter-span points across the bottom flange, and grouted, pockets containing No. 8 reinforcing tie bars were provided at 18-in. spacing.

The precaster cast two 25-ft-long beams for testing purposes by the FHWA, followed by three 51-ft-long production beams.

**Ready-mix concrete trucks were used to provide the mixing required to achieve 21,500 psi compressive strength.**

THREE-SPAN CONCRETE BRIDGE WITH A CENTER SPAN CONSISTING OF THREE ULTRA-HIGH-PERFORMANCE CONCRETE, PI-SHAPED GIRDERS / BUCHANAN COUNTY, OWNER

**PRIME CONTRACTOR:** Taylor Construction Inc., New Vienna, Iowa

**UHPC PRECASTER:** LaFarge North America, Winnipeg, Manitoba, Canada, a PCI-certified producer

**BRIDGE DESCRIPTION:** 115-ft 4-in.-long by 24-ft 9-in.-wide, three-span concrete bridge with a 51-ft 4-in.-long center span using Pi girders

**BRIDGE CONSTRUCTION COST:** $600,000

The 50-ft simple-span Pi girders are supported on plain neoprene bearing pads.

Due to the high costs of upgrading and modifying the forms, the sole fabricator interested in casting the modified Pi sections delivered a bid that was too high for the budget. FHWA officials at TFHRC suggested that further revisions be made to the first-generation section and new forms be created for a second-generation Pi girder. The FHWA agreed to fund the forms and purchase two test beams for evaluation. The three production beams would be purchased at the same time to reduce setup and casting costs for all of the beams. In addition, the revised section would be available for use on future projects by other state agencies.

This approach was taken, leading to four key revisions being made to the first-generation section:

1. Two types of fillets, 5 in. and 8 in. deep, were added at the web-to-deck connection to improve concrete flow during placement and to stiffen the slab section.
2. The interior deck thickness between the webs was increased to 4⅛ in. to reduce service load stresses.
3. The web spacing was reduced by 4 in. to provide a more balanced spacing of the webs for the three-beam cross section and to reduce service load stresses.
4. The post-tensioning was removed from the deck. Due to the lack of test data on the revised section, No. 5 reinforcing bars at 1-ft centers were included in the deck.

Two 25-ft-long test beams were cast first, followed by three 51-ft-long production beams. The three bridge beams were 8 ft 4 in. wide and 2 ft 9 in. deep with two tapered webs about 3 in. thick spaced at 4 ft 5 in. Deck thickness was a constant 4⅛ in. between the webs and a tapered thickness outside the webs from 6⅞ in. to 5¼ in. at the edge of the slab. Flanges at the bottom of the beam webs were 7 in. deep by 1 ft wide. Each flange contained nine 0.6-in.-diameter strands tensioned to 72.6% of ultimate. Total concrete quantity was 11.3 $yd^3$ of UHPC per unit.

## Ready-Mixed Concrete Trucks Used

Typically, high-speed pan mixers are used because of the large amount of time and energy needed to thoroughly mix the concrete. In this case, ready-mixed concrete trucks were used for mixing the required 21,500 psi design compressive strength. As the material's performance is affected by the alignment of the steel fibers, a horizontal bucket almost as wide as the form was fabricated to place the material so it would flow freely along the form and properly align the fibers.

The beams were cured in two stages. The first stage involved curing at ambient temperatures, although steam curing up to 115 °F could be used in a similar manner to curing precast, prestressed concrete beams. The Pi girders were covered with plastic and kept at ambient temperatures until match-cured cylinders indicated a compressive strength of 5100 psi had been achieved. Then the forms were opened but left in place to allow for shrinkage of the section. Curing at ambient temperatures continued until the compressive strength of match-cured cylinders reached 14,500 psi. The forms then were removed and the strands were detensioned.

The second curing stage began with thermal treatment applied to the UHPC beams with moisture present. The goal was to achieve a temperature of about 190 °F along with relative humidity of at least 95% for at least 48 hours. Thermal treatments have been shown to enhance not only the members' strength but their durability as well. The beams were wrapped with insulating tarps, and steam was injected underneath the girders. The temperature was increased gradually over a period of approximately 6 hours. Once the second curing period was completed, the curing temperature was decreased gradually over a period of approximately 6 hours.

The beams were fabricated in September 2008, while the contractor began mobilization, grading, and substructure work. The beams were erected in mid-October, and the concrete for the end spans was placed a few weeks later. The project was completed in November, requiring 52 days from start to finish.

## Waffle Slab Project

Work with UHPC continues, with a third bridge project now under development with Coreslab Structures (Omaha) in Bellevue, Neb., for use in Wapello County, Iowa. This project will use the UHPC mix in a precast concrete deck on a single-span, prestressed concrete beam bridge. To optimize the material, the deck panels will be cast with a waffle shape. Component casting is scheduled to begin in the winter of 2009-2010, with construction to take place in the summer of 2010.

By using UHPC in bulb-tee beams, the optimized pi girder, and a waffle-shaped deck panel, the project team will expand the knowledge base and facilitate the wider use of advanced cementitious materials to solve specific transportation challenges.

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*Brian Keierleber, is county engineer for Buchanan County, Independence, Iowa; Dean Bierwagen, and Ahmad Abu-Hawash, are with the Office of Bridges & Structures of the Iowa DOT in Ames, Iowa; and Terry Wipf, is director of the Bridge Engineering Center at Iowa State University in Ames, Iowa.*

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# SEQUENCED ARCH

by Craig A. Shutt

The Humpback Bridge on the George Washington Parkway near Washington, D.C., is being replaced with a precast concrete arch design that replicates the look of the original, including using some of the original stonework in the fascia. Photo: Cianbro Corp.

## Five-stage process keeps traffic moving during construction of precast concrete segmental arch bridge near nation's capital

Replacing the existing Humpback Bridge over the Boundary Channel on the George Washington Parkway near Washington, D.C., with a wider bridge will create efficiency and functionality, but it poses significant challenges. In addition to providing an appearance that replicates the original stone-faced arch, the work must progress with site restraints caused primarily by the need to keep two lanes of traffic open in each direction during construction.

The previous bridge consisted of a stone-faced, cast-in-place concrete arch. The 73-ft-wide structure accommodated two northbound and two southbound lanes, separated by a 4-ft median. The Mount Vernon Trail, approximately 6 ft wide, runs adjacent to the northbound lanes, with a similarly sized pedestrian walkway adjacent to the southbound lanes. Officials required the new design to incorporate features and styles of the original historic appearance while also ensuring that pedestrian traffic was segregated from vehicles. They also mandated traffic continuity during reconstruction, requiring a systematic sequencing that allowed for construction of only a few girder lines at a time.

### Construction Progressing

Designers planned the new single-span bridge to reflect the arched design and stone facing of the original bridge. The new bridge comprises segmental precast concrete girders erected as half-arches, which are joined together with a cast-in-place concrete closure. The structure, to be completed in late 2010, is 244-ft long and includes underpasses at each end to aid access for pedestrians, including access to the hiking trail. The span over the channel consists of seven match-cast segments in each half-arch component, with 11 girder lines comprising the entire width for a total of 154 girder segments. A 9-in.-thick, cast-in-place high-performance concrete deck is placed for the riding surface after construction of the arches.

profile

**HUMPBACK BRIDGE OVER THE BOUNDARY CHANNEL** / VIRGINIA

**ENGINEER:** Eastern Federal Lands Highway Division of the Federal Highway Administration, Sterling, Va.

**CONSULTING ENGINEER:** URS Corp., Washington, D.C.

**CONSULTING EXPERT:** National Park Service, Washington, D.C.

**PRIME CONTRACTOR:** Cianbro Corp., Pittsfield, Maine

**PRECASTER:** Northeast Prestressed Products LLC, Cressona, Pa., a PCI-certified producer

The project adds an acceleration lane that facilitates access from southbound I-395 onto the northbound lanes of the parkway. The added width, however, is being provided on the opposite side of the bridge, with all lanes moving over, explains Doug Nair, construction operations engineer for the Eastern Federal Lands Highway Division of the Federal Highway Administration (FHWA). It also is adjusting the grade of the road to improve sight lines, as the current sight distances over the bridge are too short as cars approach. This has resulted in frequent accidents when cars come over the rise and need to stop in a short distance.

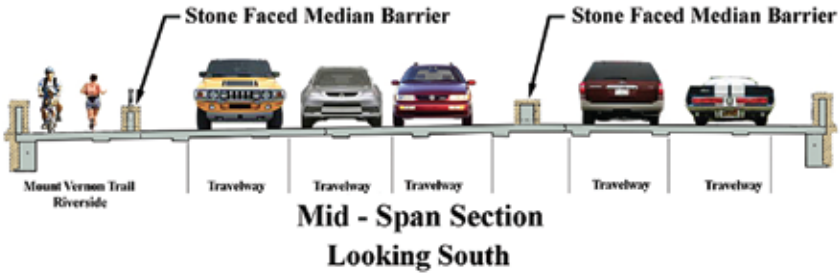
Because the precast concrete arches required a depth of 20 ft, they were cast horizontally, with all seven segments for each half-arch cast in one setup. Photo: Northeast Prestressed Products LLC.

**The precast concrete segmental design minimized site construction, aiding traffic flow.**

To replicate the look of the original cast-in-place concrete arch bridge, designers chose to use a precast concrete segmental structure, as it minimized the need for site construction, aiding traffic flow, Nair says. It also allowed the existing stonework on the structure to be saved and replaced after construction. The FHWA consulted with the engineering firm of URS Corp. and the National Park Service to achieve the final design.

In addition to the aesthetic needs, designers wanted to ensure the bridge retained a low profile while still providing the necessary clearance over the channel. The bridge is located on the parkway near the Lincoln Memorial, and officials didn't want the structure to interfere with views, explains Hong Chen, FHWA structural engineer. "The low-profile, one-span precast concrete design helped ensure we met those goals." However, the design also needed to retain the existing clearance, as recreational boats use the boundary channel to reach the Potomac River from the Columbia Island marina located north of the site.

The substructure on each side of the arch consists of a 96-in.-deep pier cap supported by four 72-in.-diameter drilled shafts, each approximately 100 ft deep.




The new bridge separates vehicles on one side from pedestrian traffic on the Mount Vernon Trail on the other side. Illustration: FHWA.

## Arches Match Cast on Their Side

Casting each half-arch component created challenges, according to Troy Jenkins, chief engineer at Northeast Prestressed Products LLC. "The original assumption was that the beams would be cast vertically, in the position in which they'd be installed," he says. But some of the pieces near the piers required 20-ft depths, which could not be cast efficiently in that position. The casting also was complicated by the need to match cast each segment to ensure alignment with its adjacent segment.

The arch pieces were cast in a horizontal position, with all seven segments for each half-arch cast in one setup. The segments were cast in a sequence of sections 1, 3, 5, and 7, after which forms were removed and the segments were used to form the intervening segments (2, 4, and 6) to ensure the match cast. A complete half-arch was cast in less than 1 week, Jenkins says. "The arches were a challenge, but match casting them removed any issues that would have arisen," he notes. "That was an excellent approach to use on a project like this."

Some of the pieces also needed to have close attention paid to so that lifting devices were properly located to ensure their center

SINGLE SPAN, PRECAST CONCRETE SEGMENTAL ARCH BRIDGE / NATIONAL PARK SERVICE, OWNER

**POST-TENSIONING CONSULTANT:** Lawrie & Associates LLC, Alexandria, Va.

**POST-TENSIONING MATERIAL SUPPLIER:** Dywidag-Systems International, Bolingbrook, Ill.

**BRIDGE DESCRIPTION:** 244-ft-long bridge with an underpass for pedestrian use on each end and an arch span consisting of 11 girder lines with 14 precast segments each and a cast-in-place closure

**BRIDGE COST:** $35 million

The diaphragms between beam lines used epoxy-coated reinforcement. Photo: Cianbro Corp.

of gravity remained balanced when they were erected, he notes. The lifting inserts were located in the sides of the pieces to make it easier to align the match-cast joints. This was critical because the pieces were particularly small segments, which made them awkward to handle, says Mike Manoski, senior project engineer at Cianbro Corp. Careful attention was given to rigging to ensure no handling problems arose.

The components were cast and transported to the site on an as-needed basis, where they were briefly stored until assembled during erection. The site provided key challenges due to the restraints and ongoing traffic. "Access was really tight," says Manoski. "There was not a lot of real estate to work in due to lane closures and maintaining vehicular and public access throughout the project."

According to Manoski, each half girder line has seven segments. A cast-in-place concrete closure piece ties the two half-arches together. Three segments of the seven sit on the 96-in.-deep pier cap, one segment cantilevers off the back of the pier cap, and three segments cantilever over the water. During Phase two construction, for example, in which four beam lines were set, three segments were erected for each beam line over the pier cap, and then temporary post-tensioning was applied. The beam lines then were locked together with a cast-in-place diaphragm. Then the segments that cantilever off the back of the pier caps were erected, post-tensioned with the previous segments, and another diaphragm was cast. Then three more segments in each beam were placed over the water before the final cast-in-place closure segments and diaphragms were added, completing four entire beam lines.

The initial precast arch-beam segments are shown being erected on top of the 8-ft-deep pier caps that rest on four 72-in.-diameter drilled shafts, each approximately 100 ft in depth. Photo: Cianbro Corp.

**The project was broken into five phases of work to allow pedestrian access and two lanes of traffic to flow during construction.**

A key challenge arose in coating the match-cast faces of the segments to protect against water penetration. An epoxy bonding agent is applied to act as a waterproof joint sealant, Manoski explains. Due to the product specifications, the crews had approximately 60 minutes from the time the epoxy is mixed until the pieces were set to the proper elevation and alignment.

## Five Phases Keeps Traffic Moving

To ensure two lanes of traffic would flow in each direction at all times, and to retain accessibility to the Mount Vernon Trail, the construction team had to break the project into five phases, explains Nair. "If we had been able to close down to one lane in each direction, we could have eliminated stages and accelerated the work," he notes. But the user costs and time delays caused by the restriction on this busy artery near the nation's capital would have been too great.

The first phase of work focused on removing the median in the center of the bridge and shifting the southbound traffic to the east to open up two girder lines on the west side. Phase two involved demolishing the outside existing two girders lines on the west side and adding two additional lanes, creating four lines of new girders in this phase.

Phase three, which was completed during fall 2009, shifted southbound traffic onto the new lanes, while northbound traffic remained on the east side. This allowed for the demolition of three girder lines in the center section and rebuilding with new arch components. With traffic on both sides, this work necessitates that construction take place within a 26-ft-wide area, Manoski notes, requiring close attention to detail and careful maneuvering.

Phase four, following in 2010, will shift northbound traffic onto the center girder lines so the four remaining girder lines on the east side can be rebuilt. When this work is completed, the final phase will shift traffic back into the proper lanes, and a median wall will be built down the center. The median wall will be taller than the original, but it will be thinner as well to avoid adding unnecessary load to the bridge.

Formwork being constructed for the cast-in-place concrete deck placement. Photo: Cianbro Corp.

## Original Stonework Replaced

To provide the stone facing on each side of the bridge, the original stonework was saved where possible, and new stone that matched the existing pieces closely was located. This saved considerable cost and allowed the new bridge to maintain a connection to its past. The precaster cast these final four segments with the fascia side down, to better control placement of dovetail slots in the faces. Galvanized-steel connectors were used to attach the stone to the dovetail slots in the precast panels.

The work is proceeding on schedule and is planned for completion in late 2010, Nair reports. Once completed, Washingtonians not only will have an attractive arched bridge similar in looks to the original, but they will experience a smoother, faster, and safer trip.

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# NEVADA'S GALENA CREEK BRIDGE

by Brad F. Durski, Nevada Department of Transportation

**A context-sensitive solution that will be the world's largest concrete cathedral-arch bridge**

## profile

**GALENA CREEK BRIDGE** / RENO, NEVADA

**BRIDGE DESIGN ENGINEER:** Nevada Department of Transportation, Carson City, Nev.

**PROJECT ENGINEER OF RECORD:** CH2M Hill, Englewood, Colo.

**INITIAL (2003) CONTRACTOR:** Edward Kramer & Sons, Castle Rock, Colo.

**COMPLETION (2007) CONTRACTOR:** C.C. Myers Inc., Rancho Cordova, Calif.

**PROJECT GENERAL CONTRACTOR:** Fisher Industries, Phoenix, Ariz.

The Galena Creek Bridge near Reno, Nev., will be the world's largest concrete cathedral-arch bridge when completed in 2011. A cathedral arch supports the bridge only at the crown; there are no intermediate spandrel columns. The bridge, in turn, is part of the state's largest ever transportation project, the $450-million, 8.5-mile-long I-580 Freeway Extension that will help connect Reno and Carson City with an improved freeway system. During construction, however, the contractor requested a change in construction plan, moving from the original steel pilot-truss design to a cast-in-place concrete alternative.

The structure serves as the centerpiece on a project that includes eight other cast-in-place concrete box girder bridges. It will complete highway improvements that the Nevada Department of Transportation (NDOT) has been planning for several decades to raise I-580 to full interstate highway standards for its entire length within the state. This segment extends the freeway from the Mt. Rose Highway to the Bowers Mansion cutoff in the Northern Washoe Valley.

The existing highway is under great strain because of increased commuter traffic and development in the area. The freeway extension will provide a safer and more efficient route to serve growing traffic needs. However, the area presents a number of challenges because of its rugged terrain and occasional high winds.

## Four Goals Established

Four key goals were set out for the project when the plan was developed and put out for bid in 2003:

1. Select a bridge type that will function efficiently as potentially the longest and highest bridge in Nevada.
2. Develop a design that blends with the terrain, minimizes impacts and is aesthetically pleasing, working with local stakeholders to ensure the design fits the community's needs.
3. Optimize alignment that balances earthwork, addresses geotechnical challenges, reduces visual and noise impacts, meets geometric freeway standards, and avoids significant impacts to wildlife and vegetation.
4. Incorporate maintenance and operational requirements, specifically addressing snow removal, bridge and roadway de-icing, drainage and incident management.

The freeway project was designed by CH2M Hill of Englewood, Colo., while the design for the Galena Creek Bridge was done by NDOT, the only portion of the project designed in-house. The initial contract for the Galena Creek Bridge, along with construction of a second bridge on the project and related improvements, was awarded to Edward Kramer & Sons (EKS) in Castle Rock, Colo. Initially, the

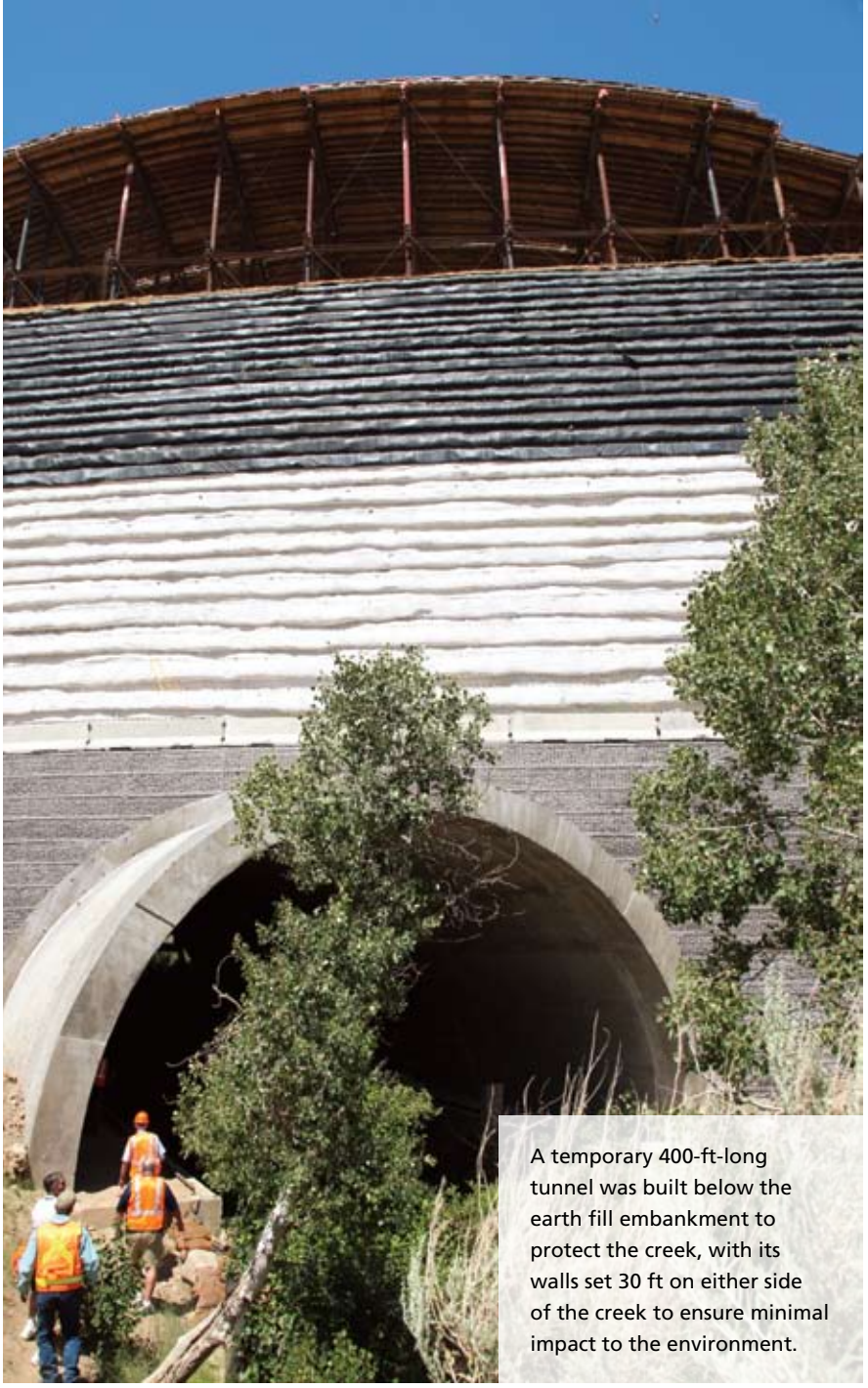
To use traditional falsework for the bridge, about 523,000 yd$^3$ of earth cut from the nearby embankment were used to raise the grade 140 ft over the creek. The fill measures approximately 385 ft wide at the base and tapers to approximately 210 ft wide at the top. Photos: Julie Duewel, NDOT. Rendering: CH2M Hill.

TWIN, 1725-FT-LONG, CAST-IN-PLACE, CONVENTIONALLY REINFORCED CONCRETE BOX-GIRDER BRIDGES WITH A CATHEDRAL ARCH HAVING A 689-FT ARCHED MAIN SPAN / NEVADA DEPARTMENT OF TRANSPORTATION, OWNER

**POST-TENSIONING CONTRACTOR:** AVAR Construction Systems Inc., Fremont, Calif.

**REINFORCING STEEL SUPPLIER:** Pacific Coast Steel, Henderson, Nev.

**CONSTRUCTION COST:** Total project: $450 million; Galena Creek Bridge cost: $80 million (plus $53 million cost for initial contract)



A temporary 400-ft-long tunnel was built below the earth fill embankment to protect the creek, with its walls set 30 ft on either side of the creek to ensure minimal impact to the environment.

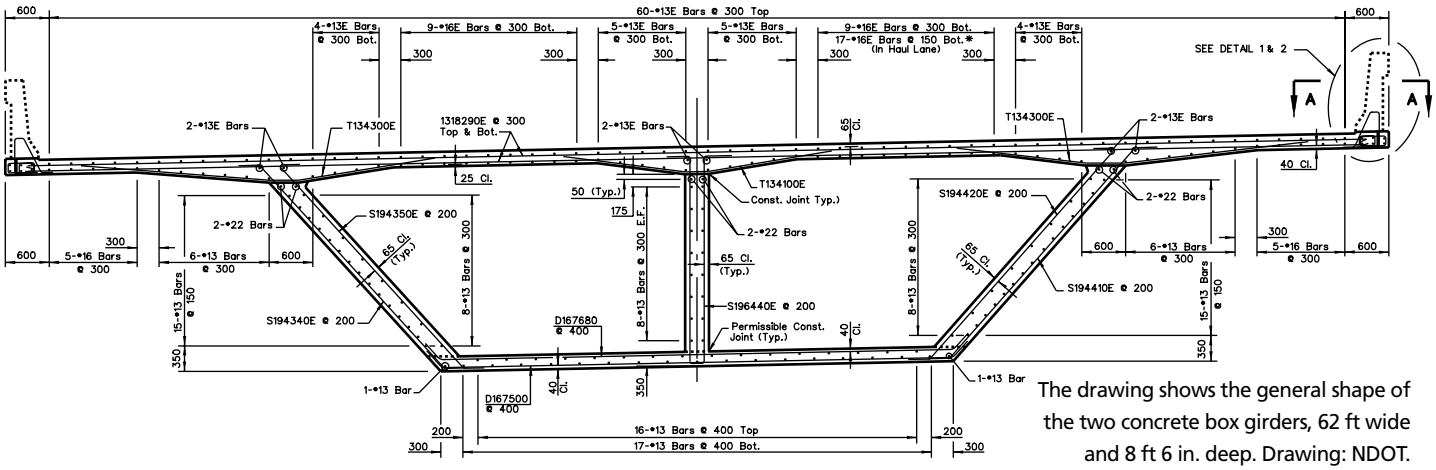
bridge was to be built using a pilot truss. However, when the project was about 40% complete, EKS and NDOT reached an agreement not to proceed. NDOT then repackaged the remaining work of finishing the bridge into a new contract.

## New Concept Developed

Fisher Industries won the rebid and worked with subcontractor C.C. Myers Inc. in Rancho Cordova, Calif., to evaluate options. They proposed using another construction alternative, with conventionally reinforced, two-cell concrete box girders and cast-in-place concrete arches. The arches and columns are hollow to allow access during inspections. This approach did not change the bridge geometry, only some of the materials used within it. To adjust to a cast-in-place concrete design, reinforcing bars were added and additional concrete was required, but no major redesign work was needed.

The Galena Creek Bridge, now under construction, consists of two parallel cast-in-place concrete arches with a span of 689 ft. Each arch has a width of 19.7 ft and a depth of 11.8 ft. The wall thickness is 1.6 ft. The arches are supported on thrust blocks founded on bedrock. Each arch supports a cast-in-place conventionally reinforced, two cell box girder, 62 ft wide and 8 ft 6 in. deep. Each box girder will carry three lanes of traffic. The columns have overall cross sectional dimensions of 19.7 ft by 9.8 ft with a wall thickness is 3.25 ft. These columns are supported by footings on piles.

This approach required the use of traditional falsework, which was placed on




The drawing shows the general shape of the two concrete box girders, 62 ft wide and 8 ft 6 in. deep. Drawing: NDOT.

After removal of the falsework under the arch, construction continues on the cast-in-place, conventionally reinforced concrete box girders.

**The structure serves as the centerpiece on a project that includes eight other cast-in-place bridges.**

a foundation created by filling the creek bed. About 523,000 $yd^3$ of earth cut from the nearby embankment were used to raise the level 140 ft. The fill measures approximately 385 ft wide at the base and tapers to approximately 210 ft wide at the top. A temporary 400-ft-long tunnel was built to protect the creek, with its walls set 30 ft on either side of the creek to ensure no impact to the environment. The new approach required a four-month approval process, and work then began again in early 2007 to finish construction. The earthen fill will be removed and vegetation restored after the bridge is complete.

Epoxy-coated reinforcement was used throughout the bridge, including the barrier rails, due to the large amount of deicing salts used to keep the bridge accessible through the winter.

Fisher Industries built a concrete batch plant along the north side of the project and is using aggregate mined from along the highway's route to save costs and speed construction. All concrete in the project included fly ash while the concrete in the deck also used silica fume. The specified concrete compressive strength for the abutments, wingwalls, thrust blocks, footings, and columns was 4060 psi. The specified strength of the concrete for the bottom slabs, diaphragms, webs, approach slabs, barrier rails, and decks was 4500 psi. Adjacent to the arch span, at piers 2 and 3, the specified concrete compressive strength for the bottom slabs and webs was 5800 psi.

The second bridge arch was constructed faster than the first one as the crew has gained experience with placing concrete on a large vertical curve. The amount of falsework needed to create the arch is impressive and complicated, but it proved to be fairly conventional in its design.

To lower the formwork for the arch, the contractor used 12 strand jacks with a capacity of 85 tons each rather than cables and winches. The strand jacks, costing $1.2 million, were computer controlled to ensure synchronization during lowering. The jacks were protected by steel enclosures.

Some minor patching and finishing of the existing columns, built several years earlier, were required prior to restarting construction. Following the completion of each arch, the box girders were cast-in-place using formwork and falsework supported by the arches. The box girders are connected integrally with the arch at the crown.

To date, the project is ahead of schedule, with all work planned for completion and the roadway expected to be opened to traffic in fall 2011 and perhaps sooner. The result will be an attractive and efficient bridge that serves the community and provides a distinctive, landmark look.

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*Brad F. Durski is the senior resident engineer with the Nevada Department of Transportation in Reno, Nev.*

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## *Public Involvement*

The arched design of the project resulted from NDOT implementing a Context Sensitive Solution format early in the process. This involved an integrated public-outreach plan to solicit public involvement and communicate openly with stakeholders about the design concept. During the final design, NDOT received integrated-stakeholder input for the proposed roadway alignments and bridge designs, to develop a project that blended with the terrain, minimized environmental impact and had community support. It also had to maintain safety and mobility.

The Galena Creek Bridge project has generated a tremendous amount of public interest. The communities impacted by the freeway extension have historically proven to be highly active and involved in the project from its start. Recognizing this, NDOT's multifaceted public-involvement program included the Stakeholder Working Group to keep everyone directly involved. Formed in 1998, the group met monthly to discuss design considerations, including noise and dust. Since 1999, the group has met every 6 months, and that will continue while construction is underway.

# **BRIDGE DESIGN** BREAKS PAR

by Tony Sanchez, T.Y. Lin International

**Golf course's cast-in-place pedestrian bridge offers clean look that complements the clubhouse**

Bridges provide connectivity to people and communities. The College Boulevard Golf Cart Bridge in Carlsbad, Calif., achieves these goals by connecting two portions of the city's new golf course in a clean, aesthetically pleasing way that ensured no disruption to traffic below during the bridge's construction. The project's attention to detail has won it two awards from local professional groups, as well as many admirers in the community.

The Crossings at Carlsbad golf course was created by the city to provide citizens with a state-of-the-art, 18-hole championship golf course. The bridge was needed to gracefully span College Boulevard while accommodating golf carts and foot traffic. City officials wanted to create an attractive design that complemented the course's stone-faced clubhouse while providing functional transportation needs and ensuring sufficient clearance above the arterial street.

A gently curving approach and stone veneer applied to the wing walls created an inviting and pleasing design for the cast-in-place concrete pedestrian bridge at the Crossings at Carlsbad golf course in Carlsbad, Calif. Photos: T.Y. Lin International.

## profile

**COLLEGE BOULEVARD GOLF CART BRIDGE** / CARLSBAD, CALIFORNIA

**ENGINEER:** T.Y. Lin International, San Diego, Calif.

**TESTING CONSULTANT:** Dudek & Associates, San Marcos, Calif.

**PRIME CONTRACTOR:** Hazard Construction Co., San Diego, Calif.

**CONCRETE SUPPLIER:** Palomar Transit Mix, Escondido, Calif.

***AWARDS:*** *2008 Best Pedestrian Bridge, American Concrete Institute, San Diego chapter; 2008 Honor Award, American Public Works Association, San Diego chapter.*

A variety of methods and materials were investigated before the design was finalized. The 199-ft-long College Boulevard Golf Cart Bridge features a clear width of 15 ft, with two 38-ft-long approach spans and a 123-ft-long main span. T.Y. Lin International performed all bridge engineering, including advance-planning studies; type selection; detailed design; final plans, specifications, and estimates (PS&E); and construction-support services.

All of the bridge components were constructed from cast-in-place concrete, totaling about 400 yd.$^3$ ASTM A706 Grade 60 reinforcing bars were used in the concrete, along with prestressing strand. The superstructure for the main span consists of a single-cell box girder that was cast-in-place and then post-tensioned. A 4500 psi compressive strength concrete mix was used for the main span.

The bridge's deck, curbs, and parapet were all constructed of cast-in-place concrete.

**Cast-in-place, post-tensioned concrete provided a clear span that eliminated the need for a pier in the street median.**

## Multiple Concepts Considered

Several options were examined before deciding on this approach. Cast-in-place, post-tensioned concrete provided the capability for a clear span that ensured there would be no pier in the street median. This was an important goal for city officials, as they wanted a clean look that provided safety for drivers. This also eliminated construction in the street that could have caused disruptions or imperiled worker and user safety during the project. Precast concrete was considered, but contractors in California determined it was more economical to produce the required components with cast-in-place concrete.

The bridge was originally designed in 2000, but construction was delayed while the city obtained a coastal permit, which required changes to the golf course. These changes did not affect the bridge's location or design. The bridge is located at the beginning of the course, between holes 1 and 2. It connects the course's west and east portions, which are separated by College Boulevard.

The cast-in-place concrete design provided an additional benefit when the bridge ultimately was constructed. During the planning stages, it had been anticipated that the bridge might need to carry at least one significant water line. However, due to the extended delay prior to construction, the final design and PS&E documents were completed without complete knowledge of utility requirements. The designers knew that the cast-in-place concrete box-girder design could accommodate these utilities if needed.

## Water-Line Addition Creates Changes

This foresight paid off, as two water lines were installed in the bridge during construction. Although the depth for a pedestrian structure of this span length could have been reduced to about 4 ft, the designers intentionally used a 5-ft-deep box girder to facilitate installation of the anticipated water lines and supports. The added space also will provide easier access for maintenance personnel.

The extra depth accommodates pressure-relief hardware required since the profile places the high point of the water lines at midspan of the bridge. Other features that were anticipated included access through the bridge deck, which are required to access the utilities, and soffit openings under the bridge, which is needed to drain the bridge void in case a water line ruptures.

In addition to this change, a code upgrade undertaken between the time of the design and the time of construction, tightened vibration

CAST-IN-PLACE, POST-TENSIONED CONCRETE BOX GIRDER PEDESTRIAN BRIDGE / CITY OF CARLSBAD, OWNER

**REINFORCING BAR SUPPLIER:** CMC Fontana Steel, Etiwanda, Calif.

**POST-TENSIONING CONTRACTOR:** DSI, Long Beach, Calif.

**BRIDGE DESCRIPTION:** Golf-course bridge 123 ft long and 15 ft wide featuring a single-span post-tensioned concrete box girder, plus two 38-ft-long slab approach spans

**BRIDGE CONSTRUCTION COST:** $1.180 million

To avoid backfilling soil against the 25-ft-high abutments, designers created bin-type abutments that would remain empty, significantly reducing earth pressures and overturning forces, which saved considerable cost by allowing smaller foundations.

guidelines for bridges of this type. This necessitated a vibration analysis to ensure that the bridge would meet the new requirements. The design passed the analysis and did not need any adjustments to meet the revised code.

Foundations on the west side consist of 6000 psi compressive strength precast, prestressed concrete piles, while the foundations to the east comprise 4000-psi compressive strength cast-in-place concrete spread footings. Abutments and parapets were constructed from 4000 psi cast-in-place concrete as well.

## Innovative Abutments Designed

An innovative approach was used to create the abutments and provide an economical and attractive design. Vertical clearance requirements for the arterial street required abutment heights of about 25 ft. To resist overturning forces from 25 ft of soil behind conventional back-filled abutments would have resulted in extensive and costly pile-supported foundations for both abutments and wing walls.

A more efficient and economical solution took advantage of the narrow width of the pedestrian bridge and used special transverse, hollow bin-type abutments. This design, popular in the 1940s and 1950s before prestressed concrete allowed longer span lengths, consists of a reinforced concrete slab that spans 15 ft transversely between the wing walls. Since the void behind the abutment is not backfilled with soil but remains empty, the large earth pressure and overturning forces that this would have created are avoided. This design allowed the abutments to be supported on smaller foundations, greatly reducing the cost and creating substantial savings for the city.

To tie the bridge's aesthetic design to the design created for the course's clubhouse, stone-veneer was applied to the 1-ft-thick sides of the abutments and wing walls. The stone veneer, which was applied similarly to tile, created a textured appearance for the walls. Colored concrete caps and curbs were installed to complement the veneered approaches.

The veneer installation provided a challenge because the panels had to fit the curved walls. The curve had been necessary due to the grading and pathways laid out for the course, but this functional requirement produced an aesthetically pleasing curvature as golfers approach the structure.

The project met its goals in providing a pleasing and functional addition to the community. This was apparent when it won local awards, which singled out its clean lines, aesthetically pleasing textures, and changing shadows due to overhangs on the exterior girders.

Concrete's economy, durability, and ability to easily conform to the bridge's curves and shape were fundamental to the success of this important component of the golf course. Careful planning, design, attention to detail, and anticipation of future needs resulted in a functional and beautiful bridge that was economical to construct and easy to maintain.

Construction could be handled from the central median on the road below the bridge, avoiding major disruptions to on-going traffic flow.

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*Tony Sanchez is a senior bridge engineer with T.Y. Lin International in San Diego, Calif.*

**For more information on this or other projects, visit www.aspirebridge.org.**

# 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.eiolca.net**
This Carnegie-Mellon University website contains the Economic Input-Output Life Cycle Assessment (EIO-LCA) mentioned in the Perspective on page 13.

**www.wbdg.org/tools/cwm.php**
Visit this National Institute of Building Sciences website for the Construction Waste Management Database referenced in the Perspective on page 14. Created in 2002 by the U.S. General Services Administration to promote responsible waste disposal, the database is a free online service for those seeking companies that recycle construction debris in their geographic location. The database is searchable by material and zip code.

**www.international.fhwa.dot.gov**
Go to this website and click on "Publications" for scanning tour reports mentioned in the Safety and Serviceability article on page 50.

## 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.

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

## Bridge Technology

**www.aspirebridge.org**
Previous issues of *ASPIRE*™ are available as pdf files and may be downloaded as a full issue or individual articles. Information is available about subscriptions, advertising, and sponsors. You may also complete a reader survey to provide us with your impressions about *ASPIRE*. It takes less than 5 minutes to complete.

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

**www.hpcbridgeviews.org**
This website contains 58 issues of *HPC Bridge Views*, an electronic newsletter published jointly by the FHWA and the National Concrete Bridge Council (NCBC) to provide relevant, reliable information on all aspects of high-performance concrete in bridges. Sign up at this website for a free subscription.

**www.fhwa.dot.gov/pavement/concrete/asr.cfm**
This new online Alkali-Silica Reactivity Reference Center provides users with one-stop access to ASR-related information. The site features an overview of ASR, as well as research reports, specifications, guidance documents, case studies, and links to other useful websites. The FHWA report titled *Report on Determining Reactivity of Concrete Aggregate and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction* may be accessed and downloaded from this website.

**NEW http://www.wes.army.mil/SL/MTC/handbook/crd_c662.pdf**
A new test method, CRD-C 662-09, titled *Test Method for Determining the Alkali-Silica Reactivity of Combinations of Cementitious Materials, Lithium Nitrate Admixture and Aggregate (Accelerated Mortar-Bar Method)* has been released by the U.S. Army Corps of Engineers and can be accessed at this website.

**NEW http://knowledge.fhwa.dot.gov/cops/ep.nsf/home**
Come join the FHWA's new online Information Exchange for Bridges at this website, which offers information on innovative products and processes for bridge construction. The report titled *Connection Details for Prefabricated Bridge Elements and Systems* is available.

**www.nhi.fhwa.dot.gov/about/realsolutions.aspx**
Presentations from a monthly seminar series offered online by the Federal Highway Administration National Highway Institute are available to listen to or download from this website. Guest speakers discuss challenges they have faced in the field and innovative solutions used to address those challenges. Seminars relevant to bridges include Probability-Based Design and Rating Methodologies, I-70 Overpass Beam Failure, New Technologies in Driven Piles, and Use of Self-Propelled Modular Trailers.

**www.specs.fhwa.dot.gov**
This site serves as a clearinghouse and electronic library where users can search, review, cross-reference, and download the most current specifications, construction manuals, and drawings. Materials on the site have been submitted by state departments of transportation and other agencies and include access to specifications, construction manuals, and standard drawings.

## Bridge Research

**www.trb.org/CRP/NCHRP/NCHRPprojects.asp**
This website provides a list of all National Cooperative Highway Research Program (NCHRP) projects since 1989 and their current status. Research Field 12—Bridges generally lists projects related to bridges although projects related to concrete materials performance may be listed in Research Field 18—Concrete Materials.

**http://www.trb.org/news/blurb_detail.asp?id=10217**
NCHRP *Synthesis 393, Adjacent Precast Concrete Box Beam Bridges: Connection Details* explores current design and construction practices that are reported to reduce the likelihood of longitudinal cracking in box beam bridges.


A drymix shotcrete process was used to repair the badly deteriorated piers on the Noblestown Road Bridge near Pittsburgh, Pa. The repair method allowed the bridge to remain open during construction and return to full operation quickly.

# Noblestown Road Bridge: REHABILITATED WITH SHOTCRETE

by Ted W. Sofis

The Noblestown Road Bridge had provided long service to citizens in Allegheny County, near Pittsburgh, Pa., but its piers had become badly deteriorated. In many places, the concrete appeared to have eroded away like a mud embankment. To repair the damage and restore the bridge, the contractors used shotcrete and a sequenced construction schedule to maintain traffic and return the bridge to full service in a short time.

Sofis Company Inc. performed the work in conjunction with general contractor Thornbury Inc. of West Sunbury, Pa. As contractors could work on only one half of the bridge at a time, to allow traffic to be maintained, Thornbury set up a pattern diverting traffic to the two westbound lanes, with one lane in each direction. Towers were erected at Piers 1, 3, and 5, and the bridge was jacked up to support the structure during removal of concrete on the bridge piers.

Due to structural concerns, removal of concrete from both sides of the piers' hammerheads at the same time was not permitted. The concrete on one side had to be removed, surfaces prepared, and shotcrete applied and allowed to cure, before working on the other side. After work was completed on the piers supporting the two eastbound lanes, traffic was diverted to those lanes so work could take place on the other piers supporting the westbound lanes.

## Drymix Shotcrete Process Used

A drymix shotcrete process was chosen for several reasons. With the drymix process, both the overhead and vertical areas could be shot to the full depth of the repair without using accelerators. This approach eliminated the possibility of laminations that can occur when shooting in layers, which can create points of failure. The scattered repair areas also allowed work to stop and start more easily without concern about wet material in the hoses, as is the case with the wetmix shotcrete process.

Utilizing the drymix process permits the nozzleman to make adjustments in water content at the nozzle and allows the material to be placed with less water content. The material being installed was essentially a zero-slump pneumatically placed concrete. The contractor saw-cut the perimeter of the repair areas, chipped out the deteriorated concrete, sandblasted the reinforcing bars, and added new reinforcing bars where needed. Welded wire reinforcement was installed, holes were drilled for epoxied anchor bars, and shotcrete gunned in place to restore the concrete piers to their original contours.

Quikrete Shotcrete MS with an added Cortec migrating corrosion inhibitor was selected. This premixed material

eliminated the need for on-site mixing, providing better quality control for the mixture. The prepackaged material was dampened with an auger-type predamper, and the Shotcrete MS was gunned in place with a rotary gunite machine.

Both the auger-type predamper and the rotary gunite machine are continuous feed devices, so as the premixed material was predampened, it was immediately conveyed into the gun and through the hose. The moist material was not allowed to sit and was dampened only moments before being fed into the gunite machine and discharged. That eliminated concerns with truck time as with ready mixed concrete or with the moist sand reacting with the cement in large holding hoppers in some of the older batch-type mixing rigs.

Shotcrete has been used for a century and has proven to offer an excellent cost-effective method for the repair of concrete structures. There is no doubt that advances will continue to be made to improve the process further and take full advantage of its engineered properties.

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*Ted W. Sofis is co-principal owner of the Sofis Company Inc., Clinton, Pa.*

*This article is an abridged version of an article published in the Winter 2009 issue of Shotcrete and is published with permission of the American Shotcrete Association. For more information on the association, visit www.shotcrete.org.*



A three-tiered repair program, including the use of a zinc-mesh cathodic-protection (CP) jacket system for major cracks, allowed the Chesapeake Bay Bridge-Tunnel authority to repair its extensive system of piers so they will provide long life and easy maintenance.

## Chesapeake Bay: REPAIRING THE WORLD'S LARGEST BRIDGE-TUNNEL COMPLEX

The Chesapeake Bay Bridge-Tunnel, carrying U.S. Highway 13 across the Chesapeake Bay at Cape Charles, Va., stands out for the superlatives it adds to engineering history. The 23-mile-long bridge-tunnel crossing has a shore-to-shore bridge length of 17 miles, making it the world's longest bridge-tunnel. But the complex's concrete piles recently required repairs that likewise stood out, such that the repair work won an Award of Excellence from the International Concrete Repair Institute.

The bridge includes 2523 piles to support the northbound side, which was built in 1964. An additional 2951 piles were added to support the southbound section, which was completed in 1999. An inspection of the structure revealed that corrosion of the reinforcing steel encased within the structure's support piles had caused the concrete piles to crack and spall.

Because of the variety of damage, several repair methods were integrated into the repair strategy. Pile conditions were rated on a severity scale and categorized according to the types of repairs needed. The Chesapeake Bay Bridge & Tunnel District in Cape Charles, Va., worked with Jacobs Engineering Group in St. Louis, Mo., to evaluate conditions. Their survey revealed that 623 bridge piles required repair. Precon Marine Inc. in Chesapeake, Va., performed the work.

The engineers determined that the most severe piles required carbon-fiber strengthening to ensure the piles didn't deteriorate further, particularly at the top region where they exhibited the most localized damage during installation.

### Zinc-Mesh Jackets Added

Piles with cracks wider than 1/16 in., were repaired with a zinc-mesh cathodic-protection (CP) jacket system from Electro Tech CP in Tequesta, Fla., and Jarden Zinc Products in Greenville, Tenn. This system was selected to provide long-term protection that would remain maintenance free. CP jackets were installed on 215 piles and will help prevent future corrosion by creating a barrier against chlorides, moisture, and oxygen.

The first step in installing the jackets was to connect each piece of steel in the concrete sections to the pile's CP system. Installers drilled from the face of the pile into the concrete to expose a portion of the reinforcing steel, including the spiral wire and each prestressing strand. Then, they brazed a copper wire onto the steel. The crews then applied epoxy at the connection point and plugged the drill hole with grout material.

Each fiberglass jacket was installed in four sections. Crew members pumped grout comprising portland cement and sand from the bottom of the jacket to the top from alternate pumping ports to create a single monolithic fill approximately 2 in. thick. When the grout fill cured, lead wires from the reinforcing steel in the pile were connected with the zinc anode in the junction box. The existing concrete and the grout fill in the jacket formed a common electrolyte.

Finally, the repair contractor bolted two 48-lb bulk zinc anodes to the bottom of each jacketed pile and connected them to the pile's CP system to add protection to the pile's submerged portion and prevent current dump-off from the jacket's lower region. The repair system, designed to protect the piles for more than 25 years, will self-adjust to meet changes in temperature, humidity, concrete resistivity, and other factors.

For piles with minor damage, including hairline cracks smaller than $^{1}/_{16}$ in., repairs were made by routing out the cracks and packing them with cementitious material. Any spalls on the piles were also patched with cementitious material. In addition, a cementitious overlay coating was applied to the rectangular concrete caps, which run horizontal across each set of three piles. The road rests atop these caps.

The three-pronged system and careful analysis allowed repairs to be closely targeted and achieve the twin goals of being long lasting and easy to maintain.

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*This article is an abridged version of an article published in the November/December 2008 issue of Concrete Repair Bulletin and is published with permission of the International Concrete Repair Institute. For more information on the organization, visit www.icri.org.*

# Sunshine Skyway Bridge: CARBON FIBER REPAIRS GIRDERS

With its signature bright-yellow stay cables, the Sunshine Skyway Bridge in Tampa Bay, Fla., is one of the most recognizable structures in the United States. The bridge comprises the main spans, the high-level approach spans, and the low-level trestle spans. The concrete girders of the low level trestle spans recently underwent repairs to provide significant new service life. The work on the project stood out to the extent that it won an Award of Excellence from the International Concrete Repair Institute.

Repairing the girders represents a monumental project. The bridge is 5.5 miles long with a main span vertical clearance of more than 190 ft. The trestle spans use 1300 precast, prestressed concrete girders. AASHTO Type IV girders are used for a majority of the 100-ft-long spans. The Florida Department of Transportation (FDOT) in Tampa, Fla., worked with SDR Engineering Consultants in Tallahassee, Fla., on the project. Intron Technologies in Jacksonville, Fla., served as repair contractor.

Shear cracks had been observed during routine inspections of the trestle span girders, leading to the repair plan. Inclined shear cracking was much more prevalent in the exterior girders than the interior girders, and numerous pier caps also showed cracks large enough to exhibit signs of water penetration and damage. The damage impacted both the flexural and shear capacity and required several repair procedures.

Shear cracks with a width exceeding 0.012 in. were epoxy-injected. Spalls were patched with a cementitious repair mortar, uneven surfaces were filled with a leveling mortar, and small cavities were repaired with an epoxy paste. A clear protective sealer was applied to protect the concrete after the work was completed.

To restore the shear deficiencies at the end of the AASHTO girders on the 5.5-mile-long Sunshine Skyway Bridge in Tampa Bay, Fla., designers used a bidirectional carbon-fiber fabric wrapped in a specific sequence to limit the number of plies while supplying additional strength.

## Carbon-Fiber Fabric Wraps Members

To increase shear strength at the end of the AASHTO girders, a bidirectional carbon-fiber fabric from Sika Corp. in Lyndhurst, N.J. was used to wrap the members. The carbon fiber was applied in a specific way to achieve the strength necessary and meet the design live load requirement.

A 24-in.-wide strip was placed vertically down the girder web, around the bottom flange and up the other face to create a U-wrap similar to a stirrup. Then a strip was wrapped around the bottom flange of the girder to strengthen the flange. Finally, another strip was placed longitudinally along and under the top flange adjacent to the soffit of the bridge deck. The bidirectional fabric allowed the members to achieve supplemental strength in multiple directions without having to install additional plies.

Most of the repairs took place over the water, from where it was difficult to access the bridge's underside to perform the repairs. The contractor worked from a barge using man lifts, because the vertical clearance from the barge to the underside of the girders on the trestle span was about 15 ft. Waves and tides also were major concerns, as was the threat of hurricanes.

## Protecting the Environment

Working in a marine environment, the contractor had to ensure no degradation of water quality occurred due to construction, and staging was not permitted in any environmentally sensitive habitats or wetlands. Also, the bridge was located in a Manatee Watch Area, so a lookout was required to watch for the protected mammals when boats were moved.

Despite difficult working conditions, the project proved a success. The repairs were able to be made underneath the bridge without having to restrict even one lane of traffic during the entire process. By close scheduling of the construction sequence, the work was completed one month ahead of schedule, making not only the contractor happy, but FDOT as well.

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# SUSTAINABILITY of Concrete Bridges

by M. Myint Lwin, Federal Highway Administration

During the past 2 years, *ASPIRE*™ has accepted the challenge to explore and illustrate the sustainability of concrete bridges. This theme will continue throughout 2010. Many of my previous articles have also addressed this theme. In this issue, I would like to address some basic questions about sustainability.

*The I-35W St. Anthony Falls Bridge used combinations of fly ash, slag, and silica fume in the different concrete mixes. Photo courtesy of FIGG, Tim Davis photographer.*

## Why Sustainability for Bridges?

As responsible citizens and engineers, we need to have a concern for (1) the deterioration of our environment, (2) the local and global economies, and (3) the instability in our society worldwide. Sustainability concepts will help us maintain a healthy, productive, and life-supporting environment so essential for a strong and resilient world economy.

**The American Society of Civil Engineers' Code of Ethics, Canon 1 states:**

> *Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.*

It is our professional responsibility to commit to improving the environment by adhering to the principles of sustainable development so as to protect the environment and enhance the quality of life of the general public.

The Secretary of the U.S. Department of Transportation has stated that the Department of Transportation's priorities are safety, economic recovery, establishment of sustainable highway programs, and the provision of livable communities. Sustainable highway programs require investments in better roads, bridges, and tunnels; reduction of $CO_2$ emissions; and the utilization of carbon-absorbing materials, while avoiding negative impact to the environment. Within our communities, we need to provide safer and healthier environments, strong economies to support jobs and families, interconnected transportation modes and systems, and sustainable mobility to encourage more walking, biking, and use of public transportation.

## What is Sustainability?

The classic definition of sustainability was advanced in 1987 in the report on Our Common Future by the United Nation's World Commission on Environment and Development (the Brundtland Commission):

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

This is our responsibility to future generations. Did the past generations meet the Brundtland Commission definition in providing us with opportunities to meet our needs and creativity?

There are many engineering examples that show that our ancestors created outstanding architectural structures that have lasted for thousands of years. Some examples are the Great Wall of China; the Aqueducts, Pantheon, and Coliseum of the Romans; and the pyramids of Egypt. They are inspirations to our generation to build durable and beautiful structures that will aspire future generations to create structures based on their imagination!

## Is Concrete Sustainable?

The historic structures cited in the previous paragraph used cementitious materials in the form of mortars and concrete over 2000 years ago! Some of these structures are still in use today. They definitely meet the Brundtland definition of sustainable development. In short, concrete is sustainable.

At the present time, there is demand for performance-based and data-driven definitions for engineering projects and accomplishments. We need a quantifiable definition, such as:

> *Sustainability is a concept that protects or enhances our natural environment, conserves our resources, reduces intrusion on wildlife and their habitats, and avoids negative impact on the ecosystems.*

Some concrete bridges that meet these criteria include the Chillon Viaduct, Switzerland; the H3 North Halawa Valley Viaduct in Oahu, Hawaii; Blue Ridge Parkway Viaduct, N.C.; the Millau Viaduct, France; and the I-35 St. Anthony Falls Bridge, Minn.

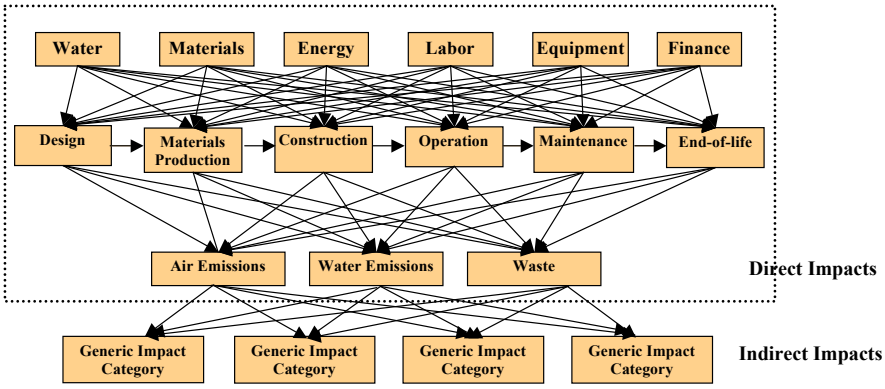



***FIGURE 1** - Total impact of bridges on the environment.*

## How Do Life-Cycle Cost and Life-Cycle Assessment Differ?

Life-cycle cost (LCC) for bridges is a function of the separate costs for planning, designing, construction, operation, maintenance, and final disposal. It is an estimate of the total cost of a bridge from cradle to grave. LCC may be used for cost-benefit analysis and the cost comparison of alternate designs. On the other hand, life-cycle assessment (LCA) addresses the environmental impacts of natural resource extraction, raw materials production, product manufacturing or construction, operation, maintenance, and final disposal. The social benefits of the transportation facility must also be accounted for to provide a complete assessment of environmental, economic, and social impacts for the whole life of the structure. When all these factors are combined, bridges become very complex products for determining the total impact on the environment as illustrated in Fig. 1.

Currently there is no computer program that will help perform the complex LCA on bridges. There is a commercially available computer program, ATHENA, for performing LCA on buildings. As a simple example in using ATHENA, the following table compares the environmental impact of a reinforced concrete beam versus a steel beam of the same moment capacity as used in a building.

From the table below, the authors concluded that the production of the concrete beam required much less energy and had a lower net environmental impact than production of the steel beam.

## What is Designing for Sustainability?

The design of bridges for sustainability needs to be based on a system concept involving three major components:

- Structural Design,
- Durability Design, and
- Environmental Design.

The rules for structural design are well established in documents such as the *AASHTO LRFD Bridge Design Specifications*. Durability design is less established and usually approached indirectly through the use of prescriptive specifications such as maximum water-cementitious materials ratio or maximum chloride permeability. Rarely is a direct design approach used in U.S. practice. Durability plays a very important role in LCC and LCA. Durability design deserves equal, if not more attention, than structural and environmental designs. Environmental design is a new challenge for bridge engineers. It needs to address designing and building bridges in ways that will reduce emissions, use recycled materials, conserve new materials, save energy, protect wildlife, and preserve ecosystems. Bridge engineers are challenged to be creative and innovative!

| Environmental Impact | Reinforced Concrete | Structural Steel |
|---|---|---|
| Materials, lb | 108 | 41 |
| Warming Potential, lb of $CO_2$ | 22 | 20 |
| Water Pollution Index | 0.34 | 0.98 |
| Air Pollution Index | 2.01 | 0.46 |
| Solid Waste, lb | 4.1 | 4.0 |
| Energy, kilowatt hour | 39 | 64 |

*Source: Struble, L. and Godfrey, J.,* How Sustainable is Concrete? *International Workshop on Sustainable Development and Concrete Technology, Beijing, China, May 2004, proceedings published by Center for Transportation Research and Education, Iowa State University, Ames, Iowa, pp. 201-211.*

## Closing Remarks

Let me conclude this article with thoughts by two prominent engineers on how we can achieve sustainable designs:

- "Sustainability will come from all of us in the bridge industry—owners, regulators, the public, academia, designers, and builders—working together towards a common goal." Paul Giroux, Kiewit Pacific Co.
- "A paradigm shift is necessary in United States practice to achieve the goals of extended service life and a sustainable bridge infrastructure…" Cliff Freyermuth, CLF Inc.

Since the 1987 Brandtland Commission report, sustainability has taken on wide-ranging definitions, which are applicable to innumerable situations and cases for sustaining quality of life on our good earth for generations to come.

*Blue Ridge Parkway Viaduct was built from the top down and incorporated iron oxide pigments in the concrete to minimize environmental impact. Photo courtesy of FIGG.*

U.S. Department of Transportation
**Federal Highway Administration**

EDITOR'S NOTE

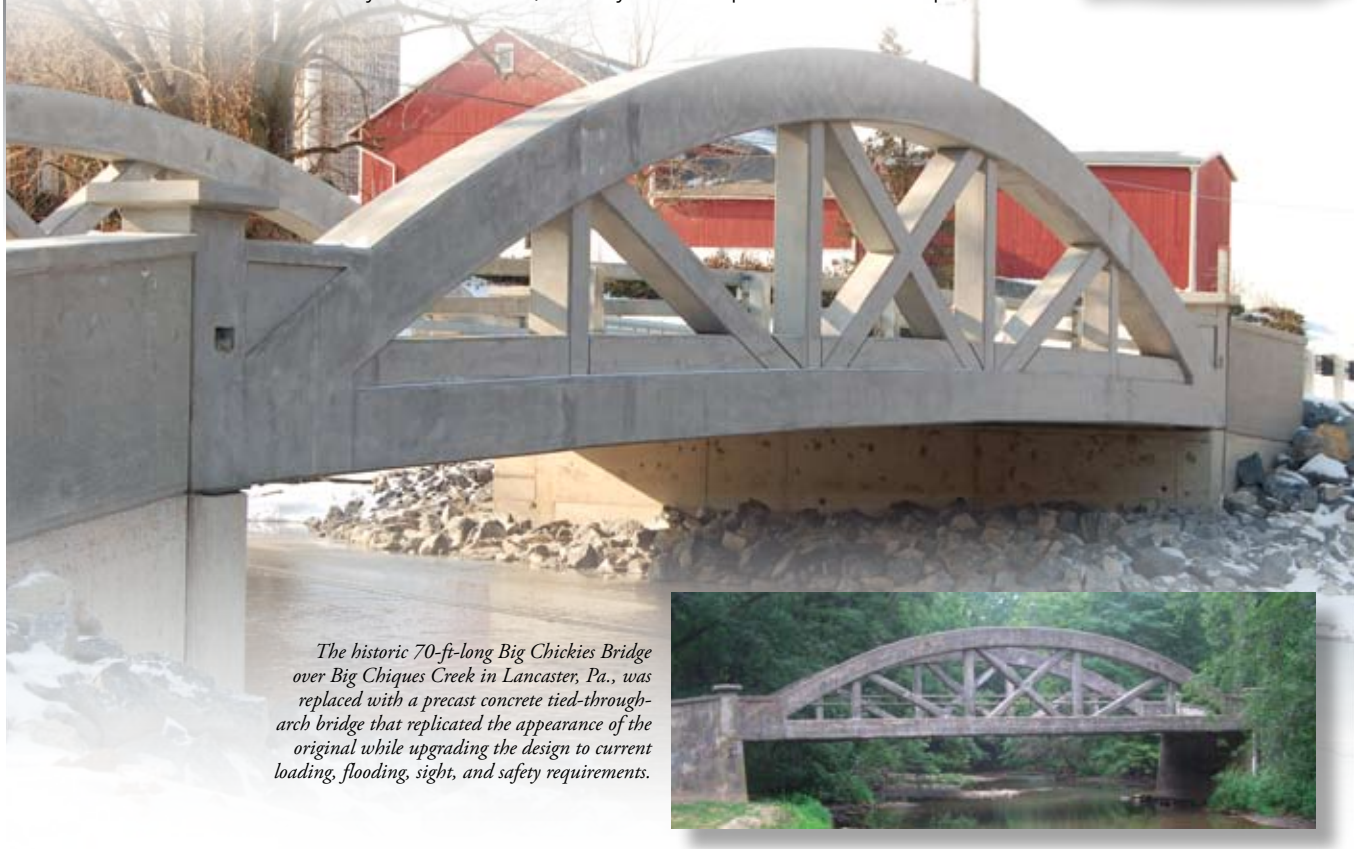
*This article was based on a presentation by the author at the 21st Annual ASBI Convention, October 2009.*

STATE

## Infrastructure Focus and Close Relationships Work in

# Pennsylvania

by Tom Macioce, Pennsylvania Department of Transportation



*The historic 70-ft-long Big Chickies Bridge over Big Chiques Creek in Lancaster, Pa., was replaced with a precast concrete tied-through-arch bridge that replicated the appearance of the original while upgrading the design to current loading, flooding, sight, and safety requirements.*

Pennsylvania has a long history of building precast, prestressed concrete bridges, going back to the first structures to use that concept beginning in the late 1940s. Today, a high percentage of the state's bridges continue to be constructed from prestressed concrete. That total has jumped substantially in recent years, led by the passionate support for infrastructure improvements directed by Governor Edward G. Rendell.

The Keystone State has a large number of bridges, but a high percentage of them are less than 100 ft long, owing to the state's rugged terrain and many streams and rivers. Some of them also have deteriorated from long service and a gap that was growing between the need for maintenance and the capabilities to fund that work. Most projects fall into the category of "Bridge Rehabilitation or Replacement," which encompasses everything from repairs to the existing structure to building a completely new bridge. The other categories of projects comprise "Bridge Preservation" and "Bridge Maintenance."

Funding for bridge projects took a dramatic leap in 2008 with Governor Rendell's Rebuild Pennsylvania initiative. Bridges benefit from those efforts through the Accelerated Bridge Program (ABP) portion. The goal is to repair or replace 1145 structurally deficient bridges over a 3-year period. The Pennsylvania Department of Transportation (PennDOT) exceeded its first-year goal of 411 bridges by opening bids on 470 contracts by June 30, 2009.

In addition to the ABP bridges, PennDOT is working toward awarding contracts to fix 105 structurally deficient bridges with federal money from the American Recovery and Reinvestment Act (ARRA). Contract spending for bridges also has been rising, from $259 million in 2002 to $787 million in 2008. For fiscal year 2009, thanks to these additional funding sources, contract spending is expected to reach nearly $1 billion.

In fact, the state has finally turned the corner on the backlog of bridge maintenance needs. In March, for the first time in memory, the number of structurally deficient bridges in the state declined, from 6034 to 5911. As of last September, the number had been lowered further to 5846.

### Concrete Bridges Dominate

Most of the bridges—as many as 90%—will be constructed using concrete materials. Prestressed concrete I-beams and box beams are the most common solutions, primarily because of the excellence of precast concrete fabricators in the area who can supply the necessary components on a fast response and competitive basis.

Many projects in Pennsylvania have presented challenges to designers and fabricators alike. Even small projects can create unique designs. A typical example is the Big Chickies No. 2 Bridge on Auction Road (T-875) over Big Chiques Creek in Lancaster, Pa. The historic concrete tied-arch bridge had degraded, lowering the maximum allowable load. Maintaining the aesthetics and contextual sensitivity for the 1920s structure, while upgrading to meet new loading, flooding, sight, and safety constraints, were key concerns. These were exacerbated by the need to widen the

bridge to two full lanes and ensure the arches could withstand the increases in deck torque and flexure.

The new 70-ft-long bridge features precast concrete, tied-through arches and a cast-in-place concrete deck to replicate the appearance of the original bridge. The precast concrete arches were erected in a single night, minimizing disruptions to traffic and speeding construction. No temporary formwork or scaffolding was needed in the creek, saving additional time and money. In production, close tolerances were needed to ensure the enormous mount of reinforcement and post-tensioning steel would fit the forms and meet clearance and cover requirements.

The project proved so distinctive that it was named a co-winner of the award for Best Bridge with Spans Less than 75 ft in the Precast/Prestressed Concrete Institute's 2009 Design Awards Competition.

**Prestressed concrete is the common solution, primarily because of the excellence of the precast concrete fabricators.**

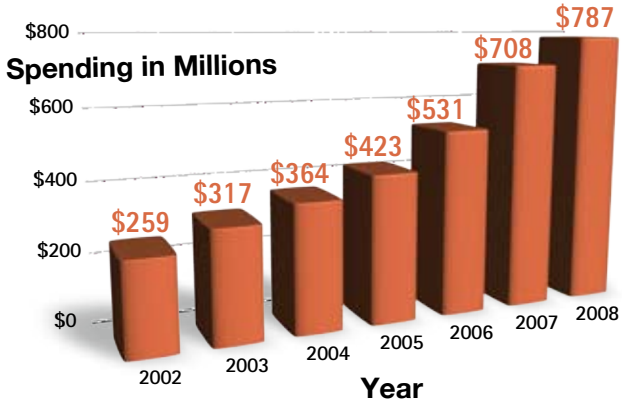
## Long Concrete History

Pennsylvania has been at the forefront of advances in prestressed concrete technology for a long time. The nation's first major precast, prestressed concrete bridge, the Walnut Lane Bridge in Fairmont Park in Philadelphia, included a 160-ft-long main span and two 74-ft end spans, and used concrete with a compressive strength of 5400 psi. It was also one of the earliest structures ever to use large-scale precast concrete components and high-performance concrete. That milestone drew engineers and scientists who were interested in this concept, to Pennsylvania. That in turn ensured manufacturers would construct facilities here, creating a long-term foundation. Pennsylvania-German engineers in PennDOT's offices also encouraged the use of precast, prestressed concrete and developed standards to make it efficient and cost competitive.

That evolution has been enhanced by regional associations that work closely with PennDOT to produce better practices on an on-going basis. The Prestressed Concrete Committee for Economic Fabrication (PCEF) consists of representatives of the Federal

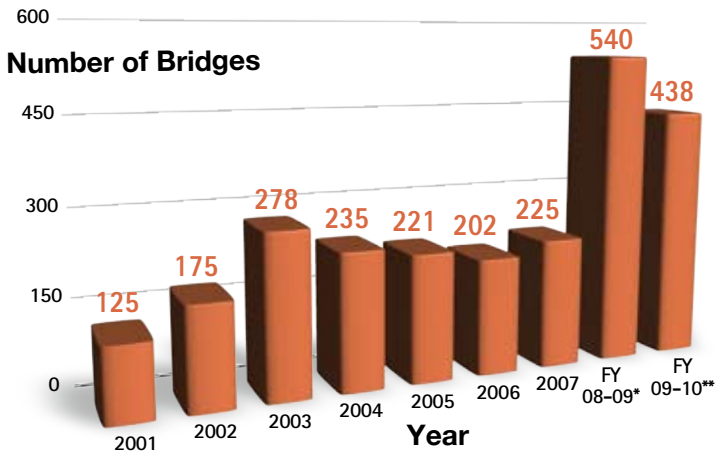
*The first major prestressed concrete bridge in America was constructed in Pennsylvania in 1950. Using concepts devised by Professor Gustave Magnel of the University of Ghent in Belgium, the Walnut Lane Bridge in Philadelphia features a 160-ft-long main span and two 74-ft-long end spans.*

## BRIDGE CONTRACT SPENDING




*Contract spending for bridge construction in Pennsylvania has grown steadily since 2002.*

## PROJECT DELIVERY




** 470 ABP Bridges and 70 ARRA bridges ** 403 ABP Bridges and 35 ARRA bridges*
*Source: PennDOT 2009*

Highway Administration, regional DOT officials, engineering firms, academics, and concrete fabricators from New Jersey, Pennsylvania, Delaware, Maryland, West Virginia, and Virginia. They work to find consensus on standardized designs and ideas to aid economical production of materials, such as quality-control guidelines, and more efficient bulb-tee girder shapes.

PennDOT also works closely with the Prestressed Concrete Association of Pennsylvania (PCAP), led for many years by executive director Hank Bonstedt. That group has spear-headed a variety of initiatives in conjunction with PennDOT to standardize precast components and create efficiencies in the designs produced by the state. (For more on their contributions, see the sidebar.)

PCAP worked with PennDOT recently to standardize the design of precast concrete bulb-tee beams to create efficiencies that will save design, fabrication, and construction time. One result of that work can be seen in the 8th Street Bridge in Luzerne County, which is now under construction. The 1319-ft-long bridge features 10 spans, with five girders per span. The project replaces the existing bridge, which was structurally deficient. The design-build project is planned for opening in summer 2010.

Another larger project, recently completed, that incorporated prestressed concrete I-girders is the Tioga River Bridge on Route 15 between Route 287 and the New York Border in Tioga County. The $26.9-million project includes four twin prestressed concrete I-beam bridges with three single-span bridges and one 11-span structure. The bridges were the "missing link"

*The Tioga River Bridge on Route 15 features twin, 11-span structures constructed with precast, prestressed concrete I-beams. The $26.9-million project connects two key roadways to speed traffic flow and accessibility in Lawrenceville, Pa.*

tying together the construction between Route 287 at Tioga and Route 49 in Lawrenceville. The twin 11-span bridges cross the Tioga River and the Wellsboro-Corning Railroad, while the single-span bridges cross a farm lane, a new township road, and a wildlife area. More than 21,000 $yd^3$ of concrete and 2.64 million lb of steel reinforcement were used in the project.

### Contractor Alternate, Design-Build Aid Process

The use of a contractor-alternate design bidding process, as well as design-build approaches, have aided PennDOT's construction techniques in significant ways. For each project, bid documents include an option that the contractor may submit an alternative bridge design to be considered. In addition, about 25% of bridge projects in the state are bid as design-build projects.

Fewer projects are taking advantage of the contractor-alternate option today, however, as PennDOT designers have learned from past projects, and incorporate those efficiencies into subsequent designs where applicable. This additional input ensures that designs continue to evolve and provide continuous improvements that feature the latest and best techniques.

One benefit of design-build and contractor-alternate approaches is that the savings are built into the project from the beginning. With value engineering after the project is let, the savings are split between the state and the contractor. This approach allows funds to be reallocated to other vitally needed projects and add greater value for Pennsylvania's residents.

The close cooperation that PennDOT garners with industry associations and designers ensures that it remains on the cutting edge in bridge designs. Those new ideas are incorporated into the thinking for each new bridge going forward. Combined with the new commitment to infrastructure construction spearheaded by the state and its long heritage with the material, Pennsylvania's position as a major state for concrete bridges will remain intact.

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*Tom Macioce is chief bridge engineer with the Pennsylvania Department of Transportation in Harrisburg, Pa.*

**For more information on Pennsylvania's bridges, visit www.dot.state.pa.us.**

## PCAP Teams with PennDOT

by Hank Bonstedt, PCAP

The Prestressed Concrete Association of Pennsylvania (PCAP) has a long and proud history of working closely with officials at the Pennsylvania Department of Transportation (PennDOT). That relationship has paid off with several key design techniques that have increased efficiency and reduced costs for construction projects. Key initiatives with which PCAP has worked with PennDOT in recent years have included:

- A new "Pennsylvania" precast concrete bulb-tee I-girder design that creates a more efficient section for design, fabrication, and erection.
- The elimination of corrugated cardboard voids in box beams, replacing them with expanded polystyrene foam. This provides for more durable, consistent, and economical fabrication.
- Self-consolidating concrete standards that ensure the material's best capabilities are achieved. Its benefits include easy workability and a better finish, making it easier to cast complex components while achieving an aesthetically pleasing finish.
- New standards for spliced girder designs, with the goal of creating economical methods to transport lighter weight components to the jobsite while retaining the material's long-span capabilities. Delivering segments that can be connected at the site facilitates transportation access and allows spans to extend from 165 ft in the past to 225 ft today, eliminating piers that add time and material costs. This work has made precast concrete more competitive with steel and provided an alternate option for longer lengths.

PCAP is committed to working with PennDOT to achieve continuous improvements in the design, fabrication, transportation, and erection of precast, prestressed concrete bridge components. These various initiatives build on each other to ensure bridges can be aesthetically pleasing and cost efficient while reaching the 100-year service life that owners want to achieve.

To learn more about PCAP's work and to see some of the design initiatives, case studies, educational programs, and other resources available to designers, visit **www.pcap.org**.

*Hank Bonstedt is executive director of the Prestressed Concrete Association of Pennsylvania, Allentown, Pa.*

*The 1319-ft-long 8th Street Bridge in Luzerne County, Pa., will feature 10 spans of precast, prestressed concrete bulb-tee girders. The project, to open summer 2010, replaces a deteriorated structure on the site.*

# International Scan on Assuring Bridge Safety and Serviceability in Europe

by Dr. Dennis R. Mertz

*The scan team with hosts visiting the large-scale structural testing facility of Laboratoire Central des Ponts et Chaussees in Paris, France.*

In June 2009, a delegation from the United States sponsored by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials, and the National Cooperative Highway Research Program visited several European countries to review their policies and procedures to assure safety and serviceability of their highway bridges. The itinerary for the 2-week scan of technology included Helsinki, Finland; Vienna, Austria; Graz, Austria; Cologne, Germany; Paris, France; and London, United Kingdom. These five countries were selected through a desk scan that identified their use of advanced practices in assuring bridge safety and serviceability.

The scan team was led by Firas I. Sheikh Ibrahim of the FHWA and Susan Hida of the California Department of Transportation (Caltrans). The remainder of the team included Gregory L. Bailey of the West Virginia Department of Transportation, Ian M. Friedland of the FHWA, Jugesh Kapur of the Washington State Department of Transportation, Barney T. Martin Jr. of Modjeski & Masters Inc., Dennis R. Mertz of the University of Delaware, Gregory R. Perfetti of the North Carolina Department of Transportation, Thomas Saad of the FHWA, and Bala Sivakumar of HNTB Corporation. Harry A. Capers of Arora and Associates was the contracted report facilitator.

The scan team conducted a series of meetings and site visits with representatives of government agencies and private sector organizations in the five countries.

Specific topics of interest to the team included:

- Safety and serviceability measures during design, construction, and operation; and
- Refined analysis applications during design, construction, and operation.

The scan team found that, as with bridge owners in the United States, the European host agencies put great value on their bridge programs not only in ensuring highway-user safety, but also that durability and serviceability expectations are met enhancing capital investment decisions regarding their existing bridge inventories. Major emphasis is placed on ensuring that there is no interruption in service and that appropriate sophisticated methods are used to evaluate structural safety. Most of the agencies visited had major programs aimed at assuring accuracy of design and rating of the highway structures on their systems.

The scan team also identified many practices and technologies related to the previously stated topics of interest.

The preliminary recommendations of the team for examination and consideration by bridge owners in the United States are as follows (in no particular order):

- Develop a strategy for promoting and increasing the use of refined analysis for design and evaluation.
- Utilize refined analysis for evaluation in combination with reliability analysis as a measure to avoid unnecessary posting, rehabilitating, or replacing bridge structures that affect commerce, schools, and the traveling public.
- Adopt the concept of annual probability of failure (exceedance) as the quantification of safety in probability-based design and rating specifications rather than the reliability index for a 75-year design life.
- Conduct research to create the basis to systematically introduce increasing levels of sophistication into the analyses and load models with the objective of assessing bridges more accurately.
- Periodically and routinely reassess traffic highway loading, using recent weigh-in-motion data, to ensure that live-load models adequately provide for bridge safety and serviceability for a 75-year design life or greater.
- Develop an overweight permit design vehicle and design for the associated Strength II load combination, particularly in high load corridors.
- Initiate and maintain a database documenting bridge failures around the world, including sufficient information and data to assist in assessing the causes of failure, for the purpose of proactively examining practices and avoiding similar problems in the United States.
- Continue efforts on the development of techniques, guidelines, and training for proper use of non-destructive evaluation techniques to detect corrosion and breakage of cables of cable-supported bridges, strands of pretensioned girders, and internal and external tendons of post-tensioned girders.
- Explore "Independent Check Engineering" and "Check Engineer Certification" as a means to augment QA/QC of bridge designs.
- Initiate an investigation and technology transfer of selected best practices and emerging technologies identified during the scan.

The technology scan was of great value to the individual members of the team, as well as impacting our nation's dialogue on bridge engineering. Susan Hida of Caltrans says, "The use of weigh-in-motion data to establish load models in the Eurocode and then adjust within each country was particularly inspiring to me for work back at Caltrans. We hope to do something similar for both permit and fatigue trucks on heavily travelled corridors."

The scan team has developed a detailed implementation plan for the recommended initiatives and practices. The implementation plan and details on the findings and recommendations are included in a soon-to-be-published final scan report. For more information, go to **www.international.fhwa.dot.gov** where scan reports are available.

# HARRIS COUNTY, TEXAS EXPERIENCE WITH CONCRETE BRIDGES

by Jackie Freeman and Willard Puffer, Harris County, Texas

*A typical example of the county's newer construction is this four-span, precast, prestressed concrete I-beam structure—the T.C Jester Road Bridge over Harris County Flood Control Ditch.*

Harris County, Tex., which includes Houston, is the third most populous county in the United States with an estimated 4.1 million residents in June 2009. The county's population has increased 19% since 2000. The unincorporated population of Harris County is approximately 1.4 million. The county would become the sixth largest city in the nation if it were a single incorporated city. The county's land area, 1778 square miles, is larger than Rhode Island and Connecticut combined.

Harris County's road network consists of approximately 5900 miles of roads and 696 bridges (44 additional bridges are coming into service pending scheduled inspections). Approximately 60% of the road network is residential, with the remaining 40% either collector roads or thoroughfares. Sixty percent of the road network is reinforced concrete pavement, with asphalt and other materials comprising the remaining pavement types.

The material of the county's bridges is almost exclusively concrete. The breakdown by materials of the main span is shown in Table 1. Seventy-seven percent of the inventory is precast, prestressed concrete multiple box girders (64%) and concrete culverts (13%).

Ninety percent of the county's bridge inventory crosses water. Twenty-two bridges are at least 50 years old. In 2007, only eight bridges had a sufficiency rating less than 50. Of those eight bridges, four are timber and four are concrete bridges. Sufficiency rating is a numeric value which is indicative of bridge sufficiency to remain in service as defined by the state and FHWA Bridge Inspection Safety Assurance Program.

**TABLE 1**
Numbers of Bridges by Material Type

| Number | Main Span |
|---|---|
| 6 | Timber |
| 10 | Steel/Plate Girders |
| 67 | Concrete Slab/Box |
| 52 | PS Concrete Multiple Girders |
| 28 | Other PS Concrete |
| 445 | PS Concrete Box Girders |
| 88 | Culverts |
| 696 | Total 2009 Active Structures |

**TABLE 2**
Age Distribution

| Age (yrs) | Number |
|---|---|
| 70 | 2 |
| 60-69 | 6 |
| 50-59 | 14 |
| 40-49 | 41 |
| 30-39 | 134 |
| 20-29 | 276 |
| 10-19 | 154 |
| 0-9 | 69 |
| **TOTAL** | **696** |

The four concrete bridges with a 2007 sufficiency rating less than 50 have provided collectively nearly 200 years of safe service to the county. One of the four has been replaced, one repaired, and two are due to be replaced.

Harris County is very pleased with the exceptional service life provided by its concrete bridges. The county has less than 1% of its concrete bridges with a sufficiency rating less than 50.

The cost of service often goes unreported. Harris County has seen growth that frequently requires changes in road alignment resulting in early bridge replacement. However, in many situations, existing bridges have been widened by extending the substructure, installing additional precast, prestressed concrete box girders, and installing a new deck wearing surface allowing the existing structure to continue to provide many years of additional service.

Concrete bridges continue to meet the Harris County's long-term needs and affordable life-cycle goals.

---

*Jackie Freeman is deputy executive director of the Harris County Public Infrastructure Department and Willard Puffer is director of the Harris County Asset Management System, Houston, Tex.*

**EDITOR'S NOTE**

*If your county has a high percentage of concrete bridges or some interesting and innovative concrete bridges and would like to be featured in ASPIRE,™ please let us know at info@aspirebridge.org.*

# Slab-on-Beam Bridge
## Live Load Distribution Factors

by Dr. Dennis R. Mertz

The slab-on-beam bridge live load distribution factors of the AASHTO *LRFD Bridge Design Specifications* were originally developed by Imbsen & Associates Inc., through National Cooperative Highway Research Program (NCHRP) Project 12-26, *Distribution of Wheel Loads on Highway Bridges*. Originally, this project resulted in an AASHTO guide specification (which is now out-of-print) for use with the AASHTO *Standard Specifications for Highway Bridges*. Subsequently, the original developers adapted the distribution factors for inclusion in the *LRFD Specifications*. The major differences between the factors in the guide specifications and those of the *LRFD Specifications* are twofold. Each set of factors reflects the different multiple-presence factors of the two bridge specifications. Second, the *LRFD Specifications* deals with vehicle or lane loads while the *Standard Specifications* deals with wheel loads. By itself, this difference in the treatment of loads would result in a difference of a factor of two.

An examination of the live load distribution factors for slab-on-beam bridges demonstrates the enhanced sophistication of the LRFD distribution factors in comparison with the original factors of the *Standard Specifications*. The multiple-lane, live load distribution factor, g, of the *Standard Specifications* for the interior beam of a slab-on-beam bridge is:

$g = \frac{S}{5.5}$ in terms of wheel loads, or:

$g = \frac{S}{11}$ in terms of vehicle or lane loads of the *LRFD Specifications*,

where $S$ equals the girder spacing.

These factors are used for both moment and shear, and are very simple and easy to apply, yet they have been demonstrated to be conservative in some cases while unconservative in others.

The LRFD multiple-lane distribution factor for moment of an interior girder of a slab-on-beam bridge, from LRFD Table 4.6.2.2.2b-1 is:

$$g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^3}\right)^{0.1}$$

in terms of vehicle or lane loads,

where $S$ equals the girder spacing, $L$ equals the span length, $K_g$ represents the longitudinal stiffness, and $t_s$ equals the slab thickness.

A different distribution factor equation is used for shear.

Obviously, the LRFD distribution-factor equation is more complicated, yet each term of the equation reflects more accuracy in determining live load distribution. The first term of the product, $(S/9.5)^{0.6}$ represents the traditional distribution factor illustrating the strong dependency on girder spacing. The next term of the product, $(S/L)^{0.2}$ reflects the aspect ratio of the girder spacing divided by length of the bridge. The wider the spacing relative to the bridge length, the less distribution of load or the higher the distribution factor. The final term of the product represents the longitudinal stiffness of the bridge divided by its transverse stiffness. The stiffer the bridge is in the longitudinal direction relative to its stiffness in the transverse direction, again the less distribution of load or the higher the distribution factor. Clearly, the more complex live load distribution equations provide opportunities to capture load-distribution effects beyond those of the traditional simple equations.

The presentation of live load distribution factors in LRFD Article 4.6.2.2 is based upon several tables. Table 4.6.2.2.1-1 summarizes the various bridge and girder types for which live load distribution is defined in the specifications. Subsequent tables are keyed to the types included in this table. Tables 4.6.2.2.2b-1 and 4.6.2.2.2d-1 specify live load distribution factors for moment of interior and exterior girders, respectively. Reduction factors based upon skew angle are given for distribution factors for moment in Table 4.6.2.2.2e-1. Tables 4.6.2.2.3a-1 and 4.6.2.2.3b-1 specify live load distribution factors for shear of interior and exterior girders, respectively. Finally, correction factors for load distribution factors for support shear of the obtuse corner are given in Table 4.6.2.2.3c-1.

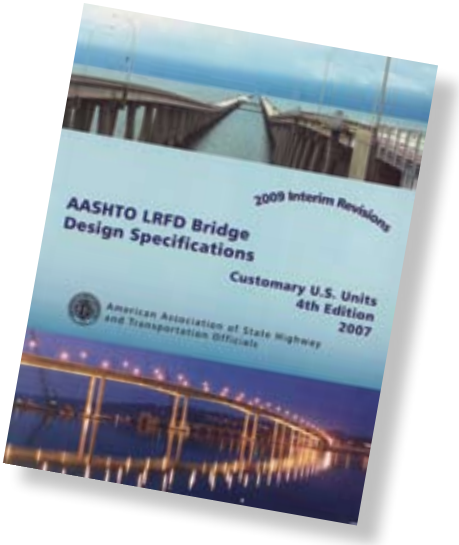

photo courtesy of PCI and Mid-States Concrete Industries

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PRESTRESSED

# CONCRETE BRIDGES

PHOTO OF ROUTE 70 OVER MANASQUAN RIVER IN NEW JERSEY (PHOTO COURTESY ARORA ASSOCIATES).
ALTERNATE STRUCTURE DESIGN UTILIZES PRECAST CAISSONS, PIERS, PIER CAPS, AND PRESTRESSED BEAMS AND WAS OPENED TO TRAFFIC TWO YEARS AHEAD OF AS-DESIGNED SCHEDULE.

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Spencer Creek Bridge
Looking NE at sunset.

## **SPENCER CREEK BRIDGE** / NEWPORT, OREGON

Precast concrete fascia panels are shown being lowered into place along the sides of the bridge to add a smooth face to the superstructure.

Two halves of each precast concrete arch were set into sockets at the foundation and connected with a large cast-in-place concrete blocks.

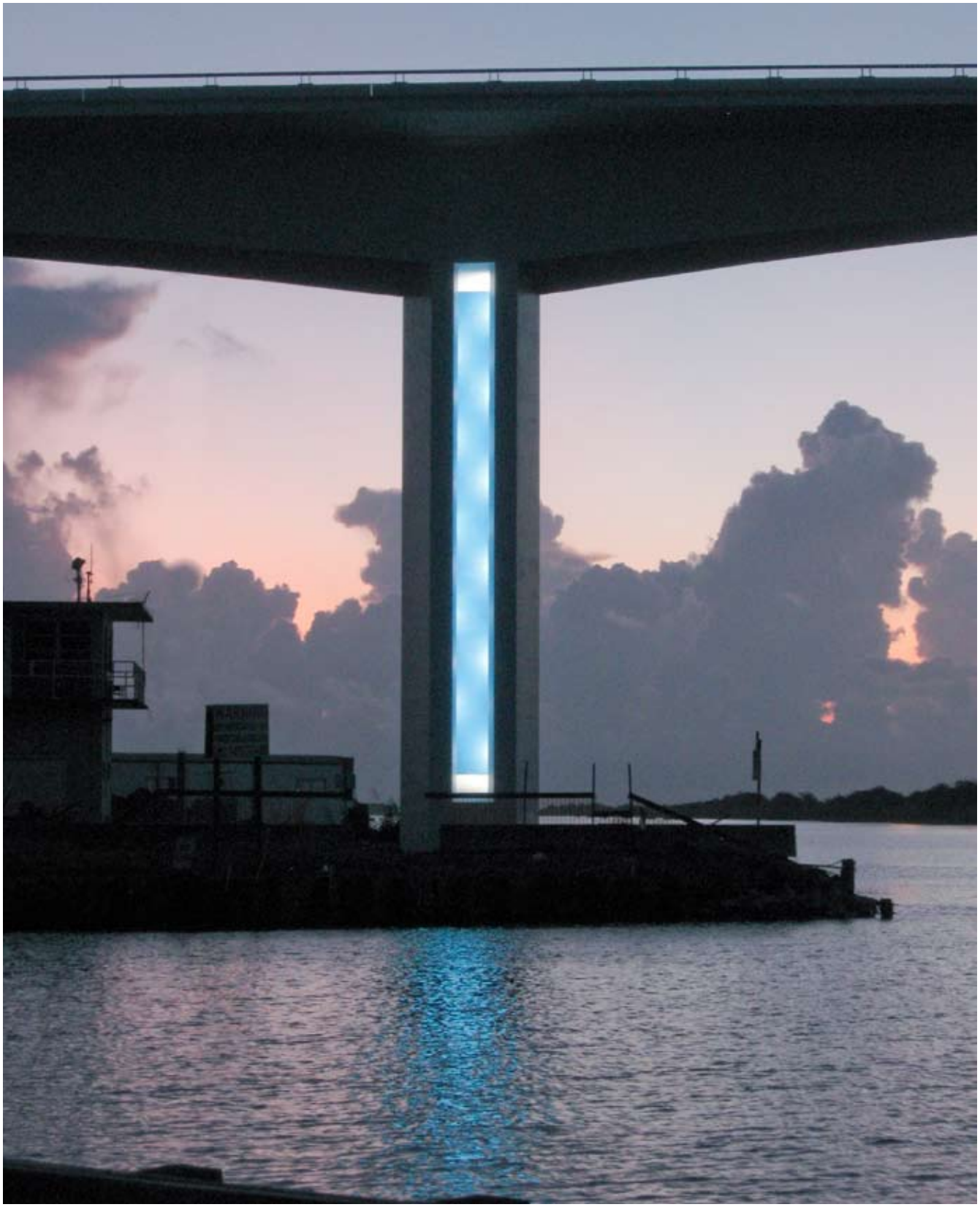
**The precast arches were shipped on their side and rotated on a specially made pedestal to prepare them for lifting into place.**

Special lifting hooks were cast into the sides of the precast concrete arches to aid in handling them prior to rotation.

Sand bags were set around the top of the precast concrete blocks to protect the components as they rolled into the lifting position.


The traveler and formwork for the segmental unit. Photo: Michael Mann.

The state of segmental construction just 2 weeks prior to the arrival of Hurricane Ike. Photo: Keith Kouba, TxDOT.



**Cast-in-place concrete segmental spans were selected early in the design process for the center portion of the bridge.**


Temporary cables were secured to the ear walls of the transition piers to reduce column torsion expected from Hurricane Ike.
Photo: Keith Kouba, TxDOT.

**Three Pi girders were used to construct the bridge's center span.**

## UHPC Properties and Design Stresses

Material properties and design stresses for the Ductal mix were based on experience with the Wapello County project, FHWA testing, and recommendations by FHWA and Lafarge. Values are shown below; note the final values are after heat curing:

| | |
|---|---|
| Modulus of elasticity at release | 5800 ksi |
| Modulus of elasticity final | 7800 ksi |
| Design compressive strength at release | 14,500 psi |
| Design compressive strength final | 21,500 psi |
| Tensile strength | 1200 psi |
| Allowable compressive stress at release (0.6x12,500) psi | 7500 psi |
| Allowable compressive stress at service (0.6x21,500) psi | 12,900 psi |
| Allowable tensile stress at service (0.7x1200) psi | 840 psi |

## New Design Relies on Past

The team took advantage of the design work for the Wapello County project, along with testing by the Bridge Engineering Center at Iowa State University and Turner-Fairbank Highway Research Center. Research reports and guide specifications listed below were also used, as well as discussions with Ben Graybeal (FHWA) and Vic Perry (Lafarge):

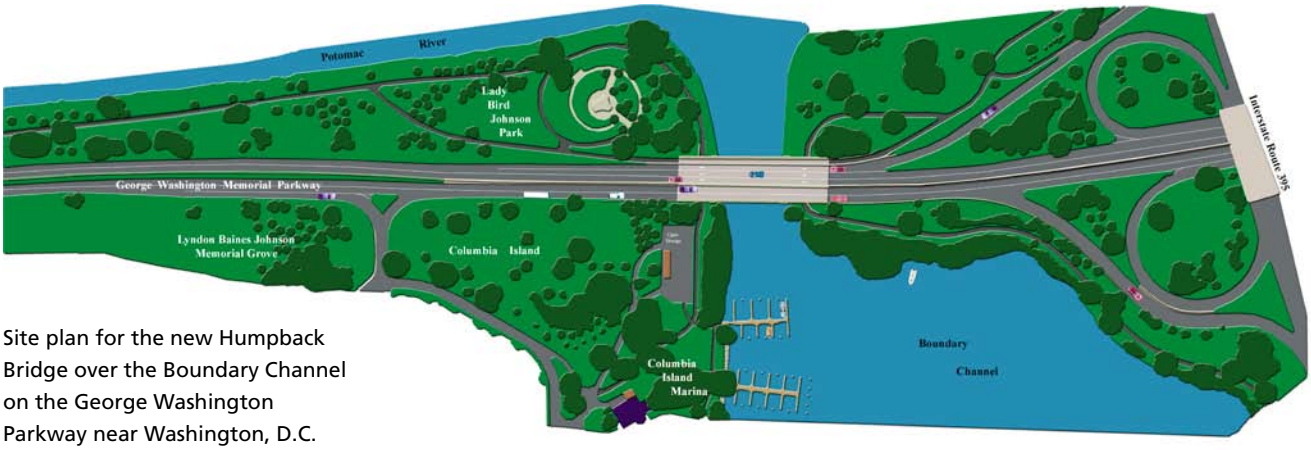
1. Gowripalan, N. and Gilbert, R. I., *Design Guidelines for Reactive Powder Concrete, Prestressed Concrete Beams,* University of New South Wales, 2000.
2. Graybeal, B. A., *Structural Behavior of Ultra High-Performance Concrete Prestressed I-Girders,* Federal Highway Administration, Publication No. FHWA-HRT-06-115, 2006, 104 pp.
3. Graybeal, B. A., *Material Property Characterization of Ultra High-Performance Concrete,* Federal Highway Administration Publication No. FHWA-HRT-06-103, 2006, 186 pp.
4. Ulm, F. J., Research and design recommendations, 2004.

The precast concrete arches had a complicated series of temporary post-tensioning and sequenced permanent post-tensioning procedures to follow. The strand and reinforcing bar layouts within the components were complex.
Photo: Northeast Prestressed Products LLC.

The arches were match cast, with odd-numbered pieces cast first. Those were then used to form the match-cast even-numbered pieces. Photo: Northeast Prestressed Products LLC.

## **HUMPBACK BRIDGE OVER THE BOUNDARY CHANNEL** / VIRGINA

High-performance, cast-in-place concrete is used for the bridge deck. Deck haunches over the beams range from about 2½ in. to nearly 7 in. Dowel bars will be screwed into inserts in the tops of the beams. The shallow recesses there complete the provisions for horizontal shear in the composite deck. Photo: Cianbro Corp.




Site plan for the new Humpback Bridge over the Boundary Channel on the George Washington Parkway near Washington, D.C.


The 123-ft main span and abutments were constructed of 4500-psi, cast-in-place post-tensioned concrete to eliminate the need for a pier in the street's median.

**Transverse, hollow bin-type abutments were used to allow smaller and more efficient abutment foundations.**

The use of a box girder allows the incorporation of utilities inside the structure, creating a more aesthetically pleasing and protective design.