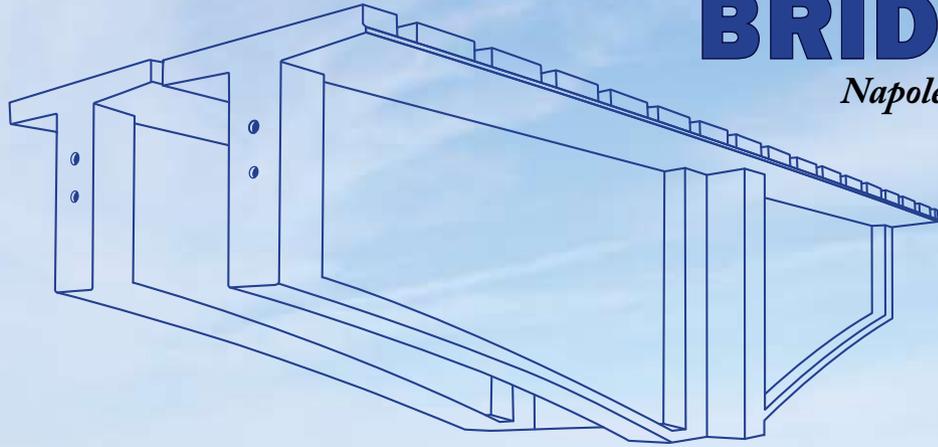


PERRY STREET BRIDGE

Napoleon, Ohio





I-280, Veterans' Glass City Skyway, Toledo, Ohio
Owner: Ohio Department of Transportation
Contractor: Bilfinger Berger

CABLE-STAYED BRIDGES FOR THE FUTURE

Landmark cable-stayed bridges are a specialty of FIGG. The FIGG Team has designed or studied 30 cable-stayed bridges in North and South America. Owners of FIGG-designed bridges have been recognized for the bridges' aesthetic and innovative designs with 249 awards; more than 100 of these in the past five years.

Join the team that brings beauty and innovation to America's bridges.

We are expanding and adding Bridge Design Engineers, CADD Designers, Construction Site Engineers and Inspectors to the FIGG Team. Please contact us at www.figgbridge.com or 1-800-358-FIGG (3444).



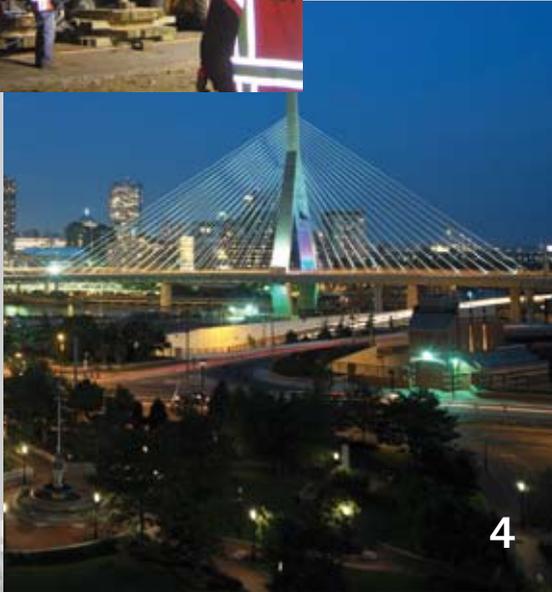
An Equal Opportunity Employer



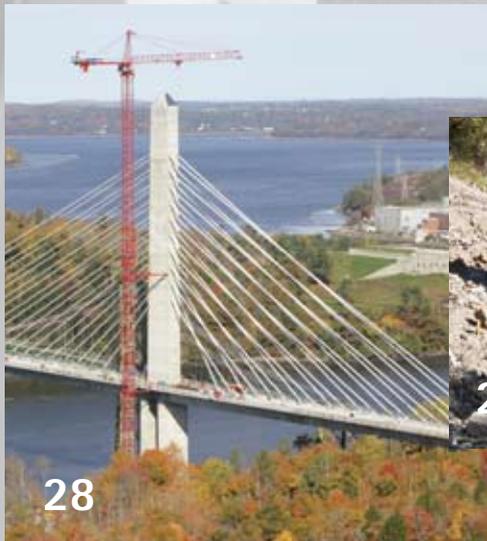
Penobscot Narrows Bridge & Observatory
linking Waldo/Hancock Counties, Maine
Owner: Maine Department of Transportation
Contractor: Cianbro/Reed & Reed, Joint Venture



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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 2007

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

March 25-28

PORTS 2007
La Costa Resort, San Diego, Calif.

March 29-31

Pile Driving Contractors Association Conference
Opryland Hotel, Nashville, Tenn.

March 30-April 2

PCI Annual Committee Days
Includes meeting of AASHTO Technical Committee on Concrete Design (T-10)
Fairmont Hotel, Chicago, Ill.

April 16-17

ASBI Grouting Certification Training
University of Texas at Austin, JJ Pickle Research Center, Austin, Texas

May 1

PCI Bridge Design Awards Entries due

May 6-8

PTI Annual Conference
Radisson Hotel Downtown, Miami, Fla.

May 7-11 Level I / Level II / Level III

PCI Quality Control & Assurance Personnel Training & Certification Schools
Embassy Suites, Nashville, Tenn.

May 14-15

ASBI Seminar on "Design & Construction of Segmental Concrete Bridges"
Seattle, Wash.

May 22-24

NRMCA Concrete Technology Forum—Focus on High Performance Concrete
Fairmont Hotel, Dallas, Texas

June 4-6

International Bridge Conference (IBC) & Exhibition
Includes ASBI Seminar on "Construction Practices for Segmental Concrete Bridges"
Hilton Pittsburgh, Pittsburgh, Penn.

July 8-12

AASHTO Subcommittee on Bridges and Structures Meeting
Also ASBI Executive Committee Meeting, July 8; ASBI Board of Directors Meeting, July 8; ASBI-AASHTO 19th Annual Reception, July 9
Hotel DuPont, Wilmington, Del.

August 1

ASBI Bridge Award of Excellence Competition Entries due

August 6-11 Level I / Level II / Level III

PCI Quality Control & Assurance Personnel Training & Certification Schools
Embassy Suites, Nashville, Tenn.

September 23-26

Western Bridge Engineers' Seminar & Exhibition, Boise, Idaho

October 14-18

ACI Fall Convention
El Conquistador, Fajardo, Puerto Rico

October 22-24

National Concrete Bridge Conference and PCI Annual Convention & Exhibition
Includes meeting of AASHTO Technical Committee on Concrete Design (T-10)
Hyatt Regency Phoenix/Phoenix Civic Plaza Convention Center, Phoenix, Ariz
Abstracts for papers being accepted until April 6.

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Cover: The Perry Street Bridge
Napoleon, Ohio
Photo: ©grandlubell.com



Photo: Ted Lacey
Photography

Welcome To *ASPIRE*™ Magazine

John S. Dick, *Executive Editor*

Welcome to the inaugural issue of *ASPIRE*,™ the first publication devoted exclusively to providing both inspirational and practical information about concrete bridge design and construction.

Targeted to you—as a principal stakeholder in the bridge design and construction community—this unique, quarterly magazine will document how owner agencies, department of transportation professionals, and consulting engineers are using concrete to solve increasingly unique design challenges. And further, how fabricators and contractors are innovating to create structures that are both beautiful and economical.

In just the past few decades, concrete has evolved from a staid commodity to a unique engineered material that can do almost anything we ask of it. Whatever the desired properties—long-lasting durability, higher strength, self-consolidating, densified, less permeable, modified with sophisticated admixtures and pozzolans, fast setting, made lighter weight, strengthened with improved/coated reinforcing steels, or prestressed to manage internal stresses—high performance concretes result in **higher performing concrete bridges and structures.**

According to the dictionary, the word *aspire* means to demonstrate “a strong desire for high achievement,” to “strive toward an end,” to “soar.” That definition aptly describes both the ambition of a bridge designer and the goal of this new magazine.

ASPIRE is a collaboration of the concrete industry. This magazine will speak with one voice and represent all concrete bridge disciplines.

Feature articles will cover dramatic and innovative new bridge projects and bridge topics that demonstrate the systems, details, applications and advantages of each concrete construction system—precast, prestressed concrete, cast-in-place concrete, and segmental construction. Each issue will profile a significant bridge engineering company, as well as provide information on trends and case histories in a high-quality, four-color format. Separate departments will provide news from FHWA, State DOTs, and county and city officials who have designed significant bridges.

In short, *ASPIRE* magazine will showcase how you and your peers are meeting challenges and expanding design boundaries with concrete bridge technology.

We have assembled a staff with an enviable record of quality in the publication business and have enlisted the technical services of professionals with unique backgrounds in both bridges and emerging materials...consultants, academics, and engineers—some formerly with public agencies. We think the read will be worthwhile, educational, and interesting. And we'll use our website (www.aspirebridge.org) to bring you more photos and “the rest of the story.” Featured articles and regular departments will be posted on the web, cross-referenced and available, along with space for your ideas, comments, questions, and suggestions. Indeed, we welcome your comments. You can reach me at jdick@pci.org.

So explore and enjoy *ASPIRE*. We covet your readership and pledge to make the time spent with us enjoyable and worthwhile.



Design firm's experience in all types of materials leads it to consider more hybrids and to examine the potential that concrete provides





Ted Zoli,
Director of
Long-Span
Bridge Design



Ray McCabe,
National Director
of Bridges and
Tunnels

HNTB

Looks To Concrete's FUTURE

By Craig A. Shutt



The 10-lane Leonard P. Zakim Bunker Hill Bridge in Boston is a concrete cable-stayed bridge featuring 270-ft Y-shaped towers. The 1432-ft-long project has won a number of design awards for HNTB.

Photo: ©Andy Ryan

HNTB's long history with bridge structures has given its engineers the culture and experience to design for a wide variety of applications and challenges. That work has only begun, its executives say, with more exciting designs and new materials on the horizon.

"We're one of the few practices that routinely designs bridges using a variety of materials and with both short and long spans," says Ted Zoli, Director of Long-Span Bridge Design. "There are circumstances where several material options are viable, but in many cases, there is a clear preference." Ray McCabe, National Director of Bridges and Tunnels, adds that such flexibility ensures clients can achieve whatever specific criteria they require.

"Right from the start, HNTB has had a culture of delivering technical excellence regardless of how that takes shape," McCabe says. "Our culture has always been to avoid forcing a bridge design to create an award-winning structure even when the challenges or demands call for it. We tailor our designs to fit the customer's needs. If one of those needs is a signature bridge, then we will deliver that while also meeting other program needs."

The company has delivered a number of signature bridges, perhaps more than any other firm in the United States, since it opened its doors in 1914. Many of them have featured concrete components. (For more on the company's history and past projects, see the sidebar and accompanying project overviews.)

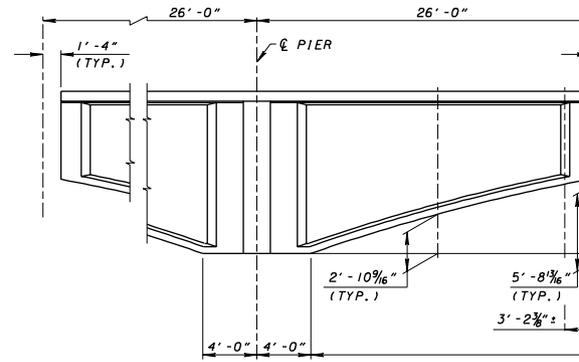
"We have some unique design elements for which we are known," says Zoli. One of those is a concrete bow-tie strut that the firm often uses with cable-stayed bridges, in which the form very much aligns with the function. "It is, in a formal sense, an optimized structure, with the depth of strut varying to match the moment demands." This design has been used on a variety of HNTB projects over the past 20 years, providing an element that is as functional as it is distinctive.

Formability Adds Advantages

The concrete bow-tie strut is an indication of how the company takes advantage of the material's inherent formability, Zoli adds. "Concrete structures may readily be shaped to resist design forces, giving us the ability to express the way that loads are carried by the structure and to meet the design goals as efficiently as possible."



Concrete bow-tie strut used with cable-stayed bridges aligns form and function.



'Concrete bridges are often ideal replacements for our nation's aging steel bridges!'



That flexibility provides a significant advantage at a time when infrastructure needs are becoming a growing concern across the country, he notes. "Concrete bridges are often ideal replacements for our nation's aging steel bridges, particularly with the advent of segmental construction." That's becoming more important in the Northeast in particular, he points out, as many bridges built during the Works Progress Administration era (1936–1943) are nearing the end of their service lives.

A key reason for concrete's popularity with owners and others around the country is the growing concerns with maintenance, both designers say. "Steel-truss bridges have been so problematic from a maintenance perspective that there's a general trend to replace steel trusses with lower-maintenance concrete superstructures, resulting in less inspection and maintenance costs," Zoli says.

Durability A Key Attribute

Durability can be enhanced by high performance concrete mixes, which are becoming more of the norm today, Zoli says. "High performance concrete has

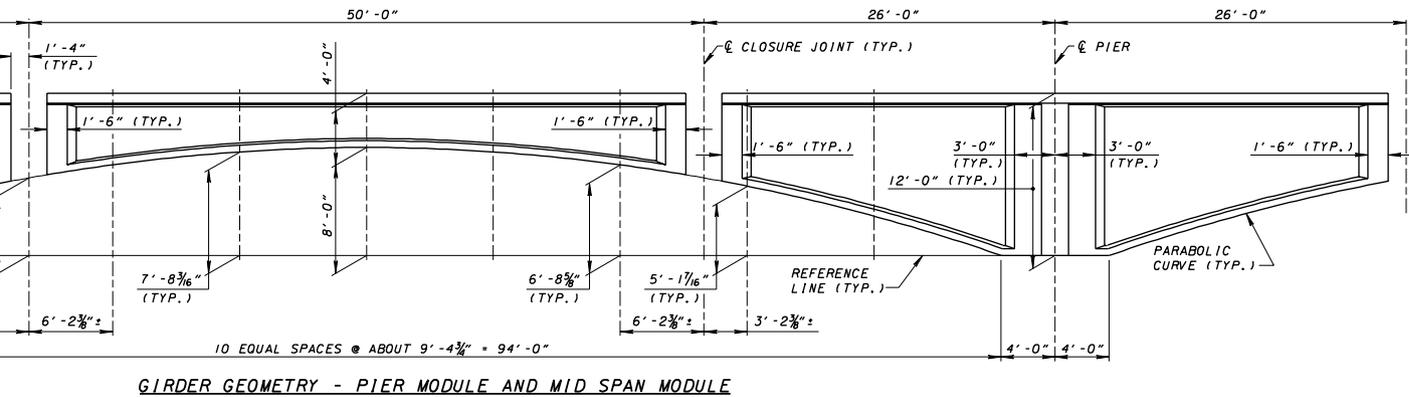


Photo: ©grandlubell.com

changed our profession in the last five to ten years. We see more and more states adopting high performance concrete throughout the United States, primarily to enhance superstructure service life. Many owners are moving to high performance concrete designs as a way to reduce maintenance costs."

High performance concrete also is being used for its strength properties, McCabe notes, but even in those instances, its low permeability and durability are key ingredients. "Durability is critical in all of our designs," he says. "That has to go hand-in-hand with other properties of the mix for it to be effective."

Construction speed is a key reason that lightweight concrete is being used more often, McCabe says. "With precast concrete bridges, weight can be an issue in delivering components to the site. Today, it's much easier to deliver lower-weight, highly efficient, and durable structures. That is the wave of the future." Lightweight concrete also provides advantages in high-seismic regions, he notes. "It can create very effective foundations and provide considerable economy." It also is being used for longer bridges, particularly those with movable portions, where weight is an issue, and for locations where foundation conditions are poor.

The Perry Street Bridge in Napoleon, Ohio, completed in only nine months, used 7000 psi compressive strength concrete to create variable-depth precast concrete modules that simulate concrete arch construction. The project recently won awards from PCI, PCA, and PTI.

The Sixth Street Viaduct in Milwaukee is the first cable-stayed bridge for vehicular traffic built in Wisconsin. Featuring high performance concrete to achieve a 75-year life expectancy, it features a post-tensioned concrete design with a cast-in-place deck. The transverse, concave-like bottom profile has a 5 ft thickness in some haunches.



The formability of concrete is one of its key attributes.

HNTB Through The Years

HNTB Corporation opened its doors in 1914 with a focus on moveable bridge designs. Originally known as Harrington, Howard & Ash, it changed its name to Howard, Needles, Tammen & Bergendoff in 1941 and shortened that to HNTB Corp. in 1993.

In 1975, a merger with Kivett & Myers launched the company's architecture practice, which became HNTB Architecture Inc. in 1994. It also draws on the experience of its 2,900-plus employees in both its transportation-infrastructure and architecture companies to serve clients through HNTB Federal Services Corporation, which was formed in 2004. The company provides government-sector clients with services that include architecture, planning, civil and transportation engineering, security planning, and military facility design.

One of the firm's first bridge projects was the Arroyo-Seco Viaduct in Pasadena, Calif., a high-rise, ribbed-spandrel arch bridge that is still in use. The company's work has resulted in a variety of innovations in design and construction through the years. Those innovations include the design of the Jesse H. Jones Memorial Bridge over the Houston Ship Channel, which opened in 1982 with the longest prestressed concrete segmental box-girder main span in America (750 ft).

More recently, the company's notable concrete bridge work has included the Sixth Street Bridge in Milwaukee; the Perry Street Bridge in Napoleon, Ohio; the Leonard P. Zakim Bunker Hill Bridge in Boston, and Florida's Hathaway Bridge, all of which are shown on these pages.

The company has won a multitude of national and regional awards for its bridge designs. Those include several for the Leonard P. Zakim Bunker Hill Bridge, including the Outstanding Civil Engineering Achievement Award from the American Society of Civil Engineers and the Grand Award from the American Council of Engineering Companies. The Perry Street Bridge was named Best Bridge with Spans between 65 and 135 Feet in the 2006 Design Awards Competition sponsored by the Precast/Prestressed Concrete Institute, one of 10 winners in the Portland Cement Association's Tenth Biennial Bridge Awards Competition, and recipient of the Post-Tensioning Institute's 2006 Award of Excellence.

Engineering News-Record magazine ranks the company as the third largest firm designing bridges, the seventh largest involved with highways, and the sixth largest involved with transportation projects of all types. It also ranks No. 25 among the Top Design Firms in the magazine's rankings.

Spliced Girders and Segmental Bridges Grow

Longer-span bridges also are using more concrete spliced girders and segmental construction, both designers agree. "There continues to be the opportunity to use either method," McCabe says. "Both have advantages depending on the application. In design-build or alternative design approaches, the decision is being left to the contractor, who typically bases the decision on past experience and risk assessment."

"Post-tensioned construction offers unique opportunities to increase the span range we can achieve while remaining competitive with long-span steel girders," says Zoli. "But the manner in which the bridge is built becomes a fundamental aspect of the design, requiring the designer to be more involved in the construction process. It creates an added responsibility and gets the engineer thinking about the exact way in which the bridge is to be built. That can create a more efficient design."

A number of these trends can be seen in the Perry Street Bridge in Napoleon, Ohio. Officials at the Ohio Department of Transportation wanted to replace the existing 700-ft-long bridge in less than one year to minimize disruptions across the Maumee River between north and south Napoleon. They also wanted to retain the original appearance and not disturb the river bottom. To achieve these goals, HNTB's designers decided the bridge "had to be constructed with as much precast concrete as possible," says James M. Barker, HNTB project manager.

To satisfy the project requirements, the designers used precast, prestressed concrete modules consisting of variable-depth, decked, bulb-tee girders. The modules contained pretensioned strands to control stresses during shipping and handling, and were spliced at the quarter points of each span using post-tensioned tendons to establish continuity. The completed structure simulates a concrete arch. The river crossing was disrupted for only nine months.

Composite structures, in which steel

and concrete components combine, are becoming more common. HNTB used such an approach recently in its design for the Leonard P. Zakim Bunker Hill Bridge, a cable-stayed structure over the Charles River in Boston. The project features heavier precast concrete box girders in the back spans, which work as counterweights to balance the lighter weight steel floor system used in the main span.

"It was an interesting choice, necessitated by the large number of subsurface utilities and tunnels, foundation locations and limited back-span length," Zoli says. Adds McCabe, "We expect we'll be doing more designs that marry the benefits of steel and concrete in composite designs, as we see improvements in high performance concrete and lightweight concrete."

Such intricate and complex designs are creating closer partnerships among the construction-team members, McCabe adds, and that's particularly apparent as more owners use design-build formats. "The design-build process is still evolving in the industry, but it's becoming more typical, because the design-bid-build process is leading to costs that go over budget too often," he explains. "Owners are being pressed to keep projects on budget and on time, and they are looking for solutions that will see the bridge they've designed be completed as planned. Design-build keeps the designer and contractor focused on ensuring the project remains on budget."

Cable-Stayed Designs Offer Efficiencies

The designers also see cable-stayed bridges becoming a more popular option for concrete bridges in the future. "Short-span cable-stayed bridges offer great efficiencies," says McCabe. "We expect to see an evolution to more efficient and quickly built concrete solutions, and flat slab cable-stayed bridges offer one approach that works."

Zoli agrees that this approach will grow. "Flat slab cable-stayed bridges provide remarkably efficient structures that are quite easy to build in either precast

'Post-tensioned construction offers unique opportunities to increase the span range we can achieve.'

Sixth Street Viaduct, Milwaukee





The Hathaway Bridge in Panama City, Fla., is a design-build replacement bridge that features two parallel structures constructed with precast concrete segmental box girders. Each structure features seven 330 ft spans, 265-ft-transition spans, and 200-ft-end spans.

'We expect to see an evolution to more efficient and quickly built concrete solutions, and flat slab cable-stayed bridges offer one approach that works.'

concrete or cast-in-place." Relatively narrow superstructures with span lengths exceeding 800 ft offer great potential for this application, he says. "They're really a missed opportunity in America, but they represent a great way to create efficient designs, particularly for small-scale bridges with spans between 500 and 700 ft—and there are many such opportunities. The flat slab cable-stayed bridge provides a cost-efficient and easily maintained design that creates a beautiful structure."

The need will grow as more steel truss bridges become functionally obsolete and need replacement, he says. "We believe the future points to more cable-stayed bridges. We're continuing to extend the span range where cable-stayed bridges are effective." The company's design of the Sixth Street Viaduct in Milwaukee shows the potential. The replacement project, representing the first cable-stayed design for vehicular traffic in Wisconsin, features a pair of post-tensioned cable-stayed bridges of 574 and 665 ft. It was designed to provide a 75-year service life.

What Lies Ahead?

Other concrete applications and innovations loom on the horizon, both designers agree. Zoli is anticipating an evolution in the use of conventional materials in new combinations, as designers consider new

concepts. One such is the use of small-diameter, high strength steel cord, such as are used on radial tires, as reinforcement in concrete. "The combination of high strength steel cord with high strength concrete has the opportunity to create an interesting new material that may result in new design and construction strategies."

McCabe also expects to see concrete production methods evolve, and he expects one area of change will focus on curing methods. "We need to achieve more foolproof curing methods," he says. He anticipates improved concrete mixes and a reduction in the heat of hydration in the mixes, as well as creating faster-setting mixes that don't crack, will encourage that evolution. "I expect in the next 10 years, we'll see more work being done to improve these mixes."

The engineers are excited about the potential designs that can be achieved as concrete expands its strength and durability while maintaining its flexibility. "Concrete is particularly suited for innovative designs, because it's not limited by the fabrication process," says Zoli. "We can form it into any shape we want. That's the freedom you get from using concrete."

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

Mark Your Calendar for the

National Bridge Conference

October 22 – 24, 2007

Hyatt Regency Phoenix/Phoenix Civic Plaza Convention Center, Phoenix, Ariz.

Cosponsored by the Precast/Prestressed Concrete Institute and the Federal Highway Administration • Featuring the Arizona Department of Transportation

Bridges For LIFE®

Featuring High Performance Bridges

The PCI National Bridge Conference (NBC) is the premier national venue for the exchange of ideas and state-of-the-art information on concrete bridge design, fabrication, and construction—particularly for precast, prestressed concrete bridges.

Concrete continues to grow as the material of choice for the nation's bridges. The continued interest in high-performance concrete and the growing excitement about methods for rapid construction promise to fuel this growth even more and dictate the need for this conference. Public agencies and industry have joined forces and are committed to bringing together the nation's most experienced, expert practitioners. Experience has shown the value of technology transfer that takes place at the National Bridge Conference.

The NBC will be held in conjunction with the PCI Annual Convention and Exhibition.

Pre-Conference

Sunday, October 21

A 60,000-square-foot exhibit hall opens with a grand reception. This year's "Spotlight State," the Arizona Department of Transportation, is featured here and in the technical sessions. Exhibitors display the materials, supplies, services, and consultants used in all facets of the industry.

PCI's active and historic Committee on Bridges continues its exciting program during an all-day meeting, which NBC registrants are invited to attend. The meeting is a premier venue for the discussion of timely technical topics on the AASHTO Design Specifications and issues facing all designers. Numerous sub-committees will also meet to continue work on new technical publications and on solutions to design challenges.

Conference Schedule

Monday, October 22

Keynote Address
General Session
Afternoon "Spotlight State" Plenary Session
Concurrent Afternoon Technical Sessions

Tuesday, October 23

Concurrent Morning Technical Sessions
Afternoon Technical Sessions
Meeting of the AASHTO Technical Committee on Concrete Design

Wednesday, October 24

Concurrent Morning Technical Sessions

Social Events and Gatherings

Throughout the event, you'll have ample time to network with colleagues and establish or renew acquaintances. Social events include an opening reception gala, lavish buffet luncheons sponsored by our exhibitors, and a dinner/dance banquet. Above all, you'll have the opportunity to immerse yourself in the state-of-the-art of concrete bridges. An exciting program of tours and activities for accompanying guests is also available.

Special Bonus

Those registering for the National Bridge Conference also have the opportunity to participate in all the exciting educational sessions of the PCI Annual Convention and Exhibition.

Call for Papers

PCI is currently accepting submissions for the NBC program, which will include approximately 11 technical sessions comprised of 44 papers, plus an additional session with papers devoted to the "Spotlight State" of Arizona. Conference proceedings will be provided to all registrants on CD-ROM and will also be available to others following the event.

Suggestions for topics of interest include:

- Beams with Integral Decks
- Bridge Aesthetics, Coatings, and Colors
- Bridge Repair and Rehabilitation
- Creative Concrete Bridge Solutions
- Contractor Alternates, Value Engineering, and Design-Build
- Designing and Retrofitting for Seismic Forces
- Designs to Facilitate Fast Construction
- Hauling and Transporting Studies
- High Performance Concrete/High Performance Solutions
- Innovative Concrete Bridges
- LRFD Issues, Research, and Monitoring
- Materials—SCC, Light Weight, High Strength
- Plant Forming/Production Reports
- Post-Tensioning Technology/Applications
- Precast Bridge Decks
- Precast Substructures
- Project Case Studies
- Research in Action
- Spliced Girder Solutions

A technical committee will review submissions. Abstracts must be no longer than one, double-spaced, typewritten page and must adequately describe the topic. It must state the author's willingness to present the paper at the National Bridge Conference if the reviewers choose the paper. If multiple authors are listed, the statement must identify the presenter.

The deadline for receipt of abstracts is **April 6, 2007**. Abstracts should be submitted electronically according to the instructions at www.pci.org. Selected authors will be notified April 18, 2007, and final written papers are due July 2, 2007. Requirements for papers can be found at www.pci.org.

For more information, contact **John Dick**; Tel.: (312) 360-3205; Fax (312) 786-0353; or Email: jdick@pci.org.



The reinforcing steel for each pier is designed to help the structure withstand a major seismic event. A circular well-confined column is located at each corner of the pier.

BUILT TO RESIST THE BIG ONE

by Daniel C. Brown

This is a bridge for the record books. Now nearly complete, the San Francisco-Oakland Bay Bridge Skyway is a world-class concrete structure for several reasons:

- Its precast girder segments are some of the largest bridge segments ever built in the world. The huge segments weigh 300 to 800 tons, whereas more typical segments weigh 40 to 60 tons.
- The structure's pre-tied reinforcement cages are among the largest ever set in North America. The pier column reinforcement cages, placed in one section, weigh up to 300 tons.
- The bridge has its foundations in deep Bay mud, yet it is close to two major California fault lines and must resist a major earthquake.

profile

SAN FRANCISCO-OAKLAND BAY BRIDGE — SKYWAY SECTION / OAKLAND, CALIFORNIA

ENGINEER T.Y. Lin International/Moffatt & Nichols, a joint venture

PRIME CONTRACTOR Kiewit/Flatiron/Manson, a joint venture

CONCRETE SUPPLIERS Pacific Cement, San Francisco (precast); RMC Lone Star, Davenport, Calif. (ready mixed)

PRECASTER Kiewit/Flatiron/Manson, a joint venture

CONSTRUCTION ENGINEER Parsons Transportation Group, Oakland, Calif.

POST-TENSIONING AND SEGMENT ERECTION EQUIPMENT Schwager Davis, Inc., San Jose, Calif.



Kiewit/Flatiron/Manson set up a precasting yard in Stockton, Calif., and barged segments to the job site. This long-line casting bed can cast all the segments needed for one cantilever.

Untold hours went into the seismic design for this \$1-billion precast concrete segmental bridge, resulting in a unique bridge that extends the limits of concrete design

The San Francisco–Oakland Bay Bridge consists of 16 separate contracts, and the Skyway, which connects the Oakland approach on the east with a self-anchored suspension span to the west, is only one component—but a major one. It consists of separate eastbound and westbound structures designed for five lanes of traffic each plus shoulders on both sides. Each structure has an overall width of 87.5 ft, a length of about 1.3 miles, and consists of four structural frames joined together by hinges that can transfer shear and moment while allowing longitudinal movement.

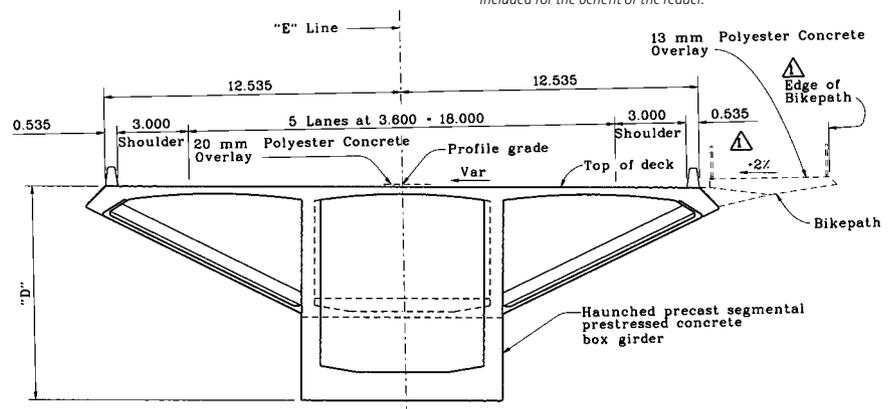
Designed for a 150-year service life, the Skyway has taken about five years to build. A section of the existing 1930s-era eastern span of the San Francisco–Oakland Bay bridge collapsed in the 1989 Loma Prieta earthquake, and the California Department of Transportation decided to replace it rather than retrofit the older bridge for seismic resistance. Preliminary design on the Skyway started in 1998, and the joint venture contractor, Kiewit/Flatiron/Manson (KFM), launched construction on February 6, 2002.

Largest Segments Ever

After consideration of baseline designs in both concrete and steel, concrete emerged as the least expensive material, says Sajid Abbas, project engineer for T.Y. Lin International in San Francisco, the bridge's designer. Each structure consists of a three-cell, variable-depth box girder built of huge precast concrete segments. "I believe these are the largest precast bridge segments cast anywhere at any time," said Tom Skoro, KFM project manager.

Seismically-resistant foundations are expensive to construct in the Bay mud, and foundation work accounted for about half of the bridge's \$1-billion-plus cost. To offset the larger costs of the foundations, the balanced-cantilever method of construction was used for the superstructure. In this method, the variable depth segments were erected in both directions working outward from the piers. This method permitted span lengths up to 160 m (525 ft).* The depths

*The Skyway Bridge was designed using SI units. Conversions are included for the benefit of the reader.



The Skyway segment is a three-cell custom design in precast concrete. Segments are 26.7 m (87.5 ft) wide and range in depth from 9 m (29.5 ft) at the piers to 5.5 m (18 ft) at the midspans.

SEGMENTAL PRECAST CONCRETE / CALTRANS, OWNER

REINFORCING STEEL FABRICATOR Regional Steel Corporation, Tracy, Calif., and Martinez Steel Corp. (Precast Segments) Harris Salinas Rebar Inc., Livermore, Calif. (Cast-In-Place Concrete)

BRIDGE DESCRIPTION A dual, 2.1-km (1.3-mile)-long parallel structure built using precast concrete segments erected in balanced cantilever with a typical span of 160 m (525 ft)

STRUCTURAL COMPONENTS 452 precast concrete segments weighing 300 to 800 tons each; 28 cast-in-place, post-tensioned pier tables, each 88 ft wide by 66 ft long by heights varying from 16 to 30 ft; cast-in-place concrete piers; 160 concrete-filled piles up to 350 ft long; and 28 steel footing boxes weighing 900 tons each

BRIDGE CONSTRUCTION COST \$1.044 billion

A segment is loaded onto a floating barge that fits into a slip at the precasting yard. The big straddle carrier, used to transport segments around the precast yard, has wheels with a diameter of 11 ft.



of the section ranged from 9 m (29.5 ft) at the piers to 5.5 m (18 ft) at midspans. Most segments have a length of 8 m (26 ft). The use of longer span lengths increased the cost of the superstructure but reduced the number of spans and, therefore, the cost of the foundations.

By contrast, span-by-span construction would have limited span lengths to about half the Skyway's 160 m (525 ft). That would have doubled the number of piers and made the bridge much more costly. On the other hand, Abbas notes, span-by-span construction for the superstructure would have been efficient because the segments would have a constant depth.

Designed In Four Frames

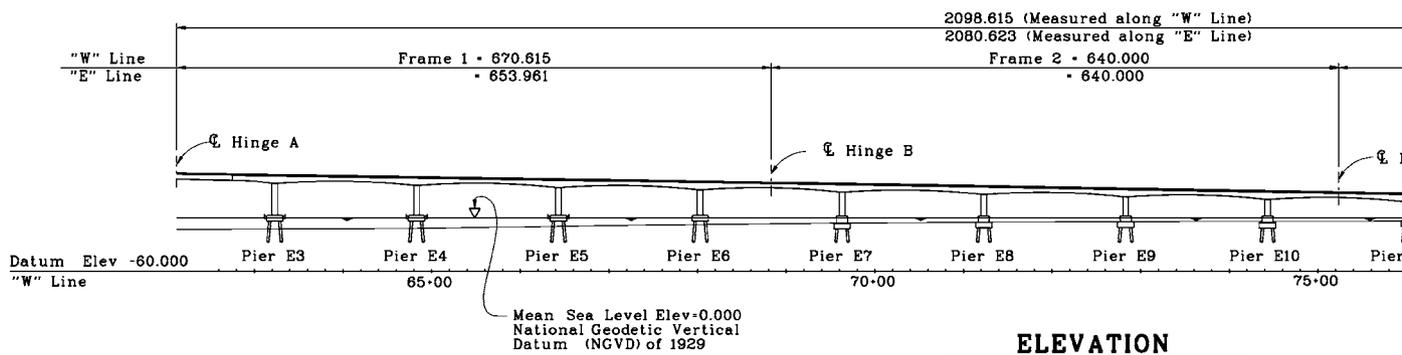
The Skyway is designed in four frames; three have four piers and one has two piers. The frames are typically connected at midspan by a large hinge consisting of twin steel-pipe beams, each 2 m (6.5 ft) in diameter and 20 m (66 ft) long. The pipe beams are supported in four diaphragms, two on each side of the joint. The hinges can transfer moment and shear while allowing longitudinal movement.

"The Bay mud shakes like a bowl of jelly during an earthquake," says Abbas. "The alignment places the bridge in deep Bay mud, and it is near two active faults—the Hayward Fault to the east and the San Andreas Fault to the west." "We

designed a seismically robust structure. During a seismic event, the hinge pipe beams constrain the adjacent ends of the cantilevers to move together transversely, as well as act as seat extenders in the longitudinal direction, precluding any potential for unseating." The Skyway is designed for a Safety Evaluation

'We designed a seismically robust structure.'

Earthquake (SEE), which has a 1500-year return period, he notes. "The piers will take the brunt of an earthquake. The reinforced concrete piers are designed to behave in a ductile manner, and the rest



'There was heightened awareness about controlling the creep and shrinkage of the concrete as well as the modulus of elasticity.'

All reinforcing steel below a line 7 m (23 ft) above sea level is epoxy-coated to resist corrosion. That means reinforcement inside the 160 steel-lined piles is epoxy coated, as is the reinforcing steel in the pier caps and the lower portion of the piers.

Construction Challenges Aboard

To complete the bridge, more than 190,000 cu yd of concrete had to be batched and delivered to the bridge for footings, access casings, piers, and pier tables. KFM worked closely with the concrete supplier, California Readymix, (a subsidiary of RMC) to locate an on-site batch plant at Pier 7. The construction team developed concrete transport barges capable of handling 40 cu yd per

barge, and the barges could deliver 70 cu yd per hour to the bridge, says KFM project engineer Paul Giroux.

At the bridge, concrete was conveyed from the transport barge to the placing barge, after which a conveyor took the concrete to KFM's barge-mounted 58-m (190-ft) concrete pump truck, from where it pumped the concrete to the desired location.

To cast the concrete segments for the big box girders, KFM built its own precasting yard in Stockton, Calif., about 70 miles from the construction site. All 452 segments were match cast at Stockton, stored for two to six months to reduce the effects of creep and shrinkage, and then barged to the bridge. The 55 acre precasting yard used two specialized long-line beds, a short line bed, and a hinged bed for the hinge segments.

The long-line casting beds could sequentially cast all the segments required for a complete half of a bridge cantilever, typically segments one through nine for each cantilever. The long-line bed consists of an inverted soffit system with adjustable geometry and a movable core that forms the interior voids of the segments, Giroux explains.

"In addition to the challenges of precasting the huge segments, we also faced a real challenge to develop and implement the necessary dimensional controls to ensure that all of the 452 segments would be match cast properly so they would all fit properly once erected in Oakland," says KFM's Skoro. "Further, as if the dimensional control challenges of the segment were not enough, our schedule dictated a three-day cycle for each segment in the casting bed."

Once segments were barged to the bridge, KFM used Self-Launching Erection Devices (SLEDs) to lift the segments into place on the cantilevers. The SLEDs are essentially computerized beam and winch systems, says Giroux. "The SLEDs are highly engineered, driven by the complexities of hoisting loads up to 800 tons from a barge that is subject to wind and wave action."

The SLEDs are anchored initially to the pier tables with 3-in.-diameter high strength bars. After a cast-in-place concrete closure placement is made between the pier table and the first segments and post-tensioned together, the SLEDs advance onto the leading segment where they are re-anchored. Then the next pair of segments are erected and post-tensioned together. The process then repeats, with the SLEDs advancing outward from the pier

At KFM's precasting yard, lightweight precast concrete sections for the sloping webs are placed before the remainder of the segment is cast.





Two Self-Launching Erection Devices (above the deck), which are computerized beam-and-winch systems, lift segments from barges into place on the cantilevers.

Designers faced the challenge of ensuring all 452 segments would be match-cast properly.

table until all nine pairs of segments of a typical cantilever have been erected. "When we are in full cycle working two shifts, each set of four SLEDs erected two segments per day," said KFM's Skoro.

High Strength Concrete Used

Normal weight concrete for the superstructure was specified to have a compressive strength of 8000 psi at 56 days. Lightweight concrete panels in the inclined webs of the segments were to have 6500 psi compressive strength at 28 days, says Abbas. In addition, the normal weight concrete was required to have a modulus of elasticity of at least 5160 ksi at 28 days, a specific creep not exceeding 0.52 millionths/psi at 365 days and a shrinkage not exceeding 0.045 percent after 180 days of drying.

"There was heightened awareness about controlling the creep and shrinkage of the concrete as well as the modulus of elasticity," says Abbas. Accordingly, segment concrete uses shrinkage-

reducing admixtures, which can reduce initial shrinkage by as much as 40 to 50 percent and long-term shrinkage by 20 to 30 percent, depending on the dosage. For the pier tables, which contained a dense concentration of reinforcement, the use of self-consolidating concrete was considered, Abbas notes. However, when conventional concrete performed satisfactorily, Caltrans decided to stay with it.

To control the effect of shrinkage, the construction team used frame jacking within the four-pier frames, which have lengths of 691, 640, and 584 m (2280, 2112, and 1927 ft). Finally there is a two-pier, 188-m (620.5-ft) Frame 4. Once all cantilevers in a frame were erected and the closures in the outside spans were cast, KFM used a set of six jacks per girder web, placed at the location of the closure in the center span of the frame, to jack the two sides apart by about 4 in. using a load as large as 4000 tons. The central closure was then cast before the jacks were released.

"The intent is to compensate for long-term creep and shrinkage," says Abbas. "There was a total of six jacking operations in the entire bridge."

Not only is the bridge built "hell for stout," as contractors say, it's a handsome structure. Abbas notes that the architectural team was very active throughout design process. The architects requested that the shape of the girder's cross section match the steel section on the self-anchored suspension bridge to the west to provide a continuity of form.

The architectural team also was concerned with the shape of the piers, the look of the bike path on the north side of the eastbound bridge, and the light standards. That attention to detail added architectural interest to a bridge that already had structural engineers looking at it as if it were a thing of beauty.

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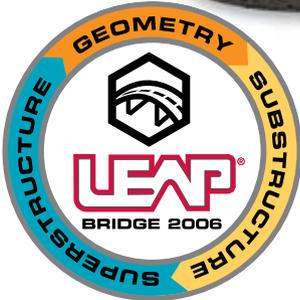


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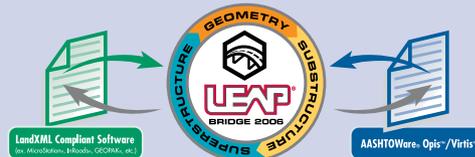
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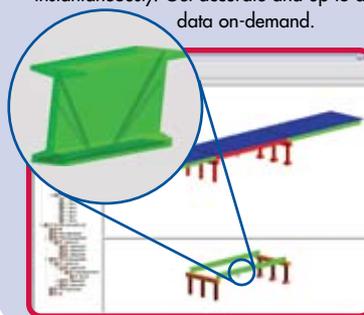
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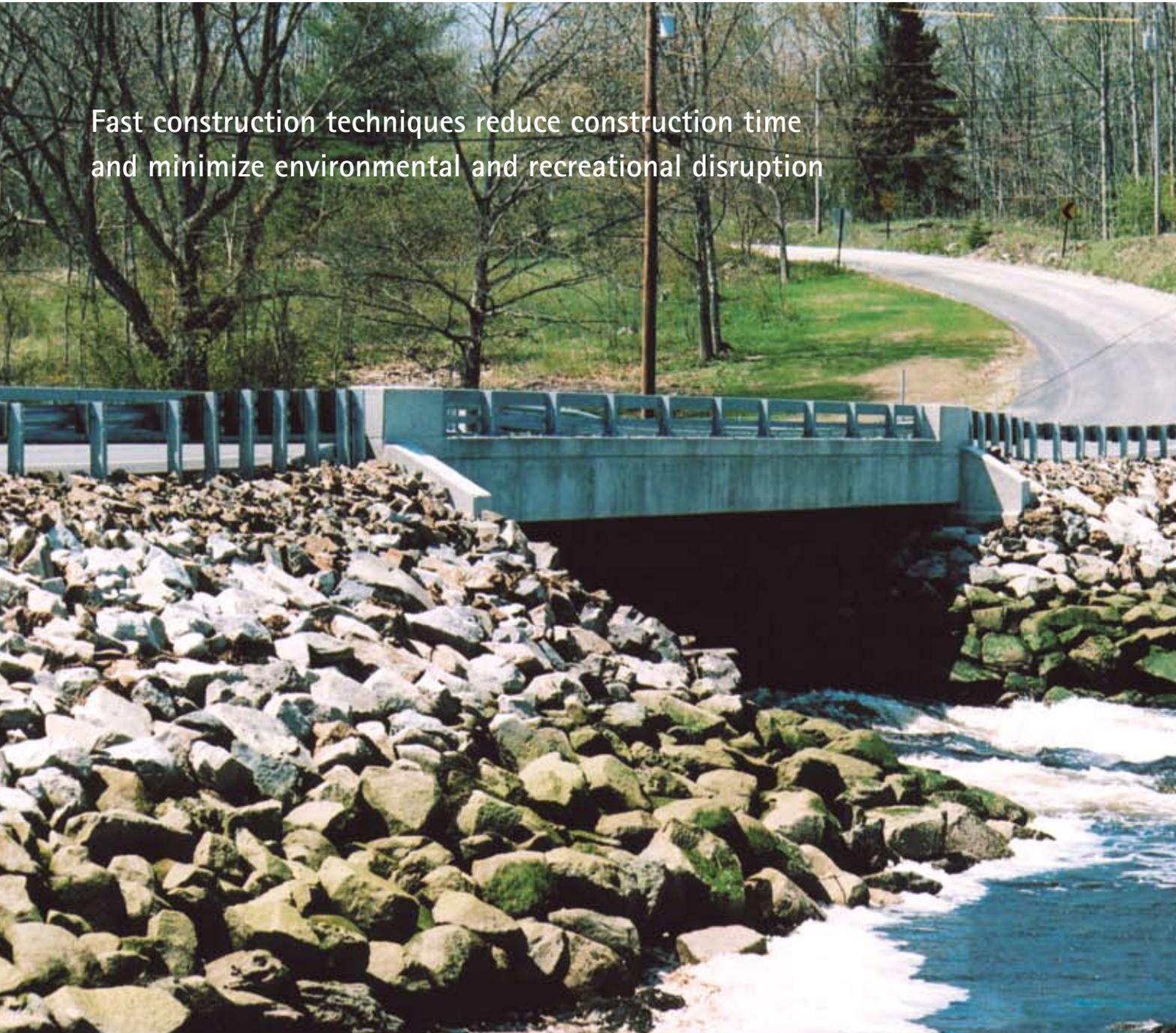


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profile

DAVIS NARROWS BRIDGE / ACROSS THE BAGADUCE RIVER, BROOKSVILLE, MAINE

ENGINEER Maine DOT

PRIME CONTRACTOR Reed & Reed Inc., Woolwich, Maine

PRECASTER Strescon Limited, Saint John, New Brunswick, Canada

***AWARDS** 2006 PCI Bridge Design Award for the Best Bridge with Spans Between 65 Feet and 135 Feet and the 2006 PCI All-Precast Solution*

COMPLETED IN 30 DAYS

by Craig A. Shutt

The new totally precast concrete bridge features abutments placed behind the existing ones to maintain the constriction on the flow of water.



Complications arose in the design of the new Davis Narrows Bridge in Brooksville, Maine, because of sensitive environmental issues and the community's desire not to lose its rapids.

Designers looking to replace a deteriorated 90-ft-long bridge in Brooksville, Maine, faced several key challenges. The principal challenge was to minimize closure time due to the long detour required, while meeting a variety of unique community needs. A totally precast concrete bridge system met all of these needs and allowed the bridge to open only 30 days after closure.

The existing bridge had been built in 1941 using painted rolled steel beams on dry-laid granite blocks. Corrosion made it a prime candidate for replacement, but the community was concerned that the new bridge would disrupt the existing structure's "recreational value" and the sensitive river environment.

"The causeways created a constriction of the daily tide that produced rapids between high and low tide," explains M. Asif Iqbal, project manager with the Maine Department of Transportation. "This phenomenon has added entertainment and recreational value on which many tourists and locals depend for

riding kayaks and inflatables during the summer. As a result, the locals didn't want any change to the hydraulic characteristics."

The river also is one of the few areas where Horseshoe crabs breed and is a natural fishing ground for local people and wildlife. Oyster farmers downstream also were concerned that silt and sediments from construction would disrupt their livelihood. Those factors, plus tourism in the area that would be disrupted by a bridge closure, created scheduling restrictions that complicated the design.

Design Minimizes Disruptions

"We decided early on that a totally precast, prefabricated system would considerably reduce construction time and the impact on the local residents and wildlife," says Iqbal. Using precast components fabricated in an off-site plant significantly reduced equipment movement, excavation, and flow of any concrete into the tidal area, he notes. The precast abutments also eliminated

PRECAST, PRESTRESSED CONCRETE / MAINE DOT, OWNER

BRIDGE DESCRIPTION A 90.5-ft-long single span bridge constructed with a totally precast concrete system

STRUCTURAL COMPONENTS Four precast abutments, two at each end; four wing walls, two at each end; four precast concrete approach slabs, two at each end; and eight precast, prestressed concrete box beams, B11-48 (89 ft long, 4 ft wide, and 3 ft deep)

BRIDGE CONSTRUCTION COST \$1.06 million

Precast components significantly reduced equipment movement and excavation, limiting debris in the tidal area.



the need for cofferdams, which would have disturbed the river sediments. "The use of silt booms at both abutments was all that was needed with precast units."

The precast concrete units also helped minimize closure time. The bridge was designed according to the AASHTO LRFD Bridge Design Specifications. The design took place during the winter of 2005 and a contract awarded in July 2005. The construction team then worked out the sequencing to ensure the fastest possible return to service. They decided to construct the new causeways leading to the bridge first, and then close the bridge to complete the project.

To minimize impact to the existing flow characteristics, the new approach roads on the causeways were built on choke-stone layers stabilized with geotextiles.

This took three weeks, after which the bridge was closed on September 6, 2005. It opened to traffic again just 30 days later on October 5.

The new integral abutments were designed to sit 12 ft behind the existing abutments, to ensure the river hydraulics remained the same. The new integral abutments are supported on four piles, which were driven to bedrock. The abutments consist of two precast center units and two precast extended wing-wall units. The units were post-tensioned together with six threaded bars. Voids were designed into the abutment units to receive the piles and were enlarged to decrease shipping weight.

Once the abutments were in place and the post-tensioning was complete, the voids were filled with self-consolidating

concrete through the 6-in.-diameter ducts on top of the abutment units. The ducts then were filled with conventional grout. "The use of precast abutments significantly reduced the impact to the river and tidal areas and reduced the construction time by a third," Iqbal says.

The superstructure features eight adjacent precast, prestressed concrete box beams that were post-tensioned transversely to act as a single unit. They were delivered and erected at the rate of three per day. The beams were slid across the river on a launching-girder system and then lifted into place using 110- and 80-ton cranes. The shear keys between the beams were filled with a pea gravel concrete mix. Transverse post-tensioning strands were located at five points along the beams.

Because cracks could have developed in concrete curbs precast on the fascia beams as they were delivered over the rough local roads, cast-in-place curbs were used. The precast approach slabs were erected after the beams and positively connected to the abutments. These slabs support a layer of gravel subbase and prevent settlement of the approaches.

'The four precast units comprising each abutment took only two hours to erect and post-tension.'

Fast Construction During Closure

The first week of closure was spent removing the tops of the existing abutments and excavating the new abutment locations. During the second week, piles were driven and the abutments were erected. "The four precast units comprising each abutment took only two hours to erect and post-tension," Iqbal reports. Grouting was accomplished at low tide.

During the third week, the beams were erected with a crane positioned on

either embankment. Work on the curbs started as soon as the first fascia beam was in place. The wing-wall tops were cast early in the fourth week, followed by installation of bridge rail and the application of a high performance membrane. The pavement riding surface was applied during the final two days of closure.

The contract specified a time limit of 35 days for construction, with incentives of \$1000 per day for beating that deadline. Equal disincentives also applied. The project was completed five days early. Guard rails were installed during the two days after the bridge opened, but traffic was light and no lane closures were needed, Iqbal reports.

"The use of precast, prestressed concrete beams significantly reduced erection time," Iqbal says. "Substantial time also was saved by not having to construct a deck like the old bridge. We were very pleased with the swiftness with which the contractors could handle the precast units and also the ease of installation."

The project will have ramifications for future designs, because it was only the second bridge in the state to use precast abutments and the only totally precast concrete bridge built over salt water. "The totally precast solution allowed fast construction and promoted low environmental impact because of the ease of construction," Iqbal says.

The community was pleased with the project as well. A group got together to buy drinks for the entire construction crew to celebrate the bridge opening. "This was truly a project that had many issues that needed to be resolved early," says Iqbal. "But they came together with the help of dedicated teams from both the DOT and the contractors, and certainly with the technology of the precast concrete units."

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



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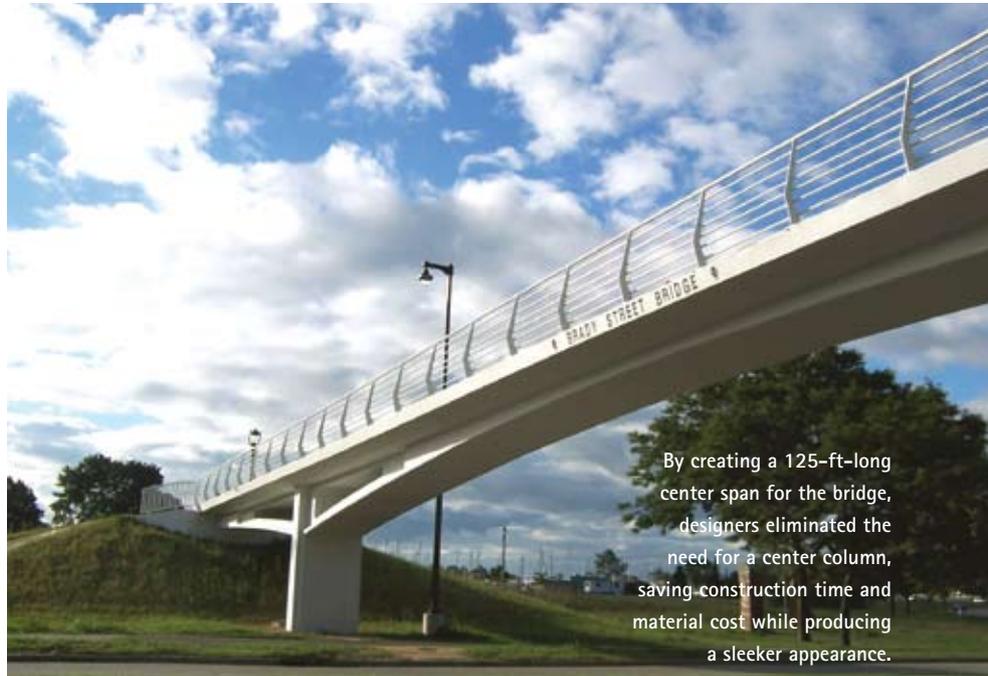
by Craig A. Shutt

Milwaukee County officials knew they faced a number of key challenges when they decided to replace the existing Brady Street pedestrian pathway along the lakefront. To accomplish the range of goals on a difficult site while providing strong aesthetic appeal, the designers created a unique post-tensioned, three-span concrete bridge that will have minimum maintenance needs throughout its lifetime.

The original structure provided access to neighborhoods on top of a bluff along a bike trail and continued to a nearby park on Lake Michigan. It included a series of stairways to accommodate steep slopes coming down from the bluff and a reinforced concrete bridge that led pedestrian traffic via another stairway to the lakefront. Aesthetics for the new bridge were of paramount concern, as the neighborhood has a high profile, hosting the Milwaukee Art Museum and the Milwaukee County War Memorial as well as a number of architecturally interesting bridges.

Vertical Slope— A Key Challenge

"The project's main goal was to address the steep vertical slope across the pathway and make it accessible to pedestrians and bicycles, and comply with the Americans with Disabilities Act (ADA)." explains Yan Nenaydykh, vice



By creating a 125-ft-long center span for the bridge, designers eliminated the need for a center column, saving construction time and material cost while producing a sleeker appearance.

Concrete meets a variety of functional challenges while providing strong eye appeal for pedestrian bridge in highly visible neighborhood

president of Bloom Consultants LLC in Milwaukee. He and his colleagues Darrell Berry, project manager; Boris Sloutsky, senior structural engineer; and Yakov Braverman and Anil Kurian, project engineers worked with Edwards & Kelcey (E&K), to create a plan to meet the various site requirements. E&K developed the overall bike trail project, while Bloom Consultants designed and engineered the bridge itself.

A key challenge was to improve the vertical alignment, which E&K proposed accomplishing with a single switchback to address the steep slope. The design offered a constant 5% vertical slope from end to end. The existing stairway at the eastern end, connecting to the lakefront, was replaced with a circular ramp that met ADA and AASHTO requirements. The goal then became finding an approach and materials that

profile

BRADY STREET BRIDGE / CITY OF MILWAUKEE

PROJECT CONSULTANT Edwards & Kelcey, Morristown, New Jersey

BRIDGE ENGINEER AND ARCHITECT Bloom Consultants LLC, Milwaukee, Wisc.

PRIME CONTRACTOR Lunda Construction Co., Black River Falls, Wisc.

CONCRETE SUPPLIER Zignego Ready Mix, Waukesha, Wisc.

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

AWARDS Award of Excellence, 2006 PCA Tenth Biennial Bridge Awards Competition

'The best aesthetic results for modern-day pedestrian bridges are achieved utilizing thin and continuous superstructures.'

could meet the design requirements and offer the appearance the county desired.

"The best aesthetic results for modern-day pedestrian bridges are achieved utilizing thin and continuous superstructures, with structural member shapes that reflect the forces acting on them," explains Nenaydykh. "Special attention had to be paid to the structures in close proximity to the project as well as to the relationship between the bridge and the surrounding landscape."

Sloutsky developed the original bridge concept and together with his structural colleagues prepared design and finite-element analyses of the structure. The bridge design features high performance concrete (HPC), allowing the engineers to take advantage of post-tensioning techniques to eliminate the center pier and create a long center span. This approach not only provided better access and aesthetics, but it reduced construction time and material. "Overall, the community received a graceful, economical structure with a service life of 100 years," says Nenaydykh.

Cost savings on the bridge will grow, as its design minimizes long-term maintenance costs, notes Nenaydykh. "There are no bearings or joints on the bridge that will deteriorate with seasonal changes," he points out. "With the combined effect of HPC, post-tensioning, and conventional reinforcement, there is

an increased reserve load capacity and load distribution, which will also result in better resistance to damaging loads."

Span-To-Depth Ratio: 71

The bridge design features two end spans of 40 ft each and a 125-ft-center span. The bridge has a 10-ft-wide travelway with 9½-in. curbs, and 4-ft 6-in.-tall railings on each side. The superstructure has a shallow arch bottom, with a minimum thickness of 1 ft 9 in. at the middle of the center span, creating a span-to-depth ratio of 71. The superstructure features a 6000 psi compressive strength HPC concrete slab section varying in thickness with the span. Triangular openings were

provided in the superstructure on either side of the piers to reduce the volume of concrete used and enhance the structural beauty. The minimum vertical clearance under the bridge is 14 ft 7 in., less than the state minimum (16 ft 3 in.), which was waived because no truck traffic is allowed on the Milwaukee's Lincoln Memorial Parkway below.

At the middle of the center span, auxiliary non-prestressed reinforcement was used, along with the post-tensioning to resist flexural tension at ultimate design loads. The non-prestressed reinforcement also provides structural redundancy during cases of overload. Five tendons were used to post-tension the superstructure. Each tendon consisted of nine 0.6-in.-diameter low-relaxation strands with an ultimate strength of 270 ksi. They were bonded



A berm was created up to the edge of the bridge along the end facing the lake to avoid the need for a long stairway and to lower budget needs.



POST-TENSIONED, CAST-IN-PLACE, HIGH PERFORMANCE CONCRETE / MILWAUKEE COUNTY, OWNER

BRIDGE DESCRIPTION: A three-span, post-tensioned concrete bridge with a 125-ft center span to eliminate the need for an interior column support

STRUCTURAL COMPONENTS Two 40-ft slab end spans and 125-ft shallow arch center span, plus piers, foundations, and abutments

BRIDGE CONSTRUCTION COST: \$450,000, including removal of old structure



PTI Celebrates 30th Anniversary... Expands Bridge Efforts

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After years of focusing its attention on other construction markets, PTI has committed to strengthening its support for the bridge engineering and construction community. Several new bridge-related efforts have been launched in recent years including the formation of a new Bridge technical committee.

Key bridge activities include:

- *6th Edition of the Post-Tensioning Manual*—this major update includes two new chapters on bridges and stay cables, authored by Dr. Paul Gauvreau and David Goodyear, respectively.
- *Grouting Specification*—developed by PTI's Grouting Committee, this new specification represents a major advance in post-tensioned construction.
- *PT Bridge Manual*—updated combination of existing PTI publications providing guidance on design and construction aspects unique to post-tensioned bridges (currently under development by the PTI Bridge Committee).
- *Design and Construction of Post-Tensioned Bridge Decks*—a new manual addressing the design and construction of post-tensioned bridge decks (currently under development by the PTI Bridge Committee).
- *Recommendations for Stay Cable Design, Testing and Installation*—the PTI Cable-Stayed Bridge Committee is currently drafting the 5th edition of these recommendations, which serve as the standard for cable-stayed bridge construction around the world.
- *Certification – Bonded Tendon Installation*—this comprehensive training and certification program is intended for all field personnel involved in the installation of bonded post-tensioning, including installers, inspectors, and construction managers.

In addition to these specific activities, PTI has other areas of interest to bridge designers. The *PT Journal* is published semiannually and often includes papers on durability and bridge design. PTI also sponsors an annual technical conference to showcase the latest in post-tensioning technology. The next conference will be held in Miami, Florida, on May 6-8, 2007.

For more information on PTI, please visit www.post-tensioning.org.

to the surrounding concrete by injecting cementitious grout after tensioning the tendons.

Piers and foundations were constructed of conventional concrete. The pier columns have a 3- by 7-ft rectangular shape and are rigidly connected to the superstructure. The piers rest on a pile foundation consisting of twenty 10³/₄-in.-diameter concrete-filled steel pipe piles driven to a minimum bearing capacity of 40 tons and an average embedment length of 55 ft.

The superstructure rests on jointless fixed-integral abutments. "The long center span, compared to the end spans, produced uplift at the abutment ends, but integral abutments were designed to provide resistance against this uplift," Nenaydykh explained. A 1-ft-thick slab at the base of the abutment and structural backfill on top of the slab provided the necessary resistance to uplift. The abutments were supported on a single row of five 10 ³/₄-in.-diameter concrete-filled, steel-pipe piles driven to a minimum bearing capacity of 50 tons and an average embedment length of 70 ft. Reinforcing bars were welded to the side of the pipe piles to transfer uplift tension in piles to the abutment.

The slenderness was further enhanced by the bridge's finishes, which included a penetrating, acidic stain for all portions of the concrete surfaces above grade level. "The white color matched the color of the Calatrava Bridge located just south of the project and also gives the Brady Street Bridge a clear definition as an object in the landscape," explains Nenaydykh.

End Spans Built First

The abutments, piers, and end spans were constructed first, with the center span using an additional temporary support at the median. Shear keys were supplied at the superstructure construction joints to transfer vertical shear across the joint. Sequential jacking of the tendons began with the middle tendon being stressed first, followed by the adjacent two and then the outermost two tendons. The

The thin lines of the metal railing help emphasize the shallow profile of the bridge.



The sleek look of the new bridge was created by post-tensioning the three spans; thereby reducing the weight of the superstructure.

'There are no bearings or joints on the bridge that will deteriorate with seasonal changes.'

tendons were jacked from both ends of the superstructure at the same time.

Approximately 125 cu yd of concrete were used for the substructure units, with another 170 cu yd used for the superstructure. The project took approximately 10 months for completion.

"Reinforced concrete rigid-frame bridges have long been a mainstay in the bridge world," Nenaydykh says. "They offer

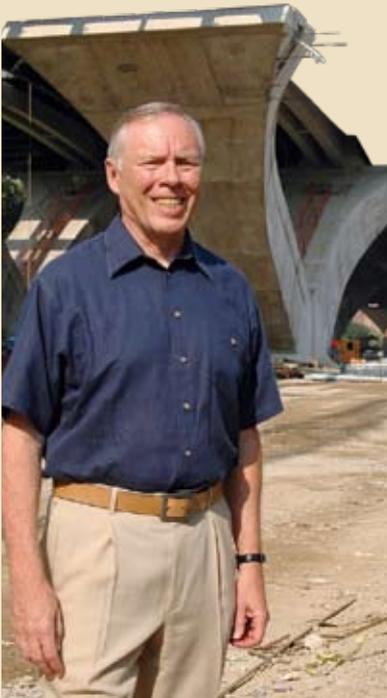
many advantages in comparison to their materials in terms of durability, economy, and maintenance. With increasing span lengths, conventionally reinforced concrete bridges tend to get bulkier, which can quickly add cost." The post-tensioning provided a continuous design and prevented that from happening in this case. "On the Brady Street Bridge, we used an innovative hybrid scheme, consisting of a concrete rigid-frame structure with a sleek shallow arch in the main central span," he notes.

"The Brady Street Bridge serves the twin purpose of functionality and architectural expression while also enhancing the beauty of the natural surroundings," he says. "The success of this project can encourage bridge designers to make use of the best technology available to design beautiful bridges that challenge the imagination."

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

AESTHETICS COMMENTARY

by Frederick Gottemoeller



Replacing an attractive and well-loved bridge is always a challenge, particularly when the bridge is in a park and crosses over a well-traveled roadway. The designers of the Brady Street Bridge have taken this challenge and mastered it. The existing bridge was one of a family of similar bridges over Milwaukee's Lincoln Memorial Parkway. These bridges have curved soffits and a very open and transparent appearance.

The new bridge provides both of these features. The curved soffit is created by the haunched girder design, which deepens the girder at the piers to match the forces there, while making it as thin as possible at center of the main span, where the forces are the lowest. The openness is created by removing triangular sections of what otherwise would be the web of the haunched girder. The openings make the bridge lighter visually as well as reducing the self weight. The openness is reinforced by the selection of a railing design with horizontal elements. The railing is transparent from all angles, which would not be the case if it were made up of vertical pickets. The railing posts are thin and are themselves shaped to reflect the forces on them.

The designers are to be congratulated on creating a bridge that is efficient, economical, and elegant, which fits into and reinforces the family of bridges over the Lincoln Memorial Parkway in Milwaukee.



UNIQUE CABLE-STAY SYSTEM CREATES LANDMARK BRIDGE

by Wayne A. Endicott

It was supposed to be a simple renovation of the historic Waldo-Hancock suspension bridge over the Penobscot River. But when engineers finished their inspection of the 74-year-old structure, which carries Maine's Route 1 over the waterway near Bucksport, Maine, it quickly became evident that deterioration had reached a point where the best solution was to replace the bridge with an entirely new structure.

The requisite urgency of bringing a new bridge on line in the shortest possible time led the state to request proposals from design-build engineers. Figg Engineering Group (FIGG) of Tallahassee, Florida, rose to the challenge by designing a bridge with a unique cable-stay cradle system.

"We looked at several possibilities for the design of the bridge," says Jay Rohleder, Jr., senior vice president and

project director for FIGG. "Eventually, we determined that the cable-stay option provided several key benefits. First, it would best fit the character of this historic area. Second, it would provide the most cost-effective solution to replacing the existing bridge. Third, it would be the fastest way to restore traffic to this important transportation corridor." The bridge, in fact, was completed in just 30 months from the time that the design was started.

profile

PENOBSCOT NARROWS BRIDGE / WALDO & HANCOCK COUNTIES, MAINE

ENGINEER OF RECORD/CONSTRUCTION ENGINEERING AND INSPECTION Figg Engineering Group, Tallahassee, Fla.

PRIME CONTRACTOR Cianbro Corp./Reed & Reed, a joint venture, Bucksport, Maine

CONCRETE SUPPLIER Sunrise Materials, Division of Lane Construction Corp., Orono, Maine

PRECASTER Strescon Limited, Saint John, New Brunswick, Canada (precast pylon panels)

CABLE-STAY SYSTEM & POST-TENSIONING SUPPLIER Dywidag-Systems International USA Inc., Bolingbrook, Ill.

REINFORCING STEEL FABRICATOR Harris Rebar Boston Inc., Rochester, Mass.



The main span of the bridge was completed on September 14, 2006, with the casting of a closure that joined the two balanced cantilevers at the center of the bridge.

Cradle system permits the continuous use of stay cables from bridge deck to bridge deck.

Community Input Was Vital

A major consideration for the design/build team was the natural desire of residents in the surrounding area to maintain the original appearance of the three-quarter-century-old existing structure. The bridge had not only provided access for commercial traffic for area businesses, such as paper mills, granite quarries, and boat constructors, but it also provided access for tourists to Maine's scenic coast. As a result, a Public Advisory Committee was formed so members of the community could provide input.

As the team worked on the design, requests for bids were sent to several contractors. FIGG's engineers participated in contractor-candidate interviews led by the Maine Department of Transportation (MDOT) with support from the Federal Highway Administration. Ultimately, a joint venture of Cianbro Corp. in Pittsfield, Maine, and Reed & Reed of Woolwich, Maine, was selected, and they joined the team.

The construction joint venture and designer had independent contracts with MDOT, explains Rohleder, but they united to create a mission statement for the project and then worked as partners with the state agency. This unique "owner-facilitated" design-build arrangement resulted in a bridge that was both beautiful and innovative.

In addition, the public participated in community workshops, where they asked that the bridge design revolve around a theme of granite, which is quarried locally, and that the new structure use simple and elegant shapes.

A major challenge in gaining the public's approval was the height of the pylons needed to support the cable-stay system on the 1161-ft-long main span of the 2120-ft-long bridge. To allay their concerns, the design team made two major decisions. First, the 420-ft-tall towers were designed with an obelisk shape as viewed from the adjacent Fort Knox State Park, reminiscent of structures such as the Washington Monument, a well recognized structure that used the local granite. They also decided that one of the pylons would serve not only as a support but would



Lower pylon structures were cast in 15-ft lifts. Construction-lift articulations replicate an impression of large granite blocks to complement the actual granite at the entrance to the pylon observatory.

CAST-IN-PLACE CONCRETE, SEGMENTAL CABLE-STAYED BRIDGE/MAINE DOT, OWNER

BRIDGE DESCRIPTION 2120-ft-long cast-in-place, cable-stayed concrete bridge with 1161 ft main span. The stay cables are arranged in pairs in the pylons but transition to a single vertical plane of cables at the bridge deck level. One pylon houses a multi-story observatory that is accessed by an elevator in the core of the pylon. The bridge was designed and constructed in less than 40 months, with a unique owner-facilitated design/build process. The cable-stay system uses a recently patented cradle system, pressurized inert gas, and pressure monitoring system to provide low maintenance over the 100-year plus service life of this concrete bridge.

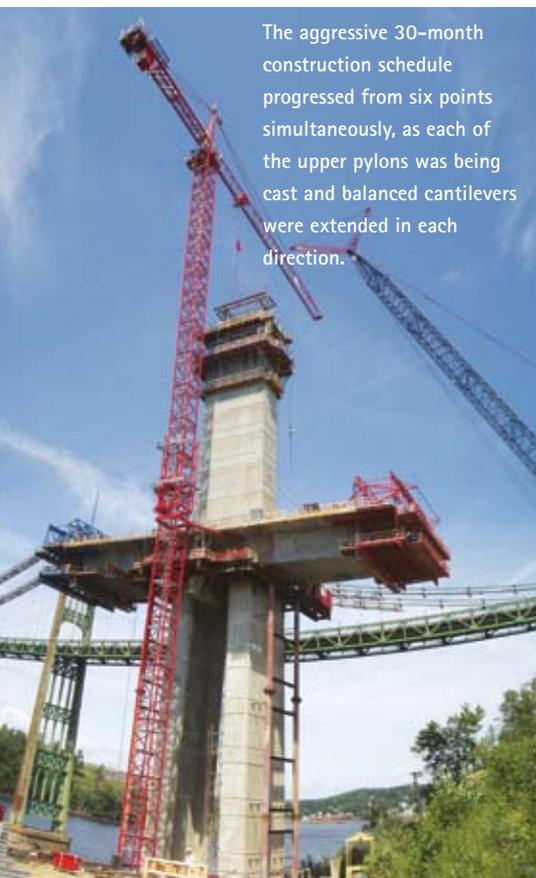
BRIDGE CONSTRUCTION COST \$68 million

contain a multi-level glass-enclosed observation deck that provides 360-degree scenic views, providing a landmark destination.

Foundation design began even before the contracting team was chosen, in an effort to speed construction. The design team, which had provided the design for Florida's monumental cable-stayed Sunshine Skyway Bridge more than two decades earlier, suggested that a similar design would provide an aesthetically pleasing solution here. The cable-stay structure also would require no pylons in the water, providing clear passage to river traffic.

Patented System Created

Although cable-stayed bridges are not a new concept, the design team proposed the use of a patented cable-stay system designed by FIGG that permits the use of a continuous stay cable from bridge deck through the pylon and back to the bridge deck. The system carries the stay cable through a stainless-steel sleeve, creating a continuous cable and eliminating the need for anchorages in the pylon. This in turn reduces forces in the pylon while allowing more streamlined pylon dimensions. The number of epoxy-coated



The aggressive 30-month construction schedule progressed from six points simultaneously, as each of the upper pylons was being cast and balanced cantilevers were extended in each direction.



Two of the cradles positioned within the pylon are shown prior to casting. The 20 cradles in each of the pylons carry the strands (from 41 to 73 per stay) through the pylon, eliminating the need for anchorages within the pylon.

The innovative nitrogen gas protection and monitoring system creates an enclosed environment of pressurized inert gas surrounding each cable stay.

0.6-in.-diameter strands in each stay cable varies from 41 to 73.

Individual sleeves protect the strands of each stay cable by eliminating strand-to-strand contact. The concept of cradle saddles is not new, notes Rohleder, but in the past, they have created a "bundling" effect caused by the top strands squeezing the lower strands as cables got larger, reducing their ability to withstand impact. In the new Penobscot Narrows Bridge, each strand has its own pipe, eliminating this concern. Another impressive benefit of the system is that at any time, it will be simple to inspect, and, if necessary, pull out and replace an individual strand. This ability is expected to extend the bridge's life, which is predicted to be at least 100 years, says Rohleder.

This ability to inspect, and if necessary, replace strands, provides a major advantage, he says. In the existing bridge, cables were encased in a wrapped system that not only retained moisture but made inspection difficult at best. With the new system, inspectors can actually perform their task inside the bridge superstructure.

Monitoring System Provided

Designers also included an innovative nitrogen gas protection and monitoring

system, which creates an enclosed environment of pressurized inert gas surrounding each stay cable. The system includes nitrogen gas, HDPE sheathing, reservoir tanks, anchorage sealing caps, and monitoring hardware. After each stay was installed, it was completely purged of moisture by injecting the nitrogen gas. The nitrogen gas, under 2 psi pressure, is maintained in a reservoir and sealed at each anchorage through the use of a sealing cap that contains a clear end plate. This allows a visual inspection of the anchor area. The gas reservoir within each stay will automatically recharge the gas if there is a drop in pressure. A gauge within the system will record any fluctuations in pressure, allowing MDOT to monitor the system's status and take necessary corrective action.

The bridge's pylons are 14 ft wide. The pylon containing the elevator and observatory sits atop an 80 by 70 ft spread footing that is 16 ft deep. The other pylon rests atop 288 steel piles driven to a depth of 16 ft. The cast-in-place pylons were jump-formed in 15.5 ft lifts. As each segment was completed, steel imbeds for a sole plate were included, and the cradles for the stay cables, some weighing as much as 8500 lb, were hoisted into place and the pylon segment finished.



This rendering of the Waldo-Hancock bridge over the Penobscot River shows its close proximity to historic Fort Knox, a contributing factor in the final design.

Taking Things For Granite

The new Penobscot Narrows Bridge & Observatory traverses the Penobscot River in one of Maine's most scenic areas. It is also historic, located in close proximity to Fort Knox, Maine's oldest historic fort.

The fort, named for Major General Henry Knox, who served as the first Secretary of War and commanded the artillery during the American Revolution, was built between 1844 and 1864 and was constructed of granite. Granite quarries also dot the Maine countryside nearby. To tie the new bridge to the area, the designers used form liners and a sandblast finish to blend with the granite look.

The 15-ft-tall forms incorporated a transverse articulation at the seams, forming a band around the pylons to hide form lines between cast segments. The surface then gives the impression of large blocks that complement the granite slabs installed around the base of the pylons.

"There is a granite outcropping very near the bridge," notes Jay Rohleder, Jr. "The design was developed to celebrate granite and be in harmony with the site." The effect is further heightened by the pylons' obelisk shape, which recalls the Washington Monument and its construction from granite quarried in Maine.

Visitors to the fort will be able to take a footpath to the bridge to access the base of the pylon, then take an elevator to the observatory at the top of the pylon. Also at the entrance to the bridge is a plaque that explains the historic significance of the area and the bridge to visitors. It is estimated that the bridge will carry up to 18,000 vehicles per day, many of them tourists.

Entrance to the observatory elevator, framed in local granite, and the observation deck atop the pylon at 420 ft above the Penobscot River. The observatory will provide 360-degree views of the scenic and historic area.



After the cradles were in place, crews ran strands between the deck and pylon and back to the deck on the opposite side of the pylon. The stays were then stressed at the anchors inside the superstructure box girder. Each strand's stress is matched to the first strand, which is stressed higher than necessary because its stress decreases as additional strands are added. Total design force for stressing is between 1000 and 1900 kips per stay.

The bridge deck itself is a cast-in-place segmental box girder 12-ft 10-in. deep. It was cast using form travelers. Segments were cast in 10- and 12-ft lengths. The casting took place as part of a cycle, with one cycle consisting of casting two main span segments, two back segments, and installing a stay.

The schedule called for a cycle to be completed every 12 days. Early on, Rohleder says, the cycle was taking as long as 16 days. Later, the addition of a small crew at night to handle critical activities brought the process down to the preferred 12-day cycle. Eventually, the process was reduced to just 10 days for casting of the four segments and the stay installation.

The concrete is post-tensioned transversely in the bridge deck and longitudinally through the box girder as part of the overall bridge system.

Final cost of the project was \$84 million that includes \$68 million for the bridge itself. The remainder of the cost included the installation of the observation deck and elevator, as well as access roads and a parking area for visitors. FIGG estimates that the unique cable-stay system cut as much as \$4 million from the final cost due to the elimination of the need for conventional anchorages.

The long-term maintenance benefits of the concrete cable-stayed design will provide Maine with reduced life-cycle costs over its estimated 100-year life span.

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



CONCRETE BRIDGE SURVIVES CRASH TO RISE AGAIN

by Wayne A. Endicott

After a backhoe ripped through the Hays, Kansas, bridge, the damaged span was repaired with cast-in-place concrete to reopen the roadway in just six months

February 13, 2006, might not have been a Friday, but it was unlucky for the Hall Street Bridge just outside Hays, Kansas. That's when the arm of a backhoe being transported on a low-boy trailer eastbound along the interstate below inexplicably raised up and smashed through the concrete span, severely damaging it. The good news? The damaged portion of the bridge was replaced in less than six months with a cast-in-place box girder.

The Hall Street Bridge is a four-span, cast-in-place, three-cell, reinforced concrete box girder bridge. The cross section is 4-1/2 ft deep with 6- to 10-in.-thick webs spaced at 8 ft on center. The top and bottom slabs are 8 and 6 in. thick, respectively. The total length of the bridge is 268.5 ft.

The impact forced the bridge to be closed, as the backhoe's arm remained

wedged tightly in the shattered concrete. Even more critical to transportation in the area, I-70 eastbound had to be closed while damage was assessed and a plan was devised for removing the backhoe and damaged portions of the bridge. That created a detour onto the U.S. 183 bypass that officials wanted to minimize.

Almost immediately, a team of engineers was dispatched to the site in northwest Kansas to devise a plan to repair the bridge and get it back into service. The team, comprising Edward Burdick, Clemens Boos, and Daniel Crosland of the Kansas Department of Transportation (KDOT) Bridge Management Section and Stephen Burnett of KDOT's Bridge Design Section, arrived the next day and began their assessment of the situation.

"We found that the two most western webs of the bridge were completely destroyed for a length of 6 ft and that

profile

HALL STREET BRIDGE / HAYS, KANSAS

ENGINEER Kansas DOT

PRIME CONTRACTOR King Construction Inc., Hesston, Kan. (Demolition and new construction)

CONCRETE SUPPLIER Apac Inc., Hays, Kan.

REINFORCEMENT SUPPLIER Sheffield Steel, Kansas City, Kan.



the bottom half of the east web was destroyed for a length of 12 ft," reports Burnett. "The remaining interior web was somewhat obscured by the rubble, but while it seemed to be intact, it exhibited several shear cracks."

Also destroyed were a 6 ft width of the bridge deck and the bottom slab of the box girder stretching from the west edge to the face of the remaining intact interior web. Additional damage was observed in the bottom slab along the east half of the bridge. The boom of the backhoe had caused spalling in the concrete on the bottom slab and reinforcing steel had been ripped out of the slab.

Kansas DOT crews moved quickly to prop up the damaged bridge in Hays, Kansas. The central column of the bridge, which spans I-70 near the west-central Kansas town, was undamaged by the impact with the backhoe.



No Sign of Sag

Despite the observed damage, the bridge showed little sign of sag along the rails, and then only at the impact area. Also, there were no new cracks in the bridge's

Almost immediately, King Construction's crews began removing the damaged portion of the bridge.

piers. Within hours, KDOT supplied Super Props to stabilize the damaged bridge. The four Super Props were installed under each web to support the weight of the now almost suspended portion of the superstructure so that the backhoe could be removed.

By Wednesday, the boom and the backhoe were removed and a closer

BOX GIRDER BRIDGE/KANSAS DOT, OWNER

BRIDGE DESCRIPTION A four-span continuous, 268.5-ft-long, three-cell, cast-in-place, reinforced concrete bridge that spans a 28-ft-wide roadway

STRUCTURAL COMPONENTS A 45-ft-long cast-in-place box section replacement in a 76-ft-long span

CONSTRUCTION COST \$625,000 (including \$134,000 for demolition)



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inspection was made. This inspection showed that the remaining intact web was also cracked. The team, consisting of, KDOT area personnel, district personnel, and headquarters personnel, with advice from bridge construction personnel and insurance company personnel, created their plan for reopening the bridge. Their decision was to remove the damaged span and rebuild with the same cast-in-place concrete design of the original structure. In fact, the contractor selected for the job was the same as the firm that originally built the bridge in 1964, King Construction Inc. of Hesston, Kansas.

The first step was to remove the damaged section of the bridge. King Construction crews stabilized the bridge and removed the damaged portion one week after the accident, completing those tasks in just four days. That left a 45-ft-long hole in the bridge. The team determined that the



Demolition crews left 3 ft or more of reinforcement exposed to allow splicing of new reinforcement.



Scaffolding supported the forms while a new concrete box girder was cast to replace the missing damaged bridge section.



The new section of the Hays bridge is nearly indistinguishable from the original portions of the structure. The bridge was reopened to traffic in less than six months after the accident.

damaged bridge could be safely repaired, since the single 4 1/2-ft-diameter column in the median remained undamaged.

It was decided to replace the section using the same construction as the original structure rather than try to widen the bridge during this rapid replacement project. This required casting a three-cell concrete box. To tie the new section into the existing construction, the demolition crew left 3 ft or more of the existing reinforcing bars exposed on either side of the opening. This exposed reinforcement was then lap-spliced with Grade 60 uncoated steel reinforcement. A new box-girder section then was cast in place.

"We considered several alternatives for replacing the damaged portion," explains Burnett, "but we felt that using a cast-in-place concrete box section was the most expedient and also promised the greatest long-term durability." Using the concrete box section also meant that the appearance of the repaired bridge is virtually unchanged, allowing this unusual (and hopefully unique) accident to fade into memory.

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RECORD LENGTH PRECAST BEAM Ensures Project Meets Deadline

by Donald P. Merwin



Single-span design of nearly 182 ft on a 60-degree skew replaces bridge on major Oregon highway over railroad tracks in less than seven months

Faced with twin challenges of a long span and short construction time to design and build a replacement bridge to carry a busy highway over an active railroad in Chemult, Oregon, project engineers turned to precast, prestressed concrete girders to create the best solution.

One of 11 bridges in a design-build project for the Oregon Department of Transportation (ODOT), the structure features a single-span precast, prestressed concrete design. That approach avoided activity near the main line of the Union Pacific Railroad and sped up construction as well, according to Terry Stones, lead engineer from David Evans and Associates Inc. of Salem, Oregon, the design-build engineering firm.

The precast design eliminated any need for intermediate bents, allowing the contractor, Hamilton Construction Company of Springfield, Oregon, to stay clear of the railroad track, which carries both freight

and passenger trains and remained operational during construction. A new roadway alignment was added to the plans, leaving the existing bridge in place during construction. The old three-span bridge was considered structurally deficient and too narrow, with practically no shoulders. It had two intermediate piers, which designers wanted to avoid by using the longer precast concrete design.

"The three-span design left significant concerns about the falsework adjacent to and above the rail mainline," Stones adds. A single span nearly 182 ft long would be needed to cross the tracks at a 60-degree skew and it would have to be constructed quickly enough to open to traffic in less than seven months.

New Casting Bed Provides Solution

Fortunately, the precast manufacturer, Morse Bros. Inc., of Harrisburg, Oregon,

had just installed a new casting bed that could fabricate bulb-tee beams up to 96 in. deep and 190 ft long. It was just what was needed for this project.

The final design called for seven precast, prestressed concrete bulb-tee beams, each with a 90 in. depth and a length of 183 ft-3 in., the longest ever used in Oregon bridge construction. Each beam has a top flange width of 5 ft, a bottom flange width of 2 ft 6 in. and contains fifty-six 0.6-in.-diameter strands. Beam spacing was at 6 ft-10 in. The beams were cast with concrete having a specified compressive strength of 9000 psi at 28 days and 7000 psi at prestress transfer.

The beams, each weighing 93 tons and two-thirds the length of a football field, were delivered one at a time on a transporter with 13 axles with the rear units steered remotely by an operator in the truck. The spans were transported from the Morse facility in Harrisburg, near Eugene in the western part of the state, along the 125-mile delivery route over the Cascade Mountains to the bridge site on U.S. 97 midway between Bend and Klamath Falls near the center of the state.

profile

U.S. 97 OVER UNION PACIFIC RAILROAD TRACKS/ CHEMULT, OREGON

ENGINEER David Evans and Associates Inc., Salem, Ore.

PRIME CONTRACTOR Hamilton Construction Co., Springfield, Ore.

PRECASTER Morse Bros. Inc., Harrisburg, Ore.

Beams weighing 93 tons each were driven about 125 miles to the job site on 13-axle transporters.

Once at the site, the beams were erected by two 350 ton cranes, lifting them from the delivery trucks parked on the existing bridge that was adjacent to the new construction.

The \$970,000 budget included \$289,000 in precast concrete elements, but did not include roadwork or retaining walls. The cast-in-place concrete deck carries two 12-ft-wide traffic lanes and two 10-ft-wide shoulders.

The end bents of the new bridge were aligned parallel to the railroad's main line to minimize the span length, according to Stones. Achieving that necessitated a 60-degree skew for the bridge. Extensive mechanically stabilized earth (MSE) walls were used to contain the roadway embankment, with the bridge supported on steel piles driven within the MSE fill. The wall facing was created with large precast concrete blocks that were economical, durable, and quick to construct. "By using the MSE walls and the large skew, the span length was reduced to 181 ft 9 in., and the 90-in.-deep precast, prestressed bulb-tee beams became the best solution for this site," he says.

Both the design and the beam fabrication proceeded quickly, Stones adds. "That speed allowed the fabricators, contractors, and designers to use their creative abilities efficiently. The use of the precast concrete beams allowed the contractor to stay on schedule and within budget. The very long beams soared over the railroad tracks and avoided the need for intermediate supports."

Precast Aided Late Start

The seven-month construction window was created "because we were late getting in," according to Stones. That helped make

the decision for precast concrete because, he notes, "it was readily available and could be constructed very quickly. Time was of the essence."

Each of the 11 bridges had its own challenges, Stones notes. "Although many of the bridges on this project were unique or complex, this one in particular stands out," he says. "This bridge was significant because its beams are the longest single-piece precast, prestressed concrete beams in the state. The greater length developed by Morse "opens the door for the construction of precast, prestressed concrete beams that would break all previous length records. With this new and exciting possibility, the designer, contractor, precast manufacturer, and client teamed together to develop the best solution for this site."

Long Life Expected

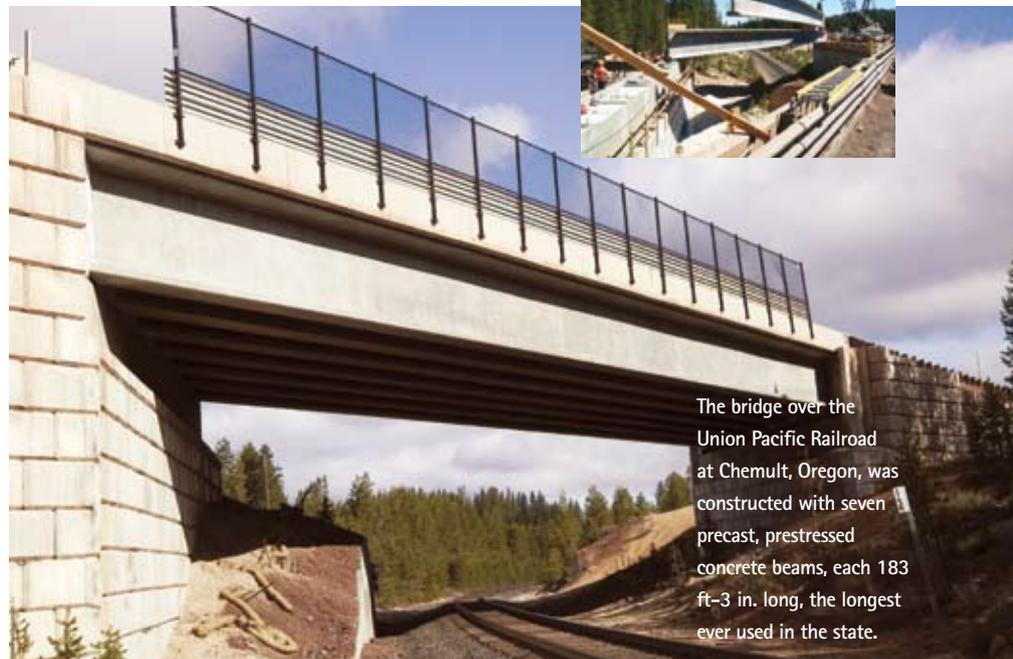
Keith Kaufman, chief engineer for Morse Bros., notes that many bridges in Oregon are using precast as "the material of choice. It shortens the schedule and reduces cost." It also provides significant durability. The

expected life span of the new structure, he notes, is at least 75 years and probably as much as 125 years.

The Chemult bridge is one of about 365, built during the 1950s and 1960s, that the Oregon DOT is examining for replacement, according to Steve Narkiewicz, consultant project manager for the state.

"We're replacing some bridges, repairing some, and doing nothing with others that are not in bad shape," he says. "A lot of the new ones are using precast concrete, depending on the length of the span. As the span gets longer, the beams become deeper and the amount of vertical clearance is critical. The depth for the Chemult bridge measured 90 in.—that's a deep beam—but it was within the vertical clearance limitations because the roadway was well above the railroad tracks."

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



The bridge over the Union Pacific Railroad at Chemult, Oregon, was constructed with seven precast, prestressed concrete beams, each 183 ft-3 in. long, the longest ever used in the state.

SINGLE-SPAN PRECAST, PRESTRESSED CONCRETE/ OREGON DOT, OWNER

BRIDGE DESCRIPTION Two traffic lanes with 10-ft-wide shoulders, with cast-in-place concrete deck and 60-degree skew

STRUCTURAL COMPONENTS Seven precast, prestressed concrete bulb-tee beams, each 183 ft-3 in. long and 90 in. deep spaced at 6 ft-3 in.

BRIDGE CONSTRUCTION COST \$970,000.

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HPC Bridge Technology: Legistration, Delivery, and Teamwork

by M. Myint Lwin

The Federal Highway Administration (FHWA) takes this opportunity to congratulate the concrete industry on this inaugural issue of *ASPIRE*[™]—*The Concrete Bridge Magazine*. This is reflective of the progressive vision of the concrete industry to continuously look for ways and means to share invaluable experiences in concrete bridge construction to assure quality, durability, and economy. *ASPIRE*, a quarterly concrete industry magazine, will feature articles containing useful information and innovative solutions from governmental agencies, consultants, and contractors on the use of concrete in bridges. The FHWA and the concrete industry have been strong partners in concrete and are looking forward to making *ASPIRE* the magazine to read for concrete bridge information and solutions.

In 1987, the United States Congress authorized a five-year \$150 million Strategic Highway Research Program (SHRP) to develop and evaluate techniques and technologies to address the deteriorating conditions of the nation's bridges and highway-related structures, and to improve their performance, safety, durability, and efficiency. High performance concrete (HPC) was identified as one of the technologies that would produce significant benefits in bridge and highway construction.

To facilitate broad implementation of HPC, the American Association of State and Highway Transportation Officials (AASHTO) introduced the Lead States Program in 1995. This program used the experience of the States that were already implementing HPC to provide technical support and guidance to their peers in other States. The HPC Lead States Team for Bridges set a goal for all the States to have at least one HPC bridge project underway by the year 2000. HPC is now standard practice with most States. The FHWA and the industry were active members of

the Lead States Team.

The FHWA forms and maintains the High Performance Concrete Technology Delivery Team (HPC TDT) chaired by Lou Triandafilou. The main objective of HPC TDT is to establish HPC as standard practice for every State DOT and to provide technical support on HPC practices in design, construction, and materials. The HPC TDT has a "Community of Practice" website at <http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home>. The site allows users to post questions on HPC, participate in discussions, share documents, and review work in progress. The HPC TDT has produced an *HPC Structural Designers' Guide* to provide information to structural engineers on using HPC in the design and construction of highway bridges and related structures. The guide may be downloaded from the above website.

The successful applications of HPC bridges will be featured in *ASPIRE*. The readers will find these articles interesting and full of information that can be put into practice. Two emerging concrete technologies will elevate HPC to the next higher level of performance. They are self-consolidating concrete (SCC) and ultra high performance concrete (UHPC). More about these two emerging concrete technologies will appear in future issues of *ASPIRE*.

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) authorizes a research, deployment, and education program on improving bridge technology using high performance concrete. This program is funded at \$4.125 million for each of fiscal years 2006 through 2009 to conduct research and deploy technology related to HPC. This is a part of the Innovative Bridge Research and Deployment (IBRD) Program established to promote, demonstrate, evaluate, and document the application of innovative designs, materials, and construction methods in the construction,

repair, and rehabilitation of bridges and other highway structures. The IBRD program is funded at \$13.1 million for each of fiscal years 2005 through 2009. The funding for the HPC program comes from the IBRD program.

The FHWA in partnership with the National Concrete Bridge Council, States, consultants, and academia has developed a research, deployment, and education plan to carry out the intent of SAFETEA-LU, the FHWA performance objectives, and the needs of the highway bridge community. The plan was developed based on needs identified by the FHWA, AASHTO, the Transportation Research Board, industrial groups, and other stakeholders. The research and development component of the plan includes high performance lightweight concrete material and structural properties, deck curing to control cracking, and shear of nonprestressed elements. On the deployment side of the plan, the FHWA focus includes a manual of HPC practice, integral abutments and jointless bridges, HPC design and rating examples, and evaluating and extending the service life of post-tensioned bridges. For continued education, the FHWA supports the transfer of technologies through workshops, conferences, showcases, training courses, and newsletters.

With the funding for HPC bridge technology research and deployment from SAFETEA-LU, the FHWA is providing leadership by engaging the highway bridge community in advancing HPC to new frontiers in the next three years.



U.S. Department of Transportation
Federal Highway Administration



ACAA
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American Coal Ash Association

The American Coal Ash Association (ACAA) advances the management and use of coal combustion products (CCPs). Generically, CCPs are the residuals from coal combustion, such as fly ash, bottom ash, and boiler slag, or byproducts from air emission controls. In addition to a myriad of core performance attributes in construction and industry, CCP use can conserve natural resources, reduce greenhouse gas emissions, and eliminate the need for additional landfill space. Nearly 40 percent of 123 million tons of CCPs produced annually are used beneficially.

Members of ACAA are located worldwide and include utility and non-utility CCP producers, as well as marketers, organizations, and individuals with commercial, academic, research, and other interests in CCP management. Members promote CCP use and management in ways that are environmentally responsible, technically sound, and commercially competitive. This mission is achieved through public and private sector partnerships, technical assistance, education, publications, meetings, and workshops. ACAA has developed strong partnerships with the Federal Highway Administration, Environmental Protection Agency, Department of Energy, Department of Agriculture, and others. Through these partnerships, the association helps provide information, education, and outreach to engineers, designers, specifiers, end users, and regulatory agencies.

Fly ash and cenospheres are CCPs often specified for high performance concrete in bridge decks, piers, and footings. The recently completed \$531 million Arthur B. Ravenel Jr. Bridge project in Charleston, South Carolina, used more than 30,000 tons of fly ash. Caltrans, a state leader in the use of fly ash in paving projects, specified high volume fly ash mixes for the largest bridge project in its history—the San Francisco-Oakland Bay Bridge. Using innovative specifications and blending techniques, Caltrans was able to improve the workability, permeability, and hardened concrete properties. A number of engineering standards and specifications define CCP applications, thus ensuring high quality performance and products.

For more information, please visit www.acaa-usa.org.



WRI Shares Best Kept Secret—Welded Wire Reinforcement



The Wire Reinforcement Institute (WRI) is the world's leading association of manufacturers, allied industries, and professionals engaged in the production and application of structural welded wire reinforcement (WWR) and related products for concrete reinforcement.

Headquartered in Hartford, Connecticut, WRI is the concrete construction industry's leading source for timely, objective, and credible information on the uses and benefits of structural WWR and related products. WRI works closely with design firms, universities, owners, contractors, and government agencies, to ensure adherence to the most accurate, up-to-date codes, standards, specifications, and regulatory requirements.

WRI has a wealth of information about structural WWR and how it may be used to help reduce bridge and paving closing times and promote public satisfaction. Many say that WWR is the best-kept, time-saving, cost-cutting secret in the concrete reinforcement industry.

The Institute's efforts to advance the industry include technical and promotional materials and a variety of outreach programs to increase the construction industry's awareness of new structural WWR products and breadth of applications. Through the WRI Education Foundation, the Institute funds a scholarship program that annually grants over \$10,000 for undergraduate and graduate level civil and structural engineering students at accredited engineering universities. Over the past two years, the Foundation has awarded over \$30,000 in academic scholarships to students majoring in civil and structural engineering.

Once known as welded wire fabric, wire mesh, or fabric, WWR provides structural concrete reinforcement. It is a highly controlled, cold-worked, structural product that possesses higher yield strength than Grade 60 reinforcement. It is produced in standard and custom prefabricated sheets. High-quality welds and computer-controlled spacing eliminate the time-consuming and less precise job-site layout and tying that is typical of traditional reinforced concrete construction.

With these superior attributes, WWR offers several key benefits. It is stronger than traditional materials and, therefore, less material is needed. And less weight means easier handling and placement—over 50% less labor when compared to traditional materials.

To learn more about WRI and structural WWR, as well as to access a variety of technical publications, visit www.wirereinforcementinstitute.org or call us at (800) 552-4WRI [4974]. Outside the U.S. please call 1-860-808-3000, X356.



Spanning the Land of 10,000 Lakes—

Minnesota's Concrete Bridges

by Dave Dahlberg, Kevin Hagen, Dave Hall, Brian Homan, Keith Molnau, and Arlen Ottman, MnDOT

Concrete bridges have been a key component of Minnesota's transportation system for the past century. Numerous arches built in the early 1900s gracefully span the rivers of the state. While cast-in-place concrete bridges were frequently used, the advent of prestressed concrete resulted in the number of concrete bridges rising dramatically and becoming the predominant type of bridge. Today, precast, prestressed concrete and cast-in-place concrete bridges represent over 80% of the new bridges built on Minnesota's highways. Despite the severe Minnesota weather conditions, extreme temperature ranges and heavy use of deicing chemicals, concrete bridges are providing increased service lives due to improvements in materials and corrosion protection systems.



Mendota Bridge, TH 55 over the Minnesota River. (Nineteen-span cast-in-place concrete spandrel arch bridge)

Precast, Prestressed Concrete Bridges

The first prestressed concrete beam (PCB) bridge in Minnesota was built in 1957 using precast, pretensioned AASHTO*-PCI Type I beam sections. This was truly the beginning of a new era in bridge design. In the almost 50 years since then, over 2,800 PCB bridges have been built in Minnesota. During this time, the PCB bridge has emerged as the preferred choice for most situations due to its economical cost and low maintenance requirements.

* AASHTO was subsequently renamed AASHTO



TH 371 over the Mississippi River, near Brainerd. (Three-span prestressed concrete girder bridge)

The first prestressed concrete beams ranged in depth from 36 to 54 in. and had narrow flanges and thick webs. Until about 1970, they also had end blocks (thickened webs at the ends of the beams). In 1986, new more efficient I-beam shapes labeled the "M" series were added. These beams have depths ranging from 27 to 81 in. with wider top flanges, narrower webs, and more room for prestressing strands in the bottom flange. The new shapes increased the available span range, expanding the use of prestressed concrete beams in Minnesota.

In 2005, an even more efficient "MN" series I-beam was added with depths of 45, 54, and 63 in. The "MN" series beams are more robust and provide more area for prestressing, thus allowing for a reduced number of beams for a given span compared to the "M" series beams.

Other factors have improved precast, prestressed concrete beam efficiency. For instance, concrete quality and strength have increased. Required concrete strengths at strand release have risen from the 4500 to 5000 psi range of the early years to a current value that can go as high as 7500 psi, and design strengths have been specified as high as 10,000 psi. Prestressing steel has also changed from the original 3/8-in.-diameter stress-relieved strands to 1/2-in. diameter and now 0.6-in.-diameter low-relaxation strands.

Slab Spans

Concrete slab spans, have always had a place in Minnesota's bridge history. Whether it is for short slabs between spandrel beams of concrete arch bridges, voided slabs for grade separations, or the modern post-tensioned slabs capable of spanning greater distances, these spans fill a niche in the appropriate structure type for a particular location.

Arch bridges, which are rare for new construction, many times require slabs to be rehabilitated for repair and greater traffic capacity. Often historical, they must utilize some of the original construction methods to retain the key classical features.



TH 57 over the South Branch of the Middle Fork of the Zumbro River, Mantorville. (Three-span, post-tensioned slab)

Reinforced concrete slabs have evolved into post-tensioned slabs to accommodate longer spans. Normally, slab spans are chosen to provide a shallower superstructure than can be obtained with the typical beam-slab arrangement. An example is that of a bridge crossing the Zumbro River in the historical town of Mantorville. Here, the highway grade could not be raised due to its proximity to the town's main street. The river carries high flow rates during periods of fast run-off. Also, the townspeople did not want a standard utilitarian bridge to replace the high-

truss spans that they had come to embrace over the years. To maintain a minimum structure depth and to provide the flexibility for aesthetics because the bridge is located adjacent to a city park, a post-tensioned, three-span slab bridge was chosen.

In 2005, Minnesota introduced its new Precast Slab Span System bridges, based on AASHTO's International Scan on Prefabricated Bridges. This Precast Slab Span System is similar in proportion to a slab-type structure, but the new system utilizes precast, prestressed inverted tee-beams to eliminate the need for falsework and forming. To further accelerate construction, precast substructures were used on one of the pilot projects. Using this innovative system, construction time was reduced by several weeks.



TH 72 over Tamarac River. (Three-span precast, prestressed inverted "tee" beam deck)

Box Girder Bridges

The Minnesota Department of Transportation (MnDOT) has completed several bridge projects utilizing various construction methods for box girder bridges. On the Highway 10 project in Blaine, the bridges were designed as multi-cell, concrete box girders, cast-in-place on falsework, and cast-in-place on fill. The Wakota Bridge is a major river crossing carrying Trunk Highway 494 over the Mississippi River in the southeast metropolitan area of Minneapolis-St. Paul. The graceful structural lines are the result of a variable depth, two-cell, box girder configuration. The main spans are 465 ft constructed using the cast-in-place, segmental, balanced cantilever method. The west end of this bridge flares considerably, which was partially achieved using variable length overhangs, and was partially constructed on falsework.

The structure type was chosen as a result of a very successful public involvement process. The final crossing includes several amenities, including a bicycle and pedestrian trail, overlooks, ornamental railings, and concrete surface treatments to give the concrete a more natural appearance. On a separate project, Minnesota is planning to construct six precast concrete, box girder bridges in the most congested segment of Interstate 35W and Crosstown Highway 62, utilizing the balanced cantilever method. The six bridges include fly-over type structures with curved 200-ft-long spans, for a total combined length of 4610 ft, or nearly 200,000 sq ft of precast segmental construction.



Wakota Bridge, I-494 over the Mississippi River. (Five-span cast-in-place segmental concrete bridge)

Land of Lakes

Minnesota's landscape includes "10,000 lakes," which contributes to the need for hundreds of small stream crossing structures. Precast concrete box culverts are often the most economical type of structure for these locations, and offer the advantage of rapid construction without the need for falsework or the curing time required with cast-in-place culverts. Minnesota has developed standard tables for culverts ranging from 6 x 4 ft up to 14 x 14 ft, for fill heights up to 25 ft. Special designs are made for precast sections up to 16-ft spans, beyond which transportation and weight of sections becomes a limitation. Local precasters have responded to MnDOT's Standard Culvert Designs, and are set up to mass-produce the precast sections to meet demand. Beyond the 16-ft span, Minnesota has utilized precast arches and precast three-sided structures for spans up to 34 ft. These types of structures have also been successfully used on small stream crossings and pedestrian trail bridges, and can be designed utilizing formliner and decorative railings on the headwalls to enhance the appearance of the portal entries.

On the local highway system, the majority of the bridges are in rural areas, have relatively low average daily traffic, and cross rivers or



TH 210 over Paul Bunyan Trail, Brainerd. (Precast concrete arch)

streams. Typically, these bridges require overall lengths less than 150 ft. Within this span length, concrete affords a number of options that are economical, durable, and adaptable to most geometric conditions.

In the past few years, over 90% of bridge spans constructed on the local system, excluding box culverts, have been prestressed concrete beam or concrete slab span bridges. Prestressed concrete beams are used for spans ranging from 30 to 150 ft. Slab spans are used for spans ranging from 15 to 60 ft.

In the last few years, the MnDOT also introduced a rectangular prestressed concrete beam section for spans ranging from 24 to 55 ft. The rectangular beam provides a more shallow structural depth than standard PCB sections and eliminates the falsework necessary for slab span structures. The rectangular beams come in 14-, 18-, and 22-in. deep sections.



Arcade Street over Channel at Spoon Lake, St. Paul. (Precast concrete arch)

Aesthetics

Aesthetic considerations have become an important design consideration in the last 20 years. The versatility of concrete has allowed Minnesota to deliver not only sustainable structures on the state highway system, but also visual assets and focal points for our communities. The MnDOT subscribes to the principles of context sensitive design and solutions as a basis for developing projects that are sensitive to the natural, environmental, cultural, and economical aspects that influence

how a project will fit into a community or location. Policy and guidance in developing aesthetically pleasing bridges and structures is provided in the state's "Policy and Procedures for Cooperative Construction Projects" and the "Aesthetic Guidelines for Bridge Design," respectively.



Pioneer Trail over TH 169, West Bloomington/Eden Prairie. (Two-span prestressed concrete girder bridge)

Working with the state's district project managers and staff, the Bridge Office enters into a public involvement process that includes local government officials and staff, other state and local agencies, and representatives from the general public to develop visual quality guidance that is appropriate and mutually acceptable to all project stakeholders. Through this involvement at the early project planning and development stages of a project, the local representatives have an opportunity to participate in what will become part of their community's fabric for the next 50 to 75 years. As illustrated in the photographs, the use of concrete has offered flexibility in structural design and the opportunity for architectural enhancement in many of Minnesota's bridge structures.



36th Avenue North over TH 100, Robbinsdale. (Two-span prestressed Concrete girder bridge)



The American Segmental Bridge Institute

The American Segmental Bridge Institute (ASBI) was incorporated in 1989 as a nonprofit organization to provide a forum where owners, designers, constructors, and suppliers can meet to further refine current design, construction and construction management procedures, and evolve new techniques that will advance the quality and use of concrete segmental bridges. ASBI is a unique organization in that all components of the bridge construction industry are included as members. Consulting Bridge Engineers, Contractors, Material Suppliers, Concrete Associations, Transportation Officials, Professional Engineers, and others with an interest in concrete segmental bridges are members of ASBI.

Some aspects of ASBI efforts to advance segmental bridge design and construction technology include:

- An annual two-day convention, which is the primary networking opportunity for companies involved in segmental bridge work
- Periodic newsletters which publicize segmental bridge projects in the United States and other countries
- Educational programs and technical publications

The ASBI website (www.asbi-assoc.org) provides comprehensive information on ASBI membership and scheduled activities.

For more information on Minnesota's bridges, visit www.dot.state.mn.us/bridge.



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The Expanded Shale, Clay & Slate Institute (ESCSI) is the international trade association for manufacturers of expanded shale, clay, and slate (ESCS) aggregates produced using a rotary kiln. The institute is proud to sponsor *ASPIRE*[™] magazine.

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For more information on lightweight concrete, including a listing of ESCSI members and available publications, please visit www.escsi.org. The members of ESCSI look forward to assisting owners, designers, and concrete producers in using lightweight concrete for bridges.



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Raftsundet Bridge—Norway
Center portion of main span is lightweight concrete.
Photo courtesy of J.E. Nilsskog



Benicia-Martinez Bridge—California
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Officials in Prince Georges County, Maryland, shifted to concrete bridges after a variety of factors made it apparent the benefits will pay off.

Thinking Long TERM

By Edward J. Binseel



The new concrete Race Track Road bridge, so named because it leads to a racing track, features the decorative touch of the straining head of a racehorse on the railings.

For many years, designers in Prince Georges County, Maryland, built bridges using steel components. But about 12 years ago, we re-evaluated the long-term costs, taking into account maintenance and other factors that were not always being considered during the initial design stages. As a result, we went entirely in the opposite direction and now specify precast, prestressed concrete beams for the superstructure of almost all of our bridges.

Over the past 12 years, we have standardized the design of our bridges, allowing us to pursue a cookie-cutter approach when replacing old, obsolete structures (although we do sometimes dress them up for special occasions). The bridges typically span streams rather than roadways and average 60 to 80 ft in length. Today, the majority of those bridges are built with precast, prestressed concrete box beams with a composite concrete deck. They typically include massive foundations, with the goal of making the bridges as permanent and as maintenance-free as possible.

The desire to obtain a minimum life span of 75 to 100 years for our bridges while minimizing their maintenance was the driving force behind our switch to concrete bridges. This change began in 1994, when we designed a standard steel bridge and advertised the bridge for construction. We were surprised when the bids received far exceeded the engineer's estimate due to a recent spike in the cost of steel beams. We immediately redesigned the bridge using precast, prestressed concrete box beams. We never looked back.

At the same time, I had been reading about the European approach to bridge design, which focused on making the structures long-term, permanent parts of the environment. That philosophy not only helped the bridges become



Most of the county's bridges, like the MB Road Bridge, use adjacent box beams with composite concrete deck.

area landmarks, but it minimized maintenance costs and extended the life of the bridges. Those attributes allowed the County to begin to manage the life-cycle costs of its bridges and to more effectively use the limited funds available. It also eliminated the problems arising with detours and high user costs during the performance of future bridge repairs or maintenance.

At the same time as these philosophies and steel prices were directing us toward concrete, other factors began to become apparent, too. We realized that trucks were likely to continue to become heavier, resulting in the need to load post bridges that had once carried full legal loads. Designing for HS20 loads wasn't feasible any more—and the use of the HS25 or HS27 design vehicles was now necessary. We realized that we were also retrofitting bridges that were functionally obsolete and were not capable of bearing full legal loads, even after updating.

Maintenance Budget Cut

Meanwhile, the budget for bridge maintenance continued to be cut, making us realize that we needed to create more durable designs within the original construction budget. This was brought home when the repainting of a large steel beam

bridge superstructure required us to clean the lead painted steel beams down to bare metal before they could be re-coated. That wake-up call to our limited maintenance budget then resulted in still further changes in the way we design our bridges.

To make the bridges more durable, the decision was made to use epoxy-coated reinforcement throughout the bridge's substructure and superstructure. We increased the minimum concrete cover usually specified over reinforcement by 1 in. for both cast-in-place and prestressed concrete components. And we incorporated the use of silane-penetrant sealers (rather than linseed oil), and we restricted the water-cementitious materials ratio of the concrete to 0.40 for all superstructure concrete and substructure beam seats. These changes are all intended to make the bridges less permeable to salt intrusion.

While we initially received criticism for "wasting" concrete as a consequence of the thicker cover over the reinforcing steel, we calculated that our approach added only \$3,000 to \$5,000 to the typical bridge budget of \$1.5 to \$2 million. We saw we could get a lot of protection for a tiny incremental cost. We can't mobilize a contractor to fix even minor concrete spalls on a bridge for that much!

The upshot of our switch to concrete bridges is that we have not been back to repair any of the 20 concrete bridges that we've built in the past dozen years, a testament to this approach. The designs also have allowed us to incorporate interesting aesthetic touches, adding the icing to this concrete cake.

Edward J. Binseel is Associate Director, Office of Project Management, Department of Public Works & Transportation, Prince Georges County, Maryland.



National Ready Mixed Concrete Association

Founded in 1930, the National Ready Mixed Concrete Association (NRMCA) is the leading advocate for the industry. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, education, and partnering.

NRMCA works in conjunction with state associations on issues such as quality, business excellence, promotion, and regulatory concerns. We strive for constant communication on the latest information, products, services, and programs to help our members expand their markets, improve their operations, and be their voice in Washington, D.C.

NRMCA offers certifications for both ready mixed concrete production facilities and personnel. Certified producers strive to provide the highest quality ready mixed concrete in the safest and most efficient ways possible.

NRMCA is a principal sponsor of CONEXPO-CON/AGG. This show features over 1.5 million square feet of exhibits including an information technology pavilion and an emphasis on live demonstrations throughout the exhibit areas. The show brings together contractors, producers, and equipment manufacturers at the largest exposition in the Western Hemisphere for the construction industry.

NRMCA is also the principal sponsor of the Concrete Technology Forum, an annual symposium on state-of-the-art concrete technologies. The Forum brings researchers and practitioners together to discuss the latest advances, technical knowledge, continuing research, tools, and solutions for ready mixed concrete.

For more information, contact the National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, MD 20910 888-84NRMCA (888) 846-7622; www.nrmca.org.



Silica Fume Association

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

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

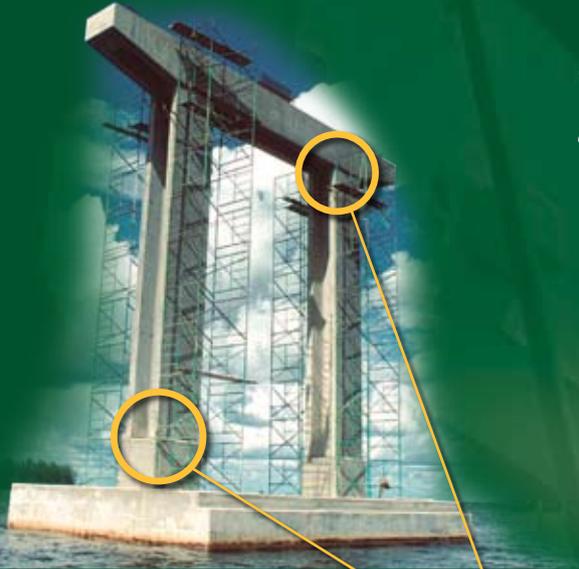
Some of the recent projects completed by the SFA, under a cooperative agreement with the Federal Highway Administration (FHWA), include:

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

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

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Background to the Specifications

by Dr. Dennis R. Mertz



Bridge designs initiated from October 2007 onwards must be in accord with the *AASHTO LFRD Bridge Design Specifications* to qualify for federal matching funds. This is based on an agreement between American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA). The LFRD Specifications was adopted in 1994 by AASHTO as a co-equal alternative to the *Standard Specifications for Highway Bridges*. The 17th and final edition of the *Standard Specifications* was published in 2002.

Since the 1920s, the AASHTO bridge specifications have been developed through the AASHTO Subcommittee on Bridges and Structures (SCOBS). This subcommittee consists of bridge engineers of the various states and other territories and agencies. The subcommittee updates and revises the specifications yearly at their annual meeting based on recommendations from their subcommittees. These meetings result in yearly interim changes to the specifications. These interim changes are published the following year as replacement pages for the loose-leaf bound specifications. Periodically, new editions of the specifications are printed incorporating all of the interim changes since the previous edition. Since the 1920s, 17 editions of the *Standard Specifications* have been issued. For a short time, 1994 through 1999, SCOBS issued yearly interim changes to both the *Standard Specifications* and the *LFRD Specifications*. Since 2000, SCOBS is only maintaining the *LFRD Specifications* through interim changes. The current *LFRD Specifications* is the third edition with Interim editions issued in 2005 and 2006.

In the mid-1980s, SCOBS determined that the *Standard Specifications* was falling behind the times due to advances in the state of practice with which their technical committees, based on volunteer participation from the various departments of transportation (DOT), could not keep pace. Through the National Academies' National Cooperative Highway Research Program, AASHTO initiated project No. 12-33, which resulted in the first edition of the *LFRD Specifications*. A team of over 50 experts including practicing consulting engineers, academics, and DOT personnel, led by the bridge design firm of Modjeski and Masters, Inc., wrote the first draft of the specifications.

The team was charged with developing design specifications that are technically state-of-the-art and easy to apply. At times, these goals were in conflict. The specifications were to include a parallel commentary but not read like a textbook. Finally, and perhaps more importantly, the specifications were to be based on a new probabilistically based design methodology, termed load and resistance factor design (LRFD).

The LRFD methodology appears very similar to the load factor design (LFD) of the *Standard Specifications*, as suggested by the LRFD equation below:

$$\Sigma(\gamma Q) \leq \phi R$$

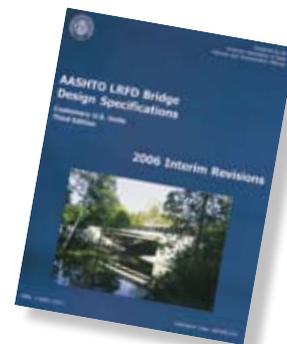
Where,
 γ = load factors
 Q = loads
 ϕ = resistance factors
 R = resistance

Whereas the load and resistance factors of the LFD provisions of the *Standard Specifications* acknowledge uncertainty (for example, with greater load factors associated with loads of

greater uncertainty), the factors were chosen rather qualitatively. The load and resistance factors of the *LFRD Specifications* were determined quantitatively using the theory of structural reliability.

The *LFRD Specifications* are not intended to yield bridges with necessarily greater or lesser reliability, but with bridges having a more uniform reliability index. The reliability index is the measure of reliability or safety associated with a probability of failure. The reliability indices represented by the bridges designed by the *Standard Specifications* range from about 1.5 to 4.7. This represents a huge range of probability of failure ranging from 7 in 100 to 3 in 1,000,000. The bridges of the *LFRD Specifications* are more uniformly reliable with a limited range of about 3.3 to 3.8, centered about the target reliability index of 3.5. The probability of failure associated with a reliability index of 3.5 is about 2 in 10,000. Thus, the *LFRD Specifications* yields bridges of much more uniform reliability.

Future columns will highlight the various additions and revisions to the *LFRD Specifications* adopted by AASHTO in 2006 and to be published in 2007.





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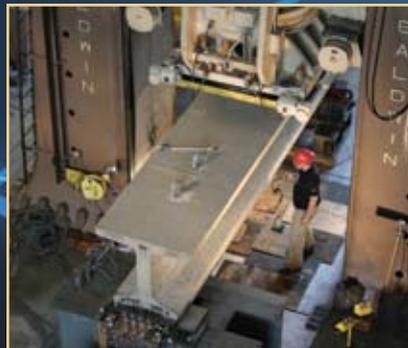
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Eriksson Technologies was founded in 1998 with a singular objective: the passionate pursuit of technical excellence. This philosophy is evident in every aspect of our company, from our highly acclaimed technical support down to the smallest technical details of our software. It's what has made us the preferred provider of engineering software to many DOTs, consulting engineers, precast fabricators, and universities nationwide.

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DF Moment, Interior Girder
For Beam-Slab Bridge (type K), Two or More Design Lanes:

$$M_{max} = 0.075 \left(\frac{S}{0.5} \right)^{0.75} \left(\frac{S}{L} \right)^{0.75} \left(\frac{K_y}{12.9L^3} \right)^{0.75}$$

where:
S = Beam spacing (ft)
L = Beam length (ft)
t = Slab thickness (in)
K_y = Longitudinal stiffness parameter



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