ASPIRE™

THE CONCRETE BRIDGE MAGAZINE

SPRING 2015

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Flagler Memorial Bridge
Variable-Depth Girders
West Palm Beach, Florida

RIEGO ROAD OVERCROSSING
Sacramento, California

NORTH MILLIKEN AVENUE RAILROAD UNDERPASS BRIDGE
Ontario, California

TILIKUM CROSSING, BRIDGE OF THE PEOPLE
Portland, Oregon

NAPLES BAY BRIDGE & CAUSEWAY
Naples, Maine

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OPEN Minds, More Accessibility!

William Nickas, *Editor-in-Chief*

I frequently meet people that inspire me to think differently about helping myself and others remain positive and focused. In my editorial in the Winter 2015 issue of *ASPIRE*,™ I wrote asking the question: Managing or Just Hanging on through Change? Recently, someone stopped me and explained that they really liked the three new additions to *ASPIRE*: contractor's profiles, concrete bridge technology articles, and the professor's perspective. They went on to say that positive change is necessary for keeping people engaged.

The articles in *ASPIRE* are selected by the Editorial Advisory Board that works to find innovative and informative topics. I wondered how other professional journals and magazines keep their energy high and their teams moving forward.

I recently read the book, *Digital Outcasts: Moving Technology Forward Without Leaving People Behind* by Kel Smith. The term "digital outcasts" was introduced by researchers from the University of Sussex, England, as a description of a group of technology users that do not keep up with technology advances due to their disabilities. In the very near term, author Smith suggests better accessibility through applications (apps) for iPads, tablets, and other devices that will improve the quality of life for the physically or mentally disabled. These kinds of changes will also identify a whole host of new challenges. The book is viewed by many in the technology arena as a game-changing concept, which makes a compelling case for universal design rather than discrete user-based solutions.

Among other things, the book brought to mind the efforts of the AASHTO Subcommittee on Bridges and Structures Technical Committee on Concrete (T-10) to completely reorganize Chapter 5 (concrete structures) of the *LRFD Bridge Design Specifications*. The committee is in the first round of this reorganization (and rethinking). While the engineering community is well-rooted in physical sciences, the medical and soft science professions can teach us a lot. Yes, I have heard that we "left brainers" are good with math and that "right brainers" are great with the creative arts. In T-10's efforts, it will take both! The next decade of changes will bring new creative tools for people to gather and understand information. These likely will come from other professions.

This cross-over concept here is captured in the name of Smith's company: Anikto, which is the Greek word for OPEN. He strives for more accessibility and his efforts to educate software and hardware developers is paying off for everyone. Imagine a design code that is technically accurate and unified for a broader range of concrete bridge types. What a model worth following.

Industries' technical organizations and associations, in a somewhat altruistic fashion, work to engage various people and groups and to provide broad access to data, tools, parametric studies, sample projects, and very specialized code interpretations. Sharing these findings creates a better built environment. In the Winter 2013 *ASPIRE* Editorial, I quoted an association president telling a group that, "those that show up help make the rules" and I concluded my editorial in the Winter 2015 edition with a discussion of how addressing change will result in accomplishment. The LRFD design philosophy has opened a new framework for bridge design code provisions. Additionally, the next decade will see many changes in concrete and concrete materials as we know them today.

To conclude these eclectic thoughts, I want to challenge our collective bridge community to further OPEN our minds and intellectual wisdom in broadly and routinely sharing the knowledge and tools needed to encourage design with the most versatile material in the construction community: Concrete!

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A close-up of precast concrete variable-depth girders for the Flagler Memorial Bridge replacement in West Palm Beach, Fla. The bridge is being constructed by PCL. Photo: PCL.

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PRESTRESSED CONCRETE BRIDGES

Route 70 over Manasquan River in New Jersey (Photo courtesy of Arora Associates) Alternate design structure utilizes precast caissons, piers, pier caps, and prestressed concrete beams. The bridge was opened to traffic two years ahead of as-designed schedule.

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Dr. Reid Castrodale is a structural engineering consultant with over 30 years of experience in prestressed concrete bridge design, research, and technical support. He also promotes the use of lightweight concrete for bridges.

CONCRETE CALENDAR 2015

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

April 3, 2015
Call for Abstract deadline
2015 Western Bridge Engineers' Seminar

April 6-7, 2015
ASBI 2015 Grouting Certification Training
J. J. Pickle Research Campus
The Commons Center
Austin, Tex.

April 12-16, 2015
ACI Spring Convention
Marriott Hotel and Kansas City Convention Center
Kansas City, Mo.

April 19-24, 2015
2015 AASHTO Subcommittee on Bridges and Structures Annual Meeting
Saratoga Hilton
Saratoga Springs, N.Y.

April 21-23, 2015
International Highway Technology Summit: Cities, Transportation and People
Shanghai, China

April 26-28, 2015
2015 PTI Convention
Royal Sonesta Houston Galleria
Houston, Tex.

April 30, 2015
Call for Abstract deadline
2015 National Accelerated Bridge Construction Conference
Miami, Fla.

April 30-May 3, 2015
PCI 2015 Committee Days and Membership Conference
Hyatt Magnificent Mile
Chicago, Ill.

May 18, 2015
PCI Call for Entries deadline
2015 PCI Design Awards

June 1, 2015
Call for Entries deadline
2015 ASBI Bridge Award of Excellence
Miami, Fla.

June 8-11, 2015
International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, Pa.

August 2-7, 2015
AASHTO Subcommittee on Materials Annual Meeting
Marriott Pittsburgh City Center
Pittsburgh, Pa.

September 9-11, 2015
2015 Western Bridge Engineers' Seminar
The Peppermill Hotel
Reno, Nev.

October 7-9, 2015
2015 PTI Committee Days
New Orleans, La.

October 15–18, 2015
PCI 2015 Fall Committee Days and Membership Conference
Louisville, Ky.

November 2-3, 2015
ASBI 27th Annual Convention
Omni Dallas Hotel
Dallas, Tex.

READER RESPONSE

Editor,
I enjoy reading ASPIRE™ *magazine. I have been very happy with the changes that you have made in the last year—increasing the number of technical articles and highlighting contractors.*

Tim Keller
Administrator
Office of Structural Engineering
Ohio Department of Transportation
Columbus, Ohio

FOCUS

Inspiring Creativity

PCL's desire to tackle complex projects encourages creativity and innovation as it meets evolving challenges of risk management, project delivery methods, and others

by Craig A. Shutt

A 100-year design life was required for the I-91 Brattleboro Bridge improvement project, Brattleboro, Vt. The bridge replaces two steel-truss bridges over the West River with a single cast-in-place concrete segmental bridge built using balanced-cantilever construction with form travelers. All Photos and Renderings: PCL.

PCL has advanced considerably since its founding 110 years ago in Saskatchewan, Canada, but one aspect hasn't changed: Its ambition and desire to take on new challenges and work on the most complex bridge projects possible. The philosophy leads most frequently to building concrete designs as the firm handles an evolving array of challenges.

"We enjoy working on complex bridges, and we're not ashamed to say that we think we're pretty good at building them," says Jim Schneiderman, area manager for the firm's Mid-Atlantic office in Raleigh, N.C. "PCL has a very strong bench of technical expertise, so anything that is challenging and complex is a good fit for us."

Adds Ankur Talwar, district manager for the Transportation Infrastructure Group based in Seattle, "Our goal is to be a value-added company. That usually leads us to more sophisticated delivery methods that allow more contractor involvement and engagement." Schneiderman agrees. "Just being the low-bidder on a design-bid-build project isn't a good win strategy for us. We prefer more involvement in the design process so we can help innovate and create an efficient project."

'Just being the low-bidder on a design-bid-build project isn't a good win strategy for us.'

Bridge owners are seeing the benefits of leveraging those talents, as more are using alternative delivery methods, including design-build, construction manager/general contractor (CM/GC), and public-private partnerships (P3). "CM/GC fits our culture very well," says Gayle Grady, district manager in the Tampa, Fla., office. "It gives us the opportunity to plan and implement construction means and methods along with delivery of the project. The owner has the opportunity to gain knowledge of the project's design and how it will be delivered to them. It absolutely aids constructability."

Grady currently is working on her third CM/GC project, in Hartford, Vt., in which the existing north and south bridges carrying Interstate 91 (I-91) over U.S. Route 5 are being replaced using the lateral slide technique. New bridge abutments will be built while traffic continues, then the new bridges will be slid into place over two weekends. The project will be completed in June 2016. "These ABC [accelerated bridge construction] techniques are a good example of the innovation and adaptability that our clients seek," she says.

She also is working on the I-91 Brattleboro Bridge improvement project, which involves replacing two steel-truss bridges over the West River in Brattleboro, Vt., with a single cast-in-place concrete segmental bridge built using balanced-cantilever construction with form travelers. The bridge, created under the design-build format, will have a design life of 100 years and feature a 515-ft-long main span and 263- and 258-ft-long back spans. It will be built on 66-in.-diameter drilled-shaft foundations with aesthetic piers replicating Vermont's iconic stone. "Our goal is to develop an iconic, gateway structure that provides an aesthetically pleasing, high-quality, environmentally sensitive, sustainable bridge."

"We are capable of working in any format the client is most comfortable with," says Talwar. "These new approaches require higher staffing

requirements upfront, but the end result is a reduction in costs and faster scheduling. Those usually are the owner's main drivers."

Brainstorming Sessions

When PCL first decides to pursue a project, a variety of personnel are involved, including designers, field personnel, and superintendents, who brainstorm ideas. "We look at how we can be creative and win the job with efficiencies," says Schneiderman. "We challenge ourselves to be more innovative, which owners like. We look for ways we can provide better, faster, and smarter solutions."

Typically, the team focuses on refinements to the client's drawings that will save money, adds Talwar. "We look to minimize the number of traffic phases and make the structure more efficient, which will save money or allow it to be shifted to landscaping and other amenities."

As projects become more complex, the firm has increased the number of joint-venture programs. "Often the key criteria to partnering is to find a common culture between firms," Talwar says. "We also look for complementary resumes and skill sets. We want to integrate, but we want to learn how the other company approaches challenges. It allows us to cross train and see who we mesh well with."

PCL recently participated in a joint venture with Granite Construction on the SR 520 Eastside Transit & HOV design-build project in Bellevue, Wash. The project, completed in 2014, widened 2.6 miles of roadway and added an high-occupancy vehicle (HOV) lane, interchanges, and other amenities. The project includes three urban green-scaped freeway lids, which are concrete structures that bridge two communities over a highway and include decorative and landscaping elements. It also featured two vehicle bridges, three pedestrian bridges, two pedestrian tunnels, retaining walls, transit stations, and eight fish culverts. The structures were built with precast concrete and cast-in-place concrete designs.

Concrete Preferred

The complexity of designs and alternative delivery methods, coupled with an emphasis on ABC techniques, plays well to PCL's expertise with concrete bridge designs. "We definitely have a preference for using concrete," says Schneiderman. "It plays to our expertise and has been our preferred material throughout our history. One of our first bridge projects in the United States was a precast segmental design, and we've gained a lot of experience with it in the 30 years since."

A key reason comes from the number of projects in coastal environments. "Concrete is favored there due to its durability and low maintenance costs compared to steel," he says. Grady agrees. "The majority of our structures are designed with concrete," she says. "We've done a lot of great concrete jobs through the years. We like concrete."

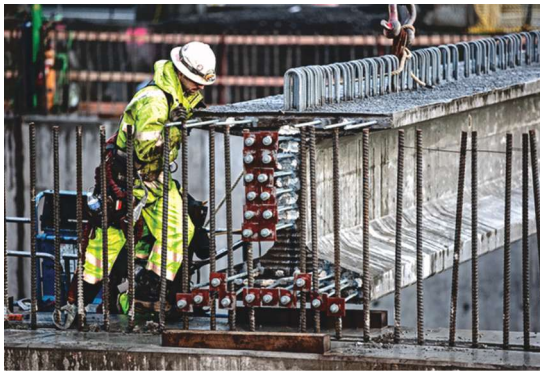
'We've done a lot of great concrete jobs through the years. We like concrete.'

One unique concrete project underway currently is the Flagler Memorial Bridge replacement in West Palm Beach, Fla., which includes a bascule bridge with long precast concrete approach spans. The approaches, which will be constructed in the spring of 2015, feature some of the first and largest precast concrete haunched beams to be used in the state. "They are absolutely magnificent beams," Grady says.

Concrete also helped PCL's design-build team create a design that was 30% lower in cost than any other proposal to replace the Herbert C. Bonner Bridge in Dare County on Hatteras Island, N.C. The $215-million, 2.8-mile-long project

PCL worked in a joint venture with Granite Construction on the SR 520 Eastside Transit & HOV design-build project in Bellevue, Wash. The project featured three lids, two vehicle bridges, three pedestrian bridges, two pedestrian tunnels, retaining walls, transit stations, and eight fish culverts.

The SR 520 Eastside Transit & HOV design-build project, completed in 2014, included a variety of precast concrete and cast-in-place concrete designs.



Erection of a girder on the SR 520 Eastside Transit & HOV project.

A rendering of the precast concrete bridge proposal by PCL's design-build team on the Herbert C. Bonner Bridge in Dare County on Hatteras Island, N.C. The cost was 30% lower than any other proposal. It consists of precast concrete segmental box-girder units main span and approaches constructed of Florida I-beams with cast-in-place concrete decks.

features multiple 350-ft-long main spans and extensive low-level approach spans. The main span units feature a precast concrete segmental box-girder design, while the approaches consist of 96-in.-deep Florida I-beams with cast-in-place concrete decks. Precast concrete cylinder piles support the structure.

The main span units' balanced-cantilever, post-tensioned, box-girder design resulted from the complex environmental restraints in the Oregon Inlet, a highly dynamic and constantly shifting inlet, with scour up to 80 ft, says Schneiderman. "We knew this was a signature bridge requiring expertise in a variety of fields and special attention to its durability." Stainless-steel reinforcement and corrosion-inhibiting admixtures were specified to help meet the 100-year service-life requirements.

'We're seeing more 100-year service-life requirements.'

Longer Service Life

"We're seeing more 100-year service-life requirements due to owners' increased focus on durability and longer specified design life, both resulting from a desire for reduced long-term maintenance costs," says Schneiderman. Talwar agrees, noting that, especially on the West Coast, seismic concerns also are a growing issue with which concrete structures can help. "Seismic issues have to be considered in every project in the west."

Extension of the design life also leads to demands for stricter quality control, which frequently leads the designers to precast concrete options. "Owners are shifting more of the quality control to contractors," Schneiderman says. "We are often required to hire inspectors to do the testing that DOTs [departments of transportation] used to do. The DOTs will spot-check those results, but we perform all the sampling and testing required to ensure a quality product."

Adds Talwar, "Clients realize the importance of quality control to achieve higher quality that better ensures durability. Precast concrete gives us that quality control by casting in the plant under controlled conditions."

Owners also are looking to concrete designs to aid with environmental concerns. "Environmental restrictions have definitely become stricter," says Schneiderman. "That, combined with an emphasis on quality control, are two of the biggest changes we've seen in recent years." In some cases, the new approach adds benefits. At the Bonner Bridge project, for instance, the existing bridge will be demolished, and the pieces will be barged to three sites located 10 miles out to sea and sunk to create reefs and fish habitats. "It's a good approach all around, because it gives us a place to dispose of the old bridge, and it creates new wildlife habitat. We can dump the pieces in as large of a size as we can handle."

Environmental conditions played a key role in the design of the Broad Avenue Bridge replacement project over the Flint River in Albany, Ga. The existing condemned bridge was replaced with a cast-in-place concrete, segmental box-girder bridge. The river contains several endangered species, creating strict environmental regulations.

The bridge features four spans, with the longest span at 320 ft. Three of the spans will be constructed by cast-in-place balanced cantilever with form travelers. The fourth span will consist of cast-in-place concrete box girders constructed on falsework. The piers, which are founded on 66- and 72-in.-diameter drilled caissons, will feature large architectural brick inlays.

"The environmental conditions were reflected in the design of our temporary works and the construction approach," says Grady. "We always work with a high regard for protecting the environment. That's becoming more ingrained as younger engineers come along, as they're sensitive to that need already. It becomes part of the planning process from the beginning as a standard aspect." That includes both the permanent structure and the construction process, she notes. "Owners don't want to inconvenience the public or have the landscape damaged during construction. That pushes us to be more collaborative to inspire creativity."

Environmental (and funding) concerns also are leading more DOTs to renovate bridges rather than replace them entirely. "Rehab is becoming more of a factor in projects," says Schneiderman. "Funding is scarce and DOTs want to allocate funds to impact as many projects as possible to buy more time until they need to do a replacement. They also are looking for longer post-construction warranties, which become a bigger factor in the RFPs [requests for proposals]. They are very savvy in balancing all of the needs in their budgets."

Rehabilitation can be more difficult than building from scratch due to the uncertainties of the condition of the

Environmental conditions played a key role in the design of the new four-span Broad Avenue Bridge over the Flint River in Albany, Ga.

The Broad Avenue Bridge consists of cast-in-place concrete segmental box girder, with three of the spans constructed with form travelers.

existing structure until work is well underway. "We typically bid such projects with a unit-price estimate based on piece count due to the number of variables," Schneiderman says. "Needs often develop as we get into it and find more deterioration than expected. It's a more dynamic environment than a replacement project."

Offices Expanding

The company has been expanding its reach in recent years, with the Bonner Bridge acting as a "seed project" to establish the firm's presence in North Carolina. Where most of the company's work had been in the Southeast, the projects mentioned here show they also are operating in the Middle Atlantic, Northeast, and Northwest. "We have a desire to grow our heavy-civil construction group. The Bonner Bridge project brought us to North Carolina, and now we want to leverage that to continue to grow."

As PCL grows, it recognizes that major challenges lie ahead. One of them will be recruiting young talent. "The biggest challenge I see in constructing complex projects today and in the future will be finding the qualified staff to build them," says Schneiderman. "We are seeing field superintendents retire at a faster rate than they are being replaced by younger talent. This is a challenge that will continue for the foreseeable future. I believe that we, as an industry, must continue to promote field management as a career choice for up-and-coming professionals."

110 Years of Service

Ernest Poole founded his construction company in Saskatchewan, Canada, in 1906 and incorporated as Poole Construction Co. Ltd. in 1913. The firm survived the Great Depression by expanding into highway and irrigation work.

In 1948, Ernest's sons John and George purchased the company and formed Poole Engineering jointly with Peter Kiewit Sons of Omaha, Neb., to pursue highway and airport work, as well as large joint venture projects. The partnership ended in 1958, and the firm became PCL Construction in 1979.

In 1975, Poole entered the U.S. market, opening an office in Denver (now its headquarters city). Offices were added in Florida and Arizona in 1986. In 2011, it achieved a record low Lost-Time Frequency Rate of 0.03.

Today, PCL generates commissions of more than $6 billion from all of its operations. Its group of independent construction companies is owned by its more than 4400 employee shareholders in the United States, Canada, and Australia.

That new workforce will face great challenges as demands grow. But it also will have a remarkable arsenal of weapons with which to work. "The scanning and modeling technology that is now available, and is continuing to grow, is a great aid in bidding and building projects," Schneiderman says. "It wasn't that long ago that this type of technology was considered exotic and 'cutting edge.' Now, it's standard operating procedure for us on every project. Our workforce is constantly adapting to keep up with the industry."

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

PERSPECTIVE

Aesthetic Master Planning

More than pretty bridges

by Joyce Kelley and Becky Borlan, formerly with Creative Design Resolutions Inc.

Communities have realized that their highways and bridges can serve more than just a functional purpose. They also can be landmarks that reflect an area's history, culture, and aspirations. A primary tool for reaching this goal has been the concept of context-sensitive solutions (CSS), which was developed in the late 1990s by the Federal Highway Administration. But the reality of putting these ideas into practice can be challenging.

One of the core tenets of CSS is to create transportation infrastructure that "exercises flexibility and creativity to shape effective transportation solutions while preserving and enhancing community and natural environments." To some bridge owners, that sounds expensive. Typically, department of transportation projects set aside 1 to 2% of construction costs for aesthetic enhancement, which leads engineers to fear that CSS aesthetic improvements will cause costs to rise and schedules to lengthen. In fact, incorporating strong aesthetics doesn't have to set back timetables or exceed the project's budget.

An example of what can be accomplished can be seen in Creative Design Resolutions Inc.'s (CDR's) creation of an aesthetic master plan for an interchange outside Little Rock, Ark. The project's engineers were won over by the plan's treatment of aesthetics as an integral part of the bridge rather than as an add-on after the fact that increased load or structurally changed the planned bridge. Aesthetic designs were created that became integral to the bridge's fabrication process.

Piers for the new 193rd Street Bridge in Catoosa, Okla., feature an aesthetic design that was able to meet the requirements of all the stakeholders. Photo: Steven Weitzman/ Creative Design Resolutions.

The design components were diverse: mechanically stabilized earth walls, bridge parapets, slope walls, and massive flyover piers. The CDR team was sensitive to the scale of the project and its budget, creating a plan that maximized aesthetics and limited costs. The designs were approached modularly, like puzzle pieces, so the client needed to invest only in a finite number of formliners that could be reconfigured to produce multiple unique vignettes. The project will be completed in spring 2015.

Bridging Differences

In some cases, mediation is required between groups having different visions for a project. One example involved a bridge in Oklahoma that was built adjacent to the Cherokee Nation's land. The city of Catoosa, where the bridge was

The aesthetic master plan created for the I-630/I-430 Interchange in Little Rock, Ark., won approval by treating the aesthetics as an integral part of the project rather than as an add-on that would increase load or change the structural design. The aesthetic design was created to be integral during the fabrication process. Photos: Arkansas State Highway & Transportation Department.

One of the mechanically stabilized earth walls for the 193rd Street Bridge in Catoosa, Okla., which features an aesthetic design that was able to meet the requirements of all the stakeholders. Photo: Steven Weitzman/Creative Design Resolutions.

located, wanted a say in the bridge's appearance, but the Cherokee Nation had a significant financial investment in the bridge's construction and also wanted their concepts considered. Oklahoma Department of Transportation, which funded and managed the project, asked CDR to listen to the differing opinions and create a design that would embrace ideas from everyone. That is typically easier said than done.

The presentation given to the stakeholders offered a variety of options for aesthetic enhancements used in other projects around the country that fit into this project's budget. The emphasis was placed on the common base on which the seemingly disparate groups agreed: ultimately, they all wanted a successful, beautiful bridge.

Feedback was gathered to draw out specific concepts each group wanted to have incorporated. This type of inclusive meeting and gathering of opinions represents a key step in using CSS concepts. It's important for stakeholders and the community to feel included from the beginning and not come to feel that an idea is being pushed on them at the last minute, regardless of its suitability.

After hearing all sides, CDR created proposals and returned to Oklahoma to meet separately with the invested parties to show them design options. The city, the Cherokee Nation, and the Oklahoma Department of Transportation all picked the same design independently. The 193rd Street Bridge now stands as an attractive testament to the process of community outreach and design mediation.

It's important for stakeholders and the community to feel included from the beginning.

Building from the Land and Community

The 1950s saw a boom in infrastructure across the country, making automobile travel faster and easier. That boom is causing a secondary one today, as many of those bridges have reached the end of their service lives almost simultaneously. As a result, we find ourselves at a critical time in highway infrastructure. These roads and bridges, built decades ago, now need reinvestment to continue to function. Fortunately, they also represent opportunities for creating new impressions by incorporating CSS concepts.

An example can be found in Norman, Okla., where the I-35 corridor traversing the city was completed in 1959. Fifty years later, the eight consecutive bridges that had made the city's development possible began to show signs of deterioration and needed to be replaced. City officials realized this simultaneous need created an opportunity to speak to the city's rich cultural and environmental history by designing new bridges that incorporated aesthetic improvements.

The master plan for the eight bridges focused on telling Norman's history. CDR worked with Oklahoma Art in Public Places to set community meetings and gather feedback that informed the design process. The goal was to have each bridge highlight a unique aspect of Norman's character.

As a result, rather than having an anonymous highway corridor bisecting the city, the new series of bridges provides a picturesque highway experience that shows residents and travelers alike the city's rich past and future. (For more on this project, see the article in the Fall 2013 issue of *ASPIRE*.™)

Bridges' proximity and importance to communities, combined with the availability of cost-effective, high-quality aesthetic designs, mean a pragmatic approach to bridge design and construction is no longer sufficient. We need to take into account the quality of life of those living near these projects and use these structures to enliven and beautify their communities. Integrated aesthetics can fill this role, without compromising the safety, budget, or scheduling concerns for a given project.

Aesthetically designed bridges that take full advantage of CSS concepts can be built economically, providing landmarks for the area that are a point of pride. CSS can help create structures that function beyond just their structural purpose to provide an aesthetic landmark that can stitch together communities.

PROJECT

RIEGO ROAD OVERCROSSING

Lessons learned on challenging bridge project north of Sacramento

by Sue Hida, California Department of Transportation

Positioning of the second wide-flange precast concrete girder for placement at the Riego Road Overcrossing. Photo: Brandi Matteoni.

Sometimes the California Department of Transportation (Caltrans) builds square bridge spans; spans that are as long as they are wide. Such was the case for the Riego Road Overcrossing over Highway 99 just north of Sacramento. New residential areas, high traffic volume to the airport and into the city, and a limited vertical clearance all had to be accommodated in the new bridge design.

Design

Fourteen lines of 5.5-ft-deep, spliced, wide-flange precast concrete girders were selected for the 156-ft 4-in.-wide, two-span, 295-ft-long overcrossing. The overall 6-ft 5-in.-deep superstructure is supported on seat-type abutments and an integral pier cap. The cap is supported on five 6-ft-diameter columns that are approximately 26 ft in height, fixed at the top, and pinned at the bottom. The columns and abutments rest on precast-concrete-pile-supported footings.

The precast concrete wide-flange girder was developed for its stability during transportation and erection. The shape is so efficient that, had bulb-tees been used on this project, the girders would have to have been 6 in. deeper. The top and bottom flanges are 4.1- and 3.8-ft-wide, respectively, and the web is 8 in. wide to accommodate 4-in.- diameter post-tensioning ducts. For the Riego Road Overcrossing, end-blocks for post-tensioning anchorage and 9 ksi concrete are used to satisfy shear requirements. Caltrans requires design for a 15-axle, 200-ton design permit vehicle.

Lesson-learned #1

Use *AASHTO LRFD Bridge Design Specifications* Table 3.5.1-1 expression for concrete unit weight when calculating dead loads; these girders exceed 150 pcf.

Splicing of the girders at the bent was required to keep the superstructure as shallow as possible. Splicing not only provides continuity of the spans, but also stiffens the integral bent cap joints with the column tops. Integral bent caps are used in most Caltrans' bridges for clean lines and context sensitivity. The detail also ensures desired seismic performance by limiting displacement and forcing damage to occur in the column top, that is, plastic-hinging.

profile

RIEGO ROAD OVERCROSSING / SACRAMENTO, CALIFORNIA

BRIDGE DESIGN ENGINEER: California Department of Transportation, Sacramento, Calif.

CONSTRUCTION INSPECTION ENGINEER: California Department of Transportation, Sacramento, Calif.

GENERAL CONTRACTOR: Teichert Construction, Roseville, Calif.

SUB-CONTRACTOR: MCM Construction, North Highlands, Calif.

PRECASTER: Kie-Con, Antioch, Calif.—a PCI-certified producer

The Riego Road Overcrossing was built using two-stage post-tensioning:

- two tendons with a total of 29 strands (1274 kips/girder) in Stage 1
- one tendon with 15 strands (659 kips/girder) in Stage 2

The first stage of post-tensioning controls stresses due to primarily self-weight of the girders and the deck, and the second stage is needed to carry additional super-imposed dead loads and all live loads.

Compared to one-stage post-tensioning, two-stage post-tensioning is better for

- reducing the total prestressing force required,
- reducing the concrete strength requirements, and
- controlling deflections.

Based on experience with post-tensioned box girders, Caltrans shifts from one-stage to two-stage post-tensioning when span lengths exceed approximately 140 ft.

Straight pretensioned strands are used along with draped post-tensioning tendons. The 150-ft-long girders for span 1 have 36 pretensioned 0.6-in.-diameter strands, and the 137-ft-long girders for span 2 require 30 pretensioned strands. One-third of the strands are debonded for 15 ft at each end, and four ⅜-in.-diameter top strands (tensioned to 5 kips/each) were added to reduce tensile stress in the top flange at the girder ends. Caltrans permits slightly more debonding than the current 25% limit per the *AASHTO LRFD Bridge Design Specifications*.

The AASHTO LRFD specifications limit the duct diameter to 40% of the gross web width in Article 5.4.6.2. The limitation seems to have come from early segmental bridge design practice. From experience in California, the duct diameter can be up to 50% of the gross web width. LRFD Article 5.8.2.9 requires that 25% of a grouted duct diameter be deducted from the web width considered in evaluating shear resistance, and LRFD Article 5.8.6.1 calls for 50% of the grouted duct diameter be deducted. Until definitive research recommendations are available, Caltrans is capping the deduction at 1 in. for post-tensioned, grouted spliced girders.

Construction

Falsework towers were erected to support the girder ends at the bent caps. Girders were placed on the towers and abutments at night using two 300-ton cranes, one of which was on rolling outriggers. In hindsight, the team wishes it had known how the camber, post-tensioning, and haunch thickness along the length of the girder would have played out.

The end diaphragms, which connected girders at abutments, and the bent cap,

The girders are connected to the pier cap with extended strands at the bottom and post-tensioning at the top. The girders frame into a 7-ft-wide integral bent cap, reinforced with 10 and 12 bundles of two No. 11 bars bottom and top, respectively, and No. 7 double- and triple-U-stirrups adjacent to the columns. Photo: Jim Ma.

Lesson-learned #2

Triple-check abutment and beam-seat elevations knowing the deck elevations; question any excessive minimum haunch thickness requirement. This can significantly increase the quantity of concrete required.

Removable formwork was used for the cast-in-place deck. Photo: Brent Bullard.

CALIFORNIA DEPARTMENT OF TRANSPORTATION, OWNER

POST-TENSIONING CONTRACTOR: Dywidag Systems International USA Inc., Long Beach, Calif.

BRIDGE DESCRIPTION: Two-span, 295-ft-long, spliced precast, pretensioned and post-tensioned girder bridge

STRUCTURAL COMPONENTS: Fourteen precast, pretensioned 5-ft 6-in.-deep girders in each span; 8¼-in.-thick, cast-in-place concrete deck and integral pier caps; cast-in-place columns and abutments supported on precast pile footings

BRIDGE CONSTRUCTION COST: $125/ft^2

Setting the first of 14 California wide-flanged girders into the second span. Extensive shear reinforcement is required for the girder-slab connection adjacent to the bent cap so that the integral bent cap behaves as desired during a seismic event. Photo: Brandi Matteoni.

which contained splices for the post-tensioning ducts, were formed and concrete was placed in the next step. The end diaphragm at each abutment is 3 ft thick and made continuous transversely with three 6-ft-long, No. 8 bars going through each girder and three bolt inserts on the interior face of the exterior girders. At the bent, the girders extend 6 in. into the 7-ft-wide bent cap. Strands extend from the bottom flange into the bent cap to develop positive moment resistance in the joint.

Top and bottom longitudinal bars of the integral bent cap consist of bundled No. 11 bars. Extensive joint shear reinforcement is required in accordance with both the *Caltrans Seismic Design Criteria v1.4* and the *AASHTO Seismic Design of Highway Bridges Guide Specifications*. After concrete placement, a minimum strength of 3.5 ksi is required prior to the first stage of post-tensioning. After the first stage of post-tensioning, the falsework towers were removed and formwork was placed for the deck.

The girders are made composite with a cast-in-place concrete deck by extending all girder shear reinforcement into the deck and bending it in the field. For Riego Road Overcrossing, which uses 11-ft 3-in. girder spacing, Caltrans requires an 8.25 in. deck thickness, and No. 5 transverse top and bottom deck reinforcement alternating every 2.75 in. for an overall spacing of 5.5 in. The standard design is controlled by serviceability.

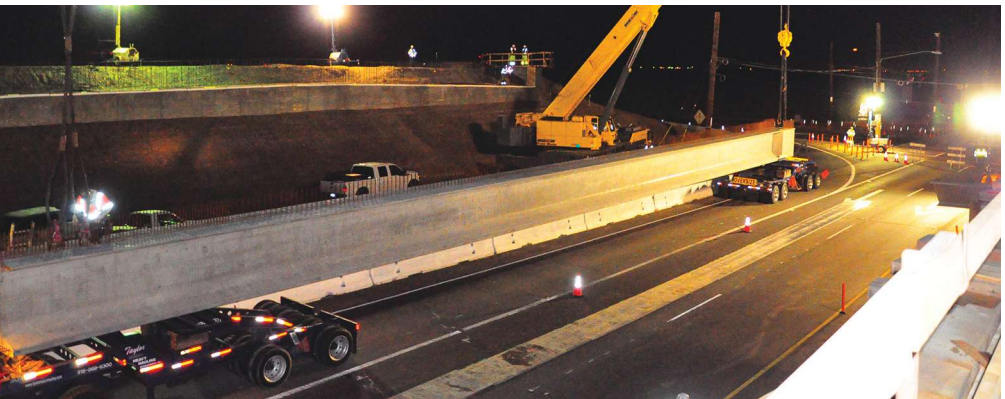
In the longitudinal direction, No. 4 bars at 18-in. spacing support the top transverse reinforcement; alternating No. 5 and No. 4 bars are provided below and above the bottom transverse reinforcement. At the bent cap, an additional eight 60-ft-long No. 10 reinforcing bars are placed in the deck over each girder. These bars further enhance the bent cap joint performance during a seismic event and help resist negative bending due to long permit vehicles with multiple axles. The climate is temperate and conventional 60 ksi, ASTM A706 reinforcing steel is used in the 5 ksi concrete deck.

Within a few weeks of placing concrete for the deck, cracks emerged parallel to and diagonal from the bent cap area. The cause of the cracking is thought to be rotation of the girder ends. The new girder shape is shallow and rotates more than the girder shapes currently in wide-spread use in California.

Stage 2 post-tensioning took place 10 days after the deck concrete was placed. For the bookkeeping of prestressing-force losses in the pretensioned girders and post-tensioned spliced girders, Mathcad was used to calculate the design with the LRFD equations. The final post-tensioning did not close the deck cracks enough to satisfy serviceability concerns. The deck was sand-blasted and a methacrylate resin treatment applied. Caltrans frequently uses this process on bridge deck rehabilitation projects.

An elevated median barrier, sidewalks on both sides, electroliers, and decorative chain link railing were added. The bridge opened to traffic on August 16, 2014, but the ribbon-cutting ceremony was performed on December 2, 2014.

The first of the California wide-flange girders arriving at the project site of the Riego Road Overcrossing. Photo: Brandi Matteoni.



Lesson-learned #3

Deck placement sequence may need to be considered and rethink removal of falsework prior to casting the deck and completion of post-tensioning. The composite strength of the girders is important.

Lesson-learned #4

The "seismic" bars added over each girder for continuity are also needed for service loads and should be spread out more into the area between the girders—or additional bars should be used. Whether or not intermediate diaphragms would have helped decrease the deck cracking is open for debate.

Sue Hida is with the Division of Engineering Services for the California Department of Transportation in Sacramento.

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

EDITOR'S NOTE

Measuring as-cast camber while stored in the precast plant prior to the field casting of the beam seats can allow haunch thickness adjustment. The engineer of record, contractor, and specialty engineer (with the data from the fabricator) need to collaborate to avoid the casting of excessive haunches. This simple step of a field adjustment can also avoid bottom mat of steel conflicts that may occur when excessive camber exceeds the minimum build up dimensioned in the plans. See page 38 to learn more about the variability in camber.

PROJECT

by Jay Holombo and Peter Smith, T.Y. Lin International, and Jon Grafton, Oldcastle Precast Inc.

North Milliken Avenue Railroad Underpass Bridge

Value-engineered redesign demonstrates economy of high-performance precast concrete

By allowing the contractor to build the North Milliken Avenue Railroad Underpass Bridge with high-performance precast concrete girders instead of structural steel, the City of Ontario has realized significant construction cost savings, reduced construction impacts, and eliminated future maintenance painting costs. All Photos: Jay Holombo.

The value-engineering cost proposal (VECP) redesign of the North Milliken Avenue Railroad Underpass Bridge demonstrates that significant savings can be achieved by using high-performance precast concrete instead of structural steel for railroad underpass structures with spans exceeding 80 ft. Further benefits of high-performance precast concrete demonstrated by this VECP redesign include rapid construction, enhanced aesthetics, and low maintenance.

Project Background

Located less than ¼ mile south of an interchange with Interstate 10, this busy railroad crossing is at the nexus of a significant freight and a commercial truck corridor. Prior to construction, exiting truck traffic backed up onto the freeway when blocked by a train crossing North Milliken Avenue, causing major delays and a significant safety hazard. The railroad needed to be elevated over the arterial because of the proximity and geometry of an adjacent freeway interchange to the crossing. As a result, the railroad underpass bridge is a highly visible element in the community.

Elevating the line at the underpass approaches required the construction of a precast T-wall-based retaining wall system extending approximately one half mile on both sides of the tracks. This was needed to meet right-of-way requirements. The underpass and approaches were constructed in two phases, allowing the busy railroad line to continue in full operation during construction.

Initially designed as a steel girder bridge with a steel plate forming the deck, the underpass is a two-span bridge measuring 171 ft long by 52 ft wide. Seven-foot-deep precast concrete fascia beams on each side support maintenance walkways, railings, and communication conduit. They are designed to be sacrificial to protect the main structural beams and can be removed and replaced if there is ever an accidental over-height truck impact. The fascia beams were cast with an architectural formliner to give the exterior surface an ashlar-stone appearance bordered with granite bands, which gives the overall structure a pleasing profile that blends well with the adjacent T-wall panels.

VECP Process

During the bidding phase, an alternate superstructure design using

profile

NORTH MILLIKEN AVENUE RAILROAD UNDERPASS BRIDGE / ONTARIO, CALIFORNIA

BRIDGE DESIGN ENGINEER: T.Y. Lin International, San Diego, Calif.

PRIME CONTRACTOR: C.C. Myers Inc., Rancho Cordova, Calif.

PRECASTER: Oldcastle Precast, Perris, Calif.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Dywidag Systems International (DSI), Long Beach, Calif.

precast, prestressed adjacent box girders was evaluated. This evaluation demonstrated significant cost savings and reduced fabrication time required for the precast concrete box girders versus the as-designed structural steel girder system. The precast design required some minor modifications to the foundation size due to the added weight of the concrete girders. However, when all costs were included, the net savings to the project was approximately $900,000, which was split between the contractor and the owner.

A further benefit of using a precast concrete box-girder superstructure is that bridge maintenance painting operations are not required.

A further benefit of using a precast concrete box-girder superstructure is that bridge maintenance painting operations are not required, as would be necessary for the as-designed steel girder system.

Redesigned Bridge Details

The redesigned two-span underpass bridge consists of 26 precast, prestressed box girders supporting ballast, waterproofing, and two mainline tracks. Ballast curbs were cast as an integral component of the exterior girders. Each span is transversely post tensioned at the quarter points within each span.

Each 4-ft-wide box girder contains fifty-six 0.6-in.-diameter strands and relatively thick bottom and top flanges of 9 and 10 in., respectively, to meet the stringent American Railway Engineering and Maintenance-of-Way Association (AREMA) strength, service, and deflection requirements. A net upward permanent deflection of 3 in. at midspan was anticipated after placement of ballast. A buildup of rubberized asphalt was used to ensure sufficient transverse and longitudinal slope to maintain drainage off of the bridge.

The architectural features of the North Milliken Avenue Railroad Underpass Bridge could not be modified as part of the redesign process. These features included formliners, coloration, and decorative column pilasters, which distinguish this highly visible gateway to the community.

The fascia beams, which are conventionally reinforced, support pedestrian walkways and communication conduit. To minimize the amount of formliner needed, the precast fabricator developed an innovative approach where the exterior was cast as 7.5-ft-long panel segments. These panel segments were then placed in the forms and cast with the rest of the fascia box girder, resulting in significant savings while meeting the aesthetic requirements of the project.

The bridge bent consists of a cast-in-place concrete cap beam with four 4.5-ft-diameter columns supported by pile caps. Headed reinforcement was used for footing stirrups and the cap beam as part of the redesign to reduce reinforcement congestion and simplify the detailing and construction efforts. Piers and abutments are hidden by decorative concrete column pilasters. These pilasters are hollow, with large blocks of differing shapes to form a cap. These caps were redesigned as part of the VECP process, allowing the contractor to fabricate them on site as precast elements as a means of reducing the cost of formliner and to accelerate construction. The connection between the cap and the column consists of a neoprene pad to prevent localized spalling and grouted No. 8 reinforcing bars in corrugated metal tubes to provide the necessary strength.

Temporary traffic barriers bolted directly to the top of the precast concrete box girders served as a ballast retainer and a safety fence support during construction of the second stage resulting in significant time and cost savings.

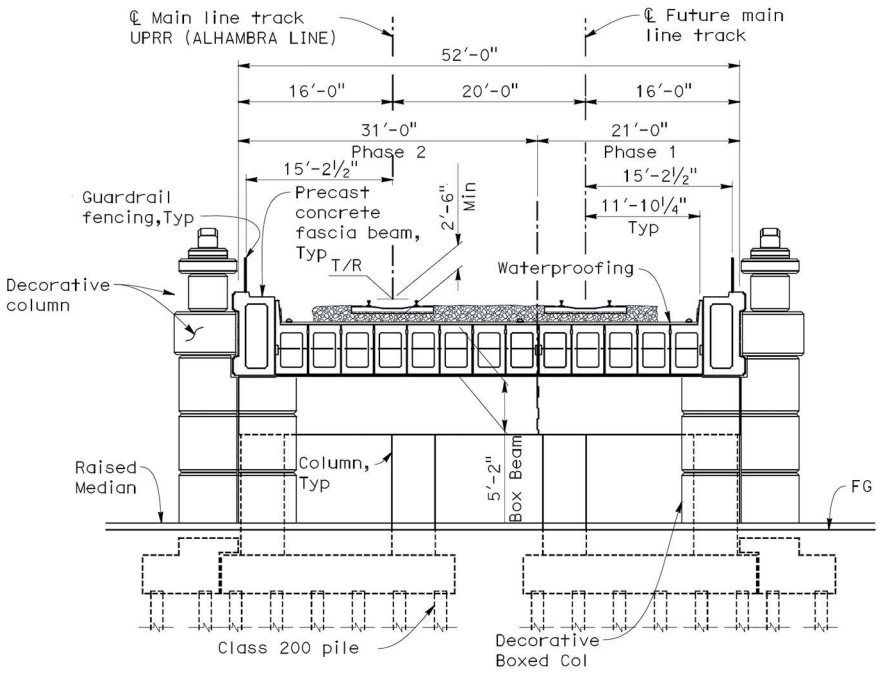
CITY OF ONTARIO, OWNER

BRIDGE DESCRIPTION: Two-span, precast, prestressed concrete box-girder, railroad underpass bridge

STRUCTURAL COMPONENTS: Twenty-six 84.5-ft-long, 62-in.-deep, precast, prestressed concrete box girders supporting tracks, ballast, and waterproofing. Four 84.5-ft-long, precast concrete fascia beams supporting a walkway and serving as sacrificial beams; cast-in-place pier cap, and circular columns with pile caps

BRIDGE CONSTRUCTION COST: $5 million ($561/ft^2)

AWARDS: 2014 Precast/Prestressed Concrete Institute (PCI) Design Award in the Best Nonhighway Bridge category



The redesigned bridge utilizes 26 high-performance precast, prestressed concrete box girders supporting train loading, tracks, ballast, and waterproofing. Constructed in stages, the beams are connected with cement grout and transverse post-tensioning at the quarter points within each span. Drawing: T.Y. Lin International.

Challenges

Schedule

To meet the contractor's schedule, fabrication had to begin 3 months after the award of the construction project. However, to accept the VECP, the owner required a completely new set of plans, specifications, and estimates (PS&E) for the bridge underpass. The first submittal of PS&E was delivered within 6 weeks of receiving the notice-to-proceed. Review, resolution of all comments, and approval from the City of Ontario; the San Bernardino Association of Governments (SANBAG), which was the sponsoring metropolitan planning organization; and Union Pacific Railroad, were completed within an accelerated, 6-week duration.

Vertical Clearance

Another project challenge was the limited vertical overhead clearance. Vertical clearance requirements limited the depth of the box girders to 5.2 ft. With spans of 83 ft, the span-to-depth ratio (S/D) of 15.8 is 38% greater than that recommended in Section 17.1.3.1 of the PCI *Bridge Design Manual*. Meeting this depth required utilizing a relatively high concrete compressive strength of

To reduce the cost of the formliner, the manufacturer sequentially cast 7.5-ft-wide precast concrete panel segments that were then placed in the forms when the fasçia beam was cast, with excellent results.

9 ksi and optimizing girder dimensions so that the required prestressing force did not exceed the available stressing bed capacity of 2400 kips at the fabrication plant. The shape was developed in cooperation with the designer and precaster without the need for custom form fabrication.

Construction Staging

Construction staging required the existing tracks to remain in service while the southern half (Phase 1) of the grade separation was under construction. Completion of the first stage of construction utilized AASHTO "Type K" barrier for a temporary concrete railing that was bolted directly to the top of the box girders and functioned as a ballast retainer and temporary hand railing support. After transfer of the rail traffic to Stage 1 construction, Stage 2 was constructed over the existing tracks. Stage 1 and Stage 2 construction are connected with 1.25-in.-diameter, high-strength rods that are post-tensioned transversely through the box girders in ducts at the quarter points within each span that were later grouted. Although the transverse post-tensioning provides a redistribution of loading, each box girder is designed to independently carry approximately half of the Cooper E80 train load.

Seismic Design

Redesign efforts required consideration of seismic design as a result of the increased mass provided by the concrete superstructure. AREMA requires analysis for three separate earthquake events to include serviceability, ultimate, and survivability limit states. Each earthquake corresponds to a different limit state. Since the bridge is relatively short, the response is dominated by the abutments longitudinally, and the bent capacity is designed for the transverse demands. To obtain the required connection stiffness between the superstructure and the abutments and bent, each end of the bridge girders is keyed in place with a 3.0-in.-diameter, Grade 50 solid steel rod that was placed after erection. At the abutment walls, the rods were grouted in both the girder and abutment, but at the bent, the rods were only grouted in the bent cap.

Summary

The value-engineering redesign of the North Milliken Avenue Railroad Underpass Bridge demonstrates that high-performance precast concrete is ideal for railroad bridge spans greater than 80 ft, and has better economy and faster production than equivalent steel spans. The City of Ontario and the surrounding community further benefitted from an accelerated construction schedule and reduced future maintenance costs. Redesign of the pilaster caps and the fascia beams allowed for significant cost and schedule savings while maintaining the original designer's vision of a highly visible and attractive gateway to the community.

Jay Holombo is a project manager and Peter Smith is a senior bridge engineer for T.Y. Lin International in San Diego, Calif. Jon Grafton is the manager of business development western region for Oldcastle Precast Inc. in Perris, Calif.

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

Tilikum Crossing, Bridge of the People

New light-rail structure over the Willamette River to open in the fall of 2015

by Norman Smit and David Goodyear, T. Y. Lin International, and Aaron Beier, Kiewit Infrastructure West Co.

Nestled between the Marquam Bridge to the north, and the Ross Island Bridge to the south, the Tilikum Crossing is a new structure spanning the Willamette River in Portland, Ore. This is the first new crossing of the Willamette River since the Freemont Bridge was constructed in 1973. This unique cable-stayed bridge is designed to accommodate the multimodal transportation needs for the sponsoring agency, TriMet, and is a critical link across the Willamette River for the new 7.3-mile light-rail transit (LRT) connection between Portland and Milwaukie. The new extension of the LRT system is expected to serve over 25,500 weekday riders by 2030. The owner, in collaboration with the design-build team, has completed the new bridge on schedule so the LRT extension can open to riders in 2015.

Bridge Type Selection

The alignment of the new LRT extension was finalized in 2008, and a citizen's advisory committee was formed to consult with the owner as to the bridge type, geometry, and architecture of the new bridge. The design was chosen by the owner prior to executing the contract to complete the final design and construction of the bridge. The two-year advisory process resulted in a cable-stayed bridge being chosen to span the Willamette River. The preliminary design was completed in 2010.

Design-Build Delivery Method

TriMet chose the design-build delivery method for the bridge because the critical path for delivering the LRT extension to Milwaukie ran through the design and construction of the new Tilikum crossing. To open the new LRT line by 2015, it was essential that the bridge had to be completed by August 2014. The following were the critical milestones for the project:

- Type selection—February 2009
- Design-build contractor selected—October 2010
- Final bridge design begins—January 2011
- Bridge construction begins—July 2011
- Final bridge design complete—August 2012

Aesthetic lighting is programmed to change colors as the river changes. Photo: Mike Brewington, 2014.

profile

TILIKUM CROSSING, BRIDGE OF THE PEOPLE / PORTLAND, OREGON

BRIDGE DESIGN ENGINEER: T.Y. Lin International, Olympia, Wash.

OWNER'S ENGINEER: HNTB Corporation, Bellevue, Wash.

OWNER'S ARCHITECT: Donald McDonald, San Francisco, Calif.

QUALITY CONTROL: Cooper Zietz Engineers, Portland, Ore.

PRIME CONTRACTOR: Kiewit Infrastructure West Co., Vancouver, Wash.

POST-TENSIONING SUPPLIER: Schwager-Davis, San Jose, Calif.

CABLE-STAY SUPPLIER: Freyssinet, Rueil Malmaison, France

FORM TRAVELER DESIGN: Parkin Engineering, Vancouver, Wash.

BEARING SUPPLIER: R.J. Watson, Buffalo, N.Y.

- Bridge turned over to owner for systems installation—August 2014
- Systems installation and testing complete—October 2015

Due to the tight construction schedule, the design period overlaps with construction by approximately 12 months, which shortened the total duration for final design and construction of the structure. This compressed schedule allowed the owner to meet the overall construction schedule for the LRT project.

Program Requirements

Having been through the public process to develop the geometry and architecture of the new bridge, the owner wanted to be sure that the final, built structure was consistent with that vision. Therefore, all the key elements of the design were prescribed in the contract documents as "program requirements." Some of the elements that could not be changed by the design-builder included: width of bridge deck, transitway geometry, angle and depth of edge beam, location of bridge expansion joints, deck geometry at tower, traffic barrier and handrails, geometry of towers, shape and dimensions of columns, stay arrangement, deck cross section, and edge girder and floorbeam dimensions.

The owner prescribed these program requirements to assure that the architecture, bridge type, and geometry from the public process was achieved in the finished bridge. The disadvantage of this prescriptive approach was that the full benefits of allowing the design-builder to provide the most efficient and constructible bridge were not realized. The emphasis placed on prescriptive program requirements in the request for proposal (RFP) provided limited opportunities for the design-builder to optimize the design. The main elements that were open to the design-builder's innovation included:

- Main pylon foundation type
- Solutions for liquefiable soils on the Portland (west) side of the bridge
- Midspan edge girder and stay anchorage design
- Construction means and methods

With the visual look of the bridge prescribed, the design-build team concentrated their efforts on cost saving items in the foundations, edge girder designs to address geometry constraints at midspan, and the methods of construction. The contractor has extensive experience constructing all types of cable-stayed bridges, beginning with the first precast concrete segmental cable-stayed bridge in the United States at Pasco-Kennewick in Washington. The design engineer has similar experience designing a wide range of cable-stayed bridges, from precast to cast-in-place bridges. So the evaluation of construction methods was comprehensive.

Balanced cantilever construction with work bridges to the main pylons to deliver material to the four construction fronts at the tips of the cantilevers. Photo: Sahnow's Air Photos, Banks, Ore.

Site logistics were a challenge, with good water access for the main span, but limited water access over much of the backspans, and a parallel contract for hazardous-material remediation under the west backspan. In addition to limited access for floating equipment on the backspans, the open-edge girder section prescribed for the superstructure was not conducive to short line precasting, a lesson learned by the design engineers on the East Huntington Bridge in West Virginia. So the contractor chose to erect the bridge using overhead form travelers, developing a scheme in conjunction with a specialty subcontractor.

The erection method had to be selected at the outset, since temporary loading

TRIMET, OWNER

EXPANSION JOINT SUPPLIER: Watson Bowman Acme, Amherst, N.Y.

RAIL EXPANSION JOINT SUPPLIER: Atlantic Track, Wheaton, Ill.

REINFORCING BAR SUPPLIER: Harris Rebar, Tacoma, Wash.

BRIDGE DESCRIPTION: A five-span, 1720-ft-long, cable-stayed bridge across the Willamette River in Portland, Ore. The main span is 780 ft long, the backspans are 390 ft long, and the two pylons are 180 ft tall. The typical bridge width is 75.5 ft; at the towers, the width is 110.5 ft. The bridge was constructed using the balanced cantilever cast-in-place segmental construction method in 16-ft-long segments.

STRUCTURAL COMPONENTS: The concrete edge girders are 6 to12 ft deep and 6 ft wide. The transverse floor beams are spaced at 16 ft on center. Cable anchors supporting the superstructure are 32 ft on center. The cables are continuous, passing through saddles in the towers.

BRIDGE CONSTRUCTION COST: $109 million

and construction means and methods for this type of structure define the final dead load condition of the completed bridge. In addition, the slender dimensions of the edge girders, the short towers, and the cable saddles made it critical that the cantilever construction did not overstress the deck or allow the cables to slip through the saddles as the segments were cast on opposite sides of the towers. Each construction operation needed to be coordinated and integrated into the design.

Pylon Foundations

The reference concept provided by the owner included a large circular foundation supported on eight 10-ft-diameter shafts. Preliminary analysis showed that much of the mass supported by the shafts was in the footing itself, so that by reducing the size of the footing the number of shafts could be reduced. The figure shows the reference concept and the final design. The shape was made more oval and the number of shafts was reduced to six 10-ft-diameter shafts. This resulted in a significant reduction in concrete quantity, lowered seismic demands, reduced the size of the cofferdam required to construct the footings, and shortened the construction duration for the main foundations. The main controlling load cases evaluated for the foundation included seismic, wind, ship impact, and light rail vehicle (LRV) live loads in combination with the dead load of the structure.

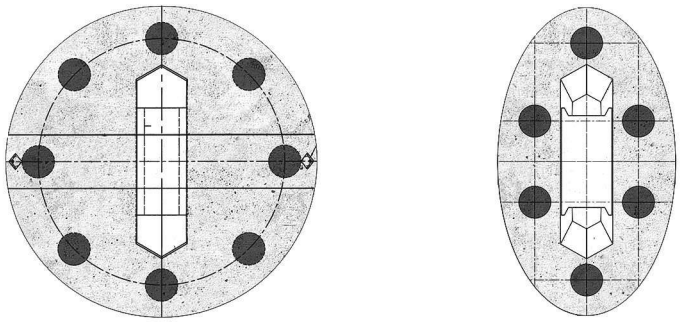
The shafts are embedded in an extremely hard deposit known as the Troutdale Formation. This formation is a dense, compact granular material that provides excellent support for the bridge. O-cell shaft capacity tests were performed to verify their ability to support the structure. This testing showed that the end bearing and side friction of the shafts exceeded even the higher predictions and, therefore, the final shaft tip elevations were reduced further based on the test results. Knowledge of the strength of local subsurface conditions allowed the design to use capacities considerably higher than classical values for both end bearing and side friction.

Liquefiable Soils

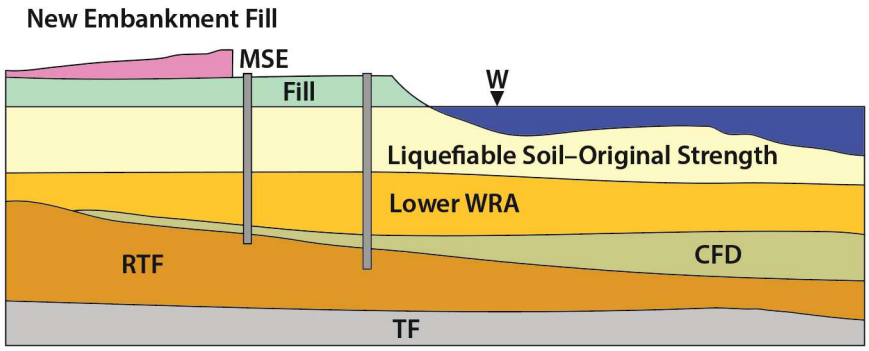
Preliminary geotechnical investigation performed by the owner during the preliminary design phase indicated that there were potentially liquefiable soils on the west side of the project. In addition, the location of the bridge was an old dock and dumping area for a shipyard that once operated on the site, and investigations showed the fill had hazardous materials. The bidding documents indicated that ground improvement might be required to stabilize the area in the event of an earthquake.

In lieu of ground improvement strategies that would require handling a large volume hazardous material, the design-build team evaluated structural solutions, and established demands from the predicted soil liquefaction on the bridge displacements and foundation strength and ductility demands. The design criteria required evaluating a 475-year return operating and a 975-year return extreme earthquake.

For the lower-level earthquake the bridge must remain operational with repairable damage, and for the higher-level earthquake the structure must not collapse. Evaluations were performed using a three-dimensional nonlinear time history model with both liquefied and non-liquefied soils in order to bracket results. The predicted displacement demands were applied to the foundations along the length of the structure in order to design the foundation-superstructure frame for the liquefied design case. This solution was compared to a ground improvement condition, and found to be both superior in terms of performance and less expensive for construction, even without considering the environmental impacts of moving large volumes of hazardous materials.



The figure shows the main foundation reference concept on the left and the final design on the right. Drawing: T.Y. Lin International.



The figure shows the soil layers that were used to model the back span piers for the soil displacement for each earthquake level. Note: WRA = Willamette River alluvium, CFD = catastrophic flood deposits, RTF = reworked Troutdale formation (still hard sand), and TF = Troutdale Foundation. Drawing: T.Y. Lin International.

Midspan Design

Due to the maximum bridge slope allowed for the Americans with Disabilities Act and the navigation clearance required, there was not adequate clearance below the bridge to permit the midspan cable anchors to be below the edge girder in the middle 150 ft at the midspan of the structure. This issue was left open in the RFP because the realization of height limitations came late in the project development process.

The solution developed by the bridge designer was to split the edge girder

Midspan framing showing the double edge girders with the anchors tucked between them to provide the navigation clearance in the middle of the bridge. Rendering: T.Y. Lin International.

and recess the anchorage between the split edge girders. This design produced a somewhat complicated forming system, but it allowed meeting the clearance requirements without significantly increasing the concrete volume and weight.

Means and Methods

One of the more critical elements for reducing the cost of construction is to efficiently move material through the construction site and out to the construction fronts. The construction of work bridges required for the two main towers allowed workers and materials to efficiently reach the construction fronts. There was a large preassembly yard on the Portland, Ore., side of the bridge where the reinforcing steel cages were preassembled prior to being lifted into place by the tower cranes at each pylon.

This efficient use of the site was one of the ways construction costs were reduced. Preassembly of the tower reinforcement along with aligning the cable saddles in the preassembly yard allowed for efficient assembly of the structure. The preassembled sections were then moved to the towers over the work bridges.

The overhead traveler system used to cast the segments was chosen because it was comparatively lightweight. This was necessary to avoid overstressing the deck. However, due to the shallow edge girder section, it was not possible to cast a full 32 ft between cable anchors. The segments were cast 16 ft long, and temporary cables were used to support the bridge as the permanent cables were installed.

Summary

The bridge is essentially complete, and the systems necessary to operate the LRT are being installed. The new LRT line will open to riders on schedule in 2015 due to the collaborative efforts of the owner and the design-build team. Portland, Ore., a city of many bridges, has a unique, new transit and pedestrian crossing of the Willamette River, which will serve the public for many years to come.

Norman Smit is a senior associate and David Goodyear is senior vice president with T.Y. Lin International in Olympia, Wash. Aaron Beier is a project engineer with Kiewit Infrastructure West Co. in Vancouver, Wash.

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

AESTHETICS COMMENTARY

by Frederick Gottemoeller

Portland, like Pittsburgh, Chicago, and several other major cities, is fortunate to have a whole array of major bridges lined up along its most important waterways. They shape everyone's image of the city. The bridges are of many types and sizes, each reflecting its purpose, ownership, and period of completion. Placement of a new bridge in the midst of such an array is always a challenge. Will the new bridge hold its own in the cityscape? Will it adequately reflect the aspirations and skills of its era? And, in a city center especially, will its details stand up to the scrutiny of the thousands of people who will see it close-up every day? It appears that the new Tilikum Crossing will do all of those things.

This cable-stayed bridge, a first for Portland, inserts a clearly twenty-first century form into the mix of existing trusses and arches. The form itself is large enough and geometrically distinct enough to stand out in the cityscape. The designers have taken the form a step farther, making it visually unique among cable-stayed bridges by such refinements as the tapered pentagonal tower legs and visually simplified floor system. They had no need to seek novelty in untried structural systems. The elegance of the design will make it a strong visual anchor for the future redevelopment of the adjoining areas upstream from downtown. The generous side paths make for a natural combination of bus/light-rail transit riders, bicyclists, and pedestrians on a single structure. One hopes that we will soon see similar arrangements in other cities.

Finally, the quality of the details will make the structure an interesting bridge to be around. The oval pedestals for the tower press into service an attractive geometric shape that responds to the flow of the river. The floor system simplifies the underside appearance for boaters and riverwalk users by integrating the cable anchorages within the paired edge girders. And the aesthetic lighting will bring the bridge to life at night. Portland has a fitting new landmark to add to its array of bridges.

Take Advantage of Precasters' Expertise

Contractor-alternate design, new casting and erecting techniques help meet growing challenges as owners tap into full range of precasters' knowledge and skills

by Heinrich O. Bonstedt, Central Atlantic Bridge Associates

The Ashcom Cove Creek Bridge in Bedford County, Pa., consists of five 120-ft-long precast concrete bulb-tee girders and a total-precast concrete structure. Photo: PennStress.

In highway and bridge construction, a continuum of options and variations exists that impact each stakeholder, including owners, designers, contractors, and suppliers. Taking advantage of all of the skills and knowledge of each member of the team ensures the creation of a high-performance structure that is efficient, cost-effective, quick to complete, and aesthetically pleasing. In many cases, offering a "contractor-alternate design" approach achieves this goal.

In this format, contractors can supplement the owner's design effort. It allows contractors to adjust the plans to take advantage of new techniques and their own skills and equipment to optimize the design at the lowest possible bid.

Contractors offer the logical choice to maximize efficiency in the design and construction. They have traditionally taken the lead in value engineering and engaging design professionals. Providing this option allows the contractor to provide extensive preconstruction services, such as estimating, value engineering, and constructability review, and they can then manage and create a comprehensive integration of supply channels. Further, the contractor assumes the risk and liability for defects and related problems.

Using the contractor-alternate design approach ensures the contractor can take full advantage of the knowledge of the precaster and other key subcontractors, leveraging their techniques and state-of-the-art facilities to maximize efficiency and design. This factor can be significant, as long delays can occur between design completion and bidding, locking projects into approaches that have been much improved in that interval.

Precasters are skilled at value-engineering projects after designs are available, and the contractor-alternate design approach maximizes those adaptations by bringing the precaster into the process earlier.

BIM Aids Designs

The use of three-dimensional building information modeling (BIM) software ensures precasters can consider every option and every possible component configuration to produce the most efficient design in terms of piece count, sizes, weights, and other factors. This works especially well with total-precast concrete designs, where all the components can be fit together comprehensively and supplied by one source, minimizing communication problems.

An example can be seen in the Ashcom Cove Creek Bridge in Bedford County, Pa. The bridge features one span of five 120-ft-long precast concrete bulb-tee girders and a total-precast concrete structure, including footings, piers, abutments, and deck panels with integral parapets, all designed and evaluated with BIM software. The changes reduced traffic detours from 7 months to 8 weeks and saved more than $125,000. The new version provided a one-for-one replacement of the original cast-in-place concrete design, maintaining similar connections with few adjustments.

Bridges for Life™

Precast concrete designs also can help owners improve durability and lower long-term maintenance costs. Precast concrete continually adapts with new concrete mixtures and new casting techniques that create longer lasting designs with lower life-cycle costs. As a highly engineered product, precast concrete continues to develop higher strength and more durable concrete as precasters test new materials and practices.

Such factors as self-consolidating concrete, lightweight concrete, cementitious formulations, pozzolan concentrations, improved reinforcement coatings, high-performance grout, and prefabricated welded-wire reinforcement are increasing the capabilities of precast concrete at an increasing rate.

The Federal Highway Administration's (FHWA's) Every Day Counts initiative

Barging of the precast concrete components that were used to construct the 3.1-mile-long Tappan Zee Bridge in New York. The precast concrete open-footing tubs were set on drilled shafts and filled with concrete to create the bases for the bridge's piers. Photo: Bayshore Concrete.

Workers place precast concrete abutments for the Ashcom Cove Creek Bridge. Photo: PennStress.

encourages accelerated bridge construction (ABC), and precast concrete designs offer many techniques to assist in ABC. Fabricating precast concrete components in a controlled, high-quality plant produces fast, efficient construction that allows work to progress as the site is prepared and keeps the site clear of congestion. Those elements create an efficient, safer environment that reduces contractor risk while speeding up construction and reducing user costs.

An example can be seen in the total-precast concrete design for the September 11 Memorial Bridge on Route 70 in Ocean and Monmouth Counties, N.J. The goal of the New Jersey Department of Transportation was to use as much precast concrete as possible to simplify the architectural concept and minimize the duration of in-water construction. The bridge was built with precast concrete pier cofferdams, columns, cap beams, and bulb-tee girders. (For more on this project, see the Fall 2009 issue of *ASPIRE.*™)

Total-Precast-Concrete Designs

The desire to speed construction is leading more designers to select more precast concrete components, leading to total-precast-concrete solutions. This understanding has taken some time to develop. Some designers that rely on traditional methods haven't realized the capabilities available to design substructure elements as precast concrete components.

The 3.1-mile-long Tappan Zee Bridge in New York, at $3.9 billion, is the largest bridge-construction project in state history. It features many precast concrete components, from precast concrete deck panels on top down to 60 precast concrete open-footing tubs for the foundations. The tubs sit on drilled shafts and are filled with concrete to create the bases for the bridge's piers. The precaster provided proof of longevity with concrete testing and continued testing throughout the casting cycle.

CABA Members Innovate

Such techniques can be provided by any of the members of the Central Atlantic Bridge Associates (CABA). Founded in 1957 as the Prestressed Concrete Association of Pennsylvania (PCAP), the group promotes the use, application, and technical development of prestressed concrete.

PCAP was the first regional marketing organization to advance and market prestressed concrete for bridge designs. The association and its members have helped bring to market many technical improvements and refinements of standards. Products it helped refine are being used throughout the central Atlantic region of Virginia, District of Columbia, Maryland, Delaware, and New Jersey.

Owners, designers, and contractors can take full advantage of the technical skill and detailed knowledge available from CABA's members to create efficient designs. Using contractor-alternate designs, bringing the precaster onto the project early in the design phase, can ensure every innovation is employed to create a cost-effective, quickly constructed, and aesthetically pleasing structure.

A total-precast concrete design was used for the September 11 Memorial Bridge on Route 70 in New Jersey, which maintained the architectural concept and minimized the duration of in-water construction. Photo: Aurora and Associates P.C.

CABA Members

To learn more about the benefits of working with precast concrete designs, contact any of the members of CABA:

- Bayshore Concrete Products
  (www.usa.skanska.com)
  (757) 331-2300
- Jersey Precast Corp.
  (www.jerseyprecast.com)
  (609) 689-3700
- Northeast Prestressed Products
  (www.nppbeams.com)
  (570) 385-2352
- PennStress, a division of MacInnis Group LLC (formerly Newcrete, a division of New Enterprise Stone & Lime Co.
  (www.pennstress.com)
  (814) 695-2016

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1042 N. 38th Street
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(610) 395-2338

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GAINING CONSENSUS

by Jeff Folsom, Maine Department of Transportation

Close, regular communication turned contentious public debate to accolades for cast-in-place, rigid-frame replacement project

The top slab for the bridge was only 20 in. deep at midspan, creating nearly 13 ft of clearance (which beat the desired goal of 12.5 ft). This allowed 95% of all boats using the lake to pass through at any time unhindered. All Photos: Maine Department of Transportation.

The Naples Bay Bridge & Causeway project saved taxpayers millions of dollars, improved mobility on one of Maine's busiest east-west thoroughfares, enhanced pedestrian safety, and increased green space in a popular lakeside resort village. Those outcomes weren't assured, as a contentious public debate from a community loathe to losing its signature (but deteriorating) bridge posed significant obstacles. A carefully managed public-participation and community outreach process eventually turned these challenges into a highly successful project.

Nowhere is Maine's $5-billion tourism industry revered more than in Naples, the heart of the Lakes Region that borders New Hampshire. Nestled between Brandy Pond and Long Lake, the town serves as the village center for summer and year-round residents who enjoy its causeway and signature—but inconvenient—movable bridge. Built in 1954, the bridge was failing and caused significant traffic delays due to its frequent openings. But when the Maine Department of Transportation (MaineDOT) proposed replacing the swing-span bridge with a fixed bridge in 2006, the outcry was swift and nearly unanimous.

A "Save Our Bridge" group formed to fight the new bridge, even though it offered a cost-effective option and would improve navigational clearances for boaters. Those factors were less important to the community than retaining the signature look that added to the resort area's charm. Rather than charge ahead or back off completely, MaineDOT created a working group with the town of Naples that included former Save Our Bridge members.

The community's concerns focused on the bridge's unique functionality and its aesthetic design. It was one of only two swing bridges left on the state's canal system. The movable bridge sat on a wide pier and used a massive counterweight to swing open, creating a distinctive operation. But the regular openings created a growing bottleneck for traffic. It also offered only 5 ft of clearance, requiring it to open for virtually every boat that needed passage.

What some in the community didn't realize was that, while the bridge attracted interest, it also caused others to steer clear of the town to avoid

profile

NAPLES BAY BRIDGE & CAUSEWAY / NAPLES, MAINE

BRIDGE DESIGN ENGINEER: Maine Department of Transportation, Augusta, Maine

GENERAL CONTRACTOR: Wyman and Simpson Inc., Richmond, Maine

COMMUNITY PARTNER: Town of Naples, Maine

becoming stuck in traffic. Defining that loss proved difficult, but the delays definitely were a detriment to the town.

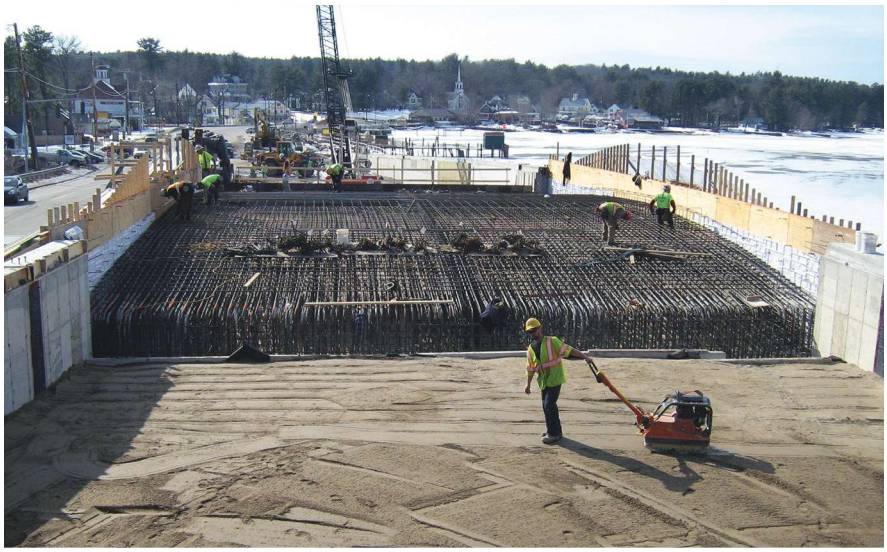
Clearance and Aesthetics Needed

The community leaders quickly understood that the swing structure could not be replicated and probably wouldn't be preferable even if it could, but they argued that if they were losing the unique design, they needed a bridge with lots of clearance to ensure easy passage and a signature style that could prove to be just as attractive. MaineDOT agreed those goals could be achieved.

The give and take with the committee proved fruitful.

The give and take with the committee proved fruitful. For instance, at an early meeting, MaineDOT proposed constructing a temporary bridge so traffic could continue to flow while the new bridge was constructed. The committee suggested instead that the new bridge be constructed on a new alignment alongside the existing bridge, using the old one during construction. This proposal saved the $2-million construction and demolition cost for the temporary bridge, allowing those funds to be shifted to other amenities. That agreement, as much as anything, made it clear that the partnership was focused on "our" bridge rather than making the discussion "us versus them."

The committee met weekly during the design process, providing input on everything from navigational clearance to lighting. As decisions were made, the group continued to meet regularly to decide structure selection, landscape design, and public outreach regarding traffic impacts.



The selected choice from three options presented featured a reinforced concrete rigid-frame structure with a variable-depth top slab and a gentle arch shape to the bottom of the slab.

The exterior-facing sides of the edge wall on the rigid frame featured a formliner with a natural-stone texture that added aesthetic value to the bridge's façade and created a timeless regionally sensitive appearance.

Critical meetings also were broadcast on cable-access television to involve all of the community. The town, as well as MaineDOT, maintained a project website throughout design and construction. In addition, the project manager and resident engineer developed a conscientious and respectful working relationship with the community.

Three Options Considered

The designers presented three options to the committee for review. The final recommendation from the group was an 85-ft clear-span concrete arch that required minimal maintenance. This shape provided the aesthetic the town sought and could meet the goal of maximizing the vertical clearance for boaters.

MAINE DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: 85-ft-long, single-span, cast-in-place concrete rigid-frame bridge

STRUCTURAL COMPONENTS: Cast-in-place concrete rigid frame with 20-in. profile at midspan, 1200-ft-long, precast concrete-faced, sheet-pile seawall

BRIDGE CONSTRUCTION COST: $9.2 million

AWARDS: 2014 Winner, Portland Cement Association's 14th Biennial Bridge Awards Competition

A sheet-pile seawall, required to shift the bridge's alignment, was created by driving piles at the toe of the bank and backfilling the area behind it. It was clad with a 6-in.-thick precast concrete facing featuring a pigmented, natural-stone texture similar to the one used on the bridge façade.

It soon became apparent that to provide adequate vertical clearance, the bridge would require a low-profile interior surface, which in turn would lead to high thrust forces at the spring line of the arch. With no bedrock present, the sandy soil would not be able to resist the thrust forces generated by the arch.

The structural design evolved to a reinforced concrete rigid-frame structure with a variable-depth top slab and a gentle arch shape to the bottom of the slab. Fortunately, the committee understood that form had to follow function, while the designers maintained their goal of creating as slim and slender of a design as possible to meet the town's vision.

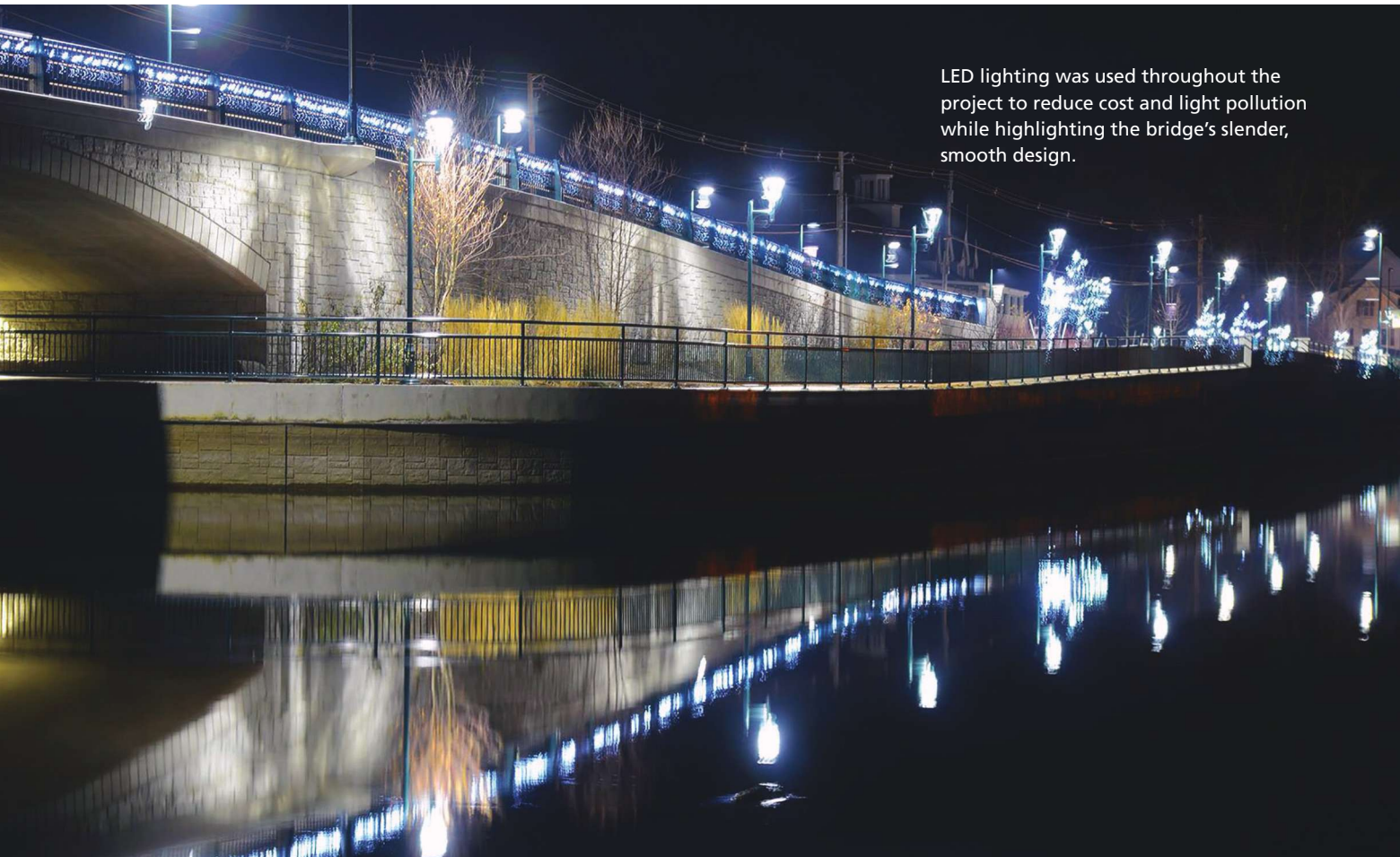
The top slab cast for the bridge was only 20 in. deep at midspan, creating nearly 13 ft of clearance (which beat the desired goal of 12.5 ft). This allowed 95% of all boats using the lake to pass through at any time unhindered. The exterior-facing sides of the edge wall on the rigid frame featured a natural-stone texture, cast using a formliner, that added aesthetic value to the bridge's façade and created a timeless, regionally sensitive appearance.

Foundations consisted of driven piles with tremie-seal foundations. The design considered varying values of soil stiffness and the resulting displacement and rotations of the rigid frame foundations to determine the maximum and minimum internal forces in the frame.

Decorative Seawall Built

The project also encountered several permitting issues, due to its location in the heart of an environmentally sensitive area. To shift the location of the bridge to allow the existing bridge to remain in operation, it was necessary to rebuild the seawall at the edge of Long Lake. This was accomplished by driving sheet piles at the toe of the existing bank and backfilling the area behind it.

The community objected to the appearance of the proposed 1200-ft-long steel-pile bulkhead, but building a traditional cantilevered concrete retaining wall proved to be too challenging for the location. Instead, the sheet-pile bulkhead was



LED lighting was used throughout the project to reduce cost and light pollution while highlighting the bridge's slender, smooth design.

The new seawall allowed a former asphalt parking strip to be converted into a beautifully landscaped park-like area with a boardwalk textured sidewalk, as well as trees and a terraced seating section for special events and concerts.

clad with a 6-in.-thick precast concrete facing cast with a pigmented, natural-stone texture similar to the one used on the bridge façade. The cladding was attached from the wall's top to just below the streambed to create a continuous look with minimal excavation.

The bulkhead's low-profile design provided another aesthetic benefit, as it helped transform what was merely an asphalt parking strip into a beautifully landscaped park-like area with a boardwalk textured sidewalk varying in width from 12 to 15 ft. The new, open green spaces allowed lawn areas, tree planting, landscaped areas, lakefront seating areas, and a terraced seating section used by the community for special events and concerts.

The bulkhead provides a dramatic appearance from the water. The boardwalk's textured sidewalk offers access to businesses and both sides of the lake without pedestrians having to cross traffic. This design, on the site of a worn-down 1950s green-tinted asphalt parking lot, improved safety and mobility while boosting the local economy. LED lighting was used here and throughout the project to reduce cost and fixtures were chosen to reduce light pollution.

Community Response

The response from the community has been tremendous. Citizens appreciated the collaborative approach and the level of transparency provided throughout the project. Bob Neault, chairman of the Causeway Restoration Committee, told the local newspaper upon the project's completion that the project "was a real gem! It's a point of pride that we can look at this causeway and see the transformation, see the change in the hearts of our local residents that were opposed to the project to begin with but are now inviting people to see the beautiful spot that's been created."

The transformation has been "amazing," he added, calling it "a beautiful garden space that has already begun causing people to stop, get out, and take a look around… the increase to local business owners will be phenomenal." Indeed, local businesses began dressing up their façades and interiors to match the new look and the growing traffic to the area.

The project was singled out by the Portland Cement Association, winning an award in its 2014 design competition. "[It] nicely balances aesthetics with cost," the jury said. "Every community that has to build a bridge of this scale should do so with this level of detail." It was also recognized in 2014 by the Northeastern Association of State Transportation Officials as part of America's Transportation Awards.

Government officials also have taken note. State Representative Rich Cebra said, "I know of no other instance where the state, local government, and interested members of the public have worked so well together…I will take this committee's example back to Augusta with me and brag about you, the people who rolled up their sleeves and worked together."

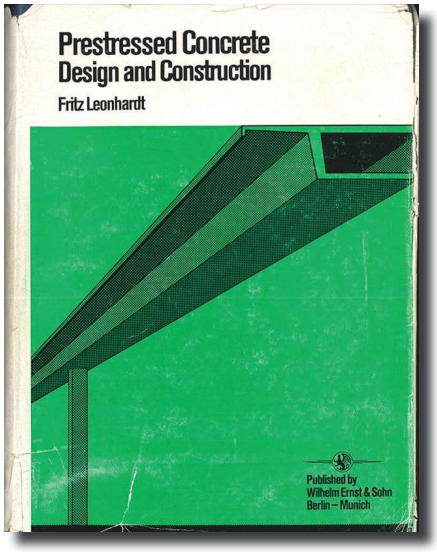
Jeff Folsom is assistant bridge program manager with the Maine Department of Transportation in Augusta.

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

Principles First

Fritz Leonhardt and Prestressed Concrete

by Dr. Oguzhan Bayrak, University of Texas at Austin



Prestressed Concrete Design and Construction[1], Fritz Leonhardt, English/Second Edition, November 1964. Photo: scan by Oguzhan Bayrak.

Structural engineering is an old profession and prestressed concrete is not new. Since the inception of prestressed concrete, there have been many great engineers, researchers, professors, and pretensioning and post-tensioning professionals who contributed to our understanding and practice of this technology. In this regard, there is much to learn from past research and the fabrication and construction experience.

In an effort to do so, I would like to cover a few things that one can learn from Professor Fritz Leonhardt's book titled, *Prestressed Concrete Design and Construction*.[1] Among other classic prestressed concrete texts, we are fortunate to have the second edition of this book in our library at the Phil M. Ferguson Structural Engineering Laboratory (FSEL). With its 19 chapters, this book covers many topics ranging from fundamental concepts to material properties and spans from structural design to fabrication and construction. To give the readers a concise summary of the most important technical issues, this book includes a section titled "Ten Commandments for the Prestressed Concrete Engineer" that precedes the formal chapters. Five of these ten principles are aimed at providing guidance to structural engineers in a design office and the other five are directed toward construction professionals.

The recommendations for designers are:

1. Being mindful of short-term and long-term deformations associated with prestressing effects and considering those effects in design.
2. Being mindful of reinforcing bar details to handle forces that stem from the directional changes in prestressing force.
3. Not pushing structural designs to their limit to where compressive stress limits are fully exploited. In this way, constructability issues that may stem from the use of an excessive number of strands can be avoided.
4. Avoiding tensile stresses under dead loads.
5. Providing ordinary reinforcing bars transverse to the direction of prestressing force within the transfer length.

The recommendations for the construction professionals are:

6. Protecting prestressing material in fabrication plants to prevent mechanical (cuts, kinks, and the like) and chemical (for example, corrosion) damage to the prestressing strands.
7. Understanding the need for high-quality, properly-consolidated concrete in constructing prestressed concrete elements.
8. Allowing room for prestressed members to deform and experience volume changes without introducing secondary stresses to the structure.
9. Understanding the advantages of post-tensioning structural components in several stages to deal with different load effects that may exist at various stages of the construction.
10. Understanding the need to follow the technical guidance for grouting post-tensioning tendons.

These principles exemplify an industry belief that has existed since the early days of prestressed concrete: A thorough understanding of fabrication/construction processes and fundamental steps in structural design are essential to the design and the fabrication/construction professionals. In other words, it is not possible to be a good prestressed concrete designer without understanding the fabrication and construction processes. Conversely, it is not possible to fabricate prestressed concrete beams without having an appreciation for the supporting engineering principles.

'It is not possible to be a good prestressed concrete designer without understanding the fabrication and construction processes.'

What does this mean for the structural engineers in the making? Hands-on experience, including time spent in fabrication plants and/or on jobsites, is invaluable. In this context, students who take prestressed concrete design at the University of Texas typically participate in PCI's Big Beam Contest. This exercise gives them a chance to

go through all aspects of the design and fabrication processes. In addition, those students test the beams they design and observe the structural consequences of their design decisions. This is an exercise greatly valued by many.

Since the inception of prestressed concrete, the constraints under which a prestressed concrete engineer works have changed. The industry now works with higher-strength, better performing materials. There have been significant innovations in construction materials (concrete, reinforcing bar, and strand) and beam fabrication and construction technologies. Alongside the technological and scientific advances that have taken place since the inception of prestressed concrete, other changes have also occurred over the past half a century. The industry now faces significant resource constraints. Everyone is being pushed to do more with less. We have to be mindful of our resource consumption in view of future generations. Rightfully, we have a growing concern for our environment and all of us would like to be better stewards of our environment.

What do these observations add up to? Better design optimization and a renewed emphasis on durability and sustainability. If we are to refine or optimize our designs to a greater extent, we need to fully understand the fabrication, construction, and design implications of our decisions. Given the age of our profession and that of prestressed concrete, we have more to read and digest. In an increasingly digital world, this implies more time spent on search engines and an increased effort to take advantage of resources that strike a balance between fabrication and construction issues alongside theory and design. With that said, we must all appreciate the fact that first principles are first.

References:

1. Leonhardt, Fritz. 1964. *Prestressed Concrete Design and Construction,* 2nd Ed., Berlin: Wilhelm Ernst & Sohn.

Frederick Avenue Bridge over Gwynns Falls and CSX Railroad

by Mike Izzo, Whitney, Bailey, Cox & Magnani

The concrete arch façades for the Frederick Avenue Bridge were manufactured to closely resemble the design of the existing two-span, closed-spandrel filled arch structure that was built around 1930. Photo: Joseph B. Fay Company.

The city of Baltimore faced several unique challenges when it began the process of replacing the bridge carrying Frederick Avenue over Gwynns Falls and the CSX Railroad. First and foremost, the community and the Maryland Historic Trust wanted the replacement bridge to closely resemble the design of the existing two-span, closed-spandrel filled arch structure that was built around 1930. To satisfy this request, the superstructure was designed as a two-span prestressed concrete-beam bridge with concrete arch façades in each span that mimicked the appearance of the existing arch. The city also had to protect an environmentally sensitive stream, maintain rail traffic for CSX and pedestrian traffic for the Gwynns Falls Trail, and convey numerous existing underground utilities.

The arch façade is comprised of a precast concrete arch rib spanning from abutment to pier in each span that supports a cast-in-place concrete arch wall. The precast concrete arch ribs were detailed as three separate box sections with concrete closure placements between each of the sections and the substructure units. Couplers consisting of structural steel splice plates were cast into the hollow portions of each precast concrete box to allow them to be bolted together in order to erect the arch prior to completing the closure placement.

Precast concrete was chosen primarily to avoid having to shore the formwork needed to construct the arch and wall because the bridge crosses both the environmentally sensitive Gwynns Falls and the CSX Railroad tracks. The completed precast concrete arches supported the formwork for the cast-in-place concrete arch walls. Each precast concrete arch rib was designed to resist its own self-weight, the vertical dead load from the arch wall, and the horizontal wind load on the arch wall, which was transferred to the arch through dowels cast in the top of the arches.

Close up of structural steel splice plate connection ready to be cast into one of the precast concrete box beams. After all segments of the arch were erected, concrete was placed around the connection to complete the arch. Photo: Northeast Prestressed Products.

Construction of the arch by the general contractor also presented several challenges. The installation of a temporary causeway over Gwynns Falls was needed to access the site and temporary shoring towers and a crane were set up in two stationary positions to erect the arches. Additionally, the contractor had to construct each arch rib to within a 1/16 in. tolerance to ensure that the ribs fit into place without a noticeable misalignment.

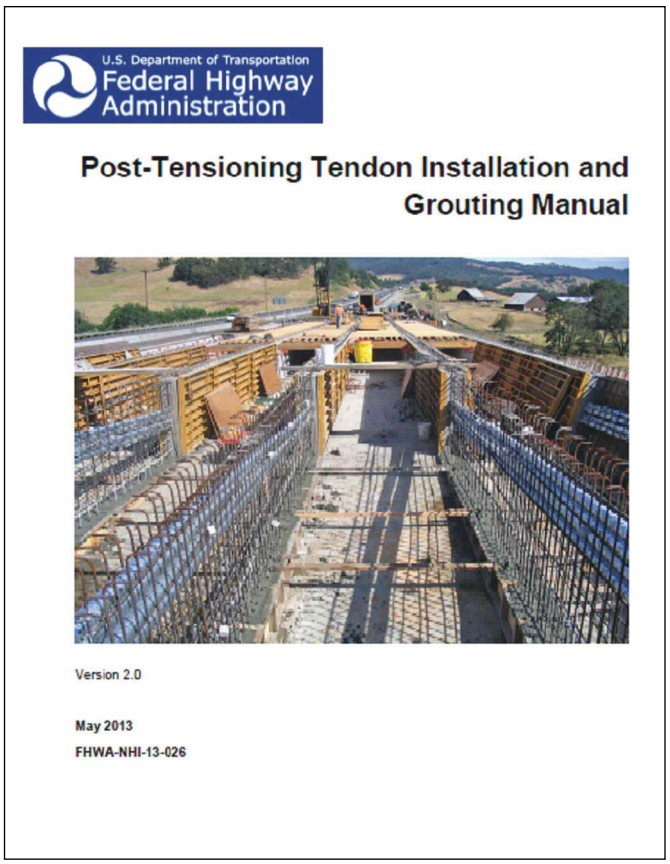
With sound engineering and creative construction techniques, the precast concrete arch ribs allowed for an efficient, low-cost solution to provide the requested appearance of the original arch.

Mike Izzo is vice president, Bridge, with Whitney, Bailey, Cox & Magnani in Baltimore, Md.

FHWA Initiatives

Advancing the state of practice in bridge design

by Reggie Holt and Dr. Brian Kozy, Federal Highway Administration



Post-Tensioning Tendon Installation and Grouting Manual.

The Federal Highway Administration (FHWA) Office of Bridges and Structures routinely develops training and guidance on engineering technologies that improve the safety, durability, and longevity of our nation's bridges. FHWA has recently completed several technology deployment projects intended to advance the state of practice for bridge engineering. This article provides a general overview of a few of these projects, as well as describing other on-going projects.

POST-TENSIONING MANUALS AND TRAINING

The recent advances in post-tensioning (PT) technologies have resulted in many FHWA deployment activities focused on this topic. The products listed below cover multiple aspects of post-tensioned bridges, including design, construction, and inspection.

Post-Tensioning Tendon Installation and Grouting Manual and Training

This manual includes state-of-the-art information relative to materials, PT systems, construction practices, and grouting of PT tendons for bridges. The manual is targeted at owners and private company personnel that may be involved in the design, inspection, construction, or maintenance of bridges that contain PT tendons. This manual serves as a reference and guide to designers, inspectors, and construction personnel for PT materials, installation, and grouting of bridge tendons.

Complementary web-based training for this manual is under development. The estimated available date for this training is May 2015 on the National Highway Institute's (NHI) website.

Post-Tensioning Tendon Inspection Training Module

A 30-minute lesson was developed on routine inspections of post-tensioned bridges. The lesson provides an introduction to PT principles and components as well as a list of good inspection techniques. In addition, the lesson provides guidance on routine inspection findings that would initiate supplementary investigations such as in-depth or special inspections. The techniques highlighted in this lesson can be performed by a typical inspection crew. This lesson is part of the Bridge Inspection Refresher Training course and can be scheduled through the NHI.

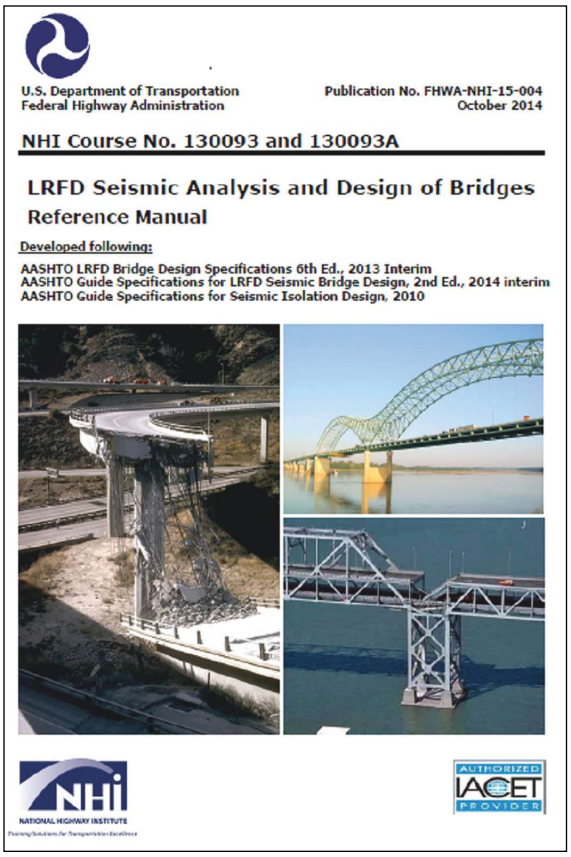
BRIDGE ANALYSIS AND DESIGN MANUALS AND TRAINING

Over the last few decades, significant advancements have been made in the way that bridge engineering analysis and design can be performed. Engineering practitioners today, with the aid of advancing computer technology, are able to solve engineering problems of great complexity and produce designs and analysis that are more refined and more reliable than in the past. The products listed below promote practical implementation of advanced techniques for improved bridge engineering.

LRFD Seismic Analysis and Design of Bridges Reference Manual and Training

This manual is intended to provide a technical resource for bridge engineers responsible for both force-based and displacement-based seismic analysis and design. The manual covers fundamental

Post-Tensioning Tendons module is part of the Bridge Inspection Refresher Training.


U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-NHI-15-004
October 2014

NHI Course No. 130093 and 130093A

LRFD Seismic Analysis and Design of Bridges
Reference Manual

Developed following:

AASHTO LRFD Bridge Design Specifications 6th Ed., 2013 Interim
AASHTO Guide Specifications for LRFD Seismic Bridge Design, 2nd Ed., 2014 interim
AASHTO Guide Specifications for Seismic Isolation Design, 2010

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LRFD Seismic Analysis and Design of Bridges Reference Manual.

topics such as engineering seismology, seismic and geotechnical hazards, capacity design, structural dynamics, and methods for modeling and analyzing bridges subject to earthquake ground motions. It also discusses the requirements and recommendations of the seismic provisions in each of the *AASHTO LRFD Bridge Design Specifications, AASHTO Guide Specifications for LRFD Seismic Bridge Design*, and *AASHTO Guide Specifications for Seismic Isolation Design*. There is complementary, instructor-led training that can be scheduled through the NHI.

Cable-Stayed Bridge Seminar and Design Guidelines

This one-day seminar is intended to provide participants with an introduction to planning, design, and construction of long-span, cable-stayed bridges. The seminar provides an overview of the features of cable-stayed bridges; their construction and maintenance considerations; and analyses needed to design these highly redundant structures including special aerodynamic studies. Major topics covered include: bridge configurations, construction methodology, component details, analysis, aerodynamics, design methodology, construction engineering, and maintenance and inspection. As part of the seminar, participants receive a copy of *FHWA Design Guidelines for the Arch and Cable-Supported Signature Bridges*. During the seminar, participants will become familiar with the features of cable-stayed bridges. They will also better understand construction and maintenance considerations, as well as analyses needed to design and construct cable-stayed bridges. This seminar can be scheduled through the NHI.

LRFD for Highway Bridge Superstructures Manual and Training

This course is a combination of instructor-led discussions and interactive exercises, and includes a comprehensive reference manual. It includes load and resistance factor design (LRFD) theory applied to design examples and illustrates step-by-step LRFD design procedures. Exercises and example problems are based on components of overall comprehensive bridge design examples using AASHTO LRFD. This course explains the background and methodology of the LRFD design and promotes proper application of code provisions.

An update to this course to incorporate the 7th Edition of the *AASHTO LRFD Bridge Design Specification* is in the final stages. The estimated release date for this instructor-led training and reference manual is July 2015. This training can be scheduled through the NHI.

FUTURE ACTIVITIES

FHWA has many projects underway intended to develop additional guidance, manuals, and training on bridge engineering. These projects include the topics of: refined analysis of bridge structures, design of post-tensioned box-girder bridges, advanced topics in precast concrete element design, system reliability in bridge systems, enhanced PT systems, bridge strengthening, and bridge durability design. A list of the expected soon-to-be-completed manuals and training are listed below:

- *Post-Tensioned Bridge Design* manual
- *Manual on Refined Analysis of Bridges*
- *Engineering for Stability in Bridge Construction*
- *LRFD for Highway Bridge Superstructures* Web-based Training

Stay tuned for future notifications of new products in upcoming *ASPIRE*™ articles.

More Information

Courses listed below can be found on the National Highway Institute's (NHI's) website https://www.nhi.fhwa.dot.gov/default.aspx.

Post-Tensioning Tendon Installation and Grouting Manual and Training

Course No. 1301103 is expected to be available through the NHI in May 2015.

The document can be viewed/downloaded electronically from http://www.fhwa.dot.gov/bridge/construction/pubs/hif13026.pdf.

Post-Tensioning Tendon Inspection Training Module

This lesson is part of the Bridge Inspection Refresher Training course (No. 130053A) and can be scheduled through the NHI.

LRFD Seismic Analysis and Design of Bridges Reference Manual and Training

There is complementary, instructor-led training (Course No. 130093) that can be scheduled through the NHI.

The document can be viewed/downloaded electronically at http://www.fhwa.dot.gov/bridge/seismic/nhi130093.pdf.

Cable-Stayed Bridge Seminar and Design Guidelines

This seminar (Course No. 130096) can be scheduled through the NHI. All seminar participants receive a copy of *FHWA Design Guidelines for the Arch and Cable-Supported Signature Bridges*.

LRFD for Highway Bridge Superstructures Manual and Training

Course No. 130081 is expected to be available through the NHI in July 2015.

Camber Variability in Prestressed Concrete Bridge Beams

by Dr. Maher Tadros, eConstruct

Beams cast with extra camber in storage yard at Concrete Technology Corporation; camber shown is exceptionally large for illustration purposes. Photo: Concrete Technology Corporation.

Precast, prestressed concrete girders experience camber (upward deflection) when the prestressing strands are detensioned and the prestressing force is transferred from the casting bed to the concrete member. When the girder is stored in the yard of the precast manufacturer, its camber continues to change with time, influenced by the ambient air conditions, and even the orientation of the girder as it is exposed to the sun. When the girder is erected on its seats at the bridge site and just before the deck is placed, its camber at that time affects the haunch (build up) concrete required to ensure that the top of deck surface meets the roadway profile requirements.

Initial camber after detensioning is used to indirectly check the quality of the product, for example, the level of prestress and other production issues. Camber at the time of girder shipping is sometimes required to be checked for contractual purposes. Camber just before deck placement and the elastic deflection due to deck weight are used to determine the elevation of the formwork supports at the edges of the top flange. Accurate measurements and calculations at this stage result in minimizing grinding of the deck to bring it to the required profile.

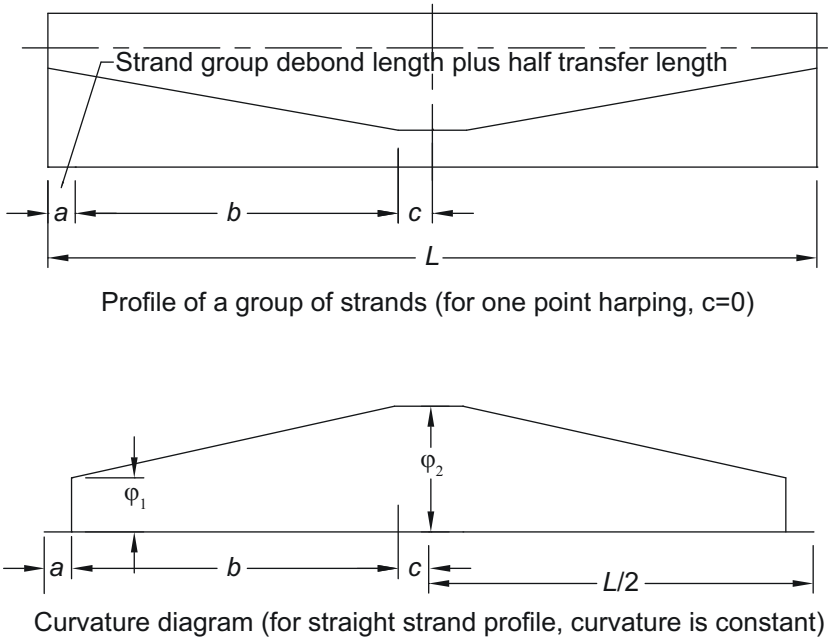

Figure 1. Beam elevation showing general profile for a group of pretensioned strands. Figures: eConstruct.

A negative camber (downward deflection or sag) while the bridge is in service may cause concern for inspectors and the public and, if excessive, may have structural and functional impacts as well. A number of state highway authorities (SHA) have specified that the final long-term camber due to all loads, except live load, must be positive, that is, upward.

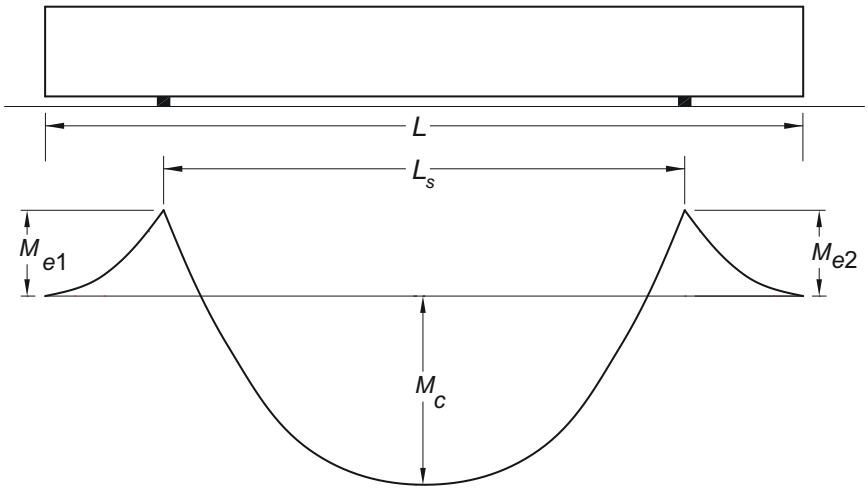

Figure 2. Bending moment diagram for beam in storage, note the considerable overhang. Figure: eConstruct.

At best, camber prediction can have ±25% variability, but more realistically it can have ±50% variability. The prediction is impacted by things that are known within a narrow band of variability such as the cross-section dimensions, amount of prestress, and span length, which are considered here to be deterministic variables. It is also impacted by random variables, outside of the control of the designer at time of design, such as source of aggregates, relative humidity and temperature of the ambient air, method of curing, method of detensioning, conditions of storage, and time elapsed between girder production and deck placement.

Calculation of Initial Camber

Reference 1 gives a survey of the history of camber prediction and proposes a method that can be programmed in a spreadsheet. Only two equations are required.

Equation 1 is used to calculate initial camber due to prestress using a general profile of a group of pretensioned strands (Fig. 1). The equation is valid for straight and draped strands and for cases where debonding at the ends is utilized. The equation may be applied to the different "types" of strand groups, and then superposition used to combine the individual results to determine the full effect.

$$\Delta_{ip} = \frac{\varphi_1}{2}(b+c)(2a+b+c) + \frac{\varphi_2}{6}(3ab+2b^2+6ac+6bc+3c^2) \qquad \text{Eq. 1}$$

The distances *a*, *b*, and *c* are defined in Fig. 1. The curvatures φ_1 and φ_2 are equal to P/EI for Sections 1 and 2 at the location at which prestress is effective at the end of the girder (dimension *a*) and at midspan, respectively. The values of *P*, *e*, *E*, and *I* are the prestress force, its eccentricity, the concrete modulus of elasticity, and the cross section moment of inertia, respectively, at the section considered for the curvature calculation. The starting section location (at dimension *a* from the end of the girder) is affected by length of debonding plus an allowance for transfer length.

Equation 2 is used to determine deflection due to beam weight (Fig. 2). In recent years, long beams have required lifting, storage, and shipping with overhangs as long as 20 ft. The equation accounts for overhang length.

$$\Delta_{gi} = \frac{5L_s^2}{48EI}(0.1M_{e1} + M_c + 0.1M_{e2}) \qquad \text{Eq. 2}$$

For this equation, the length L_s is length between supports during beam storage. Figure 2 defines the moments in Eq. 2 and their locations.

The example in Reference 1 is used here for discussion purposes. Not all data are given here. The I-beam is 72 in. deep, 137 ft 1 in. long, and prestressed with forty-four 0.6-in.-diameter straight strands, 12 of which are debonded in three equal groups for 6, 8, and 14 ft from the beam ends. Specified concrete strength at transfer is 6 ksi and at service is 8.5 ksi.

Equation 1, applied four times for the four groups of strands, yields a predicted prestress-only camber Δ_{ip} of 5.33 in. The groups are 32 strands that are 137.1-1.5-1.5 = 134.1 ft long, and three groups of four strands that are 122.1, 118.1, and 106.1 ft long. The 1.5 ft quantity used to compute the length for the 32 strand group is an allowance for averaging the effect of the 3 ft transfer length for the 0.6-in.-diameter strands.

Equation 2 is applied assuming a storage span of 135.5 ft. The corresponding deflection is 2.32 in. The net predicted self-weight camber is therefore 5.33 – 2.32 = 3.01 in.

Causes of Initial Camber Variability

Many factors influence the value of camber at transfer of prestress, some of which are random variables beyond the control of the designer. Several of the more important factors are listed here:

- The modulus of elasticity of concrete. The computed modulus of elasticity of concrete has been shown to vary from the measured value by 22% for confidence between 10 and 90 percentiles, according to the NCHRP study[2] that proposed the aggregate correction factor, K_1, which now appears in Equation 5.4.2.4-1 of the *AASHTO LRFD Bridge Design Specifications*. The stiffness of aggregates plays an important role in the modulus variability. Thus, the results are dependent on the aggregate source. Also, a designer who specifies 6 ksi concrete transfer strength is unlikely to get it matched during production of all the beams in a project.
- Curing versus ambient temperature. This factor can be very significant in the first 48 hours of concrete age. The concrete temperature may be as much as 120°F above the ambient temperature because of curing and cement hydration. This could decrease the tension in the strands by as much as 20 ksi. This temporary difference may cause significant changes in camber and prestress loss.[3] However, within about 72 hours, this temporary effect seems to dissipate.
- Location of lifting inserts and storage supports. The effect of

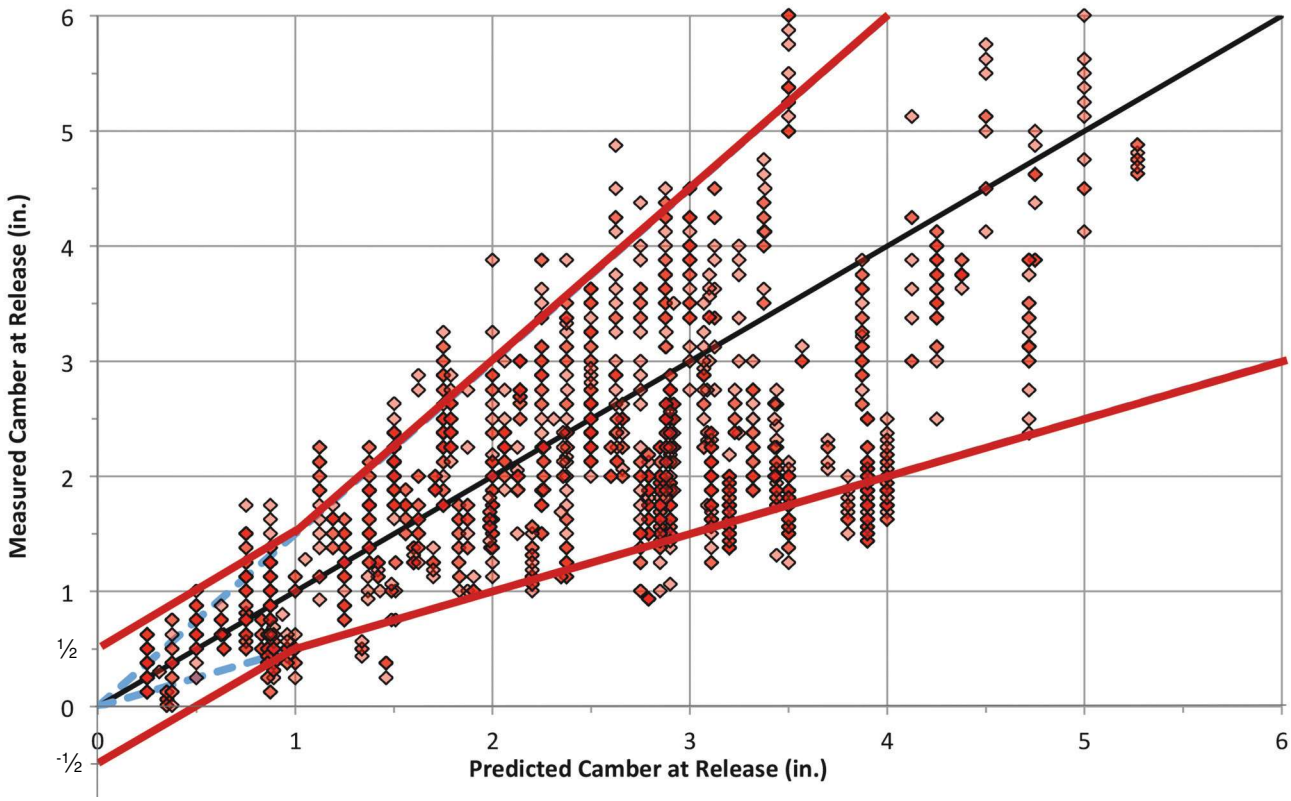

Figure 3. Initial-camber data collected by the PCI Fast Team from nine sites in eight states. The red lines show proposed ±50% ≥ ½ in. tolerance. Figure: PCI Fast Team with modification by eConstruct.

variation in support locations is illustrated using the example girder. If it is lifted and stored on supports that are 10 ft from the ends, the camber in the example used in the previous section changes by about 9%.

- If prestress is higher than the theoretical value by 5% and self-weight is lower by 5%, both of which are quite plausible, the net camber in the example in the previous section would increase by 13%.

Initial Camber Tolerance Limits

Because of the random variability of the influencing parameters, it is difficult to accurately predict initial camber immediately after strand detensioning. If the girder concrete is allowed to cool for 72 hours, prediction accuracy may be most optimistically within ±25%. Accurate formulas, such as Eq. 1 and 2, and values of the modulus of elasticity reflecting aggregate type and concrete strength would be assumed to be used. However, the designer is not likely to know producer-specific materials, environmental conditions, and production practices in advance.

The PCI Tolerance Committee has been debating in recent years how to update the tolerance limits for camber in bridge beams that are given in PCI MNL-116[4], in order to accommodate recent changes in technology. Concrete strengths in the 8 to 12 ksi range, 0.6-in.-diameter strands, and more efficient I-girder shapes have been in common use, resulting in pretensioned products as long as 200 ft.

A Fast Team was formed by the PCI Committee on Bridges and the Bridge Producers Committee to recommend adjustments to the current MNL-116 tolerances to account for the recent changes in practice. Their recommendation is shown in Fig. 3. It essentially sets the tolerance limits on camber variance from the predicted value at 0.1% of the product length with an upper limit of 1½ in. and no lower limit. Even with this proposed removal of the current upper limit of 1 in., the Fast Team report indicated that the percentage of out-of-tolerance girders longer than 80 ft was still 12%, compared to the current 37% level (using the 1 in. upper limit). Accordingly, the Fast Team stated, "out of tolerance camber should not be a sole source for rejection." While this sentence is well intentioned and justified, it seems to be in conflict with the concept of tolerance enforcement that is expected in a tolerance manual.

Proposed Initial Camber Tolerance

Because camber is an important quantity that can be easily measured, camber tolerance limits are expected to continue to be required by most owners. Based on the author's experience with this topic for nearly 40 years, and on recent discussions by PCI committees, producer groups, and state highway agencies, including Colorado, Washington, Iowa, and Pennsylvania, the following recommendations are proposed for initial camber of prestressed beams, which differ from the recommendations of the PCI Fast Team:

- Initial camber should be measured 72 to 96 hours after beam concrete placement and after the beam has been set on storage supports. This would allow for the internal concrete temperature to reach equilibrium with the ambient air and for the storage span to be set. Measurements should

be made early in the morning when the girders should have a neutral thermal gradient.

- For predicted camber ≤ 1 in., tolerance is ± ½ in.
- For predicted camber > 1 in., tolerance is ±50% of the predicted camber.
- Out-of-tolerance products should be further investigated by qualified personnel to identify the presence of possible deficiencies. Camber alone should not be the sole cause of rejection.

Camber Variability at Deck Placement

Camber prediction at time of deck placement is needed to establish elevations for beam seats and for formwork for the deck. This is necessary so that the top of road elevation and the overhead clearance below the bridge are consistent with design requirements.

Concrete creep and shrinkage cause prestress to be lost. In addition, creep causes the beam to continue to camber with time. Creep and shrinkage are functions of the concrete ingredients, section dimensions, and environmental conditions. Furthermore, it is not known in advance how much time will elapse between girder production and deck placement. Camber does not always grow between initial storage conditions and deck placement.

This observation has recently been reported for relatively long beams. The creep multiplier for prestress effects (camber) is not as large as the creep multiplier for beam self-weight because prestress continues to decrease with time. For example, a 10 in. initial camber due to prestress multiplied by a 1.7 creep factor is 17 in. An 8 in. deflection due to beam self-weight multiplied by a 2.0 creep factor is 16 in. The net predicted camber at deck placement is 1 in. This is compared to an initial camber of 10 – 8 = 2 in.

Methods of accurate prediction of camber at time of deck placement are summarized in the article by Tadros et al.[1] Several states, in collaboration with designers and precast producers, have developed their own "creep multipliers" to account for camber growth between prestress release and deck placement. It would seem reasonable to show upper and lower bound camber multipliers, based on local prevailing construction and environmental conditions.

For example, Washington State guidelines show a lower bound of 50% of the camber at 40 days, and an upper bound of 100% of the camber at 120 days. The author recommends a multiplier to be determined by each precaster for the region served by their company. For example, Supplier X serving Western State Y would provide the owner with a lower bound and upper bound multipliers of 0.9 and 2.6 applied to initial camber to predict camber at time of deck placement.

The data presented in Fig. 4, which has been supplied by Troy Jenkins of Northeast Prestressed Products, illustrates camber variability at 120 days for girders produced by his company in several states in the Northeast. The figure shows that only a few points fall outside the proposed camber tolerances indicated by the red lines.

It is suggested that the PCI Committee on Bridges and Bridge Producers Committee should consider setting up uniform national guidelines for achieving this important task.

Accommodating Differences

There are two options for accommodating differences between predicted and measured camber at deck placement.

Measured camber larger than predicted camber

Assume for this discussion that

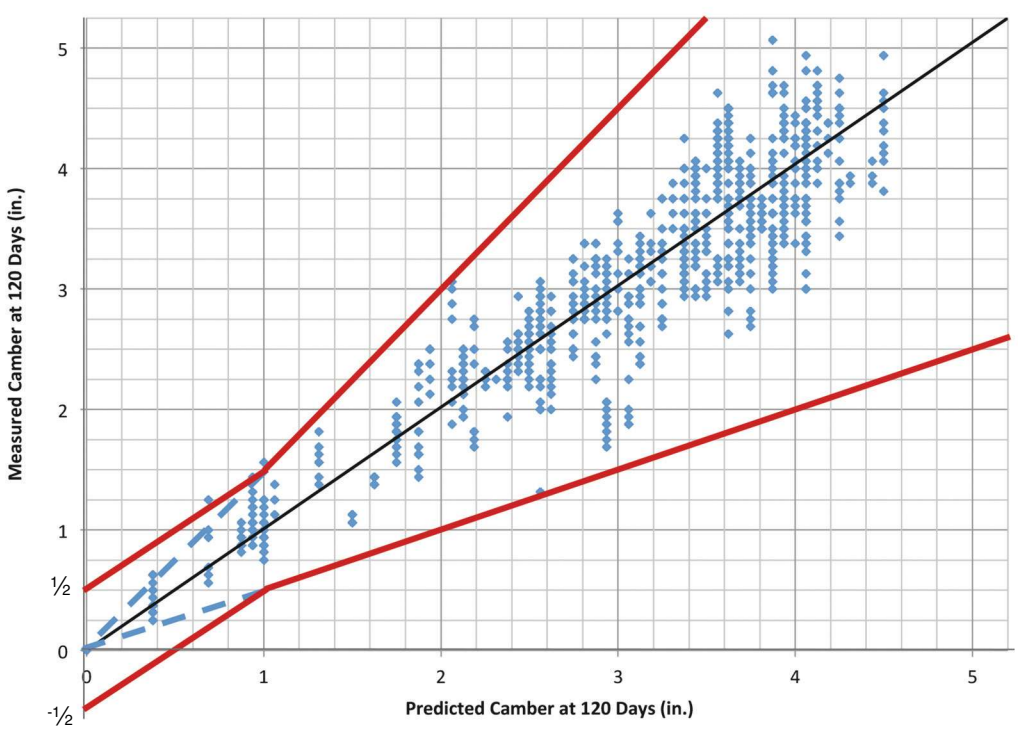

Figure 4. Measured camber at 120 days. Red lines show proposed ±50% ≥ ½ in. tolerance. Data: Northeast Prestressed Products.

predicted camber for a 150-ft-span beam is 3 in. while the measured camber is 6 in. The designer had allowed for a cast-in-place concrete haunch of 1 in. above the top flange of the beam at midspan. The simplest solution is for the owner to allow raising the roadway by 2 to 3 in. Alternatively, the girder seats could be set 2 to 3 in. lower than previously specified. This option would require appropriate preplanning.

Measured camber smaller than predicted camber

Assume for this discussion that predicted camber is 3 in. while the measured camber is 1.5 in. The seats may be raised to avoid infringing on overhead clearance below the bridge, if this is a factor, and to avoid excessive haunch concrete. Also, adequate drainage needs to be checked to avoid water ponding on the bridge.

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

PCI Precast/Prestressed Concrete Institute

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Bearing Zone Tearing and Spalling in Precast, Prestressed Concrete Girders

by Hugh Ronald, Reynolds, Smith and Hills

If there is one thing you can count on: it's that engineers will push the envelope to achieve longer spans with fewer members. What used to be an industry dominated by standard American Association of State Highway and Transportation Officials (AASHTO) girder shapes, is now an industry that has a range of new bulb tees designed to more effectively utilize higher concrete strengths and larger-diameter strands. From Florida to Washington state, new standard wide flange I-girders have been developed and are growing in use. These girders may be as deep as 10 ft and can use not only more strand, but larger (0.6-in.-diameter) strand, than was typically used in the standard AASHTO shapes.

Use of these new shapes is leading to new challenges in the casting process and may require new details to produce precast concrete girders that are both strong and durable, particularly given the need to increase the service life of bridges to 75 or 100 years.

One of the challenges to girder fabrication has been the advent of tearing (cracking) and spalling of the concrete in the girder bearing zones, a phenomenon that occurs during prestress transfer. Girders that experience tearing are generally longer, heavier, and/or more highly prestressed than their older counter parts.

Bearing Zone Tearing and Spalling

The primary causes of tearing and spalling are girder shortening and camber that occur as the prestressing force is transferred to the concrete during detensioning. As a highly prestressed girder cambers, the bearing reactions concentrate at the ends of the girder, producing a knife-edge loading condition. At the same time, the girder contracts and slides due to elastic shortening. If the girder is long, the bearing reactions will be proportionately high, and the friction that develops between the girder and casting bed soffit will produce tension along the longitudinal axis of the girder.

Surface Treatment	Coefficient of Friction, μ
Concrete on Steel (Unlubricated)	0.51
Oil Lubricant	0.46
Teflon Pad	0.27
Wax Lubricant	0.23
Steel Plate (on Steel Soffit)	0.23
Steel Plate with Oil Lubricant	0.21

Note: Adapted from Kelly, Patrick and Lawrence F. Kahn. 2007. "Bearing Zone Cracking of Precast Prestressed Concrete Bridge Girders," Final Report Research Project No. 05-14, Office of Materials and Research, Georgia Department of Transportation, Atlanta.

The magnitude of this tension is directly proportional to the friction force that develops at the ends of the girder. If not adequately addressed, this force may crack and possibly spall the concrete at the ends of the girder. Unfortunately, the strands in the bearing zone are not fully developed so they cannot mitigate the problem.

Remedial Countermeasures

To address the problem, a number of countermeasures have been employed with varying levels of success. The first countermeasure employed has generally been to lubricate the soffit pan using oil or wax at the ends of the girder (over a distance roughly equal to the strand transfer length), or to place polytetrafluoroethylene (PTFE) or plywood sheets, compression tape, or steel sheets under the bearing zone. The intent is to lower the coefficient of friction between the girder and soffit, thus reducing the magnitude of the tension associated with girder camber and shortening. The table shows that the friction coefficient is reduced from as high as 0.51 on an unlubricated soffit to 0.23 for a wax lubricant. Still, when soffits are lubricated, cracking and spalling are generally not eliminated, but are only reduced in frequency and magnitude.

The second approach has been to embed and anchor steel plates or angles in the bearing zone at the ends of the girder where the knife-edge loading occurs. Use of embedded angles anchored to the girder with headed studs decreases the frequency and magnitude of the cracking and spalling more than use of lubricants alone, but test results show that cracking may still occur. Embedded plates, adequately sized to extend from the end of girder across the bearing zone, have been used successfully to virtually eliminate bearing zone tearing. This detail has been adopted by several owner agencies.

The Florida Department of Transportation employs galvanized bearing plates in all of their new Florida I-beams, one of the new generation of wide flange girders designed for long-span, pretensioned concrete girder construction. Galvanized plates are less susceptible to corrosion and will provide the durability needed for a long service life.

A cracked and spalled girder in the location of the bearing zone for the case of an untreated soffit. All Photos: Lawrence Kahn.

A cracked and spalled girder in the location of the bearing zone. In this case, a Teflon pad was placed between the girder and the soffit.

A cracked and spalled girder in the location of the bearing zone where wax was applied to the soffit.

Are Bearing Plates the Bottom Line?

There is good reason to believe that not every girder needs a bearing plate to protect it from tearing and spalling. Recall that the problem was not prevalent when AASHTO girders were the predominant shapes in use, but developed with the advent of deep bulb tees and the use of 0.6-in.-diameter strand.

Steel angle positioned to be embedded in girder end.

There appear to be several variables that contribute to the problem. These include

- the initial prestress force applied to the girder, considering the effect of debonded strands,
- the eccentricity of the prestress force, and
- the weight of the girders (or more precisely the bearing reaction and stress due to friction between soffit and girder in the bearing zone).

The advent of spalling and tearing are directly related to these variables. Alternatively, tearing is resisted by strand development and the tensile strength of the concrete in the bearing zone, so there appears to be an inverse relationship between these variables and incipient tearing and spalling.

Tearing and spalling may also be affected by the method of strand detensioning. Two methods are used to transfer the prestressing force to a girder: flame detensioning and gang detensioning. Flame detensioning, which is used more often, transfers the prestressing force more abruptly, possibly introducing a shock load in the bearing area that may aggravate the tearing mechanism.

Gang detensioning has long been used by a number of precasters, and continues to be used to this day. When gang detensioning is used, all strands are detensioned slowly and evenly by retracting hydraulic jacks. Several fabricators who employ gang detensioning indicate that through the use of lubricants, compression tape, or plywood slip planes, there has been no need for embedded plates in their girders.

At the very least, there is probably a threshold for length, weight, or prestressing force below which girders no longer need to incorporate bearing plates to avoid cracking or spalling. There may also be a threshold below which tearing cracks will not penetrate the bottom row of prestressing strands, allowing repairs to be made by routing and grouting cracks. Further research may be needed to quantify these thresholds.

Summary

In summary, bearing zone tearing cracks will not occur in every girder, only those in which the friction force exceeds the tensile strength of the concrete. The problem can be eliminated using bearing plates, but there are likely thresholds that can be quantified to avoid the problem in less heavily stressed girders. Gang detensioning of the prestressing force may also prove to be as effective at eliminating these cracks as steel bearing plates—a choice which may be left to the fabricator when bidding a job.

Hugh Ronald is a senior engineer with Reynolds, Smith and Hills in Orlando, Fla.

Bowman Road Bridge over Shem Creek

Lightweight concrete makes heavy impact

by Adam Lansing, KCI Technologies

Side view of Bowman Road Bridge over Shem Creek (U.S. Route 17 Overpass in background). All Photos: Adam Lansing.

One of the benefits of design-build contracting is that engineers and contractors can react to unforeseen circumstances more effectively because they are partnered together through the project's life cycle. As part of the $84 million U.S. Route 17 (Johnnie Dodds Boulevard) widening and improvement project in Mt. Pleasant, S.C., that partnership had a substantial impact when the contractor encountered problems driving piles to replace the existing structure carrying Bowman Road over Shem Creek.

The new 90-ft-long, 78-ft-wide, three-span, flat-slab Bowman Road Bridge over Shem Creek, which carries the roadway across a tidal marsh, had many design challenges. These challenges included its low profile to the waterline, as well as road tie-ins in close proximity to both ends of the structure. Additionally, the Bowman Road Bridge over Shem Creek sits within the Lower Coastal Plain Physiological Province, a region of high seismic risk, which has sedimentary deposits exceeding 1000 ft thick. During an earthquake, these deposits can amplify seismic waves, which generate large ground accelerations and increase force demand on the structure. Also, geotechnical analysis indicated that liquefiable soils were present at the site along with corrosive salt water.

The design developed by the engineer specified a prestressed concrete pile foundation using 24-in.-square piles for each of four bents. However, when driven to the anticipated tip elevation, the piles in the interior bent did not attain the required resistance. The project team concluded that adding length to the piles by splicing so they could be driven farther and achieve the required resistance would not be acceptable because the splice would be located in a region with high flexural demand. After Pile Dynamic Analyzer and statnamic testing was conducted, engineers determined that the piles would meet all requirements if the superstructure design was modified to use lightweight concrete. They then worked with the lightweight aggregate and concrete suppliers to quickly obtain approval for the mixture proportions.

Although generally a more expensive material, the lightweight concrete provided additional value in this case not only by decreasing the bridge weight, which quickly solved the foundation concerns and minimized further schedule delays, but also by reducing permeability (improved resistance to chlorides), and increasing durability via enhanced internal curing provided by the pre-wetted, porous lightweight aggregate.

Through the design-build process, the team was able to bring the necessary resources together to deliver workable solutions that resulted in the Bowman Road Bridge over Shem Creek that will serve Mt. Pleasant residents and their guests for many years to come through increased vehicle capacity, enhanced safety, durability, and pedestrian accessibility.

Old Bowman Road Bridge prior to demolition.

Adam Lansing is a project engineer with KCI Technologies in Rock Hill, S.C.

EDITOR'S NOTE

For further information on lightweight concrete, visit the website for the Expanded Shale, Clay and Slate Institute: www.escsi.org.

CONCRETE CONNECTIONS

Concrete Connections is an annotated list of websites where information is available about concrete bridges. Links and other information are provided at www.aspirebridge.org.

IN THIS ISSUE

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_603.pdf
This is a link to NCHRP Report 603 *Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete* which is mentioned in the LRFD article on page 52.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_595.pdf
This is a link to NCHRP Report 595 titled *Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Flexure and Compression Provisions* which is mentioned in the LRFD article on page 52.

http://www.fhwa.dot.gov/publications/research/infrastructure/bridge/13061/13061.pdf
This is a link to FHWA Publication No. FHWA-HRT-13-061 *Lightweight Concrete: Mechanical Properties* which is mentioned in the LRFD article on page 52.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_579.pdf
This is a link to NCHRP Report 579 *Application of LRFD Bridge Design Specifications to High-Strength Structural Concrete: Shear Provisions* which is mentioned in the LRFD article on page 52.

http://www.fhwa.dot.gov/everydaycounts/
This link is to the webpage for FHWA's Every Day Counts initiative which is mentioned in the Partner Spotlight article on page 25.

http://www.pci.org/uploadedFiles/Siteroot/Education/_Related_Content/Related_Content_Files/Big-Beam-Rules-2015.pdf
This is a link to the official rules for the PCI's Big Beam Contest 2015 which is mentioned in the Professor's Perspective article on page 32.

http://www.fhwa.dot.gov/bridge/construction/pubs/hif13026.pdf
This is a link to FHWA Publication No. FHWA-NHI-13-026 *Post-Tensioning Tendon Installation and Grouting Manual* which is mentioned in the FHWA article on page 36.

http://www.nhi.fhwa.dot.gov/training/course_search.aspx?course_no=130053
This is a link to the description of NHI Course No. FHWA-NHI-130053 *Bridge Inspection Refresher Training* which is mentioned in the FHWA article on page 36.

http://www.fhwa.dot.gov/bridge/seismic/nhi130093.pdf
This is a link to FHWA Publication No. FHWA-NHI-15-004 LRFD *Seismic Analysis and Design of Bridges Reference Manual* which is mentioned in the FHWA article on page 36.

https://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=130093&course_no=130093&res=1
This is a link to the description of NHI Course No. FHWA-NHI-130093 *LRFD Seismic Analysis and Design of Bridges* which is mentioned in the FHWA article on page 37.

https://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=130096&course_no=130096&res=1
This is a link to the description of NHI Course No. FHWA-NHI-130096 *Cable-Stayed Bridge Seminar* which is mentioned in the FHWA article on page 37.

https://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=130081D&course_no=130081D&res=1#course_search.aspx?tab=0&key=130081&sf=0&course_no=130081
This is a link to the description of NHI Course No. FHWA-NHI-130081 *LRFD for Highway Bridge Superstructures* - Concrete which is mentioned in the FHWA article on page 37.

http://www.pci.org/uploadedFiles/Siteroot/Publications/PCI_Journal/2011/DOI_Articles/JL-11-WINTER-10.PDF
This is a link to the *PCI Journal* article by Tadros, Fawzy, and Hanna "Precast, Prestressed Girder Camber Variability" that was cited in the Concrete Bridge Technology article on page 38.

https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/25442/Davison_washington_0250O_12723.pdf?sequence=1
This is a link to the Master's thesis by Davison "Prediction of Time-Dependent Stresses and Deflections in Prestressed, Concrete Girders: From Start of Fabrication to End of Service Life" that was cited in the Concrete Bridge Technology article on page 39.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_496.pdf
This is a link to NCHRP Report 496 *Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders* that was cited in the Concrete Bridge Technology article on page 39.

http://www.dot.ca.gov/hq/esc/earthquake_engineering/sdc/documents/Seismic-Design-Criteria-(SDC-1.7-Full-Version,-OEE-Release).pdf
This is a link to the latest version of the *Caltrans Seismic Design Criteria* (version 1.7) that was mentioned in the Riego Road Project Profile on page 14.

Bridge Technology

NEW **http://onlinepubs.trb.org/Onlinepubs/trnews/trnews295rpo.pdf**
This is a link to the article "Second-Generation, Full-Depth, Precast Concrete Deck System" in the November–December 2014 edition of *TR News*. It reports how the Nebraska Department of Roads used a new precast concrete deck system to improve constructability and cost-effectiveness.

NEW **http://www.astmnewsroom.org/default.aspx?pageid=3646**
This link announces the new ASTM C1778 "Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete" that provides recommendations for identifying the potential for deleterious alkali-aggregate reactions in concrete construction and selecting appropriate preventive measures to minimize the risk of deleterious reaction.

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2015 Interim Changes Related to Concrete Structures

by Dr. Dennis R. Mertz

On July 22 through 26, 2014, the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures (SCOBS), chaired by Gregg Frederick of Wyoming, convened its annual meeting in Columbus, Ohio. During the meeting hosted by the Ohio Department of Transportation, SCOBS considered and adopted five agenda items specifically related to concrete structures. Technical Committee T-10, Concrete Design, chaired by Loren Risch of Kansas, moved Agenda Items 33 through 37 to the subcommittee ballot for consideration in Columbus after years of development. These agenda items represent revisions and additions to the *AASHTO LRFD Bridge Design Specifications*.

This column reviews these concrete-structures agenda items, which were approved by SCOBS, are included in the 2015 Interim Revisions to the seventh edition of the AASHTO LRFD specifications.

The first three Agenda Items—33, 34, and 35—extend selected concrete-structure provisions to members using specified concrete strengths up to 15 ksi.

Agenda Item 33

Agenda Item 33 combines the recommendations of the National Cooperative Highway Research Program (NCHRP) Report 603, *Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete*, by Julio A. Ramirez of Purdue University and Bruce W. Russell of Oklahoma State University and the provisions of the American Concrete Institute (ACI) ACI 318-11, *Building Code Requirements for Structural Concrete*, to include updated provisions for specified concrete strengths up to 15 ksi. The 2013 interim revisions already extended the provision of Articles 5.11.2.1, 5.11.2.4, and 5.11.5.3.1 to 15 ksi. This agenda item extends all the provisions regarding development and splice lengths that can be extended to 15 ksi based upon completed research. In general, development lengths, and lap splice lengths that are based upon them, increase based upon experimental data.

Agenda Item 34

Based mostly upon NCHRP Report 595, *Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Flexure and Compression Provisions*, by a research team led by Sami Rizkalla of North Carolina State University, Agenda Item 34 extends the applicability of the flexural and compression design provisions for reinforced and prestressed concrete members to concrete strengths up to 15 ksi. Provisions extending the modulus of elasticity equations for both normal weight and lightweight concrete for concrete strengths up to 15 ksi are based upon the Federal Highway Administration (FHWA) Report FHWA-HRT-13-062, *Lightweight Concrete: Mechanical Properties*, by Ben Graybeal and Gary Greene.

One of the more significant sub-items in Agenda Item 34 is the revision of the relationship for modulus of elasticity in Article 5.4.2.4. The new equation,

$$E_c = 120{,}000 K_1 w_c^2 f'^{0.33}_c$$

where

K_1 = correction factor for source of aggregate to be taken as 1.0 unless determined by physical test, and as approved by the authority of jurisdiction,

w_c = unit weight of concrete (kips/ft^3), and

f'_c = specified compressive strength of concrete (ksi)

is for concretes with unit weights between 0.090 and 0.155 kips/ft^3 and for normal weight concrete with specified compressive strengths up to 15.0 ksi. The new relationship for modulus of elasticity not only yields values consistent with the original relationship for normal weight concrete but also appropriate values for lightweight and higher-strength concrete. The original relationship is retained in the commentary as an alternative.

Agenda Item 35

Agenda Item 35 extends the shear-design provisions in the Sectional Design Model (Article 5.8.3) to concrete compressive strengths up to 15 ksi, based upon NCHRP Report 579, *Application of LRFD Bridge Design Specifications to High-Strength Structural Concrete: Shear Provisions*, by Neil Hawkins and Daniel Kuchma of University of Illinois.

The adoption of Agenda Items 33, 34, and 35, by virtue of extending the applicability to higher strength concretes, is expected to enable:

- current bridge girders to span longer lengths, support heavier loads, or both; and
- shallower concrete sections to be used for some span lengths.

Agenda Item 36

Agenda Item 36 basically represents a clean-up of the commentary to Section 5. It eliminates 26 sets of text, from as little as a single sentence to as much as several paragraphs, throughout the Section 5 commentary. Reasons for removing the commentary items include:

- The deleted material is more appropriately included in the *AASHTO LRFD Bridge Construction Specifications*,
- The deleted commentary is common knowledge to the reader,
- The deleted commentary is dated, and
- The deleted words, while valuable when this provision was first adopted, are of little value in the current edition.

Agenda Item 37

Finally, Agenda Item 37 removes all reference to stress-relieved strands from the *AASHTO LRFD Bridge Design Specifications*, as they are no longer used. In addition, several provisions insert the necessary information on stress-relieved strands into the AASHTO *Manual for Bridge Evaluation* for use in evaluating existing structures.

Interim revisions to the *AASHTO LRFD Bridge Design Specifications* are considered annually by SCOBS. Their next meeting is scheduled for April 19 through 23, 2015, in Saratoga Springs, N.Y.

EDITOR'S NOTE

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

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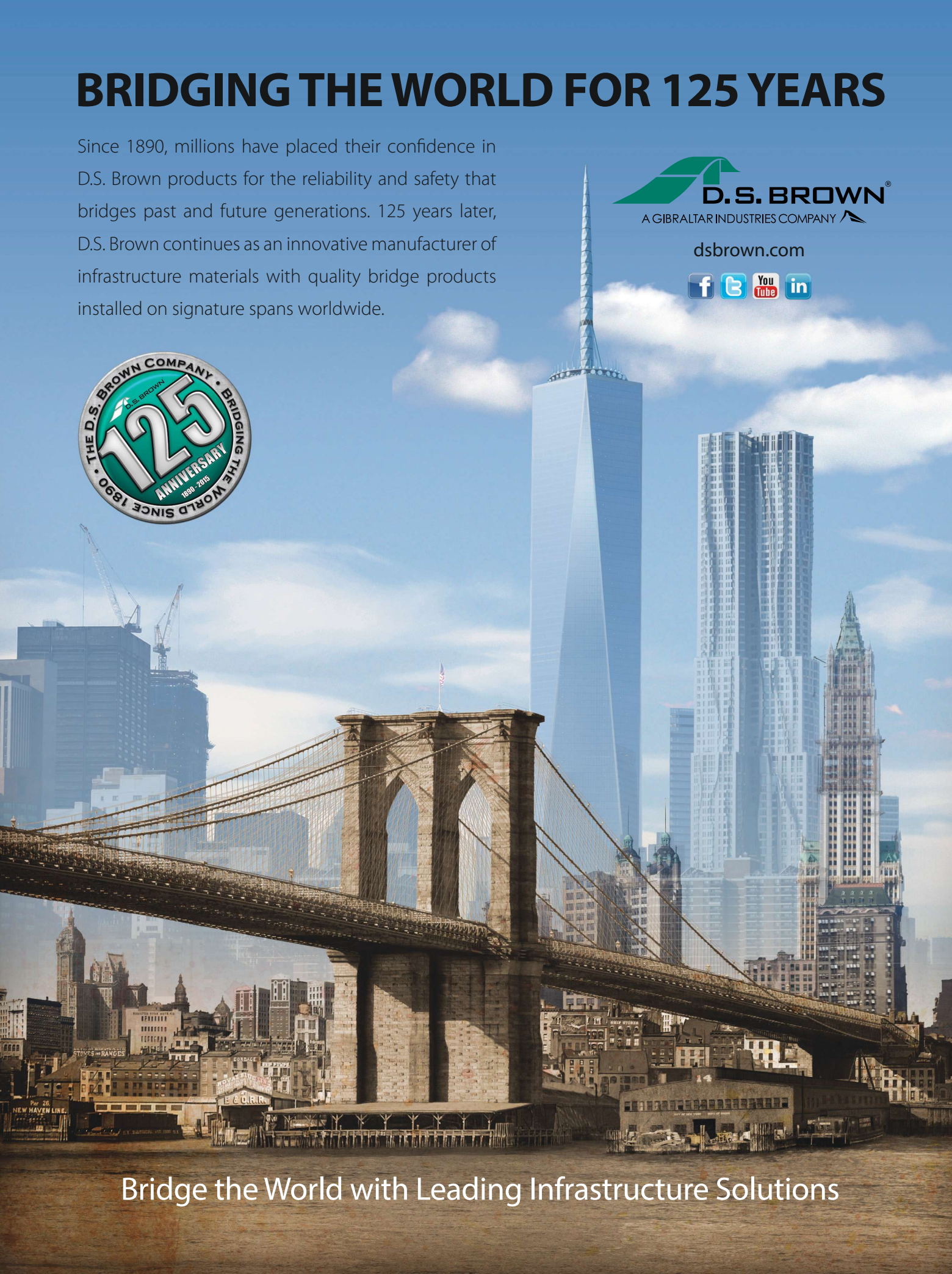

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