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THE CONCRETE BRIDGE MAGAZINE

WINTER 2024

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Structural Technologies Encompasses More Than Concrete Repair

Firm expands into additional infrastructure markets

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Honolulu, Hawaii

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Photo: PCI.

Bring 'Em Along

Dr. Krista M. Brown, *Managing Technical Editor*

For how many generations has it been said, "This younger generation doesn't want to work hard and isn't as smart as we were"? I've heard this for more than 50 years, and I'm sure my parents and grandparents heard it, too. Typically, when I ask someone to provide facts substantiating this opinion, they become flustered, offer a hearsay account, or change the topic. My supposition is that the belief is unfounded, and the root of the problem may lie with us, not "them."

Let's take the case of an employee who is six months into a position with your firm and you don't feel they are "coming along" as you'd hoped. Hmm… Have they been given the appropriate tools, training, and supervision? Or were they shown their work area, given an assignment, and left on their own to "figure it out"?

Are you concerned that they are not completing their assignment? Or is the issue that you expect the task to be completed just as you would have done it in the past? Explain what the task is, why it needs to be done, and what the time frame is. Then discuss ways to approach the work. You may find that your employee knows another way, and the alternative method may provide benefits. I was once part of a group that met on Saturday mornings to run a 5-mile loop. One day, a newcomer suggested that we run the loop clockwise. The "seasoned" runners objected: "But we've always run counterclockwise!" When they were asked why and could offer no reason, the new runner invited everyone to follow him clockwise, and we did. The world did not end, and we enjoyed a different view of the scenery.

It is important for all of us to have excellent communication skills. Create opportunities for your employees to make presentations. They will either wow you with their skills or show you where they need some help. If you do not yet feel comfortable having them present to a client, encourage them to get involved with a local school. Second graders find a hardhat and high-vis safety vest really cool! The presenter can mix concrete and have the students read and record the temperatures. With some thought, the hardened concrete could become something useful for their classroom. These opportunities should not be limited to engineers. A CAD operator could show a REVIT model and allow students to try navigating through it or adding to it. These types of presentations improve your employees' skills and are beneficial to your organization, the industry, and local schools.

Many organizations are suffering from reduced participation. Doing things as we've always done them is not improving the situation. Don't just invite members of the younger generation to join; bring them along, introduce them, and ask for their opinions! Follow up with them after the meeting. What did they find of interest? Perhaps they want to join a subcommittee, assist with an upcoming function, contribute to social media, or prepare a report or presentation slides. The younger generation typically knows how to put pizzazz in graphics! This experience will also expand employees' knowledge and skills.

I recently met with the officers of a student chapter of the American Society of Civil Engineers. I was blown away! They presented the chapter's budget, answered my in-depth questions, and told me about planning and executing a field trip to a power-producing dam. The chapter had also held an outing at a local reservoir so the chair of the civil engineering department, who is highly experienced in canoeing and kayaking, and the faculty advisor could teach the students proper rowing techniques and water safety. At this single event, the student officers recruited new members, created enthusiasm for the spring concrete canoe competition, grilled burgers, and introduced lower- and upper classmates in an informal setting. Does this sound like a generation that "doesn't want to work hard and isn't as smart"?

Traditional ways of developing employees may no longer suffice. We need to take a more active role. Let's ask our employees questions and listen to their responses. What are their short- and long-term goals? Show them the bigger picture—how their work impacts the project, the project team, and organization's bottom line. We may find out that we—not they—have a lot to learn.

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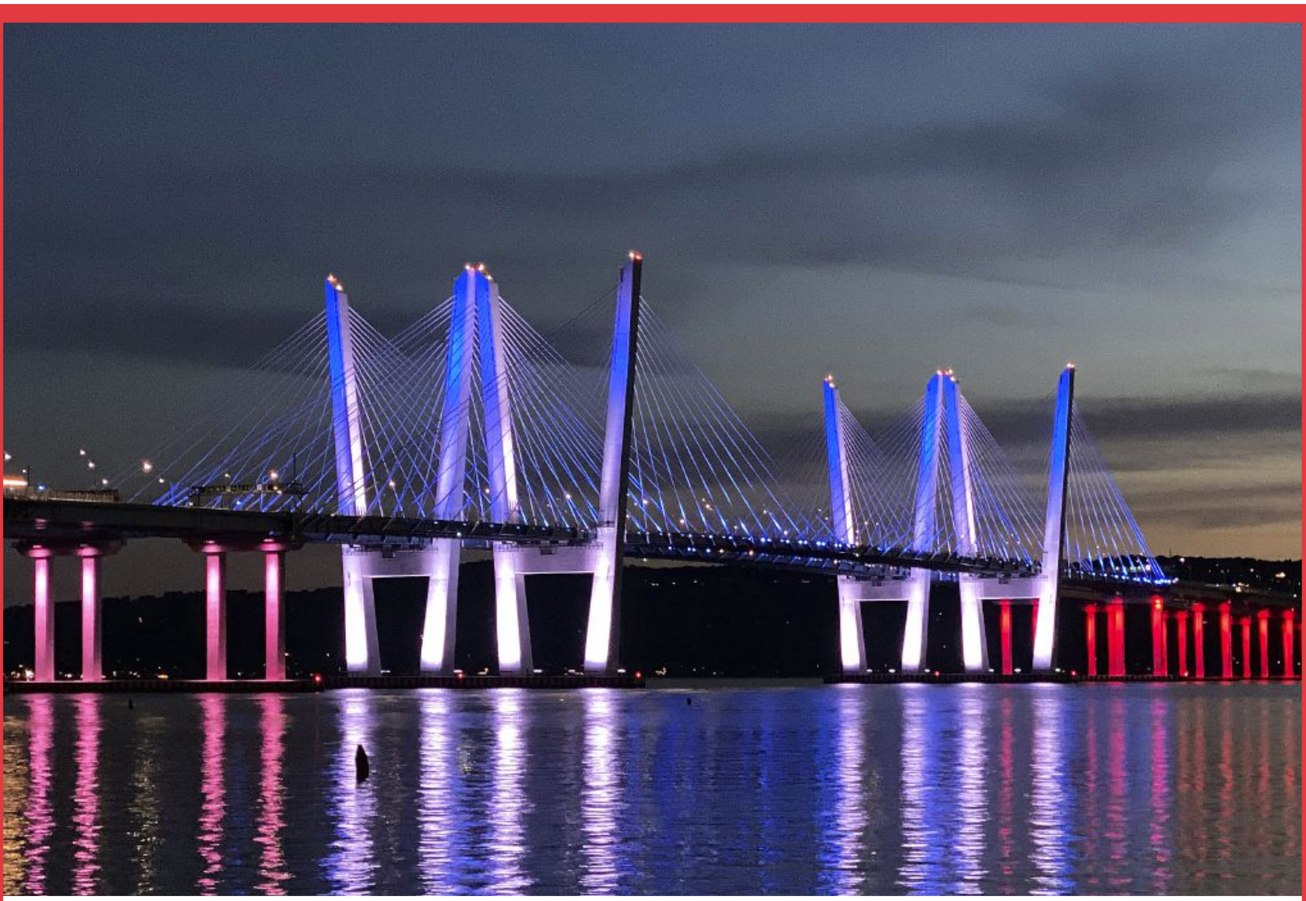

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CONCRETE CALENDAR 2024

The events, dates, and locations listed were accurate at the time of publication. Please check the website of the sponsoring organization.

January 7–11, 2024
Transportation Research Board Annual Meeting
Walter E. Washington Convention Center
Washington, D.C.

January 17, 2024
Galvanic Encasements & Jacket Systems Webinar
(The Concrete Durability Series – Part 4)
http://www.wesavestructures.info/webinars

January 22–25, 2024
World of Concrete
Las Vegas Convention Center
Las Vegas, Nev.

February 6–9, 2024
PCI Convention at The Precast Show
Hyatt Regency
Denver, Colo.

February 21, 2023
Extending Bridge Life Using Targeted Cathodic Protection Webinar
(The Concrete Durability Series – Part 5)
http://www.wesavestructures.info/webinars

March 18–21, 2024
NRMCA Annual Convention
JW Marriott Tampa Water Street
Tampa, Fla.

March 20, 2024
Surface Applied Cathodic Protection Webinar
(The Concrete Durability Series – Part 6)
http://www.wesavestructures.info/webinars

March 24–28, 2024
ACI Concrete Convention
Hyatt Regency New Orleans
New Orleans, La.

April 1, 2024
ASBI Grouting Certification Training Course
J.J. Pickle Research Center
Austin, Tex.

April 14–17, 2024
PTI Convention
Westin Indianapolis
Indianapolis, Ind.

April 15–18, 2024
CRSI Spring Business & Technical Meeting
Disneyland Hotel
Anaheim, Calif.

April 24–25, 2024
NCBC Prestressed Concrete Bridge Seminar:
Concepts for Extending Spans
Atlanta, Ga.

June 3–5, 2024
International Bridge Conference
Marriott Rivercenter
San Antonio, Tex.

June 16–21, 2024
2024 AASHTO Committee on Bridges and Structures Meeting
Westin Indianapolis
Indianapolis, Ind.

September 15–18, 2024
AREMA 2024 Annual Conference and Expo
Kentucky International Convention Center
Louisville, Ky.

September 23–27, 2024
PCI Committee Days Conference
Renaissance Nashville
Nashville, Tenn.

October 1–4, 2024
PTI Committee Days
Kempinski Hotel Cancun
Cancun, Mexico

October 20–23, 2024
ASBI Annual Convention and Committee Meetings
Loews Atlanta Hotel
Atlanta, Ga.

November 3–7, 2024
ACI Concrete Convention
Philadelphia Marriott Downtown
Philadelphia, Pa.

November 10–13, 2024
CRSI Fall Business and Technical Meeting
The Drake Hotel
Chicago, Ill.

FOCUS

STRUCTURAL TECHNOLOGIES Encompasses More Than Concrete Repair

The largest concrete repair contractor in the United States, STRUCTURAL TECHNOLOGIES is expanding into additional infrastructure markets and is dedicated to making new and existing structures stronger and longer lasting.

by Monica Schultes

STRUCTURAL TECHNOLOGIES provides a variety of services aligned to improve, protect, and enhance existing infrastructure. They are the exclusive manufacturer of VSL post-tensioning and stay-cable systems in the United States. Through acquisitions and evolution, STRUCTURAL TECHNOLOGIES also offers heavy-lifting and sliding products and services for new construction, as well as for the demolition of existing structures. While much of their work has been in the commercial building and transportation sectors, they have pivoted to increase their work on bridge construction, repair, and strengthening. These efforts to expand include new and existing public works projects, as well as water containment structures and underground structures such as pipes and tunnels.

The amount of maintenance and repair work on existing transportation structures is increasing, and with the influx of funds from the Bipartisan Infrastructure Law, STRUCTURAL TECHNOLOGIES anticipates more new construction in their pipeline. With their renewed emphasis on the transportation market, they get involved in projects through several avenues. For example their upstream group identifies long-term opportunities and the type of project delivery method. While STRUCTURAL TECHNOLOGIES is frequently a specialty subcontractor or part of a joint venture, there are occasions where operating as the general contractor makes sense.

STRUCTURAL TECHNOLOGIES has offices in Dallas, Tex.; Denver, Colo.; Washington, D.C.; and Pompano Beach, Fla., and their teams work in tandem with more than 3000 employees of parent company Structural Group Inc. which has 40 U.S. offices. According to Bob Sward, vice president of STRUCTURAL TECHNOLOGIES, "From early project stages until the end of a structure's life, we provide consultancy, engineered products, and construction services that enable durable and sustainable solutions."

On the Interstate 59/20 project in Birmingham, Ala., STRUCTURAL TECHNOLOGIES used an alternative method to the traditional span-by-span erection of the precast concrete segments using longitudinal erection trusses. Each segment within a span was erected onto custom-designed shoring towers, which allowed the use of traditional equipment and provided the contractor with flexibility in assigning crews and equipment to meet the aggressive schedule. All Photos: STRUCTURAL TECHNOLOGIES.

Durable Structures

When state agencies plan for bridges with service lives of 75 to 100 years, STRUCTURAL TECHNOLOGIES supplies VSL post-tensioning systems designed to achieve those goals. The extent of protection needed to safeguard the tendons against corrosion is specified for each bridge. The most common protection level (PL) is PL2, which refers to the tendon encapsulation of main tensile elements as defined in the PTI/ASBI M50.3-19, *Specification for Multistrand and Grouted Post-Tensioning*.[1] The highest protection level, PL3, can be reached with fully encapsulated and electrically isolated tendons. In addition to the protection of the tendons, the system can be monitored throughout the structure's entire life cycle.

STRUCTURAL TECHNOLOGIES is well versed in all aspects of post-tensioning. However, Sward says use of the higher-level PL3 systems is uncommon in the United States. "There have been some demonstration projects, but the cost-benefit ratio over the life of the structure is difficult to quantify at this stage," says Sward. "The current perception in the United States is that the extra protection from PL3 systems may not be worth the premium cost," he adds. With more long-term data amassed from test projects, that trend might change. (For more details on PL3 post-tensioning systems, see the Concrete Bridge Technology article in the Summer 2023 issue of *ASPIRE*®.)

Seismic Partnership

In August 2023, STRUCTURAL TECHNOLOGIES solidified their commitment to expand their work in the transportation sector through a partnership with SHO-BOND & MIT, a Japan-based joint venture. The alliance adds advanced Japanese technologies in seismic repair and stabilization of structures to the company's product lines.

STRUCTURAL TECHNOLOGIES already provides carbon-fiber strengthening and cathodic-protection systems. Through the new partnership, they have access to seismic devices used to prevent bridges from becoming unseated during seismic events. If there is a possibility of such a failure, a restraint device such as the "shearing stopper" is one preventive measure.

Sward is enthusiastic about the opportunities that await. "Working with SHO-BOND will bring a wide range of repair, reinforcement, and preventive maintenance technologies that are commonly used in Japan, which will improve our offerings in high-seismic zones."

Specialty Subcontractor

Post-tensioning and concrete segmental bridge construction are among the core competencies of STRUCTURAL TECHNOLOGIES. This fact is evident on the Mosquito Road Bridge project in El Dorado County, Calif. The structure is 375 ft above the South Fork of the American River and has a 536-ft main span with 322-ft end spans. The bridge is being constructed using the cast-in-place, balanced-cantilever segmental method. In addition to supplying the multistrand post-tensioning system, STRUCTURAL TECHNOLOGIES is providing the traveling forms for the project's superstructure.

As specialty subcontractor to Johnson Brothers Corporation, STRUCTURAL TECHNOLOGIES provided and installed the post-tensioning system and formwork for the precast concrete segments for the third phase of the bridge replacement project for Interstate 59/20 in Birmingham, Ala. The segmental precast concrete viaduct used custom falsework towers that were also furnished by STRUCTURAL TECHNOLOGIES for the span-by-span construction. (For more details on this project, see the Project and Concrete Bridge Technology articles in the Spring 2020 issue of *ASPIRE*.)

Prime Time

When the majority of a project's scope is in their sweet spot, STRUCTURAL TECHNOLOGIES often functions as the general contractor for the project.

History of STRUCTURAL TECHNOLOGIES

The orgin story of what is now Structural Group Inc. and STRUCTURAL TECHNOLOGIES is complex. Peter Emmons founded Structural Preservation Systems in Maryland in 1974. Since then, companies under the Structural Group umbrella have played an important part in developing concrete repair and maintenance solutions.

The Swiss company VSL, which is still in operation, was a pioneer in post-tensioning products. Its products have been used throughout the world since 1956 to build, repair, and strengthen bridges and buildings, and use of VSL products in the United States began on the West Coast in the 1960s. In 1998, Structural Preservation Systems purchased the U.S. license for VSL technologies. Bob Sward, vice president of STRUCTURAL TECHNOLOGIES, recalls that the business initially was called V-Structural LLC, but the name was changed to STRUCTURAL TECHNOLOGIES in 2012. "While we have the exclusive rights to the VSL post-tensioning, stay-cable, and heavy-lifting systems in the United States, we also work collaboratively with VSL International on select projects," says Sward.

Structural Preservation Systems was eventually folded under the Structural Group umbrella of companies. Pullman was acquired in the early 2000s. It serves as the Structural Group's "union" arm for concrete repair and restoration, while STRUCTURAL or Structural Preservation Systems are the "nonunion" arm. All the technologies that the company acquired or developed over time are housed in STRUCTURAL TECHNOLOGIES. The Structural Group family of companies offers a comprehensive suite of technology products and engineering services to make structures stronger and last longer, including carbon-fiber strengthening, cathodic-protection systems, and service-life modeling.

For decades, many have considered Emmons's book, *Concrete Repair and Maintenance Illustrated*,[2] to be the preeminent reference for evaluating concrete problems and formulating surface repair. Published in 1993, it has been translated into multiple languages and is used as an educational tool at numerous universities.

Emmons has received numerous awards as an expert on concrete repair. He served as president of the International Concrete Repair Institute (ICRI), past chairman of ICRI's Technical Activities Committee, and numerous ICRI and American Concrete Institute (ACI) committees. Emmons continues to lead the industry and has been recognized for his many contributions. In 2005 he was named one of *Concrete Construction*'s "10 Most Influential People in the Concrete Industry," and in 2014 he was awarded ACI Foundation's Innovation in Concrete Award.

During emergency repairs of the post-tensioning system in the Roosevelt Bridge in Stuart, Fla., crews severed the existing internal bonded continuity tendons in one span and replaced them with new external unbonded tendons.

Such was the case for the repair of the Roosevelt Bridge crossing the St. Lucie River in Stuart, Fla.

When a routine inspection in 2020 noted the presence of cracking in one span on the southbound structure, the Florida Department of Transportation (FDOT) closed portions of the Roosevelt Bridge. FDOT acted quickly to assemble a team to perform the emergency repairs. To expedite the work, STRUCTURAL TECHNOLOGIES was selected as construction manager/general contractor, which was FDOT's first use of this project delivery method.

The segmental precast, post-tensioned concrete bridge consists of 41 spans on two parallel structures that are each approximately 4600 ft in length. It was determined that the cracking in one of the spans was a result of corroded tendons that had failed. STRUCTURAL TECHNOLOGIES worked collaboratively with FDOT and their engineers to repair the structure, including the post-tensioning tendons that had corroded, and return the bridge to service as soon as possible. To restore the segmental precast concrete structure's capacity, 48 new external post-tensioning tendons were installed and injected with a flexible filler. This innovative solution will protect against corrosion and offers FDOT the capability to replace tendons in the future if needed. An epoxy-overlay system was installed on the bridge deck for additional protection. (For more information on the Roosevelt Bridge repairs, see the Summer 2022 issue of *ASPIRE*.)

Asheville Interstate Expansion

A key feature of the Asheville Interstate Expansion project is the modern precast concrete segmental bridge on the Blue Ridge Parkway over Interstate 26 (I-26). Six additional new bridges will be constructed as part of this corridor project that extends from Airport Road to the Interstate 40 interchange in Asheville, N.C. This portion of the I-26 widening project will expand the interstate from four lanes to eight lanes, doubling the roadway's capacity.

The three-span segmental precast concrete bridge is being constructed by a balanced-cantilever method. Serving as subcontractor to the joint venture between Fluor Corporation and United Infrastructure Group, STRUCTURAL TECHNOLOGIES has completed one cantilever pier and mobilized to start the next for the new 605-ft-long Blue Ridge Parkway structure. Construction is scheduled to be completed in 2024.

Blue Ridge Parkway Part 2

STRUCTURAL TECHNOLOGIES is also at work on another project along the Blue Ridge Parkway in North Carolina. Work is underway to replace the historic Laurel Fork Bridge in Ashe County and is expected to be completed in late 2024. The project includes a segmental precast concrete bridge with cast-in-place piers and abutments.

The project to construct the new 550-ft-long, 30-ft-wide, and 90-ft-tall structure is a joint venture with Vannoy Construction, a local contractor whose work complements STRUCTURAL TECHNOLOGIES' segmental capabilities. STRUCTURAL TECHNOLOGIES is supplying and erecting the precast concrete segments, and furnishing and installing the post-tensioning system. The original structure built in 1939 has been demolished. Construction of the piers is currently under way, and erection of the precast concrete segments will begin in the spring of 2024.

STRUCTURAL TECHNOLOGIES is using the balanced-cantilever system for construction of the Blue Ridge Parkway bridge over Interstate 26. After lifting a precast concrete segment into place, temporary post-tensioning bars are installed and tensioned to attach the segment to the cantilever.

A "shearing stopper" installed by STRUCTURAL TECHNOLOGIES. This device resists upward forces and horizontal forces in two directions to prevent the unseating or "stepping" of the superstructure, especially during seismic events.

Knowledge Transfer

To succeed in the concrete repair industry, a company needs skilled and knowledgeable field personnel. STRUCTURAL TECHNOLOGIES realizes that the best design means nothing without proper execution and therefore emphasizes the need for continuous technical training and skills improvement of field personnel. This is a worthwhile investment in employees' career growth.

Whether it is performing a repair or tensioning tendons, STRUCTURAL TECHNOLOGIES requires highly skilled professionals. Retaining and transferring knowledge across the company is vital to their success. Therefore, STRUCTURAL TECHNOLOGIES invests a considerable amount of time in training. For example, to preserve the skills and lessons that are learned on each project, they have recorded project supervisors and their crews on video and through interviews. Every activity is documented, from assembling formwork to chipping concrete, grouting, and tensioning a tendon. This vast learning library is available to everyone through the company intranet. "We have invested in our best asset—our people and their knowledge," says Sward.

"We have invested in our best asset—our people and their knowledge."

Sward emphasizes that "safety starts with our frontline, including our commitment to protective helmets instead of traditional hard hats."(See the sidebar for more about this initiative.) "Our focus is to empower the people in the field to identify potential hazards. Every morning, they complete a jobsite safety analysis and see what is required to accomplish the work that day," he adds. Cross training allows employees in the field to be prepared for a wide variety of scenarios. One day they are repairing cables that were cut in a building, and the next they are grouting tendons on a bridge.

"We are continuously trying to work smarter. We are constantly looking for ways to improve our process without sacrificing quality or safety," emphasizes Sward. For example, on a stay-cable project in Ohio, field personnel saw ways to make small adjustments to the process to eliminate the need for a person positioned on the outside of the pylon during installation.

"We are continuously trying to work smarter."

The Future

According to the American Road and Transportation Builders Association, 36% of all U.S. bridges (approximately 224,000 structures) require repair work or replacement.[3] With that in mind, STRUCTURAL TECHNOLOGIES plays a vital role in efforts to prolong the life of and strengthen aging bridges. The entire concrete industry learns valuable lessons from repairs and, as a result, gleans a better understanding of the long-term performance of bridges. To demonstrate their commitment to the industry, STRUCTURAL TECHNOLOGIES teamed with the National Concrete Bridge Council for a webinar series entitled "Preserving and Extending the Service Life of Concrete Bridges." Access to the previously recorded six-part series is available at https://www.structuraltechnologies.com/preserving-extending-the-service-life-of-concrete-bridges.

Hard Hats to Helmets

While many consider Peter Emmons's contributions to the construction industry to be his legacy, the "Hard Hats to Helmets" (H2H) initiative is his passion. Emmons has worked tirelessly on H2H since a fatal accident involving an employee on a Florida jobsite demonstrated the need for better head protection. Emmons believes that "the construction industry can reduce the number of head injuries and fatalities today by saying 'no' to continuing to use 60-year-old hard hat designs and 'yes' to helmets that deliver the best technology available for head protection." The sole mission of H2H is to educate the industry on how to reduce traumatic brain injuries and deaths in construction.

Everyone at STRUCTURAL TECHNOLOGIES is involved in promoting the change from hard hats to helmets. The American Society of Concrete Contractors and other industry groups also stand behind the initiative to evolve from traditional hard hats toward the energy-absorbing helmets that better protect frontline workers.

References

1. Post-Tensioning Institute (PTI) and American Segmental Bridge Institute (ASBI). 2019. *Specification for Multistrand and Grouted Post-Tensioning*. PTI/ASBI M50.3-19. Farmington Hills, MI: PTI.
2. Emmons, P. H. 1993. *Concrete Repair and Maintenance Illustrated: Problem Analysis, Repair Strategy, Techniques*. Kingston, MA: R.S. Means.
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National Concrete Bridge Council—Making Things Happen for the Concrete Bridge Industry

by Gregg Freeby, American Segmental Bridge Institute and National Concrete Bridge Council

In the Fall 2022 issue of *ASPIRE*®, I wrote a Perspective that introduced readers to the National Concrete Bridge Council (NCBC) and outlined the strategic objectives identified by the council. This article provides updates on NCBC's latest activities and recent progress.

New Member

Since my previous article, NCBC has welcomed a new member, the International Concrete Repair Institute (ICRI). This new member will help develop our focus on stewardship: How can NCBC help disseminate the existing body of knowledge and identify gaps in the inspection, evaluation, maintenance, and repair of concrete bridges? All these actions are aimed at extending the service life of our existing concrete bridges. In addition, maintaining bridges in a state of good repair is an objective of the U.S. Department of Transportation. Having ICRI join the ranks of NCBC will help us to further assist the industry in this area. If you missed it, you can read about ICRI's Concrete Surface Repair Technician Program in the Summer 2023 issue of *ASPIRE*.

Sustainability

Also since the last update, NCBC has embarked on a collaboration with the National Steel Bridge Alliance. While a collaboration between these otherwise competing industry groups may sound shocking, it has happened before. In 2009, the concrete and steel industries teamed up to craft a white paper on the 12 essential elements of a comprehensive quality system.[1] This latest collaboration was announced in a Concrete Bridge Stewardship article in the Fall 2023 issue of *ASPIRE*. In a nutshell, this collaboration is intended to develop fair and technically robust life-cycle assessment (LCA) requirements for the bridge market. The Federal Highway Administration (FHWA) publication *Pavement Life Cycle Assessment Framework*[2] provides a framework for performing LCA for pavements, but no similar guidance currently exists for bridges. It's time for the concrete and steel industries to work together to fill this gap.

Workforce Development

Through deliberative collaboration with the American Association of State Highway and Transportation Officials (AASHTO) and FHWA, NCBC is making progress on the workforce development front. NCBC has two recent "wins" to report.

The first win was the adoption by AASHTO of the AASHTO/NCBC

Attendees listen to William N. Nickas, past chair of the National Concrete Bridge Council, during the Prestressed Concrete Bridge Seminar: Concepts for Extending Spans workshop in Hudson, Wis. All Photos: Gregg Freeby.

Challenge coins were given to all attendees at the Prestressed Concrete Bridge Seminar: Concepts for Extending Spans workshop hosted by National Concrete Bridge Council in Hudson, Wis.

"Resources for Concrete Bridge Design and Construction." This document was balloted for publication in May 2023 at the AASHTO Committee on Bridges and Structures (COBS) annual meeting in Kansas City, Mo. As stated in the Background section of the AASHTO agenda item:

> *This new document is the first product developed under the AASHTO/NCBC Collaboration Agreement. This document is a listing of resources for the concrete bridge practitioner that are made available by the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), the members of the National Concrete Bridge Council (NCBC) and selected other relevant sources. It is intended to be a catalog or "bookshelf" of important resources for the design and construction of concrete bridges from these organizations.*

The second win for NCBC was a pilot workshop titled "Prestressed Concrete Bridge Seminar: Concepts for Extending Spans." This first-of-its-kind workshop was hosted in Hudson, Wis., for the Minnesota and Wisconsin Departments of Transportation. Two representatives from each of their prequalified engineering firms were also invited to attend. More than 100 attendees participated during two full days of instruction. Topics included an introduction to prestressed concrete, spliced girders, concrete segmental bridges, strain compatibility, design limit states, post-tensioning, fabrication, and many other subjects. Presentations on ethical issues were also included. Attendees received a challenge coin to mark the event. After refining the program from this pilot workshop, NCBC plans to host future sessions of this seminar, with the next offering likely to be in Atlanta, Ga., in April 2024.

To further help educate the workforce in bridge stewardship, NCBC sponsored a series of six webinars in the summer of 2022. These webinars covered a wide range of topics such as concrete fundamentals, evaluations, analysis and design of repair solutions, concrete repair basics, concrete bridge strengthening, and long-term bridge protection. Each session was 90 minutes long. Recordings of the sessions can be accessed on the NCBC website (nationalconcretebridge.org). In addition, on October 18, 2023, NCBC began a series of six 1-hour webinars aimed at concrete bridge stewardship. The session titles are as follows.

- Concrete Condition Assessments
- Don't Patch it, Repair it!
- ICCP and Electrochemical Treatments
- Galvanic Encasements and Jacket Systems
- Extending Bridge Life Using Targeted Cathodic Protection
- Surface Applied Cathodic Protection

Registration for upcoming webinars and recordings of those that are completed can be found on the NCBC website.

Collaborations with AASHTO and FHWA on Future Publications

Under the recently executed collaboration agreement with AASHTO, NCBC is continuing to expand workforce development resources. NCBC is working to complete a new publication called *Guide to Post-tensioned Transportation Structures*. In this document, NCBC will be updating FHWA's very popular *Post-Tensioning Tendon Installation and Grouting Manual*,[3] and supplementing it with new content. The new guide, which is on track to be balloted by the AASHTO COBS in 2024, will include details for spliced girders and troubleshooting guidance, as well as other new resources for bridge practitioners regarding all types of post-tensioned transportation structures.

NCBC also continues to collaborate with FHWA. The forthcoming *Guide to Post-tensioned Transportation Structures* is just one example where a need was identified and the two groups worked together to come up with an innovative solution in which NCBC becomes the steward for an existing FHWA publication. As such, FHWA has also committed to updating the e-learning modules that were created for the previous manual so that they reflect the new guide. NCBC has also committed to keeping the new guide current through regular updates, making this a win-win situation for the industry.

Collaboration with CBEI

NCBC continues to support the Concrete Bridge Engineering Institute (CBEI) as the various programs you have read about in previous issues of *ASPIRE* come to fruition. The collaboration between CBEI and NCBC means neither group is working alone, but rather in tandem with a common objective: to build better concrete bridges.

Visibility

If you attended the International Bridge Conference or the Western Bridge Engineers' Seminar in 2023 and visited the exhibit hall, I hope you stopped by the NCBC booth. That's right, NCBC has started exhibiting at bridge conferences. This effort is led by NCBC member volunteers to help increase the visibility and awareness of NCBC. While NCBC continues to increase our support for the industry, it is important for the industry to know about the resources available not only from NCBC but also from our individual members. The next time you're at a bridge conference, look for us. We're likely to be there.

NCBC Continues to Grow

This is an exciting time for NCBC, and I am personally honored to serve as the current chair. The numerous opportunities that have been presented to NCBC and the outstanding response and cooperation among members have already taken us places which our founders could only have dreamed of. More to come.

References

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Gregg Freeby is the executive director of the American Segmental Bridge Institute and chair of the National Concrete Bridge Council.

EDITOR'S NOTE

Visit the National Concrete Bridge Council website at nationalconcretebridge.org for more information about upcoming events, including the next Prestressed Concrete Bridge Seminar, as well as webinar recordings and registration links.

The National Concrete Bridge Council (NCBC) has begun exhibiting at various bridge conferences to help increase the visibility and awareness of NCBC and its mission.

Elastomeric Bearing Pads: Ask the Experts

Two industry experts provide insights and advice regarding the important topic of elastomeric bearings for concrete bridges

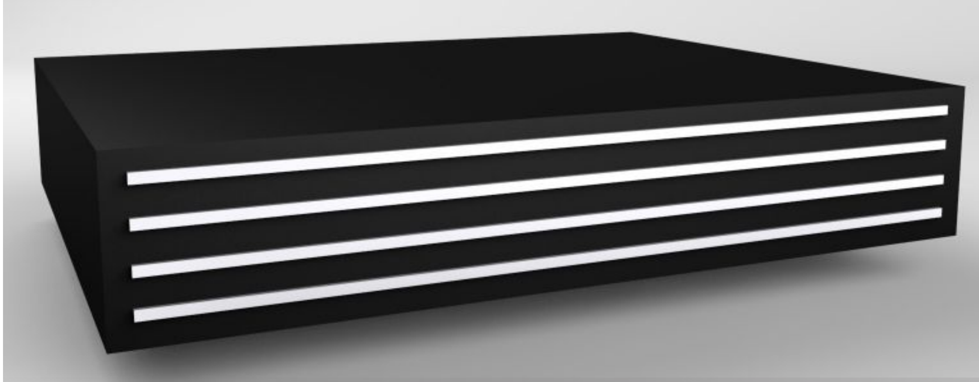
by Monica Schultes

Elastomeric bearings allow transfer of vertical loads, horizontal movement, and structural rotation. They are valued for their durability, reliability, low maintenance requirements, and low cost. Because elastomeric bearing pads are crucial for safe and cost-effective concrete bridge design, we posed questions about them to the experts. Their responses were edited for clarity and brevity.

What percentage of bridge bearing pads are elastomeric, either plain or laminated?

Rob Anderson, Scougal Rubber: We see 100% elastomeric bearing pads, unless the bridge is very large and under extreme loading. Steel-laminated (that is, steel-reinforced) elastomeric bearings are manufactured with alternating layers of neoprene or natural rubber and steel sheets; then vulcanization permanently bonds the steel laminates to the rubber.

Ryan Schade, The D.S. Brown Company: Approximately 90% of bridge bearings that we see are elastomeric (plain or steel-reinforced elastomeric pads). We supply both; however, there are a few other types of bearings, some of which we also supply: HLMR [high-load multirotational] bearings for high-load and/or rotation conditions, and cotton-duck-impregnated rubber pads, which are stiffer and utilize a harder elastomer. There are also random-oriented fiber pads, which are exceedingly rare for bridges and are not covered by the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1]



Steel-laminated elastomeric bearings are commonly specified for their versatility and low maintenance. The number and thickness of the steel laminates, the thickness of the internal layers of elastomer, the cover (external layer) thickness of the elastomer, the shear modulus of the elastomer, and plan dimensions of the bearing are among the parameters that must be designed for a steel-reinforced elastomeric bearing. All Photos and Figures: The D.S. Brown Company.

What changes or innovations in bearing pads for concrete bridges have occurred in the last decade?

Scougal: In the past 10 years we have seen higher loads and higher rotations in bridge design.

D.S. Brown: The AASHTO LRFD specifications updated the design methodology so that Method B has evolved into a strain-based design, and Method A now allows slightly increased stresses. Sampling and lot requirements were recently updated in AASHTO M251, *Standard Specification for Plain and Laminated Elastomeric Bridge Bearings*.[2]

What changes are forthcoming?

D.S. Brown: The AASHTO Product Evaluation and Audit Solutions program (formerly the National Transportation Product Evaluation Program [NTPEP]) is expanding to include more agencies that prequalify bearing manufacturers.

Scougal: NTPEP is a worthwhile program, and the independent audits provide a level of confidence similar to plant certification. AASHTO needs to encourage wider participation in the program in order to reap the benefits.

What are the advantages of AASHTO LRFD Method A (Article 14.7.6) versus Method B (Article 14.7.5)?

Scougal: In our opinion, Method A is a simpler design. AASHTO M251 has specific tests for Methods A and B. There are additional tests in AASHTO M251 that are required if specified by the project specifications. The standard tests are relatively easy to do and are completed multiple times a day by the manufacturers, who have the equipment to perform them. The optional tests can be lengthier and more difficult to perform and are very seldom specified.

D.S. Brown: Method A is a simpler and more conservative design. Only specify elastomer durometer for Method A, and only specify shear modulus for Method B. Designers can refer to Section 2.3.1.3 in the AASHTO/NBSA [National Steel Bridge Alliance] *Steel Bridge Bearing Guidelines* (G9.1)[3] for material properties of elastomeric bearings. When specifying shear modulus, follow the noted section commentary on recommended values, as it allows manufacturers to provide standard elastomer compounds and still meet tolerances.

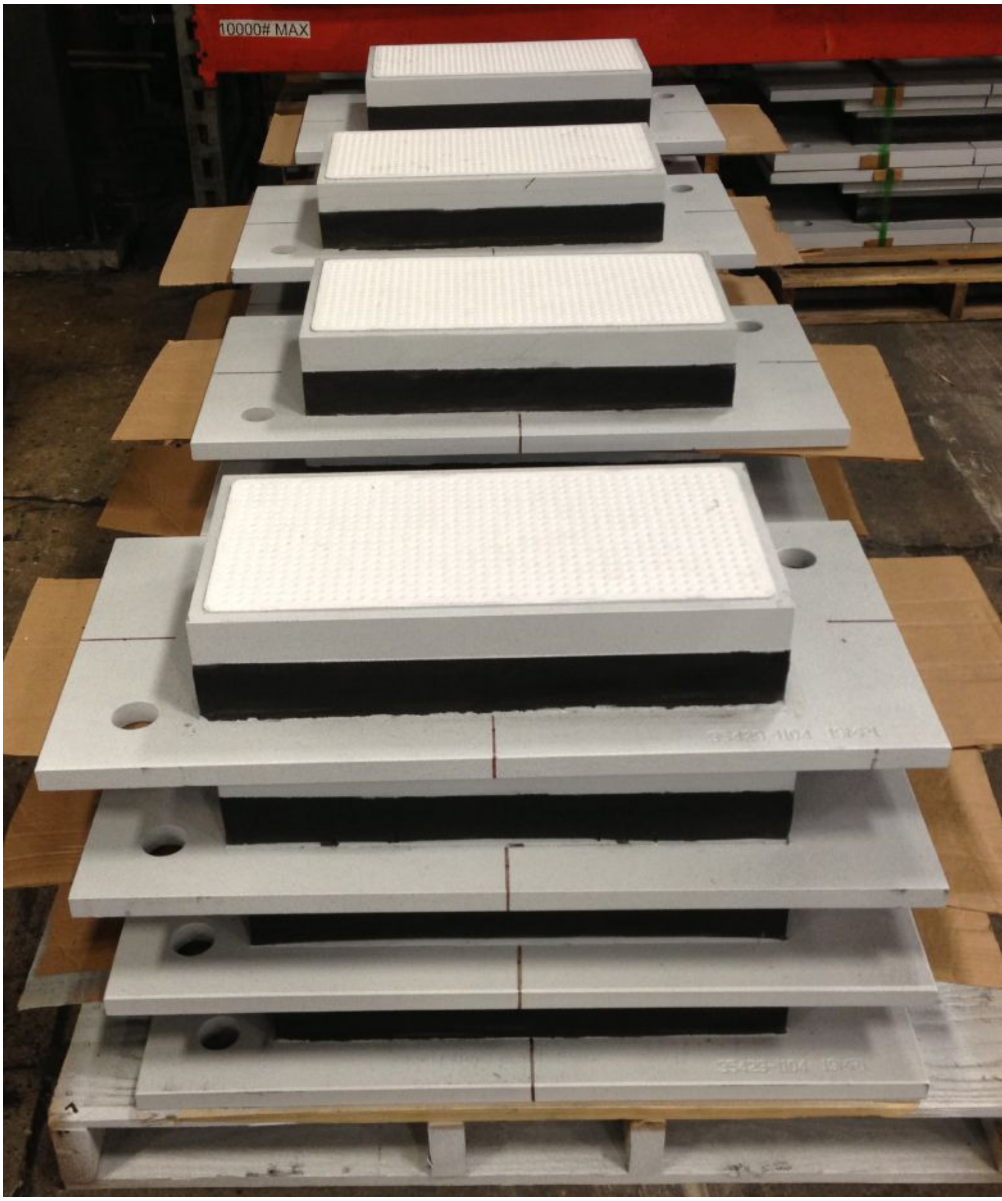
What recommendations do you have for bridge designers?

D.S. Brown: Use available reference guidelines where possible, which include all state specifications, standard drawings where available, AASHTO LRFD Sections 14 and 18, and AASHTO/NSBA G9.1. The PCI e-learning courses on bridge bearings [see sidebar] are also great references. For unique details, check with bearing manufacturers to ensure that they are feasible and economical.

Scougal: Bearing design is finding a balance between stiffness and flexibility. Steel plates are added for greater stiffness, and for greater flexibility additional rubber is used. When designers follow the AASHTO LRFD specifications in Section 14, the results are typically conservative and apply to most construction and installation settings. Some states have their own design and testing specifications. It is recommended that designers follow one and not pick and choose from different specifications, which makes it confusing for the manufacturer.

Are there poor practices that could be avoided?

D.S. Brown: There can be a lack of information on stud placement and embedded plate details. The bridge designer should specify the locations



A low-friction polytetrafluoroethylene (PTFE) dimpled sheet, which is used as a sliding top surface on laminated elastomeric bearings. Dimples on PTFE surfaces function as reservoirs that receive lubricant before assembly.

to ensure there are no conflicts with reinforcement. Verify that connection bolt locations do not conflict with bearing plan dimensions. For bearings that are bonded to external plates, identify the bond (for example, vulcanized) and provide adequate spacing between other plates, keepers, and shear blocks to allow for mold placement and removal.

Scougal: It is important to have sufficient information on shop drawings. Verify that the pad orientation and thickness agree with what is shown on the plans.

What are the recommended solutions for bearings under wide elements like box beams or for multistemmed members?

D.S. Brown: In our experience, these tend to be shorter spans and do not need to accommodate significant movement or rotations, which allows engineers to utilize continuous plain elastomeric pads or pads butted together. Elastomeric bearings require loads to be evenly distributed. If the beam width is smaller than the bearing width, adequate steel plate thickness will be required to distribute the load to counteract plate bending. For that reason, we recommend that when PTFE [polytetrafluoroethylene] sliding surfaces are used, they should have plan dimensions similar to the bearing to avoid a significant bending moment on the distribution plate. PTFE is a low-friction material, so it is used when larger movements are needed for elastomeric bearings (movement beyond what you would want to design the bearing to handle in shear).

What factors affect the service life of elastomeric bearings?

Scougal: It is important to select the best bearing type for your project. Whether your bridge requires a pot bearing, spherical, disc, elastomeric, cylinder, or seismic isolator is determined mainly by forces and movement.

D.S. Brown: The life expectancy of elastomeric bearings is typically much longer than other types of bearings. They are also economical for small-to-moderate loads, rotations, and movements, and they are relatively low maintenance as compared to other types. Installation can impact elastomeric bearing service life. Damaging the coating on external steel, damaging the external rubber layers which exposes internal laminates to the elements, scratching stainless steel or PTFE, or setting the girders at the wrong temperature or not resetting the pads when necessary can shorten the life span of the bearing pad. Trying to position the bearings by hitting them or other methods that crack or gouge the elastomer cover also shortens their life spans.

Conclusion

Ultimately, the goal is to design and detail bridge bearings that are cost effective, functional, and durable. With that in mind, take advantage of the expertise available to the industry through manufacturers and industry resources.

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Ryan Schade is the technical engineering manager at the D.S. Brown Company in North Baltimore, Ohio.

Rob Anderson is president of Scougal Rubber in Seattle, Wash.

The addition of a low-friction sliding surface such as polytetrafluoroethylene (PTFE) allows a laminated elastomeric bearing to accommodate greater horizontal displacement. This type of bearing configuration is often used for precast concrete bridges.

PCI eLearning Module on Bridge Bearings

Elastomeric bearings are commonly specified for their low cost and minimal maintenance requirements compared with mechanical-type bearings. However, proper design and installation are needed to avoid problems like crushing, delamination, and slippage of the bearing pads. In an effort to educate the design and construction community on the importance of properly specifying and installing bearing pads, the PCI Committee on Bridges has added this topic to their selection of online courses.

Elastomeric bearing pads have been used for decades for transferring loads on all types of concrete bridges. The terms "elastomeric bridge bearing," "pot bearing," and "elastomeric bearing" are often used interchangeably. The AASHTO LRFD specifications provides two methods by which bearings may be designed: Method A or B. To help designers with the proper selection, the first PCI course (T450) focuses on the simplified Method A, and the next course (T455) addresses Method B. The T455 module includes design examples and commentary as well as pitfalls to avoid for all types of rail and highway structures.

For more information, visit https://oasis.pci.org/Public/Catalog/Home.aspx?Criteria=177&Option=738&tab=2

PERSPECTIVE

Development of the AASHTO Guide Specifications for Ultra-High-Performance Concrete

by Dr. Thomas Murphy, Modjeski and Masters, and Dr. Oguzhan Bayrak, University of Texas at Austin

Recent advancements in concrete materials science led to the development of ultra-high-performance concrete (UHPC). In May 2023, to facilitate the use of UHPC-class materials in bridge design, the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures adopted a guide specification addressing the design of structural components made from UHPC. This guide specification is the culmination of the efforts of various organizations and individuals to make this advanced material available for use in bridges. The development of the guide specification was driven by the need for explicit guidance on how to design bridges using this new material, whose failure mechanisms may differ from those of conventional concrete. Use of UHPC, which began primarily in cast-in-place joints between precast concrete deck components, has been expanding into more prominent structural components and connections. Thus, there is a need for design equations that can accurately predict the capacity of components constructed using UHPC in a design framework that is consistent with the *AASHTO LRFD Bridge Design Specifications*.[1] When using UHPC for girder sections that take advantage of the properties of this material—thus resulting in much more slender webs and better-optimized flanges—the practical span lengths for precast concrete components can be extended. Reductions in superstructure weight in UHPC bridges can result in structures that employ a greater fraction of their capacities to support live loads and superimposed loads, leading to greater levels of structural efficiency.

The guide specification was developed based on research performed by the Federal Highway Administration, research and development sponsored by PCI, and other research efforts in the United States and around the world. Without the long-term vision and commitment of these organizations and the dedication of the research teams carrying out the work, the guide specification would not exist.

To be considered a UHPC by the guide specification, the material must have a strain-hardening behavior in tension, a minimum compressive strength of 17.5 ksi, and a minimum effective cracking strength of 0.75 ksi. The fibers used to obtain these mechanical properties must be steel, although other nonsteel fibers can also be included. Generally, UHPCs contain no coarse aggregate; instead, particle packing, admixtures, fibers, and a low water–cementitious materials ratio are used to obtain high compressive and tensile strengths. UHPCs are self-consolidating, but adjustments to the batching process can be required to properly mix the material.

Appearance of ultra-high-performance concrete in its fresh state as it is used for testing (left) and beam production (right). Photos: PCI.

The guide specification provides minimum and typical values for the important mechanical properties of UHPC based on the testing that has been performed to date. Designers are encouraged to open a dialogue with suppliers to ensure that the properties required by the design are practical and achievable. For UHPC used in precast and prestressed concrete components, the guide specification provides additional guidance on the values for mechanical properties that have proven to be practical and economical, in a relative sense, in prior research.

In terms of structural behavior, aside from the dramatic differences in compressive and tensile strengths, the primary distinction between traditional concrete and UHPC is the potential for a failure mode involving the localization of cracking. This mode of failure occurs when the tensile strains reach a critical value and the cracking in the UHPC, which tends to be well distributed before this strain, localizes into a single, large crack. The fibers spanning the crack will then begin to fail, resulting in an increase in tensile stress in any prestressed or nonprestressed reinforcement crossing the crack. Depending on the relative proportions of the cross section, this phenomenon can result in a rapid loss of strength with additional deflection. The phenomenon can occur both in flexure and in shear, and is predominantly a concern when the amount of reinforcement in the section is low, with the UHPC supplying a large proportion of the resistance to tensile stresses arising from either flexure or shear.

Because it is necessary to mathematically keep track of strains in the design, flexural design is accomplished using a strain-compatibility approach. For shear, the modified compression field theory (MCFT) of design has been adapted for UHPC. Since crack localization may occur before shear reinforcement yields, an iterative approach to determining the key variables in the MCFT equations is needed. However, tables are provided for these variables in an appendix of the guide specification; these tables may be used if the designer desires to avoid iterations and is willing to accept a more conservative result. Unlike typical designs employing conventional concrete, consideration for the tensile strength of UHPC is allowed in structural design. This aspect of structural design necessitated a series of considerations that are not common in designs conducted per the AASHTO LRFD specifications for conventional concrete.

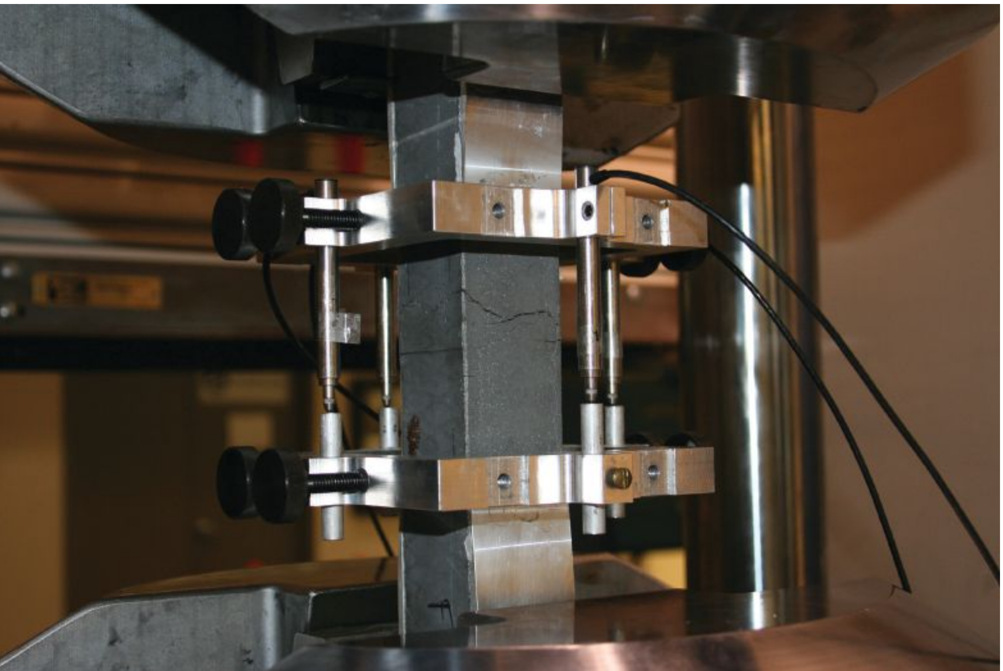
For strength limit states, the resistance factor ϕ varies depending on whether the section is expected to experience crack-localization behavior. This variable is determined through the use of a curvature-ductility ratio, with the resistance factor ranging from a maximum of 0.9 for conventional behavior to 0.75 when crack localization is expected.

In addition to providing methods for calculating capacities for flexure and shear at the strength limit states, the guide specification also addresses service limit states. For flexure, controlling stresses are provided in compression and tension. These are very similar to the stress limits governing the design of conventional concrete components, with the addition of a tensile strain check for nonprestressed components.

The calculation of creep and shrinkage strains, and the resulting prestress losses, are addressed in the guide specification. Shrinkage in UHPC can be larger than that of conventional concrete due to the action of autogenous shrinkage, which is caused by the chemical reactions that occur during curing and is more prevalent in UHPC because UHPC has a higher proportion of cement content. Available data indicate that the amount of creep exhibited by UHPC can vary significantly based on the properties of the individual mixtures and curing techniques, and designers therefore need to allow for variations in the predicted creep deformations. Other topics covered in the guide specification include interface shear capacities, and development and transfer lengths for reinforcement in UHPC.

AASHTO is currently developing a companion material specification to define how the material properties of a UHPC should be established through testing, and how these properties should be verified at the project and component level. It is expected that the material specification will be ready for consideration by the AASHTO Committee on Bridges and Structures at its annual meeting in June 2024.

Direct tension test of an ultra-high-performance concrete prism. Photo: Federal Highway Administration Turner-Fairbank Highway Research Center.



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1. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.

Dr. Thomas Murphy is a senior vice president and the chief technical officer at Modjeski and Masters.

Dr. Oguzhan Bayrak is a chaired professor at the University of Texas at Austin, where he serves as the director of the Concrete Bridge Engineering Institute.

PROJECT

Honolulu Authority for Rapid Transportation Airport Guideway and Stations Project

by William (Bill) Elkey, Parsons Corporation, and Chris Hall, SYSTRA International Bridge Technologies

In the Hawaiian capital city of Honolulu, the highway congestion is considered among the worst in the United States. For example, Honolulu ranked high in the *2019 Urban Mobility Report* for traffic congestion and commuter delays for medium-sized cities; the report found that in 2017 drivers in Honolulu spent an additional 64 hours per year delayed in traffic.[1]

While the greater area of Honolulu has a robust bus system, the city does not have high-capacity transit. To address this need, the Honolulu Authority for Rapid Transportation (HART) is constructing 20 miles of grade-separated rail in the most-populated part of the island, connecting the communities along the leeward side of Oahu to the center of Honolulu.

Figure 1. Full project build out of the Honolulu rail system, which is officially named the Skyline. Figure: Honolulu Authority for Rapid Transportation.

Project Background

The HART system will extend 20 miles and include 21 stations, starting from the suburban city of Kapolei located east of Honolulu, navigating to the city core, and terminating at the Ala Moana Mall, one of the busiest shopping centers in the state and adjacent to the popular visitor area of Waikiki (**Fig. 1**).

The project path will intersect suburban communities, popular destinations, and major work centers. Pearl City, Aloha Stadium, the Honolulu International Airport, and the Pearl Harbor Naval Base will all be included. The strategic placement of this alignment will provide access to 70% of the total population of Hawaii and 80% of the job centers.

Because the transit corridor is largely located in an urban environment, the system is designed as an elevated structure for nearly the entire length of the alignment. Even in sparsely populated areas, an elevated guideway was chosen to allow for greater flexibility in future development.

An initial operating segment covering the western 10 miles of alignment was opened in July 2023. The next major segment, which is being built under a design-build civil construction package known as the Airport Guideway and Stations (AGS) project, is nearly complete.

profile

HART AIRPORT GUIDEWAY AND STATIONS PROJECT / HONOLULU, HAWAII

OWNER'S ENGINEER: Stantec Consulting, Edmonton, AB, Canada

BRIDGE DESIGN ENGINEERS: Parsons Corporation, Centerville, Va., and SYSTRA/International Bridge Technologies, San Diego, Calif.

GEOTECHNICAL ENGINEER: Shannon & Wilson, Seattle, Wash.

CONSTRUCTION ENGINEER: McNary, Bergeron, & Johannesen, Broomfield, Colo.

PRIME CONTRACTOR: STG—a joint venture with Shimmick Construction, Traylor Bros., and Granite Construction, Honolulu, Hawaii

CONCRETE SUPPLIER: HC&D LLC, Honolulu, Hawaii

General Description

The AGS project is 5.2 miles long and entirely above grade on an elevated structure. The four stations along the alignment are integrated within the elevated structure and feature themes that reflect historical and traditional uses of the station sites.

The structure carries dual tracks for the trains, with a center walkway for emergency egress and maintenance personnel. The walkway is constructed from prefabricated concrete components with an interior void capable of carrying the low-voltage cables necessary for the operation of the train (**Fig. 2**).

Over the length of the AGS segment are many different conditions, which require customized engineering and construction solutions. The guideway structure typically consists of a trapezoidal concrete box girder that is supported by single-column piers and built using the segmental precast concrete construction method. Under this approach, individual precast concrete segments are delivered to the site in 8- to 11-ft-long sections that are assembled with an overhead erection gantry. This strategy is very useful within the dense urban environment of Honolulu, and a typical 140-ft span can be erected very quickly. In total, 2703 segments were cast for this project.

In addition to an urban landscape, the alignment crosses three environmentally sensitive streams, abuts a major military base, and encounters challenging geotechnical conditions for foundations. While the Honolulu region is defined as a moderate seismic zone, poor soil properties affect seismic-loading conditions in certain locations. Near the convergence of the Moanlua and Kalihi streams, the soil conditions amplify the seismic accelerations by a factor of 2.5 above the free-field response.

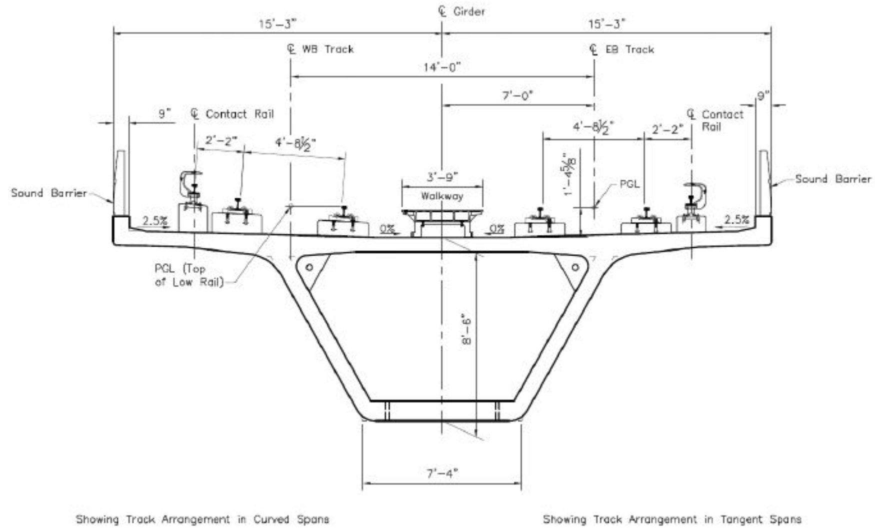

Figure 2. Typical guideway cross section. Figure: Parsons Corporation and SYSTRA International Bridge Technologies.

Typical Guideway Superstructure

The HART AGS project was originally planned as a traditional design-bid-build contract, and the construction plans were developed to a high level during that time. When the decision was made to deliver the project under a design-build procurement, the design-build team had an opportunity to refine the well-developed design details and optimize opportunities that are not usually available in a design-build project.

The first area of opportunity involved the typical span unit, the structure type for most of the alignment. Implementing concepts from other projects, the typical cross section was refined with an alternative shape that used 25% less concrete (**Fig. 3**). This change substantially reduced component weights, which led to savings in post-tensioning steel in the span and lighter loads on the foundation, while still meeting the train dynamic limits of 2.5 Hz of fundamental frequency per span. The typical 140-ft span has four tendons per web, including two tendons with sixteen 0.6-in.-diameter strands and two tendons with fifteen 0.6-in.-diameter strands.

A second design refinement optimized the length of the precast concrete segments. The original segment length of 9 to 10 ft was increased to a typical length of 10 ft 6 in., with a maximum length of 11 ft. That change resulted in fewer segments per span. Compared with the original design concept, the number of segments was reduced by 10%, which translated into fewer segments to cast and transport to the site.

These modifications are indicative of the creative collaboration in a design-build

HONOLULU AUTHORITY FOR RAPID TRANSPORTATION (HART), OWNER

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

ERECTION GANTRY AND PRECAST CONCRETE FORM SUPPLIER: Rizzani de Eccher/DEAL, Italy

BRIDGE DESCRIPTION: 5.2 miles of elevated guideway with segmental precast concrete construction carrying twin train alignments, with typical spans of 120 ft and maximum spans of 166 ft. The alignment includes the construction of four integral passenger stations.

STRUCTURAL COMPONENTS: Typical 8-ft 6-in.-deep precast concrete segments with a 30-ft 6-in.-wide deck. Segment lengths range from 8 to 11 ft. Specialty 4-ft 6-in.-deep segments are used for locations with reduced overhead clearance. Support piers are conventionally reinforced concrete with a round shaft and widened pier cap to support the span. Piers are typically supported on a single large-diameter reinforced concrete drilled shaft.

BRIDGE CONSTRUCTION COST: $963.6 million (estimate as of August 2023)

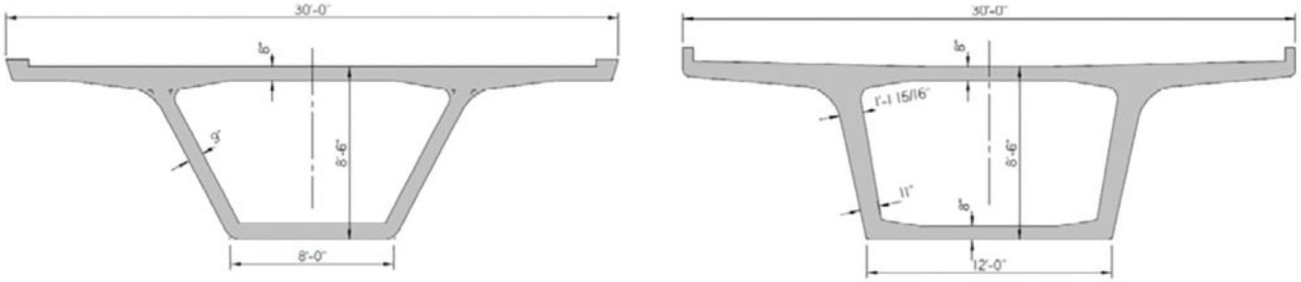

Figure 3. The guideway section on the left shows the optimized precast concrete segment section developed during the design-build refinements. The section on the right is the originally proposed section. The optimized section resulted in a 25% reduction in concrete. Figure: Parsons Corporation and SYSTRA International Bridge Technologies.

procurement. Design options can be developed with a construction team to optimize constructability and operations.

Airport Alignment

The path through the Daniel K. Inouye International Airport (HIA) presented some of the most difficult challenges along the AGS guideway alignment. The guideway configuration into the airport begins at an unusually high elevation above ground. With a maximum column height of approximately 72 ft, the HART alignment was set for future expansion of the airport and to accommodate clearance above the tail of an A380 Airbus jet.

AGS guideway construction through HIA required managing very tight geometry for both the final guideway configuration and the construction equipment and gantry, while minimizing the impact of construction on the active airport and the central post office for the island. Another concern was the project's effects on airport parking. During the construction of the guideway through this area, HIA had three parking structures and a fourth under construction. All of these structures are served by a series of at-grade and elevated roads and walkways. **Figure 4** illustrates the challenges of constructing through this highly developed and compact facility.

The entrance into the station area at HIA required some of the tallest piers constructed on the project. These piers also support the spans having the project's tightest radius of 400 ft, followed by a reverse curve and another 400-ft radius as the alignment approaches the new HIA station. This intricate route created significant uplift at certain bearings, which was accounted for by incorporating specialized uplift bearings at locations where uplift was experienced during normal (nonseismic) operations. For locations with bearings that are only subjected to uplift under seismic loadings, typical elastomeric bearings with tie-down rods were provided.

After leaving the airport terminal area, the alignment follows Ualena Street. A notable feature within this zone is the limited airspace above the guideway. Given its proximity to the airport, this part of the alignment is identified as an emergency egress for flight paths out of the airport. Because clearance below the guideway is required for vehicles, and with limited space above, a shallow superstructure was necessary.

The original design concept envisioned a cast-on-falsework guideway over 1775 ft in length. Given the limited allowable structure depth of 4 ft 6 in., a cast-in-place structure would be considered conventional. However, because the rest of the alignment has a depth of 8 ft 6 in. and was built with segmental precast concrete, the change in construction method would have required an interruption of the overhead gantry, which would have had cost and schedule implications.

Collaboration between the design and construction teams led to the development of a precast concrete solution that relied on continuous spans to make the structure feasible. The reduced structure depth was required for 722 ft along the alignment, which was divided into three- and four-span continuous units, with the last two spans requiring straddle bents with integral pier caps (**Fig. 5**). For the shallow

Figure 4. Nighttime installation of precast concrete segments within the footprint of Daniel K. Inouye International Airport. More than 2700 segments were cast at a nearby facility and transported approximately 20 miles to the jobsite. Photo: Shimmick, Traylor, and Granite Joint Venture.

Figure 5. To accommodate overhead clearance requirements at Ualena Street, shallower-depth precast concrete guideway segments are used. Photo: Parsons Corporation.

superstructure in this area, the post-tensioning was slightly modified from the typical spans and consisted of four tendons per web, typically with twenty 0.6-in.-diameter strands per tendon and additional continuity tendons over the piers. Access for future inspections and maintenance is provided by access hatches through the bottom slab of the boxes or from span-to-span through-access "doghouses."

Special Piers and Foundations

In the urban area of Honolulu, pier placement became more challenging. It was preferable for each pier to be centered directly under the guideway; however, the ground space was not always available, and offset columns or straddle bents were needed.

The offset columns are often referred to as C-bents and L-bents, with the difference being the placement of the foundation. For a C-bent, the foundation is centered under the guideway, while for an L-bent, the foundation is centered under the column. The permanent, offset loads of the guideway to the column create significant flexural demands. The most efficient means of resistance is to provide post-tensioning; however, this option is inherently nonductile, which is not desirable in a moderate- to high-seismic zone. In the C-bents, if the tendons were bonded, the strain deformations in the strand would occur over the crack widths within the hinge zone. To overcome this challenge, the vertical tendons in the column were unbonded and avoided participation with the ductile portion of the column. Thus, in the current detail, the deformation in the tendon is distributed over the height of the pier.

L-bents were used when there was limited access to place a pile cap, and the most extreme case on the project occurred over the Aolele Canal. The design was originally envisioned as a straddle bent, but construction access was extremely difficult at this location, so the design team developed an L-pier solution. The dimensions included an offset of 17 ft between the center of alignment and the column, a 7 × 9 ft oblong column, and a 12-ft-diameter drilled shaft (**Fig. 6**).

Because Oahu is a volcanic island, subsurface conditions along the AGS corridor are quite varied. Several types of soil encountered on this project present notable challenges:

- Coralline detritus and coralline reef rock: These soil layers consist of the fossil remains of coral reefs and related debris and marine deposits. The soils can be very porous and weakly cemented, and therefore are not considered for tip (bearing) resistance.
- Recent alluvium: Thick, layered, continuous beds of fine-grained marsh sediments. These medium- to very-loose sediments include organic material, shells, clays, and silts. Total layer thicknesses in some areas, such as near Kalihi Stream, exceeded the boring depths.
- Ko'olau basalt: The oldest geologic unit, it generally consists of lava flows with mantles of cobbles and boulders.

In areas toward the west end of the project, basalt elevations were relatively shallow, resulting in shaft lengths on the order of 20 ft. These dry, shallow drilled shafts were generally installed using standard auger equipment, and were either 7.2 or 9.8 ft in diameter. In contrast, in Kalihi Stream, the maximum 9.8-ft-diameter shaft is approximately 350 ft deep, which at the time was the deepest shaft of its kind ever drilled.

Conclusion

The HART AGS guideway is an example of efficient, repetitive, and economical construction that is ideal for elevated

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

"Improving aesthetics always adds cost!" How many times have you heard that one? Well, here's an example where improved aesthetics *reduced* cost. The segment cross section was optimized by the design-builder to reduce the guideway's cost, but the resulting changes also improved its appearance. The shallower angles on the webs and the more definitively rounded corners on the box give the guideway a sleeker and more streamlined shape, making the structure more transparent and thus a more welcome component of the communities through which it passes. Such "twofers" are available more often than most people imagine. They should be the goal of all engineering refinement.

There is sometimes a tendency to make decisions based on the optimization of one part of a structure, ignoring the costs that it might add to other aspects of the construction. Following widely accepted rules of thumb is one way to fall into this trap. For example, everybody knows that shorter spans are more economical, unless the additional piers cost more than the savings on the superstructure. For this project, the conventional wisdom was that the Ualena Street segment would be more economical as cast-in-place construction, but the design-builder recognized that this choice would impose costs elsewhere in the project due to the need to redeploy the construction gantry. Instead, they developed an innovative way to use segmental precast concrete construction on Ualena Street. As a result, the guideway looks the same throughout the length of the light-rail transit system, giving the whole project a visual continuity that makes it a welcome neighbor in all the varied communities it serves.

Figure 6. L-bents were used when there was limited access to place a pile cap. The most extreme case on the project occurred over the Aolele Canal, where there is a 17 ft offset between the center of the guideway and the column. Photo: SYSTRA International Bridge Technologies.

transit structures. The segmental precast concrete design allows construction on multiple fronts, with minimal impact to the surrounding work site. The design adapted the typical structure for use in multiple challenging conditions and with various configurations at the stations, at longer spans, and at tightly curved spans.

Project design started in 2017, and construction is scheduled to be completed in early 2024. Visit https://i5mc1f.p3cdn1.secureserver.net/wp-content/uploads/2023/07/2022-March-Webinar.pdf for project details that were presented in an American Segmental Bridge Institute webinar.

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First U.S. Bridge with a 100% UHPC Superstructure: A Small Bridge with Big Implications

Bricker Road Bridge over Quackenbush Drain, St. Clair County, Mich.

by Dr. Sherif El-Tawil, HiPer Fiber LLC, and William Hazelton, St. Clair County Road Commission

The Bricker Road Bridge over the Quackenbush Drain in St. Clair County, Mich., is the first U.S. bridge with a 100% ultra-high-performance concrete (UHPC) superstructure. The bridge is a demonstration project constructed under the auspices of the National Cooperative Highway Research Program (NCHRP) project "High Bond Steel Fibers for Ultra High-Performance Concrete (UHPC)"[1] in conjunction with the St. Clair County Road Commission—the bridge owner and research partner. The bridge was built to replace a deteriorated reinforced concrete slab bridge.

The entire superstructure was made of open-recipe UHPC, with the new steel fibers developed under the NCHRP project. The term "open-recipe" UHPC signifies that the UHPC mixture design is nonproprietary and available for all to use and experiment with.[2]

Although small, with a span of only 23.7 ft, this bridge represents a big step forward in UHPC technology. To the knowledge of the authors, it is the first bridge in the United States to have its entire deck panel made of open-recipe UHPC mixed in a traditional ready-mixed concrete truck.

The cost-saving aspects of this project are notable. First, although the materials for UHPC cost more than regular concrete, the materials used for the open-recipe UHPC mixture cost much less than proprietary UHPC mixtures. Additionally, compared with normalweight concrete, UHPC greatly reduces the weight of components, and as a result, the foundation, transportation, and handling costs on this project were substantially lowered.

Although the upfront cost savings are an advantage, the true benefit of UHPC is its extreme durability, which stems from its dense microstructure and its imperviousness to water and the ingress of chloride ions. With an estimated service life of 200 years (based on freeze-thaw and chloride-penetration data from Alkaysi et al.[3]), the bridge will provide great long-term savings. The bridge can also be considered a highly sustainable structure because the maintenance and

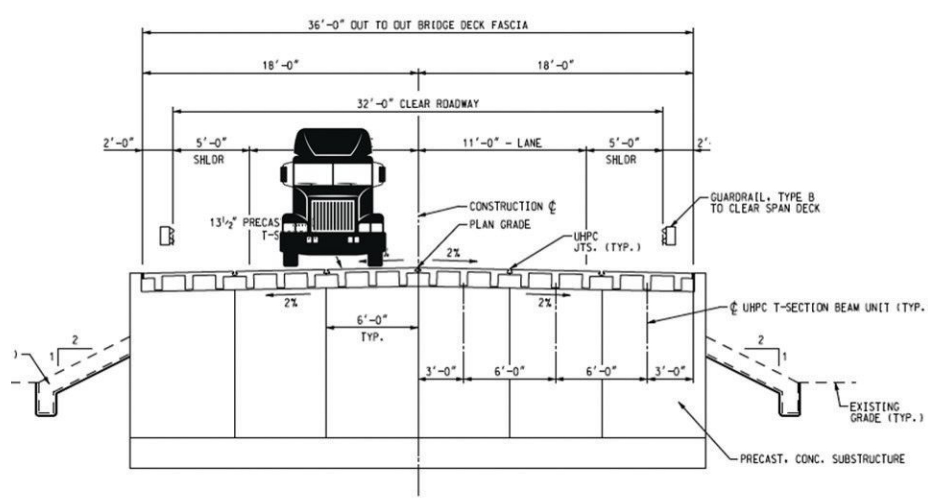

Figure 1. Bridge cross section. All Photos and Figures: HiPer Fiber LLC/St. Clair County Road Commission.

profile

BRICKER ROAD BRIDGE OVER QUACKENBUSH DRAIN / ST. CLAIR COUNTY, MICHIGAN

BRIDGE DESIGN ENGINEERS: Michael Clark, St. Clair County Road Commission, and Todd Stelma, TEG Engineering, Wyoming, Mich.

PRIME CONTRACTOR: St. Clair County Road Commission, St. Clair, Mich.

CONCRETE SUPPLIER: St. Clair County Road Commission, St. Clair, Mich.

PRECASTER: ADL Systems, Portland, Mich.

OTHER MATERIAL SUPPLIERS: Abutments: Redi-Rock, Howell, Mich.

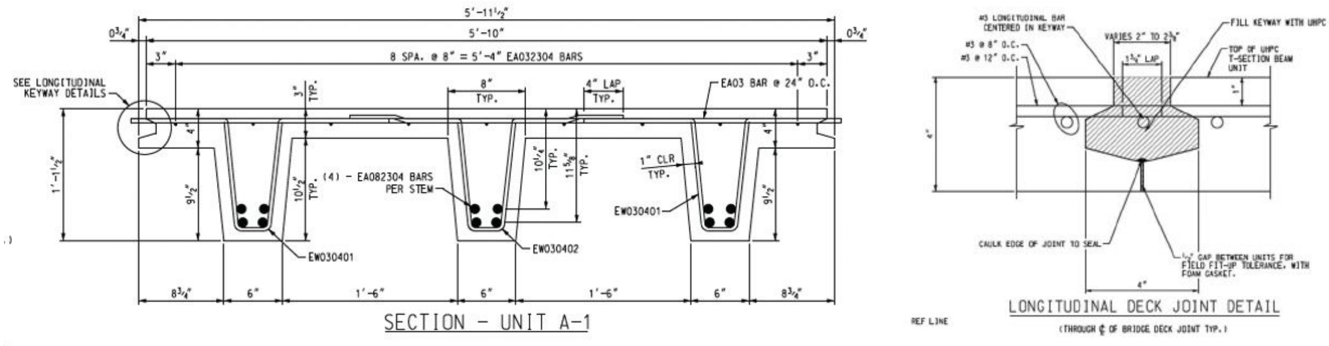

Figure 2. Three-ribbed deck panel details of the superstructure.

replacement cycles have been greatly extended.

Bridge Details

The replacement bridge comprises six ribbed panels, each 6 ft wide for a total width of 36 ft (**Fig. 1**). Each panel has a 3-in.-thick deck with 10.5-in.-deep ribs (**Fig. 2**). New forms were purchased for this project, and they have been used three times since for similar bridges. The panels were installed by county crews using a backhoe; they were light enough that a crane was unnecessary. After the panels were installed, the closure pours were filled with UHPC that was mixed in a planetary (mortar) mixer on site, and an overlay was installed. As compared to the traditional solid-slab deck bridge that was being replaced, the weight of the new structure is reduced by approximately two-thirds.

Analysis and Design

The design of the bridge was conducted according to the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[4] as well as the draft specifications proposed by the Federal Highway Administration (FHWA) that will be included in the forthcoming *Guide Specifications for Structural Design with Ultra-High-Performance Concrete*[5] (see the AASHTO LRFD article in the Fall 2023 issue of *ASPIRE*®). The UHPC compressive design strength was 21.7 ksi. Figure 2 shows the reinforcing bar arrangement. The no. 8 reinforcing bars were necessary to ensure sufficient flexural strength. However, no stirrups were required for shear reinforcement because the shear computations showed adequate shear strength compared with the demand. The stirrups shown in Fig. 2 are widely spaced and were used to facilitate longitudinal bar placement.

Bridge Construction

Figure 3 shows the construction process. The UHPC for each panel was mixed at the precaster's facility in a typical commercial ready-mixed concrete truck. Given the rather high temperatures observed during mixing, 40% of the water was replaced with ice to help cool the mixture. Experience has shown that UHPC will start setting prematurely in temperatures above 80°F. The spread of the concrete was monitored and tracked with the onboard flow meter in the truck. Previously mixed and placed material was used as a guide as to when the material was ready for placement. The flow meter on the truck had a reading of 1100 psi (the amount of pressure needed to turn the mixer drum), which equated to approximately 8.5-in. spread. Placement was not started until a reading of 1100 psi was observed.

After casting, the panels were covered with wet burlap and polyethylene plastic sheeting and left in their forms for 24 hours. After removal from the forms, the ribbed panels were wet cured while covered with burlap and polyethylene plastic sheeting for an additional six days.

Table 1 shows the results of laboratory testing of the field-cast 2-in. cubes arranged by deck panel casting date. Samples were not collected from the first mixture due to an omission. Compression testing was done by a third party. Table 1 also shows the progression of strength gain with time. Initial strength gain was rapid, with the compressive strength reaching 15.1 ksi in three days. The rate then slowed substantially, and the average strength across all UHPC mixtures eventually reached 23.9 ksi, with the lowest strength being 23.4 ksi. The measured values are all above the 21.7-ksi design strength.

Tensile tests were also conducted. The results showed that the actual tensile strengths were greater than the design values. Testing also showed that the samples exceeded the strain-hardening capacity by a large margin. For example, the forthcoming AASHTO guide specification requires a minimum strain-hardening capacity of 0.0025, whereas the capacity was 0.0045 in the test.

ST. CLAIR COUNTY ROAD COMMISSION, ST. CLAIR, MICHIGAN, OWNER

BRIDGE DESCRIPTION: First U.S. bridge with a 100% ultra-high-performance concrete (UHPC) superstructure, 36-ft wide, 23.7-ft-span precast open-recipe (nonproprietary) UHPC ribbed panels

STRUCTURAL COMPONENTS: Precast UHPC, 5-ft 11.5-in.-wide ribbed deck panels with three 10.5-in.-deep webs, 3-in.-thick deck, open recipe cast-in-place UHPC closure pours between the panels

BRIDGE CONSTRUCTION COST: $379,000

AWARD: First place, short-span bridge category, Third International Interactive Symposium on Ultra High Performance Concrete (3IISUHPC): "A Small Bridge with Big Implications"

Figure 3. Fabrication of ultra-high-performance concrete (UHPC) ribbed panels.

Pour date	Strength, ksi							
	Curing time, days							
	3	4	5	7	10	11	14	28
12-Jul	15.1			20.2				25.0
14-Jul			16.7	20.6				23.4
15-Jul		17.6			20.7			23.5
18-Jul						19.1	20.2	24.1
19-Jul					18.9		22.4	23.7
Average	**15.1**	**17.6**	**16.7**	**20.4**	**19.8**	**19.1**	**21.3**	**23.9**

Table 1. Progression of ultra-high-performance concrete compressive strength (2-in. cubes)

Project Cost

As noted, this bridge project achieved substantial cost savings. The abutment and foundation did not require piles, which helped lower construction costs. The Michigan Department of Transportation 2022 Scoping Estimate Worksheet, which is based on recent experience with similar bridge projects, projected a cost of $560,000. The actual cost for St. Clair County was $379,000. This amount included road work, new abutments, UHPC panels, county labor, and equipment rental. The short-term savings were therefore $181,000 (32.3%).

Conclusion

The bridge opened to the public in September 2022. Although the materials for open-recipe UHPC cost more than regular concrete, this project demonstrated that there are important bridge construction applications where lighter-weight UHPC can compete with traditional concrete in terms of overall costs. Ultimately, the cost savings associated with the reduction in maintenance and replacement costs due to the extreme durability of UHPC make a compelling case for new bridge construction using this unique material.

For additional project information and photos, as well as access to a recorded webinar on the project visit https://abc-utc.fiu.edu/mc-events/first-u-s-bridge-with-100-uhpc-superstructure-michigans-bricker-road-bridgeover-quackenbush-drain/?mc_id=863.

Acknowledgment

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OPEN-RECIPE ULTRA-HIGH-PERFORMANCE CONCRETE

The open-recipe ultra-high-performance concrete (UHPC) used on this project was as follows:

Mixture proportions for a cubic yard of UHPC:

Cement (portland Type I): 653 lb

Slag cement (GGBS 100): 653 lb

Silica fume (Elkem 965): 327 lb (if using Elkem 900W, reduce the HRWRA)

Water: 264 lb = 31.6 gallons

High-range water-reducing admixture (HRWRA) (3% using Sika ViscoCrete-2100): 39.2 lb (550 oz)

Steel fibers (2% by volume; Type X from HiPer Fiber): 265 lb

Fine sand (SHORT MOUNTAIN glass sand): 395 lb

Coarse sand (SHORT MOUNTAIN Silica Sands 3070): 1580 lb

Defoaming agent (such as AIR OUT from Euclid or Sika PerFin-305): 4 lb

The mixing and testing protocols are as follows:

Dry mix for 10 minutes. Add water and HRWRA over 2 minutes. Wait for turnover (fluidity), which usually occurs within 15 minutes. Mix another 10 minutes after turnover. Add fibers gradually over 2 minutes. Mix for 10 minutes; then perform a spread test before casting. You need 7 to 12 in. of spread. Steam cure for 48 hours. Perform compressive strength tests according to ASTM C109 with 2-in. cubes. The target strength is 21.5 ksi.

EDITOR'S NOTE

In 2006, a 113-ft-long, 24.5-ft-wide bridge was constructed in Wapello County, Iowa, using ultra-high-performance concrete bulb-tee girders. However, the cast-in-place deck was constructed using conventional concrete. See the Summer 2006 issue of Ascent *magazine for an article on this project (https://www.pci.org/PCI_Docs/Publications/Ascent%20Magazine/2006/Summer/Iowa%20Bridge%20Gives%20Glimpse%20Into%20The%20Future.pdf).*

Bridge Component Deterioration Models for Midwest States

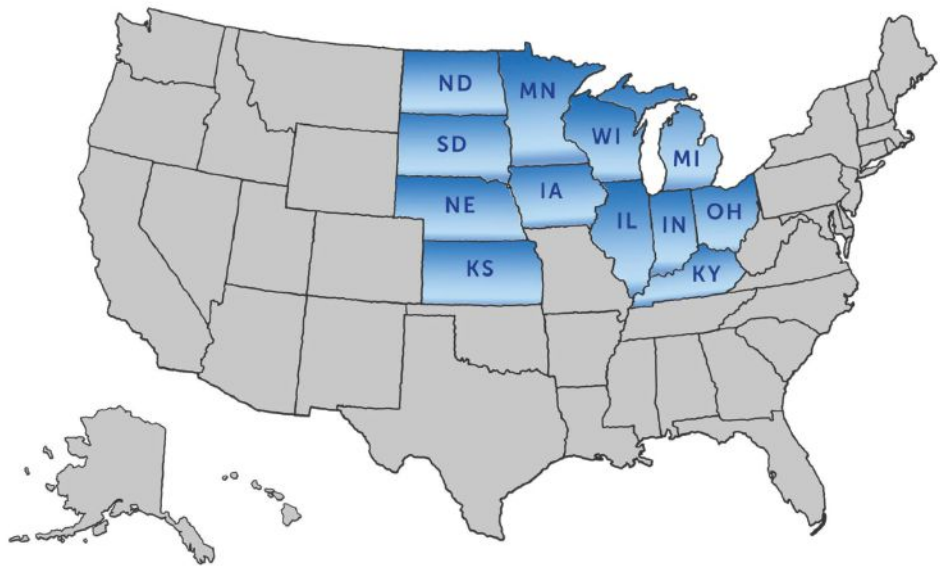
Advancements in predictive modeling of bridge component deterioration provides much-needed support for preserving concrete structures

by Philip Meinel, Wisconsin Department of Transportation Bureau of Structures

Starting in 2014, the Federal Highway Administration (FHWA) and numerous state departments of transportation began focusing on data-driven decision-making in transportation asset management. A strategy for systematically recommending the right work on the right structures at the right time had long been sought, but many state agencies did not have the tools to achieve this goal. When the FHWA initiated the collection of condition information for bridge elements according to the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Bridge Element Inspection*,[1] state agencies started compiling detailed information to support automated bridge management systems (BMSs). These automated BMSs are now able to more accurately predict what work will be needed on each structure network wide; however, accurate predictions can only be built from a correct historical database.

The new requirements for AASHTO-specified bridge elements rendered historical databases obsolete and shifted the way that state agencies thought about component deterioration. Most data from before 2014 were not useful for estimating future deterioration of the current AASHTO bridge elements. Every state faced this issue, but with limited research, agencies were left to either manufacture theoretical deterioration models based on empirical engineering judgments or rely on general component-level models to determine when major work should be performed.

In 2016, the Wisconsin Department of Transportation (WisDOT) developed its own BMS software and quickly realized that more-refined, component-level deterioration models were needed. Two years later, WisDOT attempted to generate state-specific deterioration models with the limited data available to develop age-based deterioration projections using statistical averages and typical outlier analysis. This deterministic modeling allowed WisDOT's BMS to function, but more data were needed to perform the industry-standard probabilistic modeling that most BMS software uses. Some of the early deterministic models are highlighted in the Wisconsin case study in National Cooperative Highway Research Project Synthesis 585, *Bridge Element Data Collection and Use*.[2] They are also referenced in the Transportation Research Board webinar "Bridge Element Data Use in the U.S."[3]



Transportation Pooled Fund research program TPF-5(432) participating states. All Figures and Tables: Wisconsin Department of Transportation. Data source: *TPF-5(432): Bridge Element Deterioration for Midwest States*.[5]

Midwest Partnership

The AASHTO TSP 2 Midwest Bridge Preservation Partnership[4] enabled Midwest states to collectively discuss their bridge management needs. Reliable bridge component deterioration models were identified as the top priority. The relationships developed within the multistate partnership facilitated a greater level of collaboration, with states not only sharing resources and expertise but also opening state databases for evaluation. In addition to the partnership, the Transportation Pooled Fund (TPF) research program TPF-5(432): Bridge Element Deterioration for Midwest States[5] was instrumental in providing a funding mechanism for this collaborative research to ultimately achieve high-quality, data-driven decisions for transportation structures.

TPF-5(432) began in December 2019 and the final report was published in November 2022.[5] The study used Markov-Weibull probabilistic analysis to develop reliable deterioration models for National Bridge Inventory (NBI) general component ratings (GCRs), national bridge elements, bridge-management elements, and agency-defined elements (ADE). The results from this TPF research could be immediately implemented in each state's BMS software to better predict what structure work will be needed in the future throughout the Midwest highway network. The resulting models are offered in spreadsheets that can be customized to assign a more appropriate deterioration curve for a specific subset of structure types or environments.

General Component Rating Models

NBI GCR deterioration models were the first to be developed because they gauge the overall condition of the structure. The TPF study linked structure inventory data to the bridge component ratings, which allowed some refinement of the models. **Figure 1** shows projected deck deterioration based on average GCRs for the type of reinforcement. With this graph, state transportations validated that epoxy-coated reinforcement preserves bridge decks more effectively than uncoated reinforcement. If departments of transportation solely program deck replacements based on NBI deck rating, they can quantify the benefit of using epoxy-coated reinforcement as an approximate 20-year life extension. States with more advanced BMS will also consider element condition before programming deck replacements. The models can also be refined by specific structure type. **Figure 2** shows how the average NBI superstructure GCR based on superstructure type predicts deterioriation. This figure supports the WisDOT preference to use concrete superstructures whenever practicable. In Wisconsin, prestressed concrete open-web girders (such as I-girders) are used on about 45% of state-owned structures and concrete slab spans are used on another 16%.

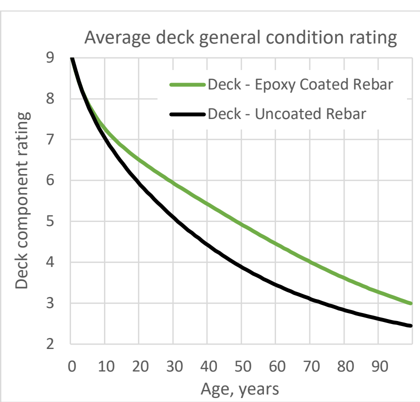


Figure 1. Model of deck deterioration as indicated by average general component ratings.

The focus of the TPF study quickly shifted to bridge elements, especially reinforced concrete decks and slabs. The AASHTO *Manual for Bridge Element Inspection*[1] defines deck elements as transmitting loads into superstructure elements and slab elements as transmitting load into the substructure elements. An advantage of having two condition evaluation systems—(a) GCR based on the NBI component data and (b) element condition states (CS) based on element-level bridge inspections and ranging from CS1 (the highest) to CS4 (the lowest)—is the ability to compare data between the two datasets. **Figure 3** compares deterioriation models for reinforced concrete deck and slab components that use NBI average deck GCRs or AASHTO measures of element deterioration, as shown by the Element Health Index.[5] The Element Health Index gives a representation of the condition states documented by an element-level inspection. It is defined as the fraction in CS1 plus two-thirds of the fraction in CS2, plus one-third of the fraction in CS3.

Figure 3 shows that the difference in the reinforced concrete slab and deck component deterioration is more pronounced in the model using the Element Health Index than in the GCR model due to the more detailed nature of the Element Health dataset.

Wearing surfaces are a key part to any bridge preservation strategy. In 2014, WisDOT established ADEs for each type of wearing surface. Many states use this data collection method, as they recognize that each type of wearing surface has a unique deterioration curve. When the Midwest data did not have an ADE assigned to each wearing surface type, the wearing surface was determined by translating the NBI item 108 code for deck surface.

Figure 4 compares deterioration of wearing surface types within the Midwest. It is important to note that every deck was assigned a wearing surface type—the "bare deck/sealed concrete" wearing surface represents the top surface of the original deck or slab component. **Figure 5**, which is from

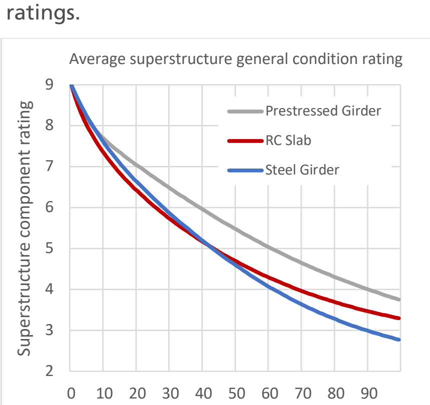


Figure 2. Model of superstructure deterioriation as indicated by average general component ratings.

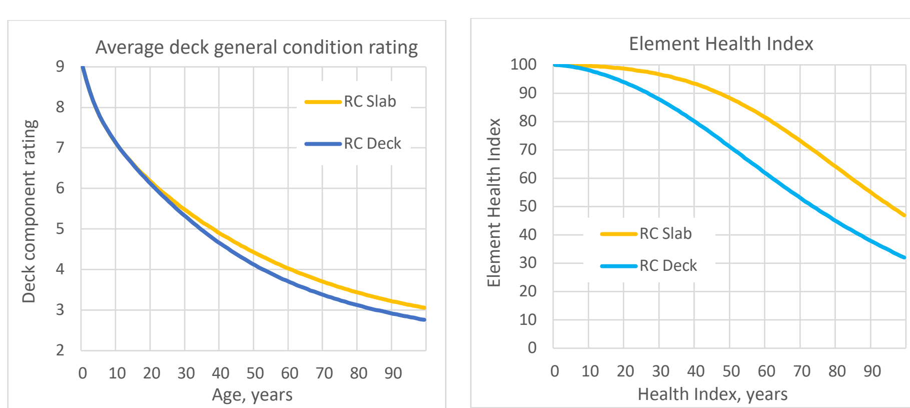


Figure 3. Comparison of reinfoced concrete (RC) deck and slab deterioration models using average general component ratings (left) and Element Health Index data (right).

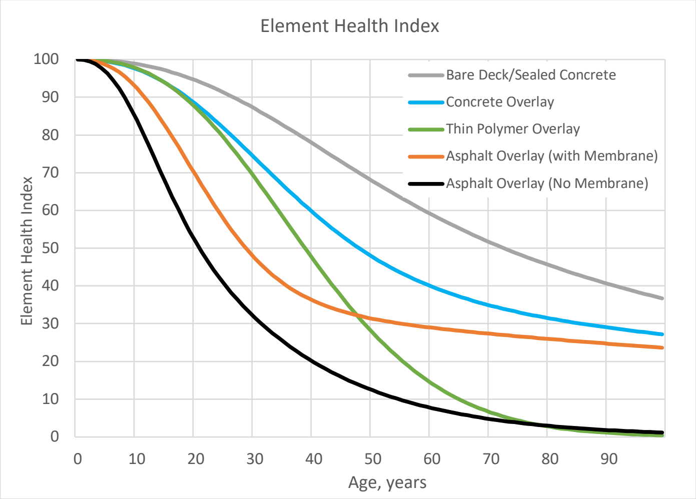


Figure 4. Wearing surface deterioration as indicated by Element Health Index data.

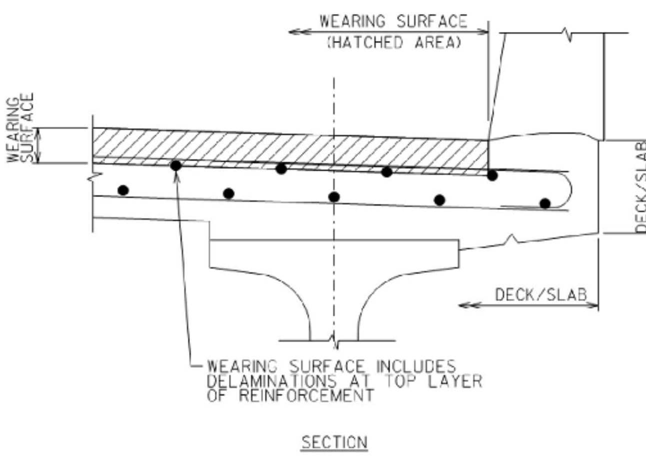


Figure 5. Wearing surface extent as defined by the Wisconsin Department of Transportation.

the WisDOT *Structure Inspection Field Manual*,[6] shows how Wisconsin defines the extent of the wearing surface. By tracking the condition of the original integral wearing surface separately from the underlying deck or slab component, WisDOT is better able to predict when the first overlay should be applied and which overlay type is most appropriate. The distinction between the top and bottom of the deck is also essential for determining when to perform an overlay and when to replace the entire deck.

Models Used to Develop Preservation Strategies

By comparing the deterioration models for various bridge components and quantifying the benefits of reinforcement types and overlay options, state transportation agencies can build an ideal preservation life cycle for each type of structure in their inventory. For example, combining the benefit of epoxy-coated reinforcing bars within a reinforced concrete deck and applying regular deck sealing or a thin polymer overlay early in the life cycle of the structure significantly extends the service life of the deck in a cost-effective manner. Bridge component deterioration models using in-service condition data and research projects to evaluate new materials and applications have helped WisDOT shape a robust preservation strategy, which is laid out in the *WisDOT Bridge Manual*.[7]

Although the TPF-5(432) study did not produce deterioration models for every component, it did establish the basis for component modeling, which can be repeated for any component of interest. The study did not evaluate prestressed concrete open-web girders, but WisDOT later created a component deterioration model from the shared Midwest data. The reason that this component was not included in the original study is the historically slow rate of deterioration overall and the significant correlation of advanced girder-end deterioration related to leaking joints above. The TPF-5(432) study focused more on deck and joint deterioration modeling to avoid exposure of the girder ends. Expansion joints were shown to deteriorate rapidly in the Midwest, a finding that supports the preservation strategy of eliminating joints whenever possible.

The TPF-5(432) study did evaluate common reinforced concrete substructure components (columns, pier caps, pier walls, and abutments). The method of data collection significanlty affected the analysis of component deterioration. Markov deterioration models rely heavily on the median transition times (that is, the time it takes for half of the quantity in a condition state to transition into the next condition state). **Table 1** compares the median transition time from CS1 to CS2 for reinforced concrete substructure elements. There is a noticeable difference between the findings for the columns, where the quantity used when collecting condition data is "each," (that is, per column), and findings for the other substructure elements, where condition data are collected per linear foot. There appears to be a consistent trend in which initial deterioration seems steeper when condition data are collected with less detail. The elements (columns) collected with less detail (using "each" instead of linear feet) transition more quickly to CS2 because any defect within the entire element height will classify the full element in CS2. State transportation agencies should strive to collect condition data in more detail (despite the minimum national standards) to produce improved deterioration models.

There was interest among the Midwest states to quantify the increased deterioration rate of components in harsh conditions as a part of the TPF-

Table 1. Median transition times from condition state 1 (CS1) to condition state 2 (CS2) for reinforced concrete substructure elements

Reinforced concrete substructure elements	Population	Median transition time from CS1 to CS2, years
Abutments, ft	33,799	40.9
Pier walls, ft	8172	50.3
Pier caps, ft	25,320	69.4
Columns, each	19,334	23.8

Table 2. Median transition times for reinforced concrete pier caps based on Average Daily Traffic (ADT) under the structure

ADT under the structure	Number of inspections with pier cap elements	Median transition times between condition states (CS), years		
		CS1 to CS2	CS2 to CS3	CS3 to CS4
ADT = 0	16,939	92.8	15.7	72.3
0 < ADT < 1000	1032	86.3	9.1	71.9
1000 ≤ ADT < 10,000	2225	67.4	10.4	89.4
1000 ≥ 10,000	5125	37.1	7.8	52.4
All	25,320	69.4	12.4	68.0

5(432) study. A significant correlation was found between traffic volume (represented by Average Daily Traffic) passing under the structure and the rate of deterioration. **Table 2** shows this correlation for reinforced concrete pier caps. When deterioration models are adapted to specific environments, both short-term project scoping and long-term funding scenarios are improved.

Refining the Asset Management Process

The asset management process is iterative: refine data collection, refine predictive modeling, and repeat. Throughout this process, data collection always serves the end goal of predictive modeling. When data collection processes are less robust—possibly due to anticipated workload or limited ability to accurately record detailed condition data—the predictive modeling is also less robust. Increased data refinement leads to increased bridge preservation activities because the refined data helps agencies identify treatments earlier in the life cycle and focus on the specific defects to be corrected to maintain the structure in good condition.

To promote more advanced data collection practices to support the desired BMS performance, the TPF-5(432) study summarized nondestructive evaluation (NDE) usage among the states, specifically NDE used on reinforced concrete decks and slabs. WisDOT has one of the few network-wide NDE programs for assessing wearing surface condition. These NDE data reveal wearing surface defects that are hidden and help WisDOT's automated BMS determine the best timing for an overlay, which is essential for an effective bridge preservation strategy. It is critical that the NDE data are recorded under a wearing surface ADE, so that BMS software can distinguish between the condition at the top of the deck component and the condition at the bottom of the deck component. That information is the difference between an overlay recommendation and a deck replacement recommendation. More information about Wisconsin's use of bridge deck NDE can be found in the *WisDOT Structure Inspection Manual*[8] and the FHWA NDE webinar "Systematic Thermography of Bridge Decks in Wisconsin."[9]

The Midwest states intend to continue to collaborate, merge inspection methods, and standardize data management practices to create a more consistent and reliable database for future bridge component modeling efforts. Specific areas of improvement as recommended in the TPF-5(432) report include the following:

- More uniform use of component defects
- More uniform use of ADEs, including wearing surface ADEs
- Improvement in the quality and consistency of construction activity data (repair and improvement history)

To the extent that Midwest states can accomplish these recommendations, dividends will be seen both in refining predictive modeling, and in refining asset management decisions throughout the region.

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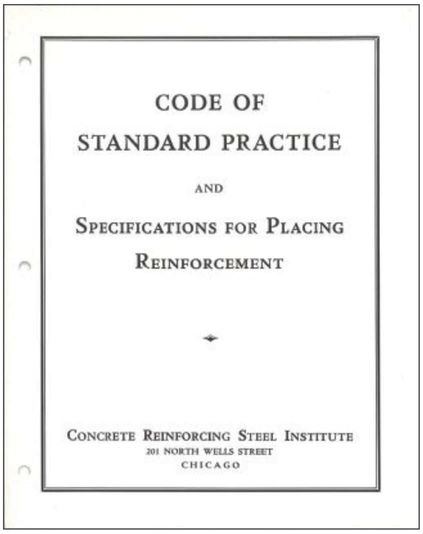
Concrete Reinforcing Steel Institute Reflects on a Century of Impact as the Institute Turns 100

by Dr. Ulrich Frisse, Historical Branding Solutions Inc., and Dave Mounce, Concrete Reinforcing Steel Institute

Today, the Concrete Reinforcing Steel Institute (CRSI) is the trusted industry resource and standards, development organization for steel reinforcement, specifically reinforcing bar, in concrete construction. Since its inception, CRSI has continually built on member involvement and partnerships to help shape the construction industry. Through its own technical committees and staff collaboration, CRSI has made significant contributions that have created an enviable legacy.

Ultimately, it has been the perseverance of CRSI's membership that has allowed the institute to traverse both political and economic difficulties over the last century. CRSI was founded in the fall of 1924, when 33 owners and executives of 25 companies involved in the manufacture and distribution of new billet-steel reinforcing bars gathered at the William Penn Hotel in Pittsburgh, Pa. Their intent was to establish a trade association for their industry. The purpose of the new organization was to promote and actively support the use of steel-reinforced concrete in construction, and to address immediate challenges faced by the industry.


CODE OF STANDARD PRACTICE AND SPECIFICATIONS FOR PLACING REINFORCEMENT

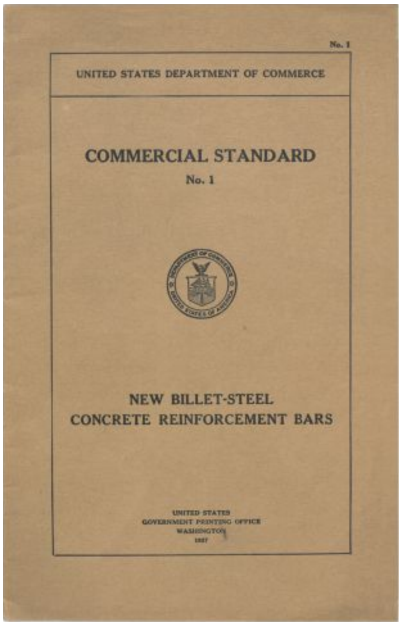
CONCRETE REINFORCING STEEL INSTITUTE
201 NORTH WELLS STREET
CHICAGO

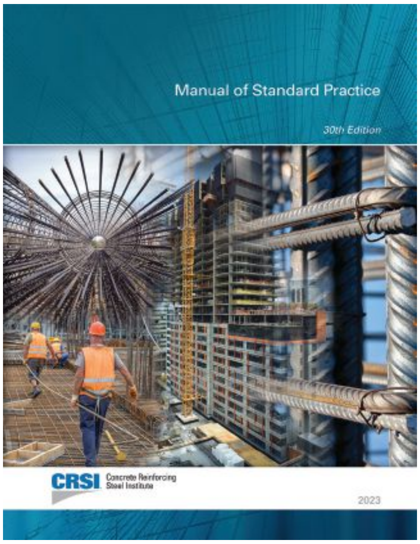
The Concrete Reinforcing Steel Institute's first industry standard document, published in 1927. All Photos: Concrete Reinforcing Steel Institute.

Against the post–World War I backdrop, the newly formed CRSI went immediately to work. Industrialization was in full swing, and among the first tasks was developing uniform contracts for fabricator members to gain legal authority to ensure they were paid by their customers. Additional initial goals were to standardize the number of grades and sizes of the steel reinforcing bars that were being produced in the United States and to create a publication addressing standards and specifications of reinforcing bars.

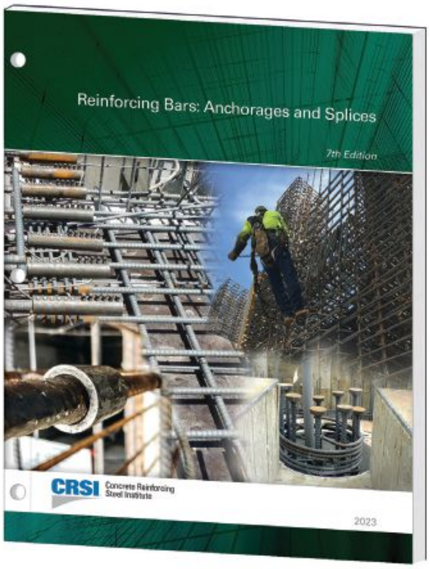
During the institute's infancy, it produced numerous written works that would become major contributions to the reinforced concrete industry. CRSI collaborated with the American Concrete Institute (ACI) to develop the *Tentative Building Regulations for the Use of Reinforced Concrete*[1] in 1928, which was the precursor for ACI's *Building Regulations for Reinforced Concrete* (ACI 318-41).[2]

Several years later, a new membership structure that included steel producers (mills) bolstered CRSI as it weathered the Great Depression and World War II. Although government intervention and war-time restrictions affected the work of the membership, it was during this time that the institute produced the precursors and first editions of publications that would become industry staples. *Reinforced Concrete:*


No. 1
UNITED STATES DEPARTMENT OF COMMERCE
COMMERCIAL STANDARD
No. 1
NEW BILLET-STEEL CONCRETE REINFORCEMENT BARS
UNITED STATES GOVERNMENT PRINTING OFFICE WASHINGTON 1937



Covers of the precursor (1937) to and the current edition (2023) of the *Manual of Standard Practice*.[4] Since 1937, this manual has presented recommendations for the design and detailing of steel reinforcing bars.



The definitive source for information on development and splicing of reinforcing bars, *Reinforcing Bars: Anchorages and Splices* has been revised several times since the first edition in 1968.

A Handbook on Reinforced Concrete Construction Containing Information of Value to the Architect and Engineer[3] (predecessor of the current *Manual of Standard Practice*[4]), *CRSI Design Handbook*[5] (now produced as a series of design guides), *CRSI Recommended Practice for Placing Reinforcing Bars*[6] (later to become simply *Placing Reinforcing Bars*[7]), and the *Reinforcing Bar Detailing* manual[8] were published throughout this period, providing industry education and guidance.

As the industry matured, CRSI evolved with the changing needs of its members, technological advancements, demographic changes, and the advent of new products and related processes. Taller buildings, new highway infrastructure, the developing building code, and corrosion resistance were all topics of focus and research.

Leading up to and entering the new millennium, CRSI expanded its membership, technical committees, standards and codes representation, and research obligations. New services included the development of industry-specific software, plant certification programs, and various initiatives to help members conform to a growing number of regulatory frameworks, from health and safety to environmental protection. The institute embraced government advocacy and developed the necessary documents for its members to comply with sustainability requirements. It also fostered the research and adoption of high-strength (80 and 100 ksi) reinforcing steel in partnership with the CRSI Foundation, Pankow Foundation, and ACI Foundation. Workforce development and outreach to universities and construction school programs also continue to be key issues within CRSI and the CRSI Foundation.

CRSI's most recent flagship publication, *Design Guide on the ACI 318 Building Code Requirements for Structural Concrete*,[9] was released during the COVID-19 pandemic. Shortly after the guide was published, CRSI created a series of companion "Design Checklists"[10] to provide additional time-saving information to designers. Currently, CRSI is developing a comprehensive design guide addressing state-of-the-art seismic design requirements for an early 2025 release.

With the commemoration of the first 100 years quickly approaching, CRSI shows no signs of slowing down. It continues to author and influence the standards, codes, and rules according to which the construction industry ultimately operates. It also remains steadfast in demonstrating its commitment to the thousands of professionals who use reinforced concrete construction in their careers through education, information, and promotion.

The anniversary celebration begins at the World of Concrete in 2024, which is coincidentally observing its 50th anniversary. CRSI will showcase a new centennial-branded booth with special giveaway items and commemorative items for purchase. Twice next year, CRSI membership will gather nationally and revelries will also continue at regional and chapter events.

The institute will come full circle when it holds its Fall Business and Technical Meeting at the same location as its first national meeting in 1925, the Drake Hotel in Chicago, Ill. The event will be the culmination of a yearlong celebration that will allow CRSI members and staff to reflect on the longevity, milestones, and future of a trade association turning 100.

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EDITOR'S NOTE

The Concrete Reinforcing Steel Institute (CRSI) is a member of the National Concrete Bridge Council. Visit their website at www.crsi.org to learn more about CRSI's mission and access valuable resources.

Fatigue Design for Concrete Bridge Structures

by Dr. Francesco Russo, Russo Structural Services

In a three-part series published in the Summer 2011, Fall 2011, and Winter 2012 issues of *ASPIRE*®, Dr. Dennis Mertz provided an overview of the fatigue limit states specified in the fifth edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] and explored their applicability to concrete structures. Since that series, there have been changes in load factors for fatigue and other changes in resistance and approach, which are summarized in this article.

It may seem odd that fatigue is being discussed here—isn't that only a problem for steel structures? Although more attention is paid to fatigue for steel structures, concrete structures are not exempt. A review of Section 5 of the ninth edition of the *AASHTO LRFD Bridge Design Specifications*[2] finds various fatigue requirements for concrete structures.

Specification Requirements

In Article 5.5.1.1, Limit-State Applicability, the AASHTO LRFD specifications states, "Structural components shall be proportioned to satisfy the requirements of the service, fatigue, strength, and extreme event limit states at all stages during the life of the structure." Article 5.6.1 reiterates certain important assumptions for concrete behavior at the service and fatigue limit states. Article 5.9.1 specifically lists the fatigue limit state as one of the required limit states that shall be satisfied for prestressed concrete component design.

Article 5.5.3, Fatigue Limit State, defines the fatigue requirements as summarized and explained in the following:

(1) Concrete decks in multigirder bridges are exempt, as are concrete box culverts. Note that slabs in other structure types, such as concrete segmental box girders, are not covered by this exemption.
Explanation: Stresses in reinforced concrete decks and box culverts have been measured and consistently found to be low. They are far below the threshold limits and are considered to have infinite fatigue life.

(2) Where a reinforced concrete section is in compression under unfactored permanent loads and prestress, fatigue must only be considered if the tensile stress in the reinforcement under the Fatigue I load combination is greater than this permanent compression.
Explanation: Fatigue can only occur if steel is in a state of net tension. In regions where the permanent loads produce compression and live-load stresses are not sufficient to cause net tension, fatigue of steel reinforcement cannot occur. The live-load stress is taken as that produced by the Fatigue I load combination. This load combination is representative of the stress ranges, and therefore peak tensile live-load stresses, from an infrequent maximum vehicle loading. If this infrequent loading can cause net tension, fatigue must be considered, and the full stress range from the Fatigue I load combination must be used for design.

(3) Prestressed concrete components designed to meet the Service III limit state tension stress limits do not need to be checked for fatigue.
Explanation: Fatigue is checked for a single lane loaded with a modified live-load distribution factor removing the inherent 1.2 multiple presence factor in the LRFD empirical equations, impact of 15% (LRFD Table 3.6.2.1-1), and a different rear-axle spacing for the design vehicle. This results in considerably less live load than the Service III loads. The range of stress produced in the reinforcement is simply the range of concrete stress times the modular ratio and is less than the fatigue resistance of prestressing steel. This holds true only if sections are designed to be uncracked at service loads; that is, the components meet the Service III requirements. The assumption of an uncracked section does not imply that a prestressed concrete section will never crack. In fact, under certain heavy loads, it is likely that small flexural tension cracks will form but that after the passage of the load, those cracks will close. However, subsequent heavy loads that produce any tension will cause the cracks to reopen. Prevention of strand fatigue is a beneficial by-product of the LRFD requirements to design sections to be uncracked under routine service loads. This helps ensure that a section is sufficiently compressed so that only a limited number of stresses in exceedance of the tensile stress limits may occur, and that fatigue failure of high-strength strands does not occur.

(4) Whenever a concrete component is evaluated for fatigue, the Fatigue I factored stress range, $\gamma\Delta f$, must be less than or equal to the constant-amplitude fatigue threshold, $(\Delta F)_{TH}$, which is dependent on the type and configuration of reinforcement materials, and other properties:

$$\gamma(\Delta f) \le (\Delta F)_{TN} \quad \text{LRFD Eq. (5.5.3.1-1)}$$

Explanation: As mentioned previously, concrete is checked at the Fatigue I limit state. This is a check of maximum stress range, and these stresses are compared with the constant-amplitude fatigue threshold—the range of stress at which a steel element is expected to have infinite life.

(5) For prestressed concrete bridges other than segmentally constructed bridges, the compressive stress in concrete due to the Fatigue I load combination and one-half the sum of effective prestress (after losses) and permanent loads shall not exceed $0.40f'_c$, where f'_c is the design concrete compressive strength.
Explanation: This check limits the magnitude of cyclic compressive stress in the concrete to ensure integrity of the section under repeated compression cycles.

(6) Stresses shall be computed on a cracked section basis when the sum of unfactored permanent load stresses, stresses from effective prestress, and the tension from the Fatigue I load combination, is tensile and exceeds $0.095\sqrt{f'_c}$.
Explanation: When the computed tensile stresses on an uncracked section exceed the limit shown, the section is assumed to crack. Stresses are then computed based on an elastic cracked section. Reinforced concrete components like slab bridges or pier caps are examples in this category.

For the constant-amplitude fatigue resistance of reinforcing bars and welded-wire reinforcement, Article 5.5.3.2 includes updated resistance values that supersede those found in part 2 (Fall 2011 issue of *ASPIRE*) of Mertz's article series. These updated resistance provisions are the result of recommendations from the Transportation Research Board's second Strategic Highway Research Program Report, *Bridges for Service Life Beyond 100 Years: Service Limit State Design.*[3] The adjustment of the fatigue resistance was to achieve levels of reliability for reinforced concrete structures that are consistent with the reliability of fatigue calculations for steel structures. The resistance equation was updated for reinforcing bars and welded-wire reinforcement to achieve this consistent reliability across a family of materials. It was determined that the equations referenced in Mertz's 2011–2012 *ASPIRE* articles were overly conservative, and a more favorable resistance has been included in the AASHTO LRFD specifications since the eighth edition.

Article 5.5.3.3 provides fatigue limits for prestressing steel, Article 5.5.3.4 includes limits on welded and mechanical splices of reinforcement, Article 5.6.1 states various important assumptions that may be used for service and fatigue limit state checks, and Article 5.9.1.4 reinforces the need to check fatigue in sections where cracking is permitted under service loads.

Summary of Fatigue Design for Concrete Bridges

The following summarizes the AASHTO LRFD specifications' considerations for fatigue design:

- Prestressed concrete components designed to meet the Service III limit state requirements do not require a fatigue check.
- Concrete decks in multigirder bridges and concrete box culverts do not require a fatigue check.
- Slabs in concrete segmental box girders must be checked for fatigue.
- Reinforced concrete structures, such as slab bridges that span longitudinally, pier caps, and footings, need to be checked for fatigue. These structures commonly have low stress ranges, but there is no blanket exemption because these components are likely to be cracked in service.
- For all concrete components subjected to fatigue, the check is performed at the Fatigue I limit state and the resistance values are provided in Section 5 of the AASHTO LRFD specifications.

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A State-of-the-Art Prestressed Concrete Facility Designed with Sustainability in Mind

by Rob Holland and Blake Johnson, Knife River Prestress

Knife River Prestress recently constructed a new prestressed concrete plant near Spokane, Wash., to replace its 65-year-old outdoor facility. The state-of the-art facility opened in August 2023, incorporating lean manufacturing, automation, and a focus on sustainability. All 57,000 yd^3 of aggregates used in the construction of the facility were sourced on site, cutting down on the need to transport materials.

With 45 total acres, including 4 acres under roof, the facility has room to expand its operations as the demand for prefabricated concrete structures continues to grow. The site's concrete batch plant uses dual mixers to produce up to 100 yd^3 per hour. Once batched, an automated concrete-delivery system mounted on electric rail delivers the concrete to remote-controlled pour buckets in each of the facility's three production bays. This process reduces waste, improves casting quality, and significantly lowers the production team's exposure to risk.

Sustainability was a key consideration in the plant's design. The use of diesel engines is reduced by using electric-powered overhead cranes, forklifts, and the concrete-delivery system. The closed-loop hydronic heating system, as compared to a "once-through" steam system, maximizes efficiency for concrete curing by reducing the amount of reheat required. The recycled process-water system reduces fresh water use by half compared with the consumption if recycling were not used. The roof is solar-panel ready, and panels may be added in the future. Lean manufacturing principles such as process mapping, visual operating procedures, kitting parts, and internal audits are incorporated throughout the facility to minimize waste—both material and time.

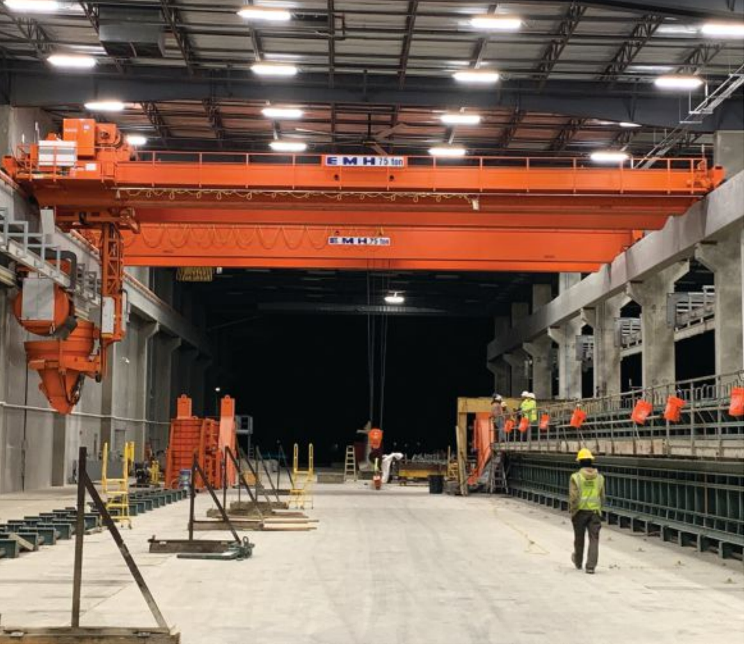
The plant is pursuing certification from the Concrete Sustainability Council, which would make it the first CSC-certified prestressed concrete facility in North America.

The plant contains twin casting beds for casting girders up to 250 ft in length or multiple shorter girders in line. It also has additional assets to produce up to 10,000 ft^2 of panels and 3600 ft^2 of hollow-core per day. Extra floor space is also available for casting one-off items such as wingwalls, footings, or other precast concrete components. The girder beds are rated for 7 million lb of pretensioning capacity, and overhead bridge cranes are sized to handle products weighing up to 300,000 lb. Girder heights up to 12 ft tall can be accommodated with the crane-mounted pour buckets. Extra space is available at the end of each bay for finishing activities, which could include secondary pours for end diaphragms and curbs on girders. This space is still under roof, with access to overhead bridge cranes and supplementary heat for efficient curing year-round. The beds are designed for quick changeovers to different bridge products, from slabs to I-girders and deck bulb tees. The two beds are expected to help service the region for the next 65 years.

Each girder bed foundation is up to 7 ft deep and composed of more than 1200 yd^3 of 8000-psi concrete, multiple drilled shafts, and post-tensioning at the end segments. With this foundation, the girder beds can accommodate up to one hundred sixty 0.6-in.-diameter strands, including up to 10 top strands. All strands are gang pulled, and girders with harped strands can also be fabricated. Also, 300-ksi strands and 0.7-in.-diameter strands can be accommodated.

The plant embodies Knife River's core values of safety, quality, environmental stewardship, and investment in people. The production of prestressed concrete components has traditionally involved large quantities of outdoor labor. This facility brings many processes indoors and uses automation to reduce hazards. An open-office floor plan and shared spaces foster communication among frontline workers and leadership, part of the "people-first" culture.

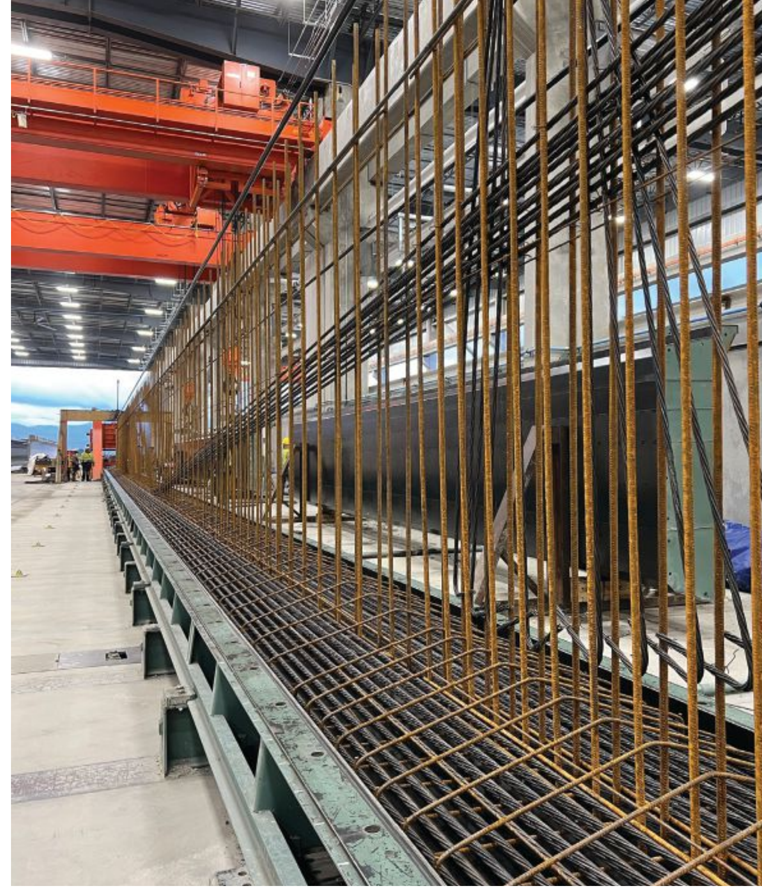
Knife River believes prestressed concrete enables sustainable construction, and this plant allows them to "walk the talk," by promoting sustainable construction, reducing waste, and decreasing transportation costs. The operation has capacity to supply major projects throughout the Northwest while leading the industry in technology, working conditions, and environmental responsibility.



An automated concrete-delivery system mounted on electric rail delivers concrete to remote-controlled pour buckets in each of the facility's three production bays.

This new facility incorporates state-of-the-art technology and will allow Knife River to continue providing high-quality solutions for decades to come. It stands as a model for how to build both a facility and a culture focused on people, community, and the environment.

Rob Holland is process manager and Blake Johnson is commercial director for Knife River Prestress in Newman Lake, Wash.



Girders up to 250 ft in length, including girders with harped strands, can be fabricated at the new facility.

Raising the Reinforcing Bar: Introducing Textured Epoxy Coating

Textured epoxy coating has the potential to significantly improve bridge life spans

by Dr. Jeffrey David Rogozinski and Anthony Del Percio, Sherwin-Williams Protective & Marine

A new approach to coating steel reinforcing bar has the potential to change a core aspect of concrete bridge construction. Known as textured epoxy coating (TEC), this novel technology is the subject of a newly approved specification: ASTM A1124, *Standard Specification for Textured Epoxy-Coated Steel Reinforcing Bars*.[1] The standard covers surface preparation, material application, coating thickness, and testing, among other requirements. As a secondary coating, TEC provides added protection for epoxy-coated reinforcing bar (ECR), commonly referred to as "green bar," which is the industry's leading corrosion-protection solution.

The application of TEC to reinforcing steel bars is a two-step, but nearly simultaneous, process in which bars pass through two powdered-coating application steps in a row. Uncoated bars are first blasted to remove surface contamination. Then the bars are heated before passing through the ECR application booth. There, a powdered fusion-bonded epoxy coating is sprayed onto the heated bar and immediately melts into a liquid coating that flows over every surface. The heated bar then moves through the TEC application booth, where a high-performance, textured fusion-bonded epoxy coating is sprayed over the first coating layer. As this textured powder melts and flows over the bar surface, it covalently bonds with the ECR layer, creating a monolithic coating despite the application taking place in two steps. The thickness and roughness of the applied coating material will vary depending on the parameters of the reinforcing bar usage as defined in the ASTM A1124 specification.[1]

In corrosion resistance, bond strength, and damage tolerance, TEC offers significant improvements over both ECR and uncoated reinforcing bar (black bar).[2–6] While various factors influence a bridge's life span, TEC has the potential to extend asset life, making a strong case for its cost-effective use to benefit taxpayer-funded infrastructure projects. Preventing structural deterioration can delay the need for bridge replacement or extend required maintenance cycles, often resulting in substantial cost savings and avoiding the environmental impacts of construction and maintenance projects. TEC also offers sustainability advantages because it is made with repurposed, "upcycled" materials that might otherwise go to a landfill. In addition, TEC may enable the use of alternative cementitious technologies, as concrete ingredients to date have typically been limited to those that do not corrode uncoated reinforcement.

Globally, most reinforcing bars remain uncoated, owing to the expense and various drawbacks associated with ECR (these drawbacks are discussed later). Applied to a green bar, TEC adds an extra layer of protection to ECR and increases an asset's durability. Recent research shows that TEC presents an opportunity to harness the benefits of coating reinforcing bar, while enhancing outcomes for concrete projects.[2–6]

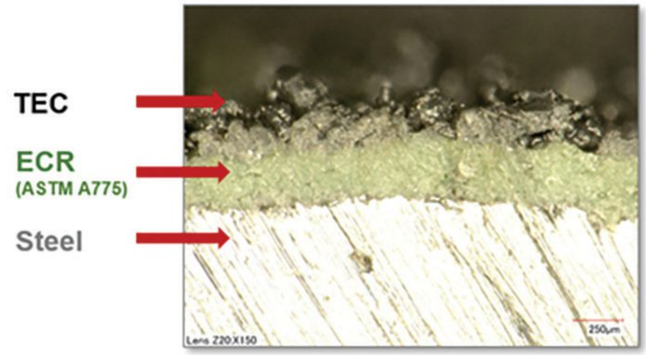
Improving Corrosion Resistance

The interface of reinforcing bar to concrete is critical. While ECR offers a layer of corrosion protection for the uncoated bar, its smooth surface reduces the bond interaction between the concrete and the steel reinforcement.

When a TEC is applied along with an epoxy coating, there are multiple benefits. The two layers cure together and covalently bond, creating a

Textured epoxy-coated reinforcing bar (left) and uncoated reinforcing bar (right) have comparable rib texture and bond strength. All Photos: The Sherwin-Williams Company.

Textured epoxy coating applied to reinforcing bar adds an extra layer of protection and durability to assets by improving bond strength, corrosion resistance, and damage tolerance.



This closeup view of a reinforcing steel bar cross section shows how the textured epoxy coating (TEC) and the epoxy-coated reinforcement (ECR) covalently bond to form a monolithic coating from the substrate to the air interface with a stratification of properties. The base ECR layer provides corrosion protection to the steel substrate, while the top TEC layer delivers damage resistance and enhanced concrete-bonding characteristics.

monolithic coating from the substrate to the air interface. The results are an enhanced barrier and durability properties that further improve the corrosion resistance and damage tolerance of the reinforcement. The resulting texture also reestablishes the desired bond interaction between the steel and concrete.

Bond Strength Comparison

In use since the 1970s, ECR provides long-term corrosion protection, creating a proven barrier to oxygen, electrolytes, and other deleterious substances. Yet, there are some well-documented drawbacks associated with the use of ECR. For example, the powdered fusion-bonded epoxy coating cures to a hard surface that smooths out the ribs on reinforcing bars. This smoother surface reduces the rough surface profile and reduces the bond strength with concrete by approximately 15% as compared with that of uncoated black bar.[7] To compensate, engineers must use longer development and splice lengths than what is required with black bar. On a project, this approach can add significant cost, weight, and reinforcement congestion.

Compared with ECR, black bar offers better interaction and bond with concrete. However, it is susceptible to corrosion. Corrosion-resistant TEC establishes a lasting connection with concrete with bond strength that is similar to that of black bar, allowing comparable reinforcing bar splice and development lengths. TEC, which adds texture, not only enhances the interaction with the concrete but also increases the available surface area for bonding by introducing texture through proprietary resin technology. This re-creates deformations on the reinforcing bar surface, establishing a more pronounced anchor profile on the reinforcing bar.

Research on Bond Strength

Sherwin-Williams has been involved in the development of TEC for 15 years. Since 2019, they have tested the technology in concert with studies at research universities. While testing will continue through 2027, available results paint a clear picture.[2–6]

At the University of Minnesota, researchers performed tests of reinforced concrete lap splice beams using uncoated reinforcing bars, ECR, and TEC bars. The results of this research have not yet been published, but the following preliminary observations are offered. In ECR tests, the concrete separated cleanly from the coated reinforcing bar, indicating weaker adhesion. Reinforcing bar coated with TEC showed the best adhesion—better than uncoated black bar—with researchers needing to chisel off concrete to inspect the reinforcing bars underneath.

In beam-end experiments at the University of Kansas,[2] the reinforcing bars with TEC showed approximately 20% better bond strength than ECR. The splice strength of TEC bars also averaged 1.05 times that of uncoated bars, indicating that TEC bars have a comparable, if not better, bond than uncoated bars.

According to a Wisconsin Department of Transportation study,[3] TEC can reduce reinforcing bar splice lengths by 10% and 60%, compared with black bar and ECR, respectively. In a related study at Clemson University,[4] researchers compared flexural cracking (vertical cracks formed from tension and bending). Concrete with ECR resulted in fewer but larger cracks when compared with TEC bars, which had cracks that were smaller and finer.

At the University of Illinois,[5] ASTM A944-10[8] microcracking testing of concrete specimens with the TEC bars showed that cracks were about half as wide as those with ECR, with a total crack area that was 33% smaller. Flexural tests demonstrated TEC reinforcing bar, compared with ECR, had substantially better slip resistance of up to 74%. On the heels of the university's testing, the Illinois Department of Transportation continues to broaden the research for implementation of TEC as a promising innovation for bridge construction projects.[6]

Damage Tolerance

TEC offers enhanced durability and chip resistance compared with ECR, contributing to better corrosion resistance by minimizing areas where steel might be exposed before being covered in concrete.

In unpublished damage-tolerance tests performed by Sherwin-Williams, in which technicians dropped reinforcing bars on gravel to mimic potential impacts at a construction site, ECR was more easily damaged than reinforcing bar coated with the TEC. The matrix of the TEC material is a molecular-level composite that provides more durability than the coating on an ECR.

If TEC is damaged, repairs can be performed as specified in the ASTM A775 specification,[9] as well as ASTM A1124.[1] Field repair is prescribed in the specification and involves using an approved spray-applied or brush-and-roll-applied liquid touchup material.

Concrete Evidence

The new ASTM A1124 specification uses several approved test methods to assess the corrosion resistance, bond strength, and damage tolerance of different coatings. These standards set the stage for establishing and documenting acceptance criteria that can be applied when specifying TEC bars. To create this standard, independent laboratories conducted the following tests on both TEC and alternative materials:

- **Relative bond strength:** ASTM A944[8] bond-strength testing, as well as lap-splice testing
- **Damage tolerance:** Durability testing covering impact resistance (ASTM G14[10]), chipping resistance (ASTM D3170[11]), abrasion resistance (ASTM D4060[12]), and flexibility (ASTM A775 A1.3.5[9])
- **Corrosion resistance:** ASTM A775[9] testing, including tests for chemical resistance (ASTM G20[13]), cathodic disbonding (ASTM G8[14]), salt spray resistance (ASTM B117[15]), and chloride permeability (ASTM A775 A1.3.4[9])

Concrete Plan

With ASTM A1124 in place, further independent testing and product evaluations by the International Code Council will evaluate TEC effectiveness and help with adoption by the American Association of State Highway and Transportation Officials. State departments of transportation can gain confidence in the material and follow suit as leading oranizations adopt guidance on the use of TEC technology for bridges. In addition, independent testing could eventually lead to code adoption in the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*.[7] The concrete industry will then have the data and support to adopt TEC and realize the increased bond strength, damage tolerance, and corrosion resistance—not to mention the reduced costs and longer asset lives—the coatings offer as compared with ECR and black bar.

To demonstrate this technology, Sherwin-Williams is constructing their headquarters in Cleveland, Ohio, using TEC reinforcing bars. It will be the first commercial building to use TEC bars.

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CBEI: Vision and Progress

by Graham Bettis, Reggie Holt, Dr. Oguzhan Bayrak, and Gregory Hunsicker, Concrete Bridge Engineering Institute

During the conceptualization of the Concrete Bridge Engineering Institute (CBEI), there were several recurring themes: continuity of concrete bridge expertise and sustained development of new subject matter experts, continuous improvement of the quality of construction, minimizing potential for construction issues, and bolstering expertise, especially in highly technical and specialized operations. Training was identified as a significant component of CBEI; however, serving as a hub for dialogue and discussion on the design and construction of concrete bridges was seen as paramount to the institute's mission. Recognition by many industry stakeholders of these and other needs led to the genesis of CBEI.

In 2015, the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee T-10, Concrete Design, identified the following characteristics of concrete bridges as part of its vision for these structures:

- Resilient, durable, sustainable, and uniformly safe over their life cycles
- Easily maintainable
- Cost-effective
- Constructed with minimal disruption to the traveling public
- Adaptable to functionality and climate change
- Proportioned and detailed for multihazards, as appropriate
- Designed, proportioned, detailed, constructed, inspected, and maintained by a knowledgeable workforce

Some of the strategies that were identified to realize this vision included items that ultimately spawned the idea for a concrete bridge center. For example, one of the strategies recognized the benefits of having a repository of information for concrete bridges.

A few years later, these concepts went from ideas to the first steps of implementation at an AASHTO Committee on Bridges and Structures meeting in Montgomery, Ala., where the theory of a national center serving concrete bridges was discussed. The AASHTO Technical Committees on Concrete Design, Construction, and Bridge Preservation played important roles in bringing the concept to fruition. Their support and collaboration remain invaluable and integral to the program.

Soon after the initial discussions, a portion of the Interstate 35/U.S. Route 183 segmental bridge connector in Austin, Tex., was decommissioned due to a change in alignment. Recognizing that the bridge was an excellent concrete sample, the Texas Department of Transportation salvaged portions of the structure and transported them to the CBEI site (**Fig. 1**). These specimens are among the first components in the Concrete Bridge Component Collection.

Figure 1. A component from a trapezoidal box-girder segment salvaged from the decommissioned Interstate 35/U.S. Route 183 direct connector is one of the first specimens in the Concrete Bridge Component Collection at the Concrete Bridge Engineering Institute. Photo: Concrete Bridge Engineering Institute.

Development of the Three Pillars

One of the first goals identified for CBEI was the creation of a post-tensioning (PT) laboratory. Initial work in this area started through a Broad Agency Announcement. Further discussions led to the concept of the PT Laboratory, followed by the development of the three pillars. Many potential topics were discussed and may be added in the future, but three topics rose to the top of the list as important areas of focus: post-tensioning, bridge deck construction inspection, and concrete materials for bridges. (See the Fall 2022 issue of *ASPIRE*®.)

Much of the initial work for CBEI was in the area of post-tensioning. An international benchmarking study on PT technology, in particular electrically isolated tendons (EIT), led to further brainstorming and discussion.[1] As part of a Federal Highway Administration (FHWA) Global Benchmarking Program study, a group from the United States visited projects in Switzerland and Italy and met with international experts to share best practices and discuss the challenges they faced. (See the FHWA article in the Spring 2021 issue of *ASPIRE*.) During the exchange, Dr. Max Meyer shared the hands-on approach his company had taken to help develop and train personnel using full-scale components at the VSL PT Academy in Thailand. Incorporating aspects of that program seemed like a natural next step for developing a PT laboratory in the United States, as well as the other pillars of CBEI's program, concrete materials and bridge deck construction inspection. (See the CBEI article in the Summer 2022 issue of *ASPIRE*.) Participants in the benchmarking program study from the United States included Graham Bettis, Dr. Michael Brown, Gregg Freeby, Dr. Zachary Haber, Reggie Holt, Miroslav Vejvoda, and Kevin Western (**Fig. 2**).

As a result of the study, international collaboration continues and brings value by advancing the state of practice in post-tensioning as well as other concrete bridge-related concerns. Since that study, there have been several meetings and initiatives. A PT Technology Exchange meeting was held in conjunction with the American Segmental Bridge Institute (ASBI) Convention in Austin, Tex., in 2022. Participants included stakeholders from around the world, such as bridge owners and transportation agency representatives, who shared their experiences with post-tensioning and advancements in the industry. FHWA and CBEI staff have also been actively engaged, along with U.S. industry partners, in international efforts with *fib* (International Federation for Structural Concrete), including participation in *fib* Task Group 5.14, Durability of Post-Tensioning Tendons. This task group, which includes CBEI staff member Gregory Hunsicker, is updating the widely referenced 2005 *fib* Bulletin 33[2] and merging it with the FHWA technical report *Methodology for Risk Assessment of Post-Tensioning Tendons*.[3]

The focus on best practices for bridge deck construction to ensure long-term performance was identified as one of the three pillars. The long-term performance of bridge decks is a function of proper initial construction, and this topic sparks a lot of interest, given the multitude of bridge decks in the United States. Nearly all departments of transportation are engaged with the construction and maintenance of bridge decks on a large scale. A focus on a training program for construction inspection of bridge decks was identified as one of the important initial programs.

The Concrete Materials for Bridges Program serves as the third pillar. The importance of proper concrete mixture proportions was recognized, as well as the need for broader understanding of the "whats" and "whys." While structural engineers tend to focus on the structure, rather than materials, a broad understanding of concrete materials can be very helpful. Ongoing changes in the industry also present an opportunity and need to increase the knowledge base within the industry. When using concrete materials in the modern environment, stakeholders must consider principles of sustainability, challenges with material availability, and new advances in materials.

Figure 2. Participants in the Global Benchmarking Program trip in Switzerland. Photo: Federal Highway Administration.

Much of the training in the industry has been solely web based or classroom based. However, the use of in-person training outside of the production environment represents a unique and valuable experience. The ability to illustrate concepts, defects, and best practices in a hands-on manner can accelerate and strengthen the learning process, especially for technically demanding operations such as post-tensioning. Whether the goal is to explore outdoor concrete durability exposure sites (see the Winter 2023 issue of *ASPIRE*) or gain knowledge about mixing, testing, and injecting grout, a hands-on component makes a huge difference in the educational experience. When learning about a concrete deck, working through a dry run and seeing issues like insufficient clear cover in person is a good exercise.

Given the national scope of CBEI, it is important that the three pillars incorporate regional perspectives about construction methods, detailing, defects, and the environment.

It is also critical that robust training and certification programs be available for specific applications. As seen in examples involving other types of structures, such as welding in steel bridges, detailed and stringent training and certification programs can be developed to align workmanship requirements with the importance of the application. Training and certification programs for the various roles are important not only for contractors but also for engineers and inspectors.

Progress and Schedule

We are excited to see the progress at CBEI. The concrete bridge component collection already includes several impressive items and will continue to grow. The kickoff meeting for the Transportation Pooled Fund (TPF) for CBEI was held in mid-June 2023. Several participating state transportation agencies and the FHWA are shaping the future of CBEI. Since the June kickoff for the TPF, the Florida Department of Transportation and Tennessee Department of Transportation have joined, and the fund has exceeded its initial funding target. One of the most exciting developments is that the pilot presentation of the Concrete Materials for Bridges Program is ready and scheduled for January 3–4, 2024.

Meanwhile, progress continues with our other programs. Working with industry partners such as ASBI, PCI, the Post-Tensioning Institute (PTI), and the National Concrete Bridge Council

(NCBC) has been critical. The input and collaboration of these organizations and their members is key to establishing best practices and training personnel. We are all working toward the same goals and see value in the partnerships. The recent approval and adoption of the PTI/ASBI M50.3-19[4] and PTI M55.1-19[5] specifications in the next editions of the *AASHTO LRFD Bridge Design Specifications*[6] and *AASHTO LRFD Bridge Construction Specifications*[7] represent a collaborative effort among FHWA, AASHTO Concrete Technical Committee, AASHTO Construction Technical Committee, ASBI, and PTI, and supported by CBEI.

Through CBEI, a significant effort is being made to collect and reinforce best practices. However, there is also room to advance new and under-used technologies. In general, the items being considered are relatively advanced in their technology-readiness level, and we look forward to CBEI helping to shape the best practices and develop the next generation of concrete bridge experts. Thank you to our state transportation agency partners and industry partners for their support.

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Wisconsin

Leveraging data and technology to put more local bridge projects into production

by Aaron Bonk, Wisconsin Department of Transportation Bureau of Structures

Thinking about locally owned bridges in Wisconsin can conjure up a variety of images, from small timber bridges blending in with the countryside or older stone arches spanning small creeks to concrete T-beam bridges, and any number of other structure types in an array of settings. While all these structures are unique in some way, they can also have much in common.

Over the past several years, the Wisconsin Department of Transportation (WisDOT) Bureau of Structures (BOS) has focused on the similarities among smaller structures to develop a Standard Bridge Design Tool (SBDT). After successful pilot testing, the SBDT is now being widely used. Its implementation comes at arguably the perfect time given the historic funding opportunities of the Bipartisan Infrastructure Law.

The SBDT provides a catalog of solutions for single-span, cast-in-place concrete slab bridges, which are found throughout the local program and are the types most used for replacements. Designers and planners can download these standard plans to streamline the work, allowing the local program in turn to preserve resources to maximize overall output.

Having such a tool has been an ongoing consideration at WisDOT, and it became a greater priority as the Bipartisan Infrastructure Law navigated the federal legislative process. Anticipating this opportunity, WisDOT management asked engineering staff to explore options to help maximize investment in local bridges. The focus made sense, considering there are almost 9000 such bridges statewide, making up roughly 63% of the total bridge inventory. In addition, local bridges are more likely to carry load postings and poor condition ratings compared with their counterparts in the state system (**Table 1**).

As an organization, WisDOT has shifted to a more data-driven, condition-based asset management philosophy over the last decade. This shift helped set the stage for SBDT development. The WisDOT BOS has long been a supporter of making the right maintenance and replacement choices at the right time. This approach has historically included recommending proper cycles of routine maintenance; completing bridge rehabilitations as close as possible to the time when they are needed, with the understanding that other work in the project vicinity may shift timelines slightly; optimizing material choices given project-specific criteria; and making the appropriate structure-type selection when replacement is necessary based not only on up-front construction costs but also the associated life-cycle maintenance costs. Each of these decisions can extend the life of the structures and effective stewardship of taxpayer dollars. For more on WisDOT's asset management philosophy and the development of our process, see the Concrete Bridge Stewardship article on page 28 of this issue of *ASPIRE®*.

With Bipartisan Infrastructure Law funds in place and WisDOT ready to funnel significant

In Racine County, the 58th Road Bridge over the west branch of Root River Canal served as a pilot project for implementation of the Wisconsin Department of Transportation's Standard Bridge Design Tool. All Figures and Photos: Wisconsin Department of Transportation.

Table 1. Comparison of load-posted bridges in the Wisconsin local and state inventories			
	Total bridges	Load-posted bridges	Percentage of bridges with postings
Local System	8957	460	5.1%
State System	5363	16	0.3%

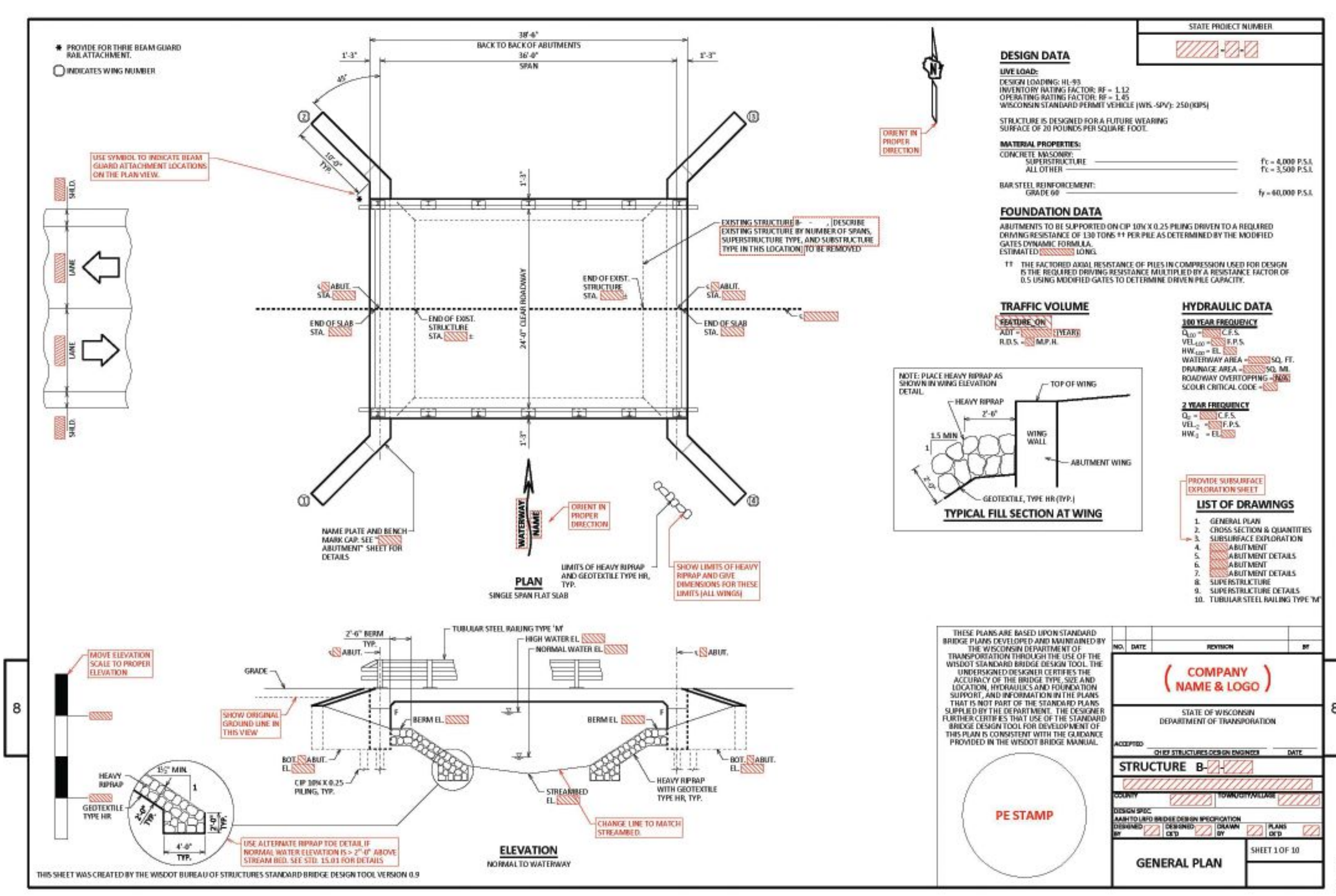
funding to the local system, BOS recommended developing standardized bridge plans for use on locally owned bridges. Concrete bridges, in one form or another, make up approximately 70% of the Wisconsin bridge inventory. In most situations, concrete is the structural material of choice for Wisconsin bridges because it is durable and can resist deterioration due to deicing agents, which are used throughout the winter months. When reviewing local bridge-replacement projects completed in the last two decades, BOS found that cast-in-place concrete slab bridges were the most common structure type selected, used in almost 50% of cases. Given the data, standardizing the design of one of the state's bread-and-butter bridge types—single-span concrete slab bridges—made all the sense in the world.

WisDOT BOS strategically set out to create a tool that would not only produce standard bridge plan sets, but also be able to dynamically change with shifts in design codes, design policy adjustments, and drafting standards. Approximately 20 years ago, WisDOT had a catalog of standard bridge plans, but they quickly became obsolete as the process of updating each individual plan set whenever something changed was incredibly resource intensive. The current version of standard bridge plans that WisDOT developed uses C# coding and the AutoCAD ObjectARX programming environment to connect the design model to Civil 3D, which creates the plans. The coding effectively allows WisDOT to adjust one set of inputs that can be applied across different bridge configuration parameters, as opposed to editing all options individually.

Once the strategic vision for the coding and programming of the SBDT was set, BOS next determined how the designers would interface with the tool to receive the designs and plans and efficiently work with them. The SBDT program uses WisDOT BOS proprietary slab span design and rating software and WisDOT standard details to create the standardized bridge plans. These plans come in the form of PDF and Civil 3D files, which are downloaded by the designer from the BOS website and the program's user interface. To obtain the appropriate standardized design and plans from the website, the project designer completes the preliminary structure design by first defining the type, size, and location of the bridge and then determining seven input parameters (span length, bridge clear width, skew, railing/parapet type, minimum abutment height, paving notch, piling type). The SBDT programming was set up to efficiently create over 12,000 combinations of bridge designs and plans from the input parameters to fit a wide array of local program bridge site constraints. For further information about the SBDT parameters and an example of the standard plans, visit https://wisconsindot.gov/Pages/doing-bus/local-gov/lpm/lp-standarized-bridge-plan-pilot.aspx.

As a part of the SBDT development, WisDOT needed to address the legal aspect of shared liability for completion of the final bid documents and plans. Attorneys for WisDOT

Standardized plans that are provided to the designer from the tool's website user interface. The red boxes indicate items that the designer must update



developed an agreement form that all consultant engineering firms must sign to be eligible to take on the design work for projects involving the tool. The agreement states that WisDOT takes on the liability for the accurate design, analysis, ratings, and plan assembly, while the consultant firm that stamps the final plans takes on the liability for the proper sizing of the bridge, use of the tool, and updating the plan items requiring modification when received from the tool's website.

WisDOT BOS's development of the SBDT started in 2020 and was finalized for pilot-project use in 2021. Ten pilot projects representing the five regions of Wisconsin were identified, with construction slated for 2022 and 2023. As of publication of this article, all the pilot projects were designed, bid, let, and constructed with no significant issues identified within the process, designs, or plans. For these 10 pilot projects, savings of approximately 33% of average historical costs were seen in the design phase. Moving forward, WisDOT BOS has identified an additional 134 candidates for bridge-replacement projects scheduled for construction between 2023 and 2027 that fit the parameters of the SBDT. It is anticipated that the cost savings in the design phase for these projects will be close to 67% of typical projects because designers will become more familiar with the tool. All savings in the design phase will help WisDOT invest more money in the local program and replace additional bridges.

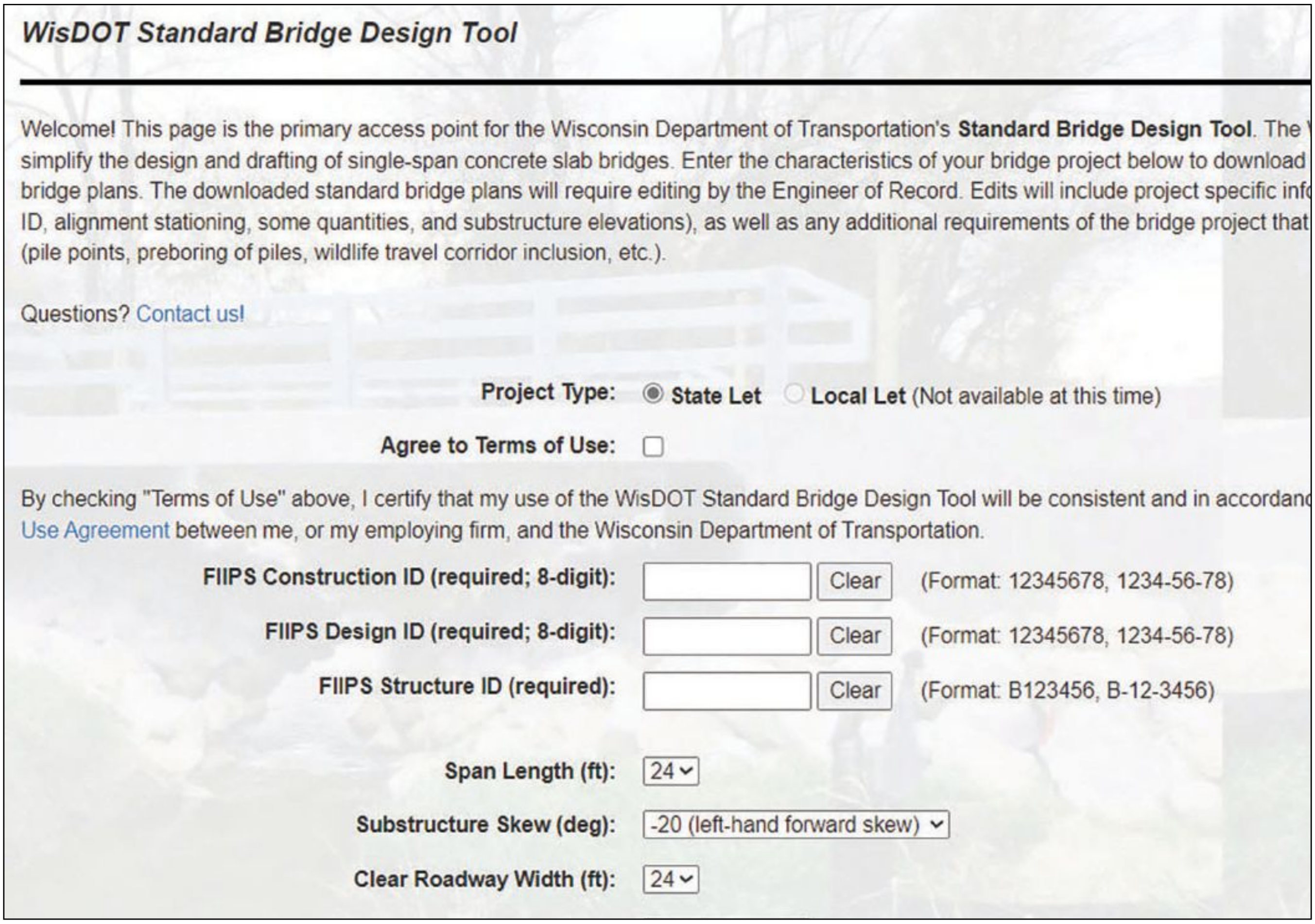
Wisconsin has always sought to allocate program resources efficiently, and the creation of a standardized bridge program for single-span, cast-in-place concrete slab bridges is another way of accomplishing this objective. WisDOT is already seeing the benefits of this structure type on the local system as well as the benefits of having a consistent delivery process for the design of these structures.

For more information about Wisconsin's bridges, visit https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/default.aspx. A

Single-span cast-in-place concrete slab bridges were designed and constructed throughout Wisconsin using standardized plans under a new pilot program. The inset map shows the locations of the 10 pilot projects, which were spread across the five regions of the state.

Aaron Bonk is the chief structures design engineer for the Wisconsin Department of Transportation Bureau of Structures, in Madison, Wis.

Part of the website user interface showing inputs required by the designer to receive standard bridge plans output.



Operational Strategies for Truck Platoon Permits—Effective Use of Prestressed Concrete Girders

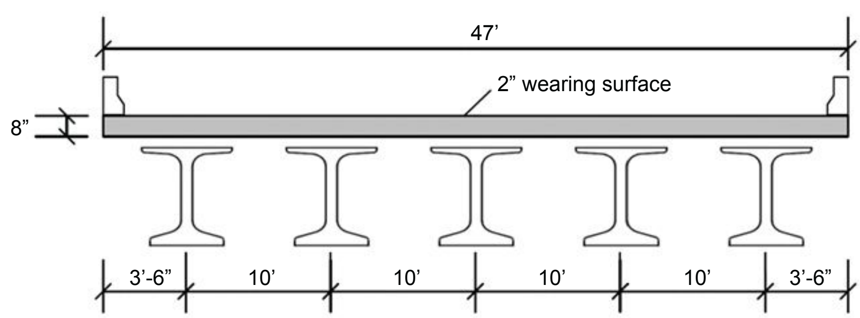
by Dr. Jay Puckett and Dr. Joshua Steelman, University of Nebraska

We recently studied effective strategies for truck platoon operations for strength, service, and fatigue limit states. (For more information about truck platoons and their effect on bridges, see the FHWA article in the Summer 2019 issue of *ASPIRE®*.) The premise of this work is that some trucks are—or will become—"smart," with the ability to drive long distances autonomously. With such intelligence, these trucks can likely report their axle weights and spacings as well as control their relative headway distances. Given such controls, the traditional statistics used to calibrate live-load factors become better known. For example, the truck live-load variability is much smaller than the variabilities used for typical permitting or design. Dynamic headway controls can also position trucks to maintain safety and service performance thresholds as platoons cross bridges of varying spans along a route. Our recent studies are one of the first efforts to study truck platooning from a reliability perspective.[1,2]

If and when a new permit process that allows larger live loads than current legal loads is created, new calibration using reliability indices β that are reasonably based on current practice and bridge performance will be required. For example, the strength limit for design is typically targeted to be $\beta = 3.5$ (0.023% probability of exceeding the limit). For load rating, $\beta = 2.5$ (0.62% probability of exceeding the limit) is often used for strength. To date, limited studies have been performed on calibrating load factors for service and fatigue limit states.

To develop a platooning permit strategy, the service and fatigue limit states must be addressed to enable larger loads and minimize damage to concrete components. For prestressed concrete girder bridge design, prestressing strands are selected to limit concrete tensile stresses, with stress limits depending on the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications,*[3] the state transportation agency's standards, and/or the owner's practice. For permit ratings, some owners might limit tensile stresses to zero (bottom fibers always in compression). In contrast, others might allow $0.19\sqrt{f'_c}$, where f'_c is the design concrete compressive strength in ksi, similar to the Service III limit state in the AASHTO LRFD specifications. Performance assessment computations are complicated by various assumptions either adopted by agencies or left to the discretion of individual engineers, such as prestress loss calculation methods, use of gross or transformed section analysis, consideration or neglect of elastic gains, and live-load factor selection. Furthermore, computations for the same girders designed with different assumptions would yield different numbers of strands, which provide various resistances to cracking and potential damage due to repetitive loads from heavy platoons.

The aforementioned assumptions complicate the live-load factor calibration process for platoon permitting by affecting resistance computations. For example, should permit computations use zero or $0.19\sqrt{f'_c}$ for the tensile-stress limit?



Design Parameters
- 120-ft simple-span bridge
- Optimally design for tensile stress limit = $0.0948\sqrt{f'_c}$
- Optimal design = exact number of strands for Service III limit state
- Refined losses with elastic gain
- Design live load factor $\gamma_{LL} = 1.0$
- NU 1600 girder
- Haunch = 1 in.

Prestress Parameters
- 270 ksi low-relaxation strand
- $f_{py} = 243$ ksi

Concrete Parameters
- $f'_{c\_girder} = 8$ ksi
- $f'_{c\_deck} = 4$ ksi

Figure 1. Example prestressed concrete bridge. All Figures: University of Nebraska–Lincoln.

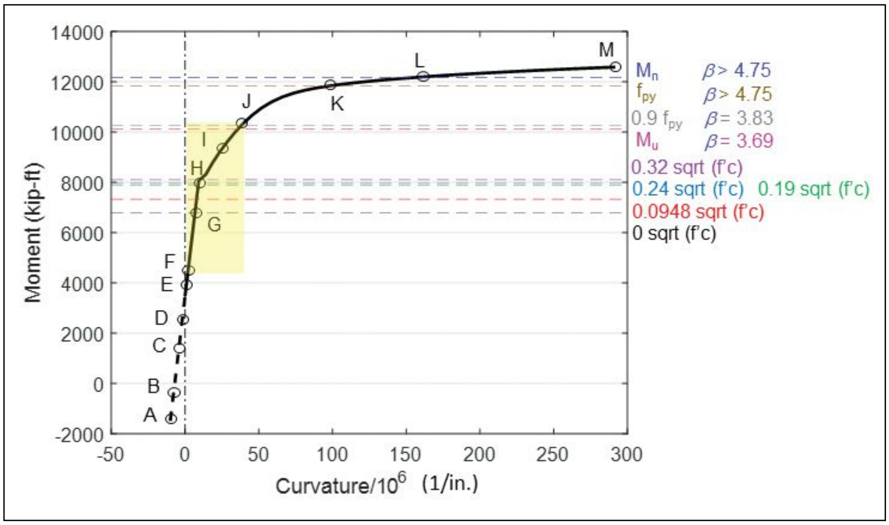


Figure 2. Moment-curvature diagram of the example prestressed concrete girder.

Should permit computations allow tensile stress up to the full modulus of rupture ($0.24\sqrt{f_c'}$) cracking strength? If so, should the average statistical value or the higher value be used for estimating cracking moment? The Service II limit state for steel girders uses an allowable stress $f_{allowable}$ of $0.95F_y$ (where F_y is the yield stress of steel) for composite sections, which anticipates permanent deformations due to partial plastification with residual stresses. Should concrete girders use similar limits, considering that recompression can still be achieved even after some degree of prestressing strand yielding?

So, the question arises: Are the traditional methods for evaluating prestressed concrete girder service performance suitable for effectively using the bridge inventory for innovative strategies such as platoons?

Basic Mechanics

When considering difficult engineering problems, it is often best to return to mechanics for understanding, or at least as a framework. Let's start with an example.

Consider the prestressed concrete girder bridge shown in **Fig. 1**. The girders were optimally designed for HL-93 loading using tensile stress limits from the AASHTO LRFD specifications' Service III limit state. **Figure 2** shows the girder moment-curvature (M-ϕ) diagram.

The M-ϕ diagram best represents the behavior of flexural components (or beam-columns) from the transfer of prestress to the strength limit. Items that influence flexural behavior, such as gross cross-section geometry, elastic gains, cracking, yielding, and tension stiffening, are all included in Fig. 2 as the diagram tracks the mechanistic behavior. This method is used in many research areas and advanced analysis in performance-based seismic design. Numerical and experimental data comparisons have demonstrated excellent agreement over various load levels. Example reliability indices are shown for the 75-year design life. The reliability index at the strength level can be confidently determined from common methods and assumptions used in bridge reliability assessment and calibration. At the Service III limit state considered for this design (noted in Fig. 1), the reliability index is an evolving topic that will be the focus of future *ASPIRE* perspectives.

In Fig. 2, the M-ϕ diagram "starts" at point A, which is at transfer of prestress, moving next to include girder self-weight. Then after the composite deck has been placed and cured, the superimposed dead load and any potential wearing surface loads are applied, and finally superimposed live load is applied (at point F).

Information presented in the yellow-shaded box in Fig. 2 includes limiting tensile-stress formulations from relevant specifications that have been used in the related research activities.[3,4] They consider various levels of permitted tension stresses such as zero tension, $0.0948\sqrt{f_c'}$, or $0.19\sqrt{f_c'}$ (which are traditional limits for various levels of environmental exposure and potential corrosion), and $0.24\sqrt{f_c'}$, which is associated with the modulus of rupture (that is, the theoretical cracking limit). The yellow box also contains information demonstrating that under increased live load (at point I), the section moves toward a high fraction of yield such as $0.9f_{py}$, which is used

Table 1. Moment-curvature diagram operational points of interest

Operational Point	
A	Transfer of prestress excluding girder self-weight (A and B occur simultaneously)
B	Transfer of prestress including girder self-weight
C	Deck is placed, not hardened, slight camber
C	Deck is hardened and slope changes to composite section
D	Composite dead load of components (DC stage II) is placed; perhaps dead load of utilities and wearing surfaces (DW) are as well; all small load effects
E	Zero curvature, only P_e/A_g stress
F	Live load is applied
G	Zero tension in bottom fiber
H	Section cracks
I	Tension increases, neutral axis rises, curvature increases, concrete behavior is nonlinear
J	Strand stress at $0.9f_{py}$, the AASHTO *Manual for Bridge Evaluation*[4] limit state per Article 6A.5.4.2.2b
K	Yield of prestressing steel in bottom layer
L	Code-based nominal moment M_n, at concrete strain ε_c of 0.003
M	Actual plastic moment M_p

Source: University of Nebraska–Lincoln.
Note: A_g = gross area of the concrete section; e = strand eccentricity; f_{py} = yield strength of prestressing strands; P = prestressing force after prestress losses.

in Article 6A.5.4.2.2b of AASHTO's *Manual for Bridge Evaluation*.[4] There is a significant range of operational resistances that might be rationally adopted to effectively use bridge inventories for platoon loading.

Conclusion

The history of taking a stress limitation approach is long, but that approach may impose unnecessary limitations on platooning operations. Thus, platoons are a prominent motivation for better understanding heavy loads on prestressed concrete girders. Perhaps a more rigorous computation approach, based on mechanics, could be used to better understand the performance of girders operating with permits that allow repeated platoon travels. This future activity should involve deterioration and fatigue modeling coupled with economic modeling that can be linked to various operational strategies associated with bridge service life.

In future articles, we hope to expand to reliability indices associated with different load levels and the target reliability indices associated with various design assumptions mentioned in this article. Platooning was the impetus for our research, but the findings will also help guide design more generally.

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Lessons from Dr. Paul Zia

by Dr. Gregory Lucier, Dr. Sami Rizkalla, and Dr. Rudolf Seracino, North Carolina State University

The passing of Dr. Paul Zia this past August has provided an occasion to reflect on the life, achievements, and lessons of this extraordinary man. Dr. Zia was 97 years old at the time of his passing, and he is survived by his wife, two children, and four grandchildren. In addition, the hundreds of students, faculty, and professional colleagues he advised and mentored over the years, including the authors of this article, remember him fondly and with gratitude. Many of us have Dr. Zia to thank for positively influencing our lives and for shaping major portions of our careers. He was recently described by a colleague as an "educator, mentor, scholar, researcher, engineer, and true gentleman."

We will briefly summarize some of the lesser-known details of Dr. Zia's fascinating biography here. More detailed accounts of his life and career are available from a variety of sources, including the Fall 2012 issue of *PCI Journal* and the October 2023 issue of *Concrete International*.[1,2] The most unique source is a nearly two-hour interview conducted in 2015 by the North Carolina State University (NCSU) Libraries, in which Dr. Zia describes his personal history and offers insightful recollections and commentary on his teaching, research, and work with industry.[3]

Born near Shanghai, China, in 1926, Paul Zung-Teh Zia was the youngest of seven children, six of whom studied engineering. By the time Paul graduated from Chiao Tung University in 1949 with a degree in engineering, Mao and the Chinese Communist Party had encircled Shanghai and were beginning to drive out the Nationalist government. Paul had been admitted to a work-study program at Florida Southern College (FSC) in the United States. As the Nationalists retreated to Taiwan, Paul was able to secure passage out of Shanghai on one of the final freighters to leave the besieged city, eventually arriving safely in Hong Kong.

After reaching Taiwan, Paul was eventually able to obtain his passport from the exiled Chinese Nationalist government's Hong Kong consulate. He then traveled to Florida, along with his future wife, Dora Yun-Qing Liu, who was enrolled in the same program. Upon arriving in the United States, Paul worked as the school janitor as part of his work-study arrangement. He reflected on this position later in life as one of his best experiences because the job taught him how things worked and how to fix things that were broken—practical skills that no doubt served him well later in his career. In due time, Paul and Dora were both accepted as master's degree students at the University of Washington (UW) in Seattle. Paul would work for Professor Bert Farquharson, who, interestingly, can be seen in a famous historical video as the last person walking off the Tacoma Narrows Bridge before its collapse in 1940.

The summer before leaving for UW, Paul's work-study arrangement at FSC had ended, so he applied for temporary work at a local employment office. Upon reviewing his qualifications, the employment office clerk suggested that he instead ask for work at Lakeland Engineering Associates (LEA), a small firm housed in the same building as the employment office. Paul landed a summer internship with the firm and continued to work for LEA while pursuing his master's degree at UW. After graduating from UW in 1953, he returned to work full time for LEA at a new subsidiary, Lakeland Engineering Associates Prestressing (LEAP). During these years, a brand-new prestressed concrete industry was created, which led directly to the founding of the Precast/Prestressed Concrete Institute (PCI). Paul was at the forefront of early prestressed concrete concepts, designs, and experiments, and he helped implement many of the first prestressed concrete building projects in Florida.

Despite being recognized as an international expert in prestressed concrete by this early stage of his career, Paul was not content with the limits of his knowledge and decided to join the University of Florida in 1955 as an instructor and PhD student. He desired to earn a PhD, to teach, to conduct research, and to "find out the answers to some interesting questions [about prestressed concrete]."[3] His

Dr. Paul Zia and a PCI Research and Development Council advisory group observe testing on punching shear in prestressed concrete beam ledges at the North Carolina State University Constructed Facilities Laboratory in 2013. All Photos: North Carolina State University.

Dr. Paul Zia and his grandchildren observe a prestressed concrete beam experiment at the North Carolina State University Constructed Facilities Laboratory in 2015.

career from this point forward is well documented, as he went on to accept a faculty position at NCSU, serve as a visiting faculty at the University of California at Berkeley with Professor T. Y. Lin, and eventually become a head of the Civil Engineering Department at NCSU. Dr. Zia's achievements in these positions, which are too numerous to list here, include hundreds of research projects, publications, and awards. He was elected in 1983 to the National Academy of Engineering, arguably the highest honor an engineer can receive, and he served as president of the American Concrete Institute (ACI) in 1989. His vision and effort were central to the creation in 1996 of the Constructed Facilities Laboratory at NCSU, an experimental testing facility that enables the type of large-scale structural engineering research for which Dr. Zia is well known. His research on precast and prestressed concrete spanned nearly seven decades, from the mid-1950s until 2023, and his work heavily influences modern prestressed concrete engineering design. Dr. Zia is also recognized for his role in the highly technical move of the Cape Hatteras Lighthouse in 1999, an ambitious project undertaken by the National Park Service to save the 200-ft-tall brick structure from encroaching seas.

Having the opportunity to work closely with Dr. Zia for many years was a true honor and a privilege for the authors of this article. We have learned many lessons from Dr. Zia that we carry with us today. He was solidly grounded in the fundamental sciences that underpin engineering and he distilled every problem down to its basic components. Dr. Zia ensured that his students would gain a strong working knowledge of mathematics, statics, dynamics, and mechanics, and apply a deep understanding of those topics to the engineering problems at hand. He enjoyed problems that seemed complex at first, but with the right pieces of fundamental knowledge, could be solved easily with an elegant approach.

As an academic, Dr. Zia greatly valued research, teaching, and collaboration with industry, which are the three main components of the NCSU land-grant mission. Dr. Zia frequently articulated that each of the three elements of this mission are strengthened by the other two, and he worked tirelessly throughout his career to involve students in all aspects of his work. He encouraged and exemplified a practical approach to research and to engineering problem-solving by routinely spending significant portions of his time in the laboratory—engaged with students and staff—personally conducting and observing the experiments he supervised.

His teaching followed a similar philosophy, as he instructed his students from the basis of sound fundamentals and practical design problems. Dr. Zia also encouraged his students to follow his example of implementing and applying work in the public and private sectors by engaging with practitioners, engineering associations, regulatory agencies, code-writing bodies, and industry groups. He strongly advised students to get involved with the regional and national organizations that support our shared engineering profession such as the American Society of Civil Engineers, ACI, and PCI.

Most importantly, we observed the kindness, patience, and respect Dr. Zia showed to all with whom he interacted. Despite his incredible depth of knowledge, his endless awards and accolades, and his fascinating and sometimes difficult life, Dr. Zia was always ready and willing to listen carefully to any suggestion, concern, or comment that a student or colleague wanted to share. He was dedicated to his family, and he and Dora would frequently welcome students and colleagues into their home. He allowed students the space to develop their own ideas, while helping guide those ideas from the perspective of solid first principles. He would debate colleagues from a position of respect, even when he disagreed with their viewpoints. Dr. Zia was a student of everything around him, and he did not limit his desire to learn to the boundaries of his own profession. He was a strong supporter of integrating research, teaching, and the application of knowledge in industry to tangible problems.

Dr. Zia was truly a model academic, an outstanding engineer, and an inspiring person.

Note: The authors are grateful to Dr. Zia's children, May and Lee, for sharing some of the historical details of his biography.

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Approved Changes to the Ninth Edition *AASHTO LRFD Bridge Design Specifications*: Use of High-Strength Steel in Concrete Bridges and Bar Cut-Offs

by Dr. Oguzhan Bayrak, University of Texas at Austin

This article focuses on two of the changes to the ninth edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] that were approved at the May 2023 meeting of the AASHTO Committee on Bridges and Structures (COBS). These changes were prepared by AASHTO Technical Committee T-10, which is now known as AASHTO Concrete Committee. The changes will be included in the forthcoming 10th edition of the AASHTO LRFD specifications.[2]

High-Strength Steel in Concrete Bridges (Working Agenda Item 168, COBS Agenda Item 31)

This agenda item makes modifications to three different parts of the AASHTO LRFD specifications and adds new references[3–5] that underpin the changes:

- The fourth paragraph of Article 5.4.3.1 will be revised as follows: *Where ductility is to be assured or where welding is required, steel conforming to the requirements of ASTM A706/A706M, "Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement," shall be specified. Reinforcement to be welded and the weld design and details shall be specified in the contract documents. Welding of steel reinforcement shall conform to the current edition of the AWS D1.4 Structural Welding Code—Steel Reinforcement Bars.*
- Article 5.4.3.3 will be revised to read: *Where permitted by specific articles listed in Appendix D5, reinforcement with specified minimum yield strengths of less than or equal to 100 ksi may be used for all elements and connections in Seismic Zone 1. The following ASTM designations and grades of reinforcing steel shall be used in members containing potential plastic hinge regions:*
    - *For bridges in Seismic Zones 2 and 3, ASTM A706 Grade 60, except that ASTM A615 Grade 60 or ASTM A706 Grade 80 may be used with the owner's approval*
    - *For bridges in Seismic Zone 4, ASTM A706 Grade 60, except that ASTM A706 Grade 80 may be used with the owner's approval*

  In Seismic Zones 2, 3, and 4, unless prohibited by the owner, the following ASTM designations and grades of reinforcing steel may be used in members not containing potential plastic hinge regions:
    - *ASTM A615 Grades 60, 80, and 100*
    - *ASTM A706 Grades 60 and 80*
    - *ASTM A1035 Grade 100.*
- The commentary to the Article 5.4.3.3 (C5.4.3.3) will be revised as follows: *In 2004, ASTM published A1035/A1035M, "Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement." This reinforcement has a yield strength equal to or greater than 100 ksi and offers the potential for corrosion resistance. Material and column specimen tests conducted by Overby et al. (2015), Barbosa et al. (2016), and Barcley and Kowalsky (2020) showed that ASTM A706 Grade 80 reinforcing steel has acceptable elongation characteristics and may be used in members containing plastic hinge regions to reduce steel reinforcement congestion. When Grade 60 reinforcing steel along with the minimum specified material properties are used for designing members subjected to high load demands, a large amount of reinforcing steel may be needed, which may cause rebar congestion and construction challenges. The use of high strength bar reinforcement may result in a more reasonable amount of reinforcing steel in the members, leading to savings in material, shipping, and placement costs. Reducing reinforcement congestion also leads to better quality of concrete construction.*
- The background on these changes as found in the ballot item is as follows: *The 2012 Interims of the AASHTO LRFD Bridge Design Specifications (Agenda Item 38) permitted the use of high strength reinforcing bars with minimum yield strength of 100 ksi in non-seismic regions. High strength reinforcing bars could be used for structures in non-seismic zones and with some limitation in moderate to high seismic zones. ACI 318-19, Article 20.2.1.3 specifies additional requirements for ASTM A615 Grades 40, 60, 80, 100 rebar and ASTM A706 Grades 60, 80, and 100 rebar. The requirements include ratio of actual tensile strength to actual yield strength, tensile properties, and elongations for use in design of reinforced concrete elements. A number of states have been using high strength bars, especially ASTM A706 Grade 80, in structural elements including capacity-protected members, such as drilled shafts, cap beams, etc. Over almost a decade, a large amount of material test data for ASTM A615 Grade 80 and Grade 100 and ASTM A1035 Grade 100 bars has become available. The data showed that steel rolling mills have been manufacturing high strength bars that meet the requirements of the material specifications for construction.*

Reinforcement Detailing and Bar Cut-Offs (Working Agenda Item 208, COBS Agenda Item 32)

This agenda item makes modifications to six different parts of the AASHTO LRFD specifications and adds a reference.

- A new term will be added to the Article 5.3.
  L_{CLR} = *clear span between supports (in.) (5.10.8.1.2a)*
- The first paragraph in Article 5.10.8.1.2a will be revised to read:
  Critical sections for development of reinforcement in flexural members shall be taken at points of maximum stress and at points within the span where bent or terminated tension reinforcement is no longer required to resist flexure.
- The items in the bullet list in Article 5.10.8.1.2a will be revised as follows:
  - *The effective depth of member, d,*
  - *15 times the nominal diameter of bar,* d_b, *or*
  - *1/20 of the clear span,* L_{CLR}.
- **Figure 1** will be added to the beginning of Article C5.10.8.1.2a.

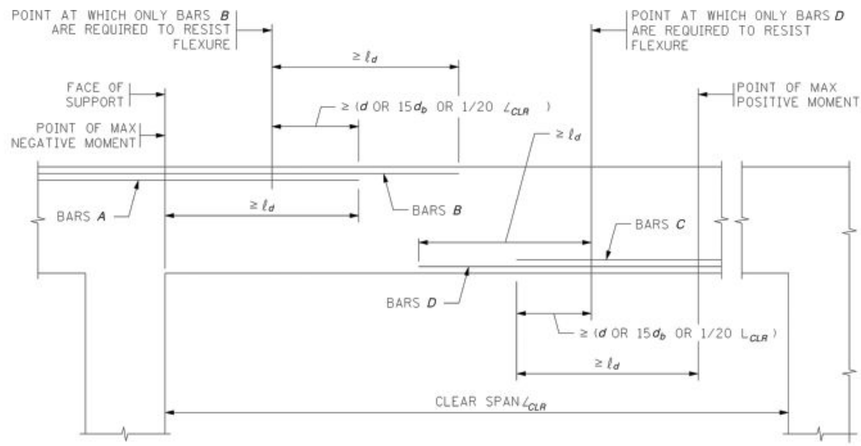

Figure 1. General flexural reinforcement termination requirements. Adapted from Fig. C5.10.8.1.2a-1 of the forthcoming *AASHTO LRFD Bridge Design Specifications*, 10th edition.[2]

Note the extension of bars D in Figure C5.10.8.1.2a-1 (Fig. 1) must also meet the requirements of Article 5.10.8.1.2b.

These provisions vary from those in the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*,[6] requiring a slightly greater bar diameter limit (15 instead of 12) and including a ratio of the clear span. (ACI has no span requirement.) The reinforcement extension accounts for the possibility of higher-than-anticipated moments due to live-load positioning, support settlements, or other causes.

- The items in the bullet list in Article 5.10.8.1.2c will be revised as follows:
  - *The effective depth of member, d,*
  - *12 times the nominal diameter of bar,* d_b, *or*
  - *1/16 of the clear span,* L_{CLR}.
- **Figure 2** will be added to Article C5.10.8.1.2c.

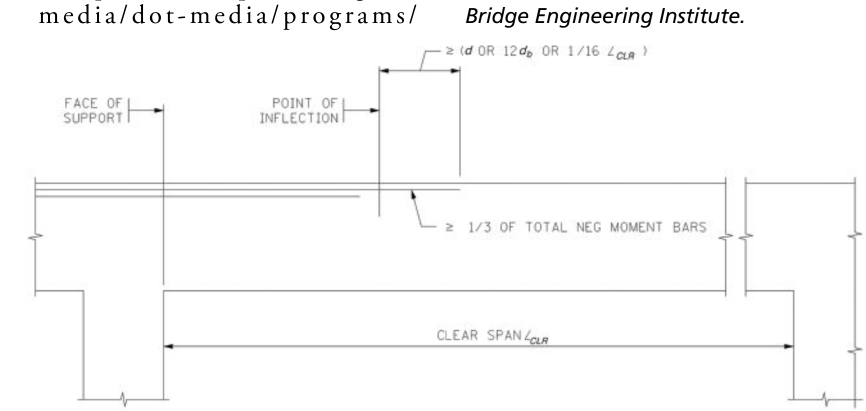

Figure 2. Negative-moment reinforcement termination requirements. Adapted from Fig. C5.10.8.1.2c-1 of the forthcoming *AASHTO LRFD Bridge Design Specifications*, 10th edition.[2]

While no background on these changes was provided in the ballot item, these changes are intended to clarify for the designer the bar cut-off requirements for typical structures. Importantly, the newly developed figures provide additional clarity for the subject design provisions.

In upcoming issues of *ASPIRE*, I will discuss the details of the remaining agenda items approved by COBS in May 2023.

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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.com.

IN THIS ISSUE

https://nationalconcretebridge.org
The National Concrete Bridge Council (NCBC), along with its supporting organizations, is offering a free six-part webinar series on concrete durability. Registration for upcoming webinars and recordings of previous presentations can be accessed via this link. Recent collaborations and forthcoming publications from the NCBC are discussed in the Perspective article on page 10.

https://highways.dot.gov/research/publications/infrastructure/FHWA-HRT-23-077
The Perspective article on page 16 discusses the forthcoming *Guide Specifications for Structural Design with Ultra-High-Performance Concrete* (UHPC), which was adopted by the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures at its May 2023 meeting. The guide specifications are a culmination of the efforts of many individuals and organizations. This is a link to a download the 2023 Federal Highway Administration (FHWA) report *Structural Design with Ultra-High Performance Concrete*.

https://highways.dot.gov/research/laboratories/saxton-transportation-operations-laboratory/Truck-Platooning
The FHWA webpage at this link provides information, resources, and a video demonstration about truck platooning. The Perspective article on page 47 describes some of the research and strategies that are being developed to properly account for truck platoons in concrete bridge design.

https://www.structuraltechnologies.com/case-studies/?f=transportation
The firm STRUCTURAL TECHNOLOGIES is featured in the Focus article on page 6. This is a link to a web page of its transportation case studies, which include projects such as the fiber-reinforced-polymer applications for the rehabilitation of the Indian Creek Village Bridge in Florida and post-tensioning systems for the Kanawha Bridge in West Virginia.

https://international.fhwa.dot.gov/programs/mrp/electrically_isolated_tendons_webinar.cfm
The webinar recording available at this link was created as part of the FHWA's global benchmarking study on electrically isolated tendons for the nondestructive evaluation of post-tensioning (PT) systems. The presentation includes information on the PT Installer Training Center, which was one of the inspirations for the PT Academy mentioned in the Concrete Bridge Engineering Institute article on page 41.

https://tsp2bridge.pavementpreservation.org
The Concrete Bridge Stewardship article on page 28 outlines how the Wisconsin Department of Transportation (WisDOT) has used bridge-element condition data and automated bridge management software to predict component deterioration and better plan for bridge preservation activities. A collaboration enabled by the AASHTO TSP-2 Midwest Bridge Preservation Partnership played an important part in developing WisDOT's modeling and preservation strategies. This is a link to the AASHTO TSP-2 website, which includes many resources for bridge preservation.

FHWA Report Offers a Fresh Look at Partial-Depth Precast Concrete Deck Panels

by Romeo Garcia, Federal Highway Administration (retired)

Partial-depth precast concrete deck panels (PDDPs) are relatively thin prestressed concrete panels that span between girders. When combined with a cast-in-place (CIP) concrete topping, they act compositely with the CIP concrete to provide the full structural thickness of a bridge deck. PDDPs can have many advantages, including faster and safer construction, which makes them appropriate for accelerated bridge construction, as well as ease of design and improved quality.

PDDPs were first used in the United States in the construction of bridges in the 1950s, including a project for the Illinois Tollway in 1956. At least 25 state departments of transportation used PDDPs over the subsequent decades, and at least six states currently use them regularly.

In 1987, the Federal Highway Administration (FHWA) published a memorandum on PDDPs that addressed the issue of reflective cracking that had been observed in the CIP concrete topping in some states.[1] The FHWA memorandum shows design, detailing, and construction techniques that had been successfully used by state transportation agencies to construct bridge decks with minimal to no reflective cracking.

The problems with cracking (in relatively few states) hindered the growth of PDDPs. Today, some states use PDDPs in a limited manner, some have never used PDDPs, and others have used them but stopped after concerns with performance. Nevertheless, several states have been successfully using PDDPs for decades. Colorado, Missouri, and Texas use PDDPs for a large majority of bridge construction projects. A few other states, such as New Hampshire, Tennessee, and Utah, also have an established record of PDDP use.

In 2022, FHWA released a state-of-the-practice report titled *Partial-Depth Precast Concrete Deck Panels.*[2] The objective of this report is to encourage the use of PDDPs as a construction option. To help achieve that objective, the report summarizes the state of the practice for PDDP design and construction based on a review of standard practices of six states that are longtime and regular users of PDDPs.

State-of-the-Practice Overview

In the FHWA report, the "state of the practice" refers to the practices generally used by the state transportation agencies of Colorado, Missouri, New Hampshire, Tennessee, Texas, and Utah, which are the most frequent users of PDDPs. The following sections summarize the state of the practice of PDDP use in these six states.

Design

The six states typically use panel thicknesses ranging from 3 to 4 in., with ⅜- to ½-in.-diameter prestressing strands.

The *AASHTO LRFD Bridge Design Specifications*[3] and *PCI Bridge Design Manual*[4] provide guidance and requirements for pretensioning force and minimum concrete strength at transfer f'_{ci} that generally result in satisfactory performance, according to the six states. However, some states use a lower strand jacking force of $0.63 f_{pu}$ (where f_{pu} is the ultimate strength of prestressing steel) and limit the concrete compressive stress at transfer to $0.19 f'_{ci}$ to reduce the risk of panel cracking.

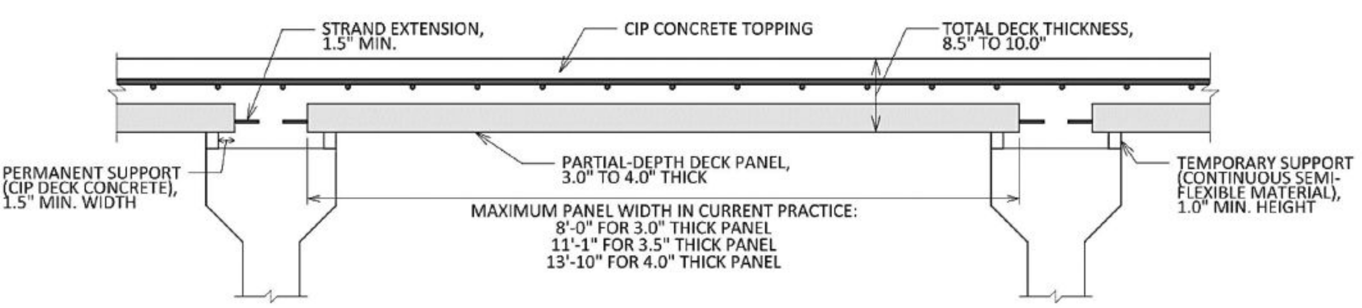
The state of the practice for the six states also includes providing minimum longitudinal distribution reinforcement (per Article 5.9.4.2 of the AASHTO LRFD specifications) and splitting reinforcement at the panel ends to minimize cracking.

To ensure composite behavior between the PDDPs and the CIP concrete, the state of the practice is to roughen the top surface of the PDDPs to a minimum amplitude of ⅛ in. The six states have found that roughness pattern and orientation are not important.

In the states' experience, PDDPs can be used with any type of steel or concrete girder.

Figure 1 shows a CIP concrete deck that includes only one mat of reinforcement in the CIP concrete topping, with the strands in the PDDPs serving as the bottom mat of reinforcement. Figure 1 also illustrates options for supporting the PDDPs. In some cases, a grout bed is installed to support the ends of the PDDPs.

Figure 1. Example section of a bridge deck composed of partial-depth precast concrete deck panels with a cast-in-place reinforced concrete topping. All Figures and Photos: Federal Highway Administration.



Fabrication and Handling

For fabrication, the states generally use PCI MNL 116, *Manual for Quality Control for Plants and Production of Structural Precast Concrete Products*.[5] Similarly, for repairing PDDPs, the state of the practice is to use PCI MNL 137, *Manual for the Evaluation and Repair of Precast, Prestressed Concrete Bridge Products*,[6] or PCI Northeast's *Guidelines for Resolution of Nonconformances in Precast Concrete Bridge Elements*.[7]

PDDPs must be designed for handling, shipping, and erection. The *PCI Bridge Design Manual*[4] states that the locations of the lifting devices should ensure that the panel concrete stresses remain within limits during handling. The lifting devices must also be designed.

Panel Installation and Placement of CIP Deck Concrete

To minimize the potential for cracking of the CIP concrete deck, the panels should be in a saturated surface-dry state at the time the CIP concrete is placed. During CIP concrete placement, it is important that the panel ends are continuously supported with concrete or grout to minimize the potential for reflective cracking and ensure the deck's long-term performance.

Emerging Concepts

The FHWA report discusses several emerging concepts and variations of typical PDDPs. This includes the use of new materials such as ultra-high-performance concrete and fiber-reinforced polymer reinforcement. Additionally, the report discusses the use of the AASHTO empirical design method for the CIP concrete portion of the deck, along with the studies that have been performed and the states that allow it.

International Practices

The report also looks at PDDP practices in countries other than the United States. PDDPs are being used in countries that have similar practices to the United States, such as Canada. In the United Kingdom, the typical panels are quite different, being only 12 in. wide with a single lattice bar truss per panel in lieu of prestressing. In Spain and Australia, PDDPs are fabricated for the full width of a bridge deck, with lattice bar trusses extending above the panel with no prestressing.

Precast concrete partial-depth deck panels stored at the fabricator's facility. The panels must be designed for handling, storage, shipping, and erection, as well as the placement of the cast-in-place concrete topping and service conditions.

Precast concrete partial-depth deck panels after installation, but before placement of cast-in-place concrete topping.

Perceived Barriers and Solutions to the Use of PDDP Technology

The report addresses barriers to the use of PDDP technology as perceived by state transportation agencies, including concerns about reflective cracking of the CIP concrete above PDDPs, panel rejection due to cracking during fabrication, and cost. Each concern is addressed in detail along with the experiences of the states that are regular users of PDDPs.

Strategies to Effectively Deploy PDDP Technology

The report concludes with possible strategies to deploy PDDPs. These strategies include developing standard specifications and details for PDDPs, ideally combined with a demonstration project. A flowchart depicting a suggested implementation plan is also provided in the report. Sometimes, in thinking about the future, we can find the answers in the past. PDDPs are a good example of a past practice that can meet many present and future needs, with a little technical assistance.

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