ASPIRE®

THE CONCRETE BRIDGE MAGAZINE

SPRING 2023

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Engineering Consulting Giant Spans the Globe

WSP leverages local and global talent to bring the best solutions to its clients

LAWRENCE TO BRYN MAWR GUIDEWAY
Chicago, Illinois

NICE-MIDDLETON BRIDGE
Newburg, Maryland

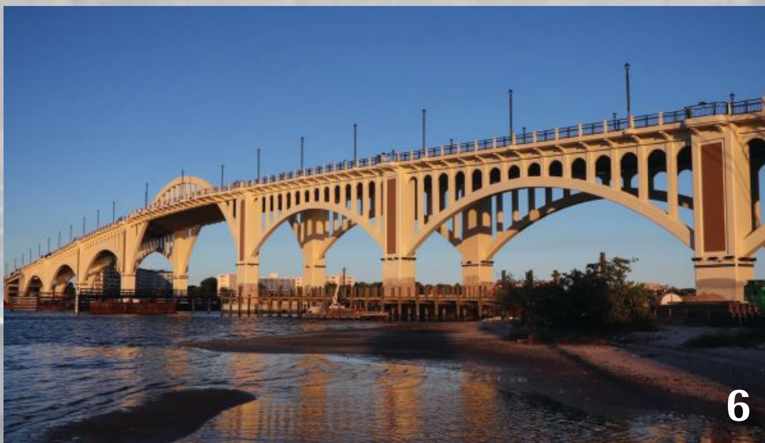

Photo: WSP.

Photo: Walsh-Fluor Design-Build Team.

Photo: Skanska/Corman/McLean JV.

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Photo: WSP.

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Photo: PCI.

Time to Become an Industry Influencer

William N. Nickas, *Editor-in-Chief*

We have all been hearing and learning more about environmental product declarations and life-cycle assessment (LCA), which are allowing civil engineers to bring rigor (and hopefully credibility) to the evaluation of resiliency and sustainability. My daughter mentioned to me a lesson that her science teacher taught on sustainable practices for our Earth. The teacher started by stating that my daughter's generation deserves a better globe. Most of us would probably agree with that premise. She then pointed to countries that are less developed than the United States and explained that although these countries may have fewer pollution controls than U.S. manufacturing standards, industrialized nations must lead by example. As my daughter recounted her lesson, I was still agreeing with the teacher. Finally, the teacher stated that concrete is not a sustainable construction material because its use necessitates mining materials, cooking them at high temperatures using lots of energy, and releasing carbon dioxide. This is where she lost me. We should not be talking about sustainability without considering performance.

When I shared this story during a recent industry stakeholder meeting, Chris Lechner of the Precast Concrete Manufacturers Association was kind enough to tell me about a similar experience he had in Texas when a local newspaper published an article about new wood structures.[1] Here is what Chris wrote in response to that article.

> *Dear Editor,*
>
> *Given Josh Baugh's third paragraph in the September 25, 2019, article in the* San Antonio Express-News, *"San Antonio Office Structure Includes More Wood," he obviously expected a response. The gist of the story appears to be that going to Canada and Austria, cutting trees, grinding them up, soaking them in chemicals, and sending what remains to a factory to be glued back together then shipped via train, ship, and truck halfway across the world is not only environmentally friendly but sustainable. Really?*
>
> *The article then attempts to portray concrete as bad by confusing it with cement and ignoring the continuing reduction efforts of the industry. Concrete's carbon footprint will continue to drop while the wood industry tries to convince you cutting trees just prior to their most environmentally beneficial years is a good thing.*
>
> *And, while wood takes shots at other materials, Texans along the Gulf Coast deal with [Hurricane] Harvey's gifts of mold and rot. Each year Texans, and our friends to the north, haul away tons of the splintered remains left behind by hurricanes and tornadoes. Moreover, wood is trying to convince fire and code officials across the country that their high-rise wood buildings won't burn.*
>
> *Steel-reinforced precast concrete is an engineered solution to the future challenges facing the built environment. We have our challenges and face them honestly and aboveboard. The wood industry's "greenwashing" is a disservice to those who build and inhabit these buildings believing they are helping the environment. Breathe deep, Josh, but be aware that what you're really smelling is not the trees but the chemical off-gassing of volatile organic compounds.*

Chris, thank you for sharing your well-written letter.

Why do I share these stories? Because I'd like to motivate you to get engaged. We all need to educate ourselves on all aspects of sustainability, not just the focus of the moment. Emily Lorenz's Concrete Bridge

Cover
The main span of the 1884-ft-long, 15-span, high-level Tom Staed Veterans Memorial Bridge over the Halifax River in Daytona Beach, Fla., was the first precast concrete deck through-arch structure in the United States. WSP led the design team.

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Publisher
Precast/Prestressed Concrete Institute
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Postmaster: Send address changes to *ASPIRE*, 8770 W. Bryn Mawr Ave., Suite 1150, Chicago, IL 60631. Standard postage paid at Chicago, IL, and additional mailing offices.

ASPIRE (Vol. 17, No. 2), ISSN 1935-2093 is published quarterly by the Precast/Prestressed Concrete Institute.

https://doi.org/10.15554/asp17.2

Stewardship article in the Fall 2022 issue of *ASPIRE®* provides an environmental impact primer with 16 references to help get you up to speed.

Stewardship has been a big part of our industry for a long time, and it is the basis of the LCA and life-cycle cost analysis (LCCA) methods that our industry uses. In 2021, the American Association of State Highway and Transportation Officials published its *Guide to Bridge Preservation Actions*,[2] which aids owners in the decision-making processes associated with extending in-service bridge life. It includes a suite of actions, which can be included in an LCA or LCCA, to preserve and renew all types of bridges.

Our industry continues to evolve in its stewardship and sustainability-related efforts. Gregg Freeby, chair of the National Concrete Bridge Council (NCBC), and Chris Garrell of the National Steel Bridge Alliance (NSBA) have initiated a collaborative effort related to the sustainability of competing bridge materials—concrete and steel. These two groups are looking to participate in efforts by the Federal Highway Administration (FHWA) to develop a sustainable infrastructure guidance document (similar to the one developed for concrete and asphalt pavements through the program mentioned in Lorenz's latest Concrete Bridge Stewardship article on page 28 of this issue).

This effort by NCBC, NSBA, and FHWA will discourage the practice of picking and choosing among sustainable attributes, which can hinder the civil engineering profession from providing the best solution for the performance requirements of a project. This industry-agnostic guidance, which will encourage evaluation of a full set of environmental and social impacts together with LCCA, will be based on industry best practices, existing standards, and value-engineering principles. These tools will enable the civil engineering profession to make the most sustainable choice for a given project.

Bridge engineers can understand that using sustainability analysis for materials' selections without evaluating performance is shortsighted. And to understand and manage impacts with performance in mind, we must evaluate sustainability for the full project life (from cradle to grave) and beyond. To keep performance relevant, we must stop using cradle-to-gate analyses and evaluate the full service life of the investment. I hope you will be inspired by Chris's letter to the editor and my thoughts here to take action as an industry advocate. Let's redirect the conversations in our hometowns by sharing the full picture.

References

1. Baugh, J. 2019. "Wood Makes a Difference in New Six-Story Office Building in San Antonio." *San Antonio Express-News*, August 26, 2019. https://www.expressnews.com/news/local/article/Wood-makes-a-difference-in-new-six-story-office-14377710.php?cmpid=gsa-mysa-result.
2. American Association of State Highway and Transportation Officials (AASHTO). 2021. *Guide to Bridge Preservation Actions*. Washington, DC: AASHTO.

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Dr. Eric Matsumoto serves as the lead for the California State University, Sacramento, Precast Bridge Studio. His research, teaching, and service focus on precast concrete bridge systems.

Shelley Row is the founder and CEO of Blue Fjord Leaders and a certified speaking professional. An engineer and former senior government executive, she coaches leaders in management skills such as decision-making, delegation, and difficult discussions.

EDITOR'S NOTE

The *ASPIRE* team wishes to thank all readers who participated in the recent survey. We are in the process of evaluating the responses and planning changes to address some of the items. Look for an article in a future issue of *ASPIRE* that summarizes the results of the survey and outlines forthcoming changes. Winners of the random drawing for the gift cards are Tim Breen, Peter Cruz, Haitham Abdelmalek, Chuck Prussack, and John Lange.

CONCRETE CALENDAR 2023–2024

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

April 2–6, 2023
ACI Spring Concrete Convention
Hilton San Francisco Union Square
San Francisco, Calif.

April 24, 2023
ASBI Grouting Certification Training
J. J. Pickle Research Campus
Austin, Tex.

April 28–May 4, 2023
PTI Convention
JW Marriott Marquis Miami
Miami, Fla.

May 9–12, 2023
PCI Level I–III Quality Control School
Chicago, Ill.

May 21–25, 2023
AASHTO Committee on Bridges and Structures Annual Meeting
Loews Kansas City Hotel
Kansas City, Mo.

May 22–23, 2023
PTI Certification Week
Hyatt Regency DFW International Airport
Dallas, Tex.

June 4–7, 2023
Third International Symposium on Ultra-High-Performance Concrete
Hotel Du Pont
Wilmington, Del.

June 5–10, 2023
PTI Certification Week
Embassy Suites by Hilton Miami International Airport
Miami, Fla.

June 12–14, 2023
International Bridge Conference
Gaylord National Resort & Convention Center
National Harbor, Md.

September 5–8, 2023
Western Bridge Engineers' Seminar
Phoenix, Ariz.

September 11–15, 2023
PTI Certification Week
Embassy Suites by Hilton Scottsdale Resort
Scottsdale, Ariz.

October 1–4, 2023
AREMA Annual Conference with Railway Interchange
Indiana Convention Center
Indianapolis, Ind.

October 3–6, 2023
PTI Committee Days
Ritz-Carlton Cancun
Cancun, Mexico

October 4–8, 2023
PCI Committee Days Conference
JW Marriott Tampa
Tampa, Fla.

October 14–16, 2023
PTI Certification Week
Terracon Consultants
Nashville, Tenn.

October 29–November 2, 2023
ACI Fall Concrete Convention
Boston Convention Center and Westin Boston Waterfront
Boston, Mass.

November 5–8, 2023
ASBI Annual Convention and Committee Meetings
Westin La Paloma Resort and Spa
Tucson, Ariz.

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

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.

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

FOCUS

Engineering Consulting Giant Spans the Globe

WSP leverages local and global talent to bring the best solutions to its clients

by Monica Schultes

WSP led the design team for the Tom Staed Veterans Memorial Bridge over the Halifax River in Daytona Beach, Fla. The 1884-ft-long, 15-span, high-level bridge was completed in 2020. Its main span was the first precast concrete deck through-arch structure in the United States. Prestressed concrete Florida I-beams were used on the approach spans. All Photos: WSP.

WSP's acquisitions of iconic consulting firms have created an engineering powerhouse of approximately 66,000 employees around the world. The firm's global headquarters are located in Montreal, Quebec; WSP also has 300 offices in the United States and maintains a presence in the Middle East, Europe, Asia, and Australia.

Matthew Chynoweth, national bridges and structures market leader for WSP, believes the global presence of WSP is an asset. Whether colleagues are across the country or across the world, employees can readily tap into a deep pool of technical expertise to the benefit of clients.

Shared Resources

"We do a good job of communicating with each other, understanding the needs of our clients, and assembling the right people into the best project team," says Barton Newton, national bridge asset management leader for WSP. "We operate in a matrix organization—a team approach—not individual silos of talent," he adds.

"We do a good job of communicating with each other, understanding the needs of our clients, and assembling the right people into the best project team."

While sharing work across offices is commonplace for many large firms, what differentiates WSP is its ability to operate across so many sectors. "There is not much that we can't do at WSP," says Newton. "That is the strength of this company. We can provide expertise to our clients in every field. If by chance we lack a specialty or expertise, we augment our project teams with qualified outside partners. We do it all."

WSP's expertise extends to all types of bridges, including concrete segmental, post-tensioned, viaducts or interchanges, and movable and long-span bridges for all transportation modes. Having designed, analyzed, maintained, and managed thousands of bridge projects, WSP is able to offer fully integrated services. The firm can also provide a range of rehabilitation services such as seismic retrofits, cable replacements, and deck replacements using orthotropic systems. When appropriate, WSP project teams use innovative materials such as ultra-high-performance concrete (UHPC) and fiber-reinforced polymer (FRP) reinforcement.

To further advance the strategy of WSP, the firm recently rebranded the business line focusing on complex bridges in the United States as the National Bridges and Structures Practice. This change ensures greater integration and connection between national resources and regional staff, allowing WSP to put together the best technical teams and collaborative solutions for WSP's clients.

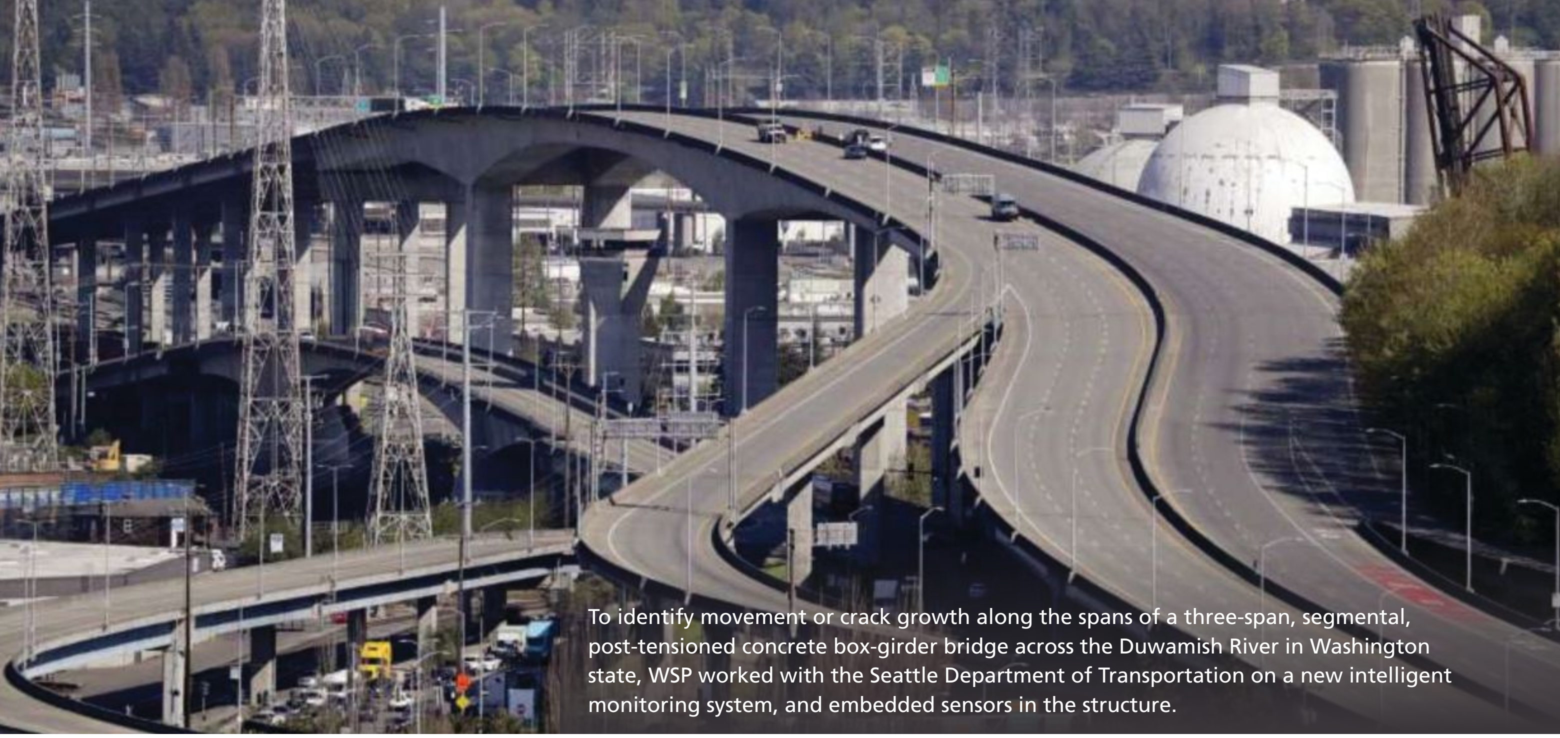
Technical Bench

WSP makes every effort to ensure that all bridge professionals, not just engineers, have the skills and know-how to use the latest technology and stay abreast of industry advancements. Involvement in associations such as the American Segmental Bridge Institute, American Association of State Highway and Transportation Officials, Transportation Research Board, and National Cooperative Highway Research Program, and others, is encouraged. "We want to be part of the conversation in the transportation industry and part of the future," says Newton.

Local Ties

WSP believes that local connections happen through being present in local communities. These connections also help the company retain top talent, including young engineers who will be future leaders.

Therefore, WSP encourages employees to engage at the local level. Every office has a developing professionals' network to facilitate interactions amoung WSP professionals, and, more importantly, to establish a framework for volunteering and networking in the local community. Some employees get involved at the high school level to support science, technology, engineering, and math (STEM) programs. Others teach the practical side of structural engineering at the university level. Such grassroots efforts give back to the community and are personally rewarding for the employees.



To identify movement or crack growth along the spans of a three-span, segmental, post-tensioned concrete box-girder bridge across the Duwamish River in Washington state, WSP worked with the Seattle Department of Transportation on a new intelligent monitoring system, and embedded sensors in the structure.

Client Involvement

The WSP approach involves a deep commitment to excellence and a dedicated focus on the needs of its clients. The technical aspect of client services is important, but WSP also helps clients manage stakeholders, apply for grants, and seek funding. Before joining WSP, Chynoweth was the chief bridge engineer for the Michigan Department of Transportation. "My experience as a former bridge owner hopefully brings credibility during discussions with agency clients. I know what keeps them up at night, as I used to walk in their shoes," he says. "Our approach is focused on their goals and not just selling them services. We don't advocate for a specific type of bridge or material, but we do advocate for the best solution," he adds.

One key strategy is to communicate to the owner the potential and probable consequences of decisions made at every stage in the life of an asset. Design decisions affect constructability, maintenance, and, ultimately, the overall life-cycle cost of the asset. WSP's portfolio ranges in size and scope from simple studies and assessments to complex multi-billion-dollar projects. In every case, the firm is committed to responding to clients with cost-effective, sustainable solutions that promote safe and efficient travel. "At the end of the day, we are concerned about the owner, the traveling public, and the bridge," says Newton.

"At the end of the day, we are concerned about the owner, the traveling public, and the bridge."

A good example of client collaboration occurred when WSP led the design team for the Tom Staed Veterans Memorial Bridge over the Halifax River in Daytona Beach, Fla. The owner wanted a durable, resilient structure with very limited post-tensioning and no exposed steel. The 1884-ft-long, 15-span, high-level bridge was completed in 2020, and the main span was the first precast concrete deck through arch in the United States. Prestressed concrete Florida I-beams were used on the approach spans.

The main challenges for the bridge design involved the constructability of the arch approaches and main span through arch. The use of precast concrete components significantly simplified erection for this "maintenance-free" structure. Interaction among steel reinforcement, post-tensioning ducts and tendons, and other elements caused for congestion that required careful planning, execution, and inspection during fabrication.

Digital Twins

WSP is keeping pace with advancements in digital-delivery technologies. According to Newton, digital delivery

History of WSP

WSP, which was founded in London in 1969, entered the U.S. transportation market in 2007 via the acquisition of Chas. H. Sells Inc. With the acquisition of Parsons Brinckerhoff in 2014, WSP can now trace its origins in the United States back more than a century, with early projects including the design of the original New York City subway system and the original Sunshine Skyway Bridge over Tampa Bay in Florida. The firm has worked on many major U.S. transit systems and has designed countless highways, bridges, and tunnels.

Other major acquisitions that have expanded WSP's capabilities in the transportation sector include:

- Louis Berger and its subsidiaries BergerABAM and Ammann & Whitney (2018),
- Golder Associates (2021),
- Knight Engineers and Architects (2021), and
- the Environment & Infrastructure business of John Wood Group PLC (2022).

In total, more than 85 companies have been joined together in a shared future under the WSP brand. Frequently ranked in the top five of *Engineering News-Record's* list of global design firms, WSP has used acquisitions to help create a $10 billion professional-services giant.

WSP designed the Genesee Avenue Viaduct in La Jolla, Calif. It was the first curved, spliced precast concrete U-girder light-rail transit bridge in Southern California. The use of precast concrete girders eliminated several months of nighttime closures. The construction of a straight section is shown here. (For more information, see the Spring 2020 issue of *ASPIRE*®.)

involves assembling the available data for an asset, accessing that information throughout the planning process, updating it during design and construction, and maintaining it over the asset's lifetime.

WSP is at the forefront of planning and using digital twins. "The industry is moving that way, but slowly. Requirements for a digital-delivery approach are starting to be included in a few RFPs [requests for proposals]. In comparison, five years ago we saw none. This is going to be a new way of doing business," predicts Newton.

Digital twins and multiple independent bridge models are often used to supplement in-person inspections and subsequent safe load-carrying capacity analyses and determination. Such was the case with the West Seattle Bridge (see the Concrete Bridge Preservation article in the Summer 2022 issue of *ASPIRE*®). Working with the Seattle Department of Transportation, WSP tracked the performance of that bridge structure over the years. The 2600-ft-long structure was shut down in March 2020 after inspections conducted by WSP indicated accelerated growth of new and existing structural cracks.

Finite element modeling of the bridge and input of restraint conditions observed in the field resulted in models accurately predicting structural behavior and distress that was visually observed on the bridge. This validation allowed inputs of various strengthening techniques using external longitudinal post-tensioning and FRP wraps for flexural strengthening and confinement. WSP then developed and implemented a repair scheme.

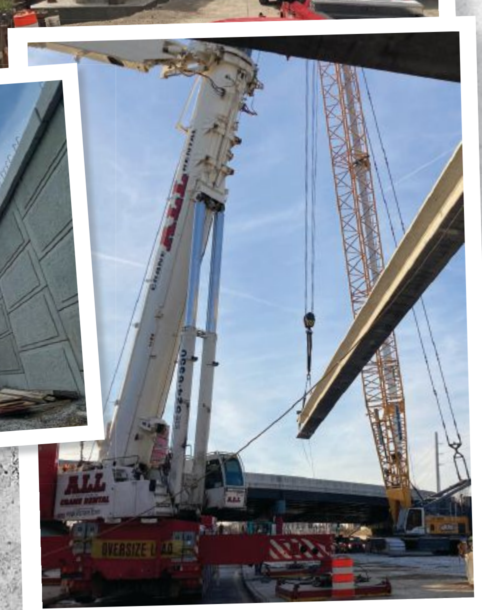
After repairs were completed and before the bridge was reopened to the public, a load-testing program was performed using gauges to measure strain and deflections, which were then compared with theoretical strains and deflections from the analytical bridge models. The load-testing program provided excellent results and validated the repairs as being sufficient. The bridge was reopened in 2022.

Internal Challenges and Goals

Like the rest of the industry, WSP is on the lookout for talent. "Whether you are a private or public entity, you are resource challenged," says Chynoweth. And like other firms, WSP must continually educate employees and clients about the benefits of today's best bridge solutions.

"We have made vast improvements in concrete materials and construction methodology," Chynoweth says. "Take post-tensioning, for example. There are robust specification and material requirements now, which include inspection, verification, and best practices, which were not available two decades ago. Materials are getting better and better every year, and there is a constant need for education to advance the concrete bridge industry. Another example is UHPC. Since its infancy, WSP has been involved in the research and study of UHPC and deploying it on projects. The possibilities that await with UHPC are quite exciting."

In 2021, with an eye toward the future, WSP committed to making changes to reach net-zero emissions status as outlined in the WSP climate transition plan. The plan presents key strategies and actions to reach the firm's science-based targets, which will eventually lead to net-zero emissions across WSP's value chain by 2040. WSP has also committed to the SE 2050 Commitment Program developed by the Structural Engineering Institute to reduce embodied carbon from structural systems, and it has published an embodied carbon action plan. An entire group within WSP is focused on climate, resiliency, and sustainability. "We are very proud of these efforts," says Newton. "It is really about how we contribute to the health of the planet and the public at large."



The Secret to Communicating Technical Topics to Nontechnical Audiences: The Four "Cs"

by Shelley Row, Blue Fjord Leaders

You're ready. You collected the data, did the analysis, interpreted the results, and have a sound, well-thought-out recommendation—but the presentation does not go as expected. The public is disgruntled and won't listen; the boss makes a politically motivated decision that runs counter to your analysis. How do you make them listen? How do you make them understand logic?

You don't. The secret to communicating technical topics to nontechnical audiences is for you to understand *them*. All too often, we spend time understanding and analyzing our technical material but invest little, if any, time in understanding the audience.

When you have only one chance and it needs to go well, use the secret of the four "Cs" to effectively communicate technical topics to nontechnical audiences:

- Clarity of purpose
- Context of the audience
- Conciseness of content
- Collaboration with your audience

Clarity of Purpose

Briefings come in many forms. You may need to inform a group or seek specific action. Perhaps there is a decision to be made, or maybe you are there to listen. Whatever your purpose is, make sure you have clarity about it. That may seem obvious, but all too often, the meeting ends and the key players are left wondering, "What was the point?" Next time, before you walk in the door, know why you are there. What is your ideal outcome? What does success look like? What is the "ask"?

Don't sleepwalk through this step. Seriously contemplate your purpose and desired outcome. Before you walk through the real or virtual door, think through the purpose until you distill it into a crystal-clear statement.

Context of the Audience

It is easy to focus on the material, the facts, and the analysis. But, for an important presentation, you should dedicate substantial time to understanding the audience and their needs. Know their context, their concerns, and their comfort levels. Put yourself in their shoes and ask, "What's in it for me?" (WIIFM). Spend time thinking about the audience. What do you know about the group's interests, fears, and history? What do you know about the political climate? What is the career trajectory and risk profile of the decision maker? What are the consequences of the decision? Is credibility, embarrassment, power, or an election at stake?

Imagine that you are briefing a decision maker about a major project design decision that incorporates a new technology approach. You know she likes to be on the cutting edge, and she wants to be viewed as an innovator. What are your key points? With what approach will you lead? Perhaps you can point out that this project is ideal for demonstrating this new technology. While the technology has been fully tested, this will be the first use of it in this specific application. There is already interest from other states to learn about the experience. This will be a high-profile project.

Now imagine that you are briefing a risk-averse decision maker about the same project. In this case, what are your key points and your approach? This time, you may emphasize the level of testing that supports the new technology. You may focus on the previous applications where it has been used. You may emphasize the risk-management approaches that are in place to mitigate unforeseen issues.

In these two scenarios, your approaches are not the same. The project and the issue to be decided may be the same, but your approach and key points change based on the interests of the audience.

When we walk into the meeting armed only with facts and figures, we come across as tone deaf. Decision makers shake their heads and think, "They just don't get it." And unless we know as much about our audience as we do about the topic, they are right.

Conciseness of Content

Benjamin Franklin said, "I have already made this paper too long, for which I must crave pardon, not having now time to make it shorter." Franklin was right: it takes time and effort to whittle a topic down to its essence. However, that is exactly what you must do. Earlier in my career, I gave many briefings to congressional staff and the secretary of transportation. If we were lucky, we had a half hour, but we frequently had less time. I quickly learned that it is essential to be crystal clear on the "ask," understand the audience's WIIFM, and be concise.

What is the *one* thing you want your audience to remember? Can you simply and easily explain that one thing to a "regular" person? If you cannot, try again. Really. Try again. You also need to know how the people in your audience best consume information. You may love a great graph or infographic, but do they? Do they prefer a detailed PowerPoint deck or is a story better? Do they want you to get straight to the point or do they need background information? It's your job to know and design your approach to fit their communication style. Hone the message, tighten the content, and make a clear point.

It's your job to know and design your approach to fit the audience's communication style. Hone the message, tighten the content, and make a clear point.

Collaboration with Your Audience

In every meeting, keep in mind that you are not presenting *to* your audience; you are communicating *with* them. Communication is a collaborative, two-way process. You must focus as much energy on understanding your audience's concerns, answering their questions, and gauging their reactions as you spend trying to get your point across. It is good to hone your presentation skills, but how are your listening skills?

Conclusion

When you must communicate technical topics effectively, make time to work on the four "Cs." Shift your perspective to see your audience's point of view and tailor your briefing to meet them where *they* are. Yes, this approach takes more effort. Yes, it takes time. But without attending to the four "Cs," your strong technical work could be lost.

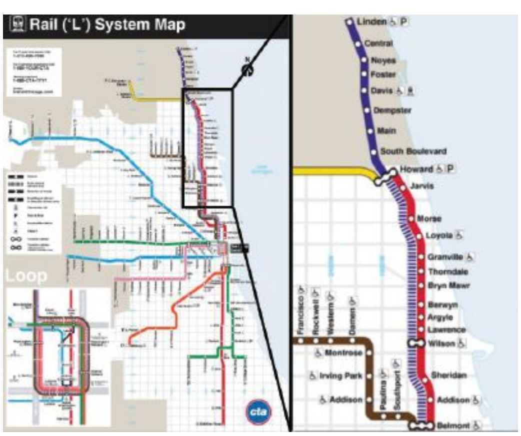
PROJECT

Precast Concrete Segmental Box Girders for the Red-Purple Modernization Program

by Erin Schultz and Kevin Buch, Walsh-Fluor Design-Build Team, and Ben Soule, SYSTRA International Bridge Technologies

The $1.2 billion Red-Purple Modernization Phase 1 design-build project is the largest capital project in the history of the Chicago Transit Authority (CTA). In its entirety, this project affects 9.6 miles of the Red and Purple lines, which carry 20% of CTA's rail traffic and run 24 hours a day, 7 days a week. The request for proposal was issued at the end of 2017 and awarded in 2018. In February 2019, notice to proceed was given to the design-build team.

A major section of Phase 1 is the Lawrence to Bryn Mawr modernization project, which includes replacement of 1.3 miles of four tracks currently supported by aging retaining walls with a new viaduct structure. The alignment snakes through a highly congested area on the north side of Chicago, sandwiched between a city alley and buildings built against the project right-of-way. Most of the new viaduct consists of two separate parallel structures that carry two tracks each. In one area the structures are connected by a fifth middle (pocket) track with crossovers to facilitate train movement (reversing direction) and storage. Construction is staged, with trains running on two tracks while the adjacent two are constructed, resulting in an extended construction schedule that does not interrupt service.



Location of the Lawrence to Bryn Mawr Modernization project within the Chicago Transit Authority system. Figure: Chicago Transit Authority.

Precast Concrete Segmental Box-Girder Solution

CTA's original base design consisted of 60 ft steel spans supported by two drilled shafts at each concrete bent. The request for proposal for the project stated:

> *The Contractor will not use through girders, steel box girders, trusses, tied arches, prestressed concrete beams, prestressed precast voided slabs, deck bulb-tee girders (including thin flange deck bulb-tee girders), prestressed or post-tensioned concrete U-beams, tri-beam sections, double tee girders, post-tensioned members or non-prestressed precast slabs for permanent structures.*

During the pursuit phase, the design-build team brainstormed innovative solutions to mitigate the challenges and risks inherent with the tight work-zone access restrictions. When evaluating potential alternative structure types, a simple-span precast concrete segmental box girder supported by single drilled-shaft bents emerged as the best-value solution. Major benefits of this solution included implementing a span-by-span erection with a launching girder, reducing the number of foundations, minimizing on-site craft labor by using an off-site precaster, and lessening the project's impact on the surrounding community by minimizing the duration of construction. The staging of the project, with two main phases of demolition and construction, provided excellent opportunities to advance precast concrete fabrication activities while limiting the investment in forms.

CTA has used steel as its preferred building material throughout the agency's long history (see the Authority article

profile

LAWRENCE TO BRYN MAWR GUIDEWAY / CHICAGO, ILLINOIS

PRIME DESIGN ENGINEER: Stantec, Chicago, Ill.

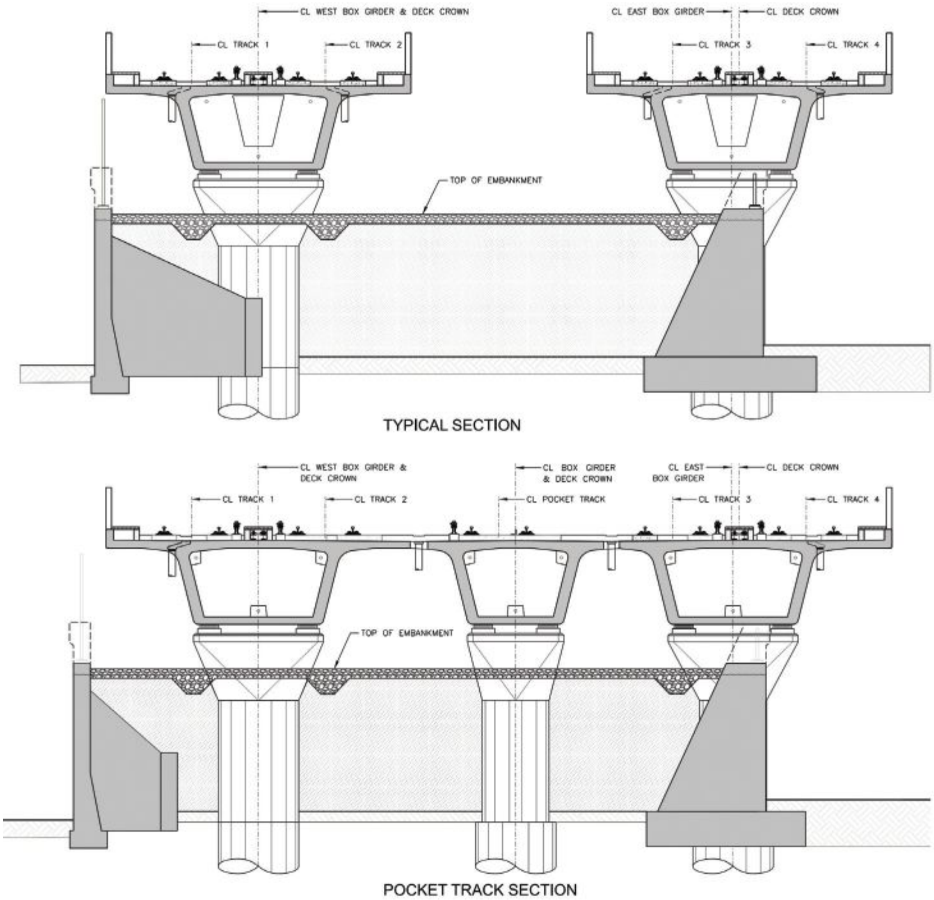
BRIDGE DESIGN ENGINEER: SYSTRA International Bridge Technologies, San Diego, Calif.

OTHER CONSULTANTS: Prime construction engineer: Collins Engineers Inc., Chicago, Ill.; segmental construction engineer: SYSTRA International Bridge Technologies, San Diego, Calif.

PRIME AND POST-TENSIONING CONTRACTOR: Walsh-Fluor Design-Build Team (a joint venture), Chicago, Ill.

CONCRETE SUPPLIER: Ozinga Ready Mix, Chicago, Ill.

PRECASTER: Utility Concrete Products, Morris, Ill.—a PCI-certified producer



Typical four-track and pocket-track configurations. Figure: Walsh-Fluor Design-Build Team.

on page 44 of this issue). CTA relies on the predictability of its steel structures and how they respond to the corrosive weather conditions as well as to stray current from the third-rail, 600-volt direct-current traction power system. Moreover, while prestressed concrete beam structures are common in the Chicago metropolitan area for highway structures, precast concrete segmental box-girder structures are not. Only a handful of precast concrete segmental bridges exist in Illinois, and none are found in Chicago.

The design-build team knew that a segmental box girder would be a significant alternative technical concept (ATC) for CTA, so the concept was introduced early during the first mandatory one-on-one meeting that was held with each prospective team during the pursuit phase. CTA was interested, but its representatives had several technical concerns, chiefly the effects of stray current within a concrete structure, replaceability of the structure without adversely affecting revenue service, and overall maintainability of the structure. Over the next five months, the team worked with CTA through their one-on-one meetings to develop solutions and commitments that would address CTA's concerns, leading to approval of the ATC and ultimately a successful bid.

Upon receipt of the notice to proceed, the team began detailed design work in earnest. As the design of the post-tensioned, precast concrete segmental viaduct progressed, it became clear that the effort could be grouped into two distinct areas: structural design and interdisciplinary coordination.

Design Challenges

At first glance, the structural design appears to be straightforward. The entire viaduct is composed of 100-, 110-, and 120-ft-long simple spans. The alignment is straight, and the structure is low to the ground. Furthermore, the foundations and substructure are repetitive and simple, with a monoshaft foundation and a single-column pier. The seismic demands are low, and the wind environment is not exceptional. However, this simplicity masked multiple project-specific requirements that kept the design team fully engaged.

Much of the effort stemmed from the design criteria. While many metro projects have design criteria based on the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*,[1] CTA has a history of designing in accordance with American Railway Engineering and Maintenance-of-Way Association's (AREMA's) *Manual for Railway Engineering*.[2] Critical differences are the higher load factors associated with AREMA (one load factor design combination has a factor of 1.8 on dead, live, and impact loads, which is significantly higher than typical AASHTO load factors) and an outdated segmental design section in the AREMA manual. As the design progressed, CTA adopted modernized design criteria: the

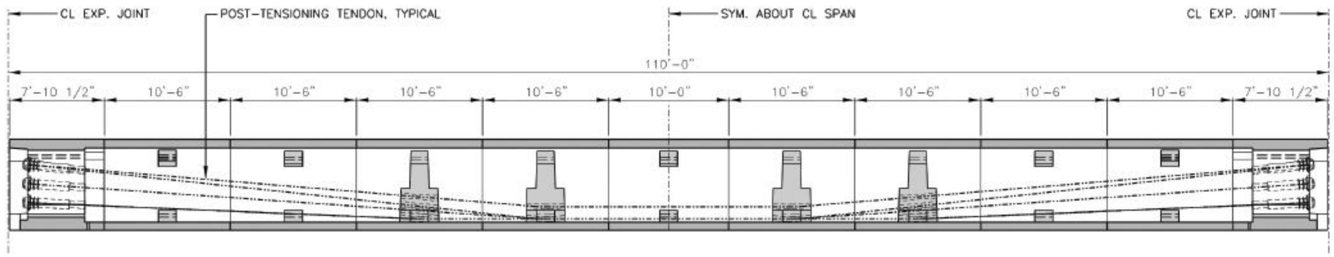
CHICAGO TRANSIT AUTHORITY, OWNER

OTHER MATERIAL SUPPLIERS: Erection equipment and segment molds: DEAL, Bay Harbor, Fla.; post-tensioning: Tensa (a Rizzani-DEAL company), Miami, Fla.; bearings: Scougal, McCarran, Nev., and RJ Watson, Buffalo, N.Y.; temporary post-tensioning: Dywidag Systems Inc., Bolingbrook, Ill.; epoxy for segmental joints: Sika Corporation, Lyndhurst, N.J.

BRIDGE DESCRIPTION: Twin 1.3-mile-long guideway bridges, each carrying two tracks of the Chicago Transit Authority's Red and Purple lines

STRUCTURAL COMPONENTS: Post-tensioned, precast concrete segmental box-girder spans varying from 100 to 120 ft, supported by reinforced concrete columns and reinforced monoshaft foundations

OVERALL PROJECT CONSTRUCTION COST: $1.2 billion



Elevation view showing the trajectory of the post-tensioning tendons of a typical 110-ft-long, simply supported span. Figure: Walsh-Fluor Design-Build Team.

agency retained the AREMA loads but based the capacity of segmental girders on AASHTO LRFD specifications. In this way, CTA benefits from two decades of specification development while continuing to target the original goals for reliability.

As a condition for approval, CTA required tendons that are replaceable under live load. This requirement led the team to design external tendons with custom anchorages. Because the design coupled high load factors with external tendons, the amount of post-tensioning was greater than the amount that would be required for a comparable transit structure. The extra amount was recognized and included in the bid-phase quantities.

Interdisciplinary Coordination

A transit viaduct interacts with several different systems and designs, all of which are vital to the functionality of the finished product. The interactions can involve something as obvious as the trackwork to details like lighting the signage at stations. CTA is also one of the oldest transit systems in the United States, and the new viaduct must remain compatible with the legacy hardware in operation adjacent to it.

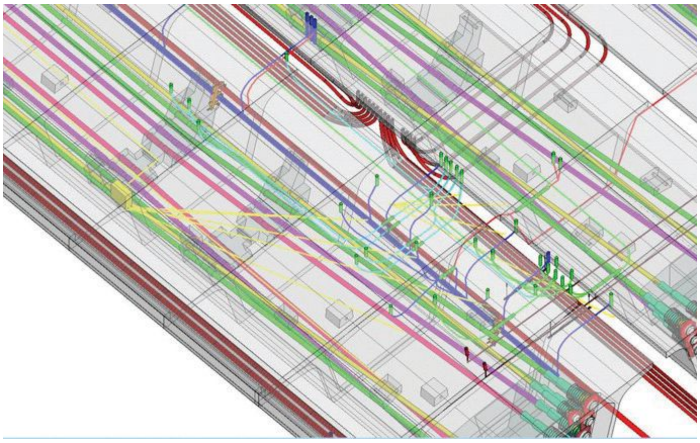
As the project progressed, the team incorporated building information modeling (BIM) into the interdisciplinary efforts and found it to be an effective tool. The stakeholders in the major disciplines—structures, track, signals, communications, and traction power—often struggle to coordinate through independently developed two-dimensional plans. BIM allowed these stakeholders to develop a common language and better understanding of each other's needs. For complex areas such as the pocket track, weekly meetings were established so that every element of the design could be accurately drawn. The real-time collaboration was critical to identifying and resolving the many potential conflicts. The modeling was also useful in creating a holistic system for managing stray-current and grounding mitigation.

Construction Phase

Given the site restrictions, erection with an overhead gantry was an obvious choice. However, the logistics for assembly of the 285-ft launching girder and delivery of the precast concrete segments to the viaduct posed their own set of challenges.

Precast Concrete Segment Casting

The project schedule afforded a unique opportunity to advance the casting of the precast concrete segments with a limited number of forms. However, significant space would be needed to store precast concrete segments until erection. The design-build team enlisted the help of a



Building information modeling (BIM) was implemented on the project to improve interdisciplinary coordination. BIM was an effective tool that allowed stakeholders in the structures, track, signals, communications, and traction-power disciplines to develop a common language and better understanding of each other's needs. Figure: Walsh-Fluor Design-Build Team.

Clearances were extremely tight during erection. The precast concrete segments are shown hanging from the launching girder. Later, epoxy adhesive was applied at the segment joints, the segments were temporarily pressed together, and the post-tensioning tendons were installed and tensioned. Photo: Walsh-Fluor Design-Build Team.

Precast concrete segments in storage at the precaster's rural facility. Photo: Walsh-Fluor Design-Build Team.

A precast concrete segment is hoisted from a haul truck on the street onto a completed viaduct span before being moved into position by a segment transporter. Photo: Walsh-Fluor Design-Build Team.

qualified, established precast concrete producer located in rural Illinois, approximately 80 miles southwest of Chicago. With a sophisticated facility and large storage yard, the precaster was able to supply the project using only three forms: two for typical segments and one for pier segments.

Segment Delivery

Because only 5 of the 11 cross streets along the alignment could be closed for extended periods, options for segment delivery locations were limited. For this reason, the launching girder was designed to accommodate segment delivery from the rear. Precast concrete segments were delivered at the various cross streets, hoisted onto the newly constructed viaduct, and then brought to the launching girder with a segment transporter.

Launching-Girder Assembly

Assembling the 285-ft launching girder between two buildings on a small neighborhood street required an innovative (but not necessarily efficient) solution. The design-build team worked

A rubber-tired segment transporter delivers a segment to the launching girder. Photo: Walsh-Fluor Design-Build Team.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

When discussing aesthetics, designers often hear the question, "But won't it cost more?" The Chicago Transit Authority's Red-Purple Modernization is an example of a project that achieves improved aesthetics while costing less. The design decisions that were most significant in making this viaduct attractive were made not just for aesthetic reasons. They were made to improve durability, reduce costs, facilitate construction staging, and reduce construction impact on the surrounding urban area. Many were made by the owner before design even started. The aesthetic improvement was a by-product, but a very important and welcome by-product.

Let's start with two predesign decisions: to raise the height of the tracks above the streets and to substitute a viaduct for the existing embankment. The first decision allowed more light to penetrate the under-bridge area. The second created more space for other uses in this crowded urban area.

Then the concrete box girders simplify the appearance of the structure while eliminating overhead nooks and crannies that accumulate dirt and shelter avian critters. Plus, the girders' light-gray surfaces not only appear relatively bright and clean but also bounce the light around so that it penetrates even more completely through the crossing. Finally, the mass of the concrete girders absorbs noise, making the passage of trains less disruptive. All of these design choices will make the act of crossing under the elevated tracks or living in their vicinity more attractive, especially for pedestrians.

The Chicago Transit Authority is to be congratulated for its willingness to consider, think through the technical requirements of, and apply this new (to them) technology. The neighbors of the Lawrence to Bryn Mawr Guideway will benefit, and so will the neighbors of future modernizations.

The launching girder assembly. Photo: Walsh-Fluor Design-Build Team.

Erection of a precast concrete segment. Photo: Walsh-Fluor Design-Build Team.

with construction engineers to develop an assembly scheme that allowed the main girder of the launching girder to be preassembled directly over the cross street, then relocated onto the first span by self-propelled modular transporters. At this point, a gantry system was erected underneath the main girder to lift the launching girder to the final elevation, where final supports were installed.

A pocket-track girder slides laterally into position. The post-tensioning hardware is visible in the box girder. Photo: Walsh-Fluor Design-Build Team.

Typical Erection Sequence

All precast concrete segments were delivered to the rear of the launching girder and hung in position. Next, epoxy adhesive was applied at the segment joints, and the segments were temporarily pressed together. Then the post-tensioning tendons were installed and tensioned. Post-tensioning tendon assemblies were prefabricated off site and delivered as needed. Each span contained eight tendons with 19 to 27 strands per tendon.

The eastern alignment (consisting of 63 spans) was constructed first, along with the 11 pocket-track spans.

Upon completion of the first phase of erection, the launching girder will be removed from the alignment and stored. Once the next construction phase commences, the launching girder will be reassembled on the west alignment and the remaining 63 spans assembled.

Pocket Track Erection Sequence

The 11-span pocket track is supported by a third, narrower box girder. The pocket track and east alignment spans were erected during the same construction phase. Each pocket-track span was erected with the launching girder on the east alignment and slid transversely into its final position using a shallow-depth beam that was temporarily set on the two adjacent piers. Upon completing the erection of all precast concrete segments in that phase, the eastern and center box girders were connected transversely with a cast-in-place concrete stitch pour. A similar connection will be used to connect the center and western box girders in the next phase.

Project Status

The design-build team reached a major milestone at the end of 2022 with completion of the precast concrete segment erection and post-tensioning for the first of two construction phases. After the new system's equipment is tested and commissioned, train traffic will be diverted to the new viaduct, the existing structure will be demolished, and the next construction phase will begin. The project is expected to be complete in the summer of 2025.

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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.
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Erin Schultz is chief engineer and Kevin Buch is the Lawrence to Bryn Mawr Modernization construction manager with the Walsh-Fluor Design-Build Team in Chicago, Ill. Ben Soule is technical director with SYSTRA International Bridge Technologies in San Diego, Calif.

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New Potomac River Crossing Replaces 82-Year-Old Structure

by Ken Butler, AECOM

The new Nice-Middleton Bridge project is a $463 million design-build project that replaces a 1.9-mile-long, two-lane bridge over the Potomac River between Maryland and Virginia. The project is one of the Maryland Transportation Authority's (MDTA's) largest transportation initiatives to date. MDTA elected to use the design-build delivery method to take advantage of significant time savings and design innovation. The project was awarded in January 2020, design was completed in 11 months, and construction was completed in 30 months.

Like its predecessor, which opened in 1940, the new Nice-Middleton Bridge is 1.9 miles long; however, the new bridge provides four lanes of travel. With 59 spans, the 61-ft-wide structure was designed to cost effectively and aesthetically balance the number of spans against the number and heights of the supporting piers and foundations. The sleek new river crossing gradually ascends from the Maryland shore, rising 135 ft above the Potomac River to allow passage of tall vessels, and then descends to a level just above the water as it approaches the Virginia shoreline. The design leverages a combination of prestressed concrete girders in the low-level and high-level approach spans with haunched steel girders over the main channel. The substructure and foundations vary from precast concrete pile bents for the low-level spans to concrete columns and caps supported by waterline footings for the high-level and channel spans. Deep foundations consist of 36-in.-square prestressed concrete piles and 66-in.-diameter prestressed concrete cylinder piles

Designed and constructed in less than three years, the new Nice-Middleton Bridge over the Potomac River was opened to traffic on October 12, 2022. Photo: Skanska/Corman/McLean JV.

profile

NICE-MIDDLETON BRIDGE / NEWBURG, MARYLAND

BRIDGE DESIGN ENGINEER: AECOM, Richmond, Va.

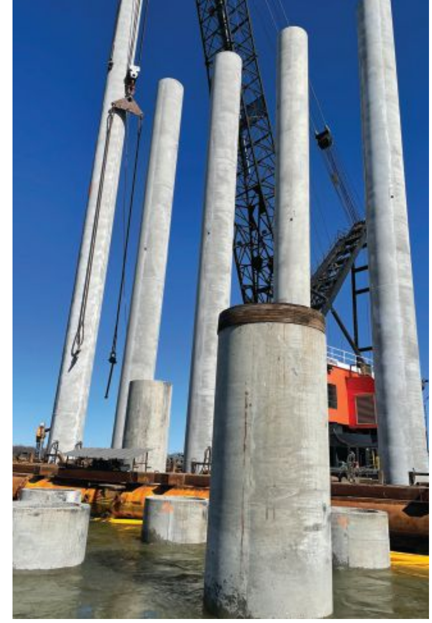
OTHER CONSULTANTS: Geotechnical engineering: Schnabel Engineering, Rockville, Md.; civil design: Wallace Montgomery & Associates, Hunt Valley, Md.; corrosion control plan: Siva Corrosion Services, West Chester, Pa.

PRIME CONTRACTOR: Skanska/Corman/McLean Joint Venture, Newburg, Md.

CONCRETE SUPPLIER: Chaney Enterprises, Gambrills, Md.

PRECASTER: Coastal Precast Systems, Cape Charles, Va.—a PCI-certified producer

The new concrete bridge (right), designed for a 100-year service life, will be more durable and require less maintenance than the previous steel structure (left). Photo: AECOM.



The main channel piers are supported by 66-in.-diameter prestressed concrete cylinder piles. Photo: AECOM.

driven to depths of up to 200 ft without splices. Most of the piles weigh more than 100 tons.

Planning for Efficiency and Durability

A simple, repetitive concrete design increased construction efficiency and reduced costs while promoting quality and durability. The design provides a 100-year service life by leveraging strategies such as minimizing the number of deck joints, using drainage details that reduce exposure to salt-laden water, using custom-designed high-performance concrete, using precast concrete components as much as possible, and selectively using corrosion-resistant reinforcing steel.

The use of concrete for the foundations, substructure, and superstructure components was key to providing the most economical and durable bridge. The greatest economy in design and construction is attained by making the structure as simple as possible, with duplication of spans, superstructure, substructure, and foundations. With this type of design, every aspect of the project, including shop drawings, fabrication, and erection, becomes less time consuming and costly. Repetition also results in higher quality.

During the proposal phase, MDTA provided engineering data and comprehensive performance specifications, as well as other pertinent information regarding the design. This

Installation of 741 prestressed concrete piles (36 in. square) and 80 prestressed concrete cylinder piles (66 in. diameter) was accomplished in 18 months. The piles were cast full length and delivered by barge directly from the precaster. Photo: Skanska/Corman/McLean Joint Venture.

MARYLAND TRANSPORTATION AUTHORITY, OWNER

OTHER MATERIAL SUPPLIERS: Expansion joints (modular joints and strip seals): Watson Bowman, Amherst, N.Y.; disc bearings: RJ Watson, Alden, N.Y.; elastomeric bearings: Cosmec/Dynamic Rubber, Athens, Tex.

BRIDGE DESCRIPTION: 1.9-mile-long, 61-ft-wide bridge with 56 prestressed concrete girder approach spans and 3 steel girder navigational channel spans

STRUCTURAL COMPONENTS: One hundred sixty-two 79-in.-deep, prestressed Maryland precast concrete economical fabrication (PCEF) girders, two hundred three 95-in.-deep Maryland PCEF prestressed concrete girders, seven hundred forty-one 36-in.-square prestressed concrete piles, eighty prestressed concrete 66-in.-diameter cylinder piles, and an 8½-in.-thick cast-in-place concrete deck reinforced with low-chromium reinforcing steel. The substructure and foundations vary from precast concrete pile bents for the low-level spans to concrete columns and caps supported by waterline footings for the high-level and channel spans.

Precast concrete "bathtubs" were an innovative detail developed by the contractor. They created a dry work space and were also used as sacrificial forms for the waterline footings. Photo: AECOM.

information allowed the design-build team to make key decisions in their proposal and before beginning final design-build, which greatly reduced the risk of unforeseen circumstances. To construct a bridge in this aggressive marine environment, it was critical that the team understood the river mechanics, subsurface conditions, climate, and exposure conditions as they relate to durability. The level of development accomplished during the proposal phase facilitated starting construction as quickly as possible after project award. Pile driving commenced six months after project award.

Low-Level Approach Spans

The low-level approach spans extend 3975 ft from the Virginia shoreline. The typical span length is 150 ft, with a typical five-span expansion unit of 750 ft. The minimum low-chord elevation is set to account for the 100-year flood elevation and wave action. The superstructure consists of six lines of prestressed, 79-in.-deep Maryland precast concrete economical fabrication (PCEF) girders spaced at 10 ft 7 in. centers, and an 8½-in.-thick cast-in-place (CIP) reinforced concrete deck, which includes a ½-in. integral wearing surface and a silane sealer. Three alternative technical concepts were accepted by MDTA: the use of 0.6-in.-diameter prestressing strands in the girders, increased concrete strength for the prestressed concrete girders, and galvanized steel intermediate diaphragms between the prestressed concrete girders. The design concrete compressive strength of the girders is 10,000 psi. Low-chromium carbon steel reinforcement was used in the deck and barriers, and the deck concrete includes synthetic fibers to reduce cracking for added corrosion protection.

The precast concrete girder anchorage zones were designed in accordance with the strut-and-tie procedure provided by the Virginia Transportation Research Council (VTRC)[1] and checked against the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[2] The VTRC procedure specified more reinforcement—approximately 350 lb of additional reinforcement per girder—than what would be required to strictly meet AASHTO requirements. With the additional reinforcement, no cracks were

The 95-in.-deep, prestressed Maryland precast concrete economical fabrication girders were fabricated with 10,000-psi self-consolidating concrete and sixty 0.6-in.-diameter strands in each girder. The use of the 10,000-psi concrete and the 0.6-in.-diameter strand was part of an alternative technical concept submitted by the design-build team and accepted by the Maryland Transportation Authority. Photo: AECOM.

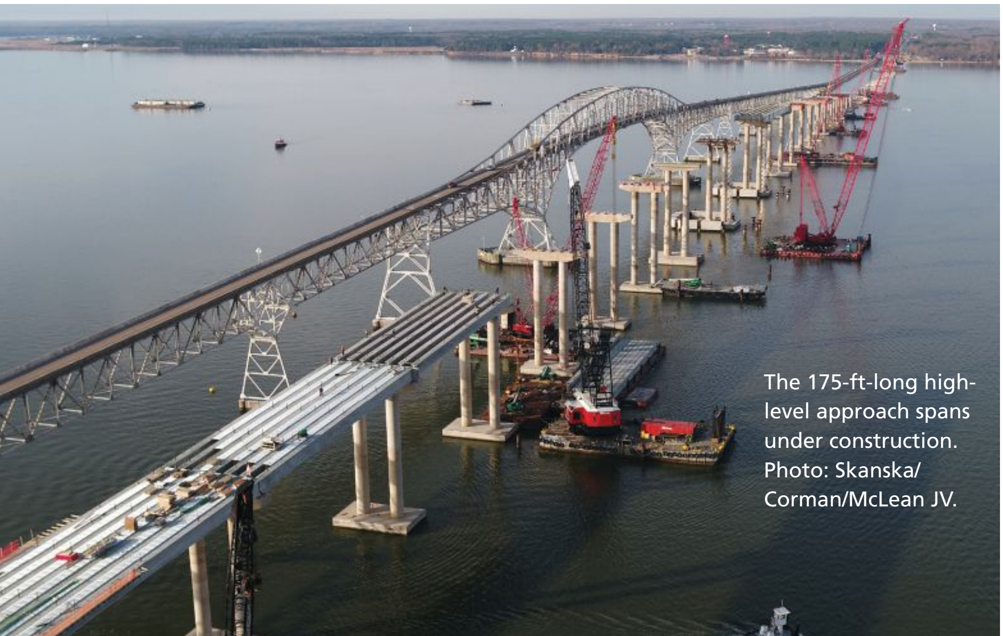
observed in the end anchorage zones of the girders.

Drainage was accommodated using MDTA-approved slotted barrier scuppers. The details for expansion joints at piers use drainage details developed by Virginia Department of Transportation and precast concrete troughs.[3]

The substructure consists of pile bents composed of concrete bent caps supported by 36-in.-square prestressed concrete piles. The typical pile bent includes six piles, each fitted with an 8-ft-long fiberglass protective jacket.

High-Level Approach Spans

The high-level approach spans begin where the height of the pile bent reaches approximately 25 ft. The high-level approach spans are almost symmetrical about the centerline of the navigation channel spans, with lengths of 2446 and 2625 ft on the Maryland and Virginia approaches, respectively. The total length of the high-level approach spans is 5071 ft, including twenty-eight 175-ft-long



The 175-ft-long high-level approach spans under construction. Photo: Skanska/Corman/McLean JV.

Virginia Department of Transportation drainage trough details were used at the piers where there were expansion joints. Minimizing the number of deck joints and using drainage details that reduce bridge components' exposure to salt-laden water are two of the strategies used on this project to provide the structure with a 100-year service life. Photo: AECOM.

spans. To minimize the number of expansion joints (seven total), the typical expansion unit is 875 ft long, comprising five continuous spans. The high-level approach superstructure consists of seven lines of prestressed 95-in.-deep Maryland PCEF girders spaced at 8 ft 11 in. centers, and the same deck details as the low-level approach spans.

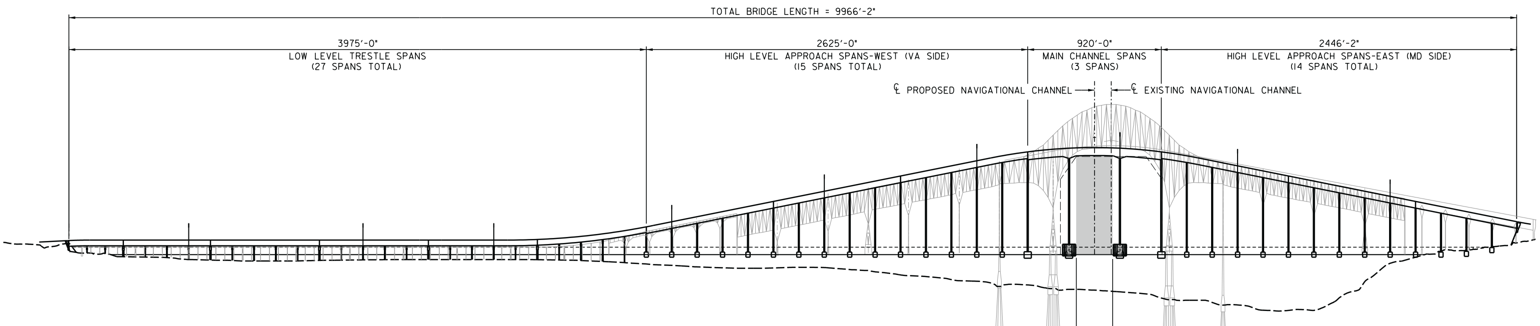
The substructure foundations consist of waterline footings supported by 36-in.-square prestressed concrete piles. The number of piles in each footing varies depending on pier height and vessel-collision requirements. The piles are designed for nominal bearing resistances up to 1086 kip. The concrete for the prestressed concrete piles is self-consolidating concrete with a 28-day design compressive strength of 7000 psi. The 36-in.-square piles contain thirty-two 0.6-in.-diameter seven-wire, low-relaxation steel prestressing strands with an ultimate tensile strength of 270 ksi. The spiral ties in the piles are hot-dipped galvanized steel. The ground conditions include a soft-clay alluvium at both approaches. The depths of the combined water and very soft soils range from 70 to 150 ft. Foundations were driven below the soft alluvium to the dense sand and gravel of the Aquia Formation to ensure axial capacity and lateral stability, and meet long-term settlement criteria.

The footings and pile layouts were designed for repetition to facilitate construction and maintain visual consistency and aesthetics. All footings are 28.5 ft wide longitudinally; waterline footings were constructed with precast concrete tubs. The tubs are sacrificial—designed for a minimum life expectancy of 75 years—and the bottom of each tub is about 2 ft below mean low water elevation.

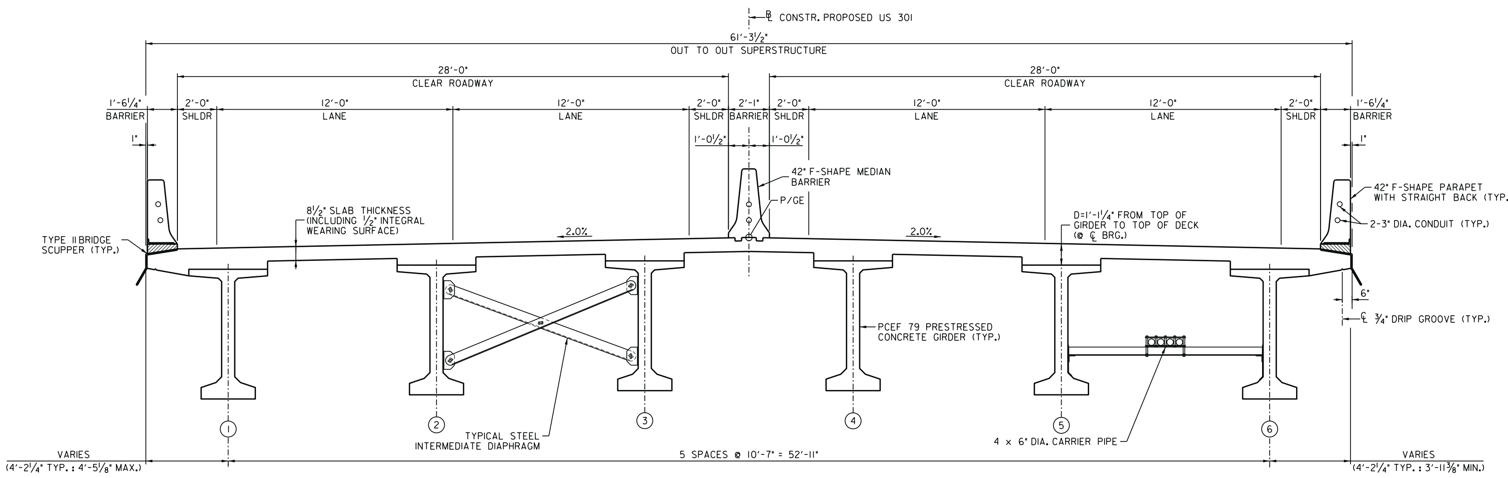
The substructure piers consist of CIP reinforced concrete circular columns with diameters of 6 ft 6 in., 7 ft 6 in., or 8 ft 6 in., depending on pier height. Traditional cantilever CIP concrete pier caps are used.

Navigational Channel Spans

The navigational envelope of 250 ft horizontal and 135 ft vertical was maintained throughout construction by shifting the existing centerline of the channel 115 ft to the west (toward the Virginia shoreline).



The new Nice-Middleton Bridge gradually ascends from the Maryland shore (on the right), rising 135 ft above the Potomac River to allow passage of tall vessels, and then descends to a level just above the water as it approaches the Virginia shoreline (on the left). The design leverages a combination of prestressed concrete girders in the low-level and high-level approach spans. The old bridge is shown in gray. Figure: AECOM.



The superstructure for the low-level approach spans consists of six lines of prestressed, 79-in.-deep Maryland precast concrete economical fabrication girders spaced at 10 ft 7 in. centers, and an 8½-in.-thick cast-in-place reinforced concrete deck, which includes a ½-in.-thick integral wearing surface and a silane sealer. Figure: AECOM.

The substructure foundations for the four channel spans consist of waterline footings supported by 66-in.-diameter prestressed concrete cylinder piles. Each cylinder pile contains thirty-six 0.6-in.-diameter carbon-fiber-reinforced polymer (CFRP) prestressing strands with an ultimate tensile strength of 370 ksi. The spiral ties are CFRP with an ultimate tensile strength of 258 ksi. The substructure piers consist of CIP reinforced concrete circular columns with diameters of 10 ft 6 in. for the first 40 ft starting from the base of the column, and then transitioning to 8 ft 6 in. for the remainder of the pier height.

The impact criterion specified for vessel protection design is a 5000 deadweight tonnage design vessel at a speed of 8 knots. For the piers adjacent to the navigation channel, the perimeter fender system is designed to absorb the total kinetic energy of the design impact. The fender system consists of a precast concrete cap beam that surrounds the pier, supported by steel-pipe piles. The 200-ft-long steel piles supporting the cap are designed to absorb impact energy by ductile yielding at plastic hinges; one of these hinges forms beneath the cap whereas another forms deep underground. For the remaining piers within the design vessel impact zone, sufficient lateral capacity is accounted for in the substructure. For the rest of the piers falling outside of the impact zone, sufficient capacity is provided to sustain impact from a 200-ton barge drifting at 1.4 knots.

Construction

The design-build team developed the construction approach for the project through a series of workshops and three-dimensional computer animation sequences. The team used the construction sequences, combined with cost- and schedule-benefit analyses, to validate the concept and virtually build the project in both three-dimensional and four-dimensional environments. This strategy enabled the team to optimize the design and construction approach, operational aspects, construction access, and land and marine construction activities, including construction over a navigable waterway and demolition of the existing bridge.

Key aspects of the project were construction access, staging, and logistics for deliveries and maneuvering the large marine fleet of equipment. The design-build team negotiated leases for parcels of land to stage materials and operate a project office. MDTA provided a 2.5-acre space adjacent to the existing bridge for the on-site batch plant. The closest ready-mixed concrete plant was located 30 minutes from the project. The on-site batch plant provided schedule and cost benefits and ensured quality.

Concrete from the on-site plant was transported from land to a set of transport barges via a conveyor system that included the redundancy of two belts. The barges, which each housed six agitators and were capable of transporting up to 90 yd^3 of concrete, were moved by tugboat to the point of placement. Concrete was then conveyed into a placement barge complete with a remixer and 140-ft-long placing boom that allowed placement of concrete at footings, columns, caps, and decks.

At the ribbon-cutting ceremony on October 12, 2022, Maryland governor Larry Hogan commented that the new bridge is "graceful in form and useful in function." The structure also has double the vehicle-carrying capacity of the bridge it replaced, and it has significantly improved safety for the traveling public.

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Ken Butler is senior vice president and director of complex bridge practice for AECOM in Glen Allen, Va.

Bridge Preservation Program: Maintaining Best Practices

by Rex L. Pearce, Virginia Department of Transportation

Bridge maintenance, preservation, and service-life extensions represent primary challenges for departments of transportation across the United States. These agencies must ensure that they have effective, sustainable programs to manage their aging bridge inventories, and when available resources—such as funding, materials, and industry response—are subject to a complex system of variables, it can be especially difficult to develop and maintain a bridge management program guided by best practices.

Adam Matteo's article, "Virginia's Strategic Approach to Bridge Management," in the Winter 2023 issue of *ASPIRE*®, aptly described the Virginia Department of Transportation's (VDOT's) bridge inventory conditions, projections, and asset management strategies. My Fall 2016 *ASPIRE* article, "Introducing New Ideas to an Aging Bridge Inventory," outlined VDOT's district-level means and methods that have evolved into best preservation practices in recent years. This article provides an update of the latter article for one VDOT district, the Staunton District. In particular, the article focuses on the district's recent asset management challenges and preservation projections and reflects on the effectiveness of ongoing methods.

Staunton's Place in the Virginia Bridge Inventory

VDOT maintains 21,000 bridges and large culverts across nine regional districts. Among all VDOT districts, the Staunton District Bridge Section is responsible for the greatest percentage of the statewide bridge inventory: the district is home to 2200 bridges (45% of which are concrete) and 1300 culverts (85% concrete). Given the size of the Staunton District inventory, the performance and condition of the district's bridges greatly influence statewide performance and condition trends. Building on a history of innovation and preservation, 97% of Staunton District's bridge inventory is currently classified as being in fair or better condition. **Figure 1** shows the VDOT statewide general condition rating (GCR) trends, which resemble the Staunton District trends.

Interstate corridors are crucial to travel, commerce, and defense, and those corridors that rely on bridges that have reached the ends of their design service life are therefore of paramount concern. Absent the fiscal resources to support a large-scale bridge replacement program, bridge maintenance, preservation, and service-life extension are critical. Staunton District's attention to the

Figure 1. General condition ratings for bridges and large culverts maintained by the Virginia Department of Transportation. All Photos and Figures: Virginia Department of Transportation Staunton District Bridge Section.

importance of bridge preservation has resulted in no poor-condition interstate bridges in this district.

Bridge Inventory Assessment

The Staunton District bridge maintenance program is founded on a current, comprehensive inventory assessment. In our data-rich era, using this valuable asset to the utmost is sound logic. Trends for structure aging, conditions, materials, techniques, and successes found through the inventory assessment help ensure the best program maintenance and preservation responses and can be used to guide decisions about future construction. Asset-query software affords extensive programmatic evaluation through condition and element-level screening.

It is crucial to remain current with deterioration trends and evaluations. Although ever-changing conditions can lead agencies to continually reprioritize target goals, annual trend updates have proven to be sufficient for Staunton District. Alignment with funding, staffing, and industry resources is integral to assessments and projections.

Deck Evaluation and Response

A good example of the district's ongoing prioritization efforts is its complex deck-aging assessment. This assesment takes into account both the bridge's GCR and the structure's element-level condition states (CSs). GCRs are ranked on a scale from 0 (failed condition) to 9 (excellent condition). CSs are ranked as 1 (good condition), 2 (fair condition), 3 (poor condition), and 4 (failed condition).

The Staunton District's interstate corridors represent a primary focus for hydromilling and overlay deck-preservation prioritization. The target structures are initially culled from the interstate bridge inventory by capturing structures with decks classified as GCR 5 (fair condition). No interstate bridges in this district have GCRs lower than 5, which is a testimony to successful preservation practices. These fair-condition bridges are then further classified by CSs. Higher priority is given to decks that have more CSs of 3 to 4. This prioritization is then refined by determining the significance of areas where CSs of 3 to 4 are coincident within both the top- and bottom-of-deck assessments. Such a condition may correspond to the highest of all deck preservation priorities, as a greater potential exists for a full-depth deck void due to deteriorated conditions.

The tabular nature of the element CS data does not lend itself to determining coincident top- and bottom-of-deck defective areas. A graphic mapping approach was recently initiated for interstate decks with GCR 5 to supplement the tabular CS data collection, enhance condition interpretation, and improve prioritization.

The deck assessment can be more complicated when a bridge has an overlay. According to National Bridge Inspection Standards, when a bridge deck is overlaid, the top of deck is then described only as a wearing surface and the deck itself is considered to be hidden beneath the overlay. This qualification may be accurate for a bituminous overlay, but interstate bridges in Virginia typically have a concrete wearing surface.

A milled or hydromilled rigid overlay is quite different from a bituminous overlay. When deteriorated deck concrete is removed to a specified depth through the milling process, that material is then replaced with new concrete to the elevation of the original traveled surface. This restoration is integral to the existing deck and most accurately described as a new top of deck. The complication is that this type of restoration may also be described as an "overlay," a term that should be further clarified.

Furthermore, while the restored top of deck would likely be classified as GCR 6 (satisfactory condition), deterioration of the bottom of deck may still govern. For efficient program management, it is best to include bottom-of-deck restoration at the same time so that classification as GCR 6 fully describes both deck surfaces upon completion of the preservation effort.

Deck Service Life: Preservation and Limitations

Staunton District interstate bridges were constructed primarily during the 1960s. By the 1980s, interstate bridge decks began to exhibit deterioration due to chloride contamination. At that point, the district set out to overlay all interstate corridor decks, which was accomplished through the 1990s.

To offset the permeable concretes used in earlier eras that allowed greater chloride penetration, epoxy overlays were initially applied to the sounder decks. Milling followed by placement of silica fume or latex-modified concrete rigid overlays restored the more deteriorated traveling surfaces (**Fig. 2**). In the 2000s, Virginia bridge decks began to be constructed with low-permeability concretes, which are considered substantially more chloride resistant than the types of concrete used previously.

Today, more than 25 years have passed since the earliest Staunton District interstate bridge deck overlays. The next generation of deck preservation must

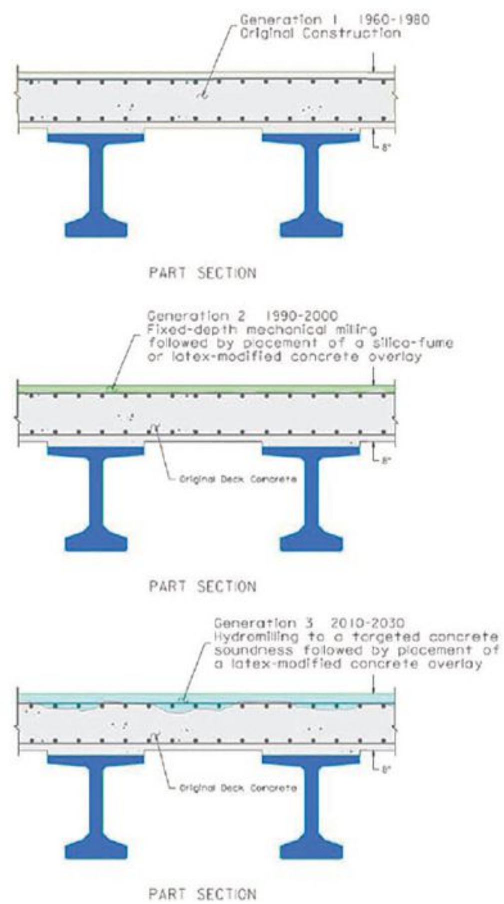


Figure 2. Three generations of concrete bridge decks on interstate bridges illustrate the evolution to the Virginia Department of Transportation's current bridge preservation practices.

Figure 3. For new construction, continuity and jointless bridge solutions are good options. This bridge has a 1915-ft-long, 100-ft-wide continuous reinforced concrete deck.

address deterioration related to ongoing chloride contamination, aging, cracking, and subsequent patching.

Hydromilling is becoming a standard practice in this arena. Unlike standard mechanical milling operations, which proceed with a fixed depth of removal and must remain above reinforcement, hydromilling dials in a targeted soundness, reaching below reinforcement where necessary to remove chloride-laden concretes. The result is a stable, deeply roughened concrete matrix that is extremely well suited to overlay.

The nature of this more in-depth restoration approach will considerably extend the program-delivery time frame for restoring the targeted structures in the district interstate system. It will likely take more than 20 years to hydromill and overlay all the bridges, whereas the earlier milling and overlay initiative was accomplished within a decade.

The true service life of a structure or its components can only be determined upon its demolition. If the third-generation deck restoration program is accomplished as described herein by the year 2030 and the program yields up to a 30-year life extension, structures will achieve nearly 100 years of service life. Considering the original service-life projection was 50 years, this is a notable accomplishment. It is fair to suggest that not all decks will reach the 100-year target and that the next effort will likely be replacement.

Preservation Methods and New Construction

Best methods and materials used in preservation retrofits will likely replicate new construction standards and solutions. All preservation practices—deck hydromilling and overlays, joint elimination, deck extensions, beam repairs, and superstructure and substructure restoration using shotcrete and self-consolidating concrete—will eventually yield to new construction. A necessary part of a bridge infrastructure maintenance program will inevitably be full replacement.

For new construction, where possible, an integral-abutment bridge type is best. The Route 340 bridge over the Shenandoah River South Fork pushes the limits of continuity and jointless bridge solutions with its 1915-ft-long, 100-ft-wide continuous reinforced concrete deck (**Fig. 3**). With deck extensions and jointless Virginia abutment types, it is exemplary of a truly jointless bridge environment and will likely achieve a century of service life. (For details of the Virginia abutment, see the "Atkinson Boulevard Over CSXT Railroad and Interstate 64" Project article in the Fall 2021 issue of *ASPIRE*.)

In other cases, the routine "workhorse" bridges that make up the majority of the bridge inventory can be preserved instead of replaced. Preservation of Interstate 64 bridge (**Fig. 4**) involved bearing reconfiguration to accommodate joint closures, deck extensions, hydromilling, and overlay replacement for a comprehensive jointless solution.

Conclusion

Virginia's bridge infrastructure is sustained only through the tireless efforts and dedication of VDOT district bridge engineers, state bridge engineers, designers, builders, and inspectors. Supported by the Virginia Transportation Research Council and Virginia's engineering universities, VDOT represents an enviable standard of agency ownership and well-met responsibilities. The common goal is to determine the best preservation approach for the previous 100 years of bridge inventory while applying the knowledge and experience gained to construct the next century's transportation system.

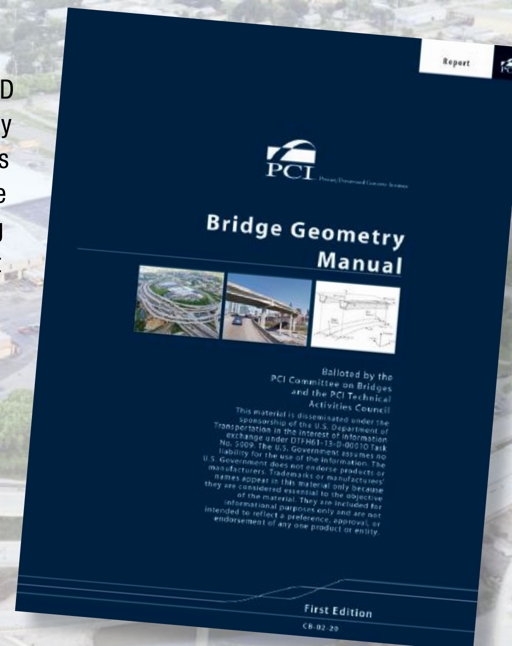
Rex L. Pearce is the Staunton District bridge engineer for the Virginia Department of Transportation.

Figure 4. Preservation strategies for this Interstate 64 bridge included bearing reconfiguration to accommodate joint closures, deck extensions, hydromilling, and overlay replacement for a comprehensive jointless solution.

Bridge Geometry Manual

FREE PDF (CB-02-20)

The *Bridge Geometry Manual* has been developed as a resource for bridge engineers and CAD technicians. In nine chapters, the manual presents the basics of roadway geometry and many of the calculations required to define the geometry and associated dimensions of bridges. This manual and course materials are not linked to any software tool. The first five chapters are dedicated to the fundamental tools used to establish bridge geometry and the resulting dimensions of bridges. The vector-based approach to locating the north and east coordinates of a point defined by a horizontal alignment is then used to define the geometry of bridges. This manual includes the bridge geometry developed for straight bridges and curved bridges. The geometry of curved bridges using both straight, chorded girders and curved girders is presented. The PCI eLearning Center has 4 courses T505, T510, T515, and T517 for on-line training based on this publication.



www.pci.org/cb-02-20

Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges

FREE PDF (CB-03-20)

The *Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges* has been developed as a resource for bridge engineers. In nine chapters, the guide documents the advancement of this bridge technology. This technology, which originated and progressed initially in Colorado over approximately 20 years, has evolved through the collaboration of designers, contractors, and owners. Much of the current technology is in its second or third generation. Agencies and builders have shown interest in replication of this bridge technology in several areas of the United States. However, there are certain areas of practice that have not been quantified. This has made it difficult for owners and the design community to fully embrace the technical solutions needed to design, construct, deliver, and maintain curved, spliced U-beam bridge systems. This document addresses those practices. The PCI eLearning Center has 4 courses T350, T353, T356, and T358 for on-line training based on this publication.

For more information on eLearning, visit page 57 of this issue.

PCI Precast/Prestressed Concrete Institute

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Advancing Sustainable Solutions—Together

by Emily Lorenz

The idea of incorporating sustainability into all phases of bridge design and asset management may seem daunting. With shorter schedules, lower budgets, and fewer employees, most agencies are reluctant to take on additional work. Yet the risks due to climate change and related policies have forced many to consider how to incorporate sustainability into bridge design, construction, maintenance, and end-of-life scenarios. For National Concrete Bridge Council (NCBC) members and others, the question is how to incorporate sustainability in the least painful and most expeditious way.

That question was advanced in November 2022, when NCBC members attended the Second Workshop of the Federal Highway Administration's (FHWA's) Concrete Pavement and Materials Technical Feedback Group (CPM-TFG) in Austin, Texas. Although the CPM-TFG hosted the workshop, NCBC members were invited by the FHWA Office of Bridges and Structures. Thus, the invitation demonstrates the partnerships among FHWA's various offices and points to the considerable challenge that all federal agencies face when it comes to the rapid implementation of more-sustainable solutions.

The work done to date on the pavement side of the FHWA may prove to be a perfect example for a similar program for bridges and structures.

The Push to Reduce Negative Impact

Several recent federal, state, and local initiatives are driving the push toward more-sustainable solutions. Federal initiatives that involve FHWA include the following:

- FHWA issued a vision for pavements: "To advance the knowledge and practice of designing, constructing, and maintaining more-sustainable pavements through stakeholder engagement, education, and development of guidance and tools."[1]
- The White House has set economy-wide targets to reduce U.S. greenhouse gas emissions by 50% by 2030 and 100% by 2050 (based on 2005 baseline).[2]
- The Federal Buy Clean Initiative was announced in September 2022.[3]
- A carbon reduction program was created through the Bipartisan Infrastructure Law.[4]

These initiatives are spurring agencies, academia, consultants, and industry to share solutions and challenges related to implementing programs to reduce negative environmental impacts.

Technical Working and Technical Feedback Groups

FHWA has a few tools available for collaboration with outside entities. Two of these options, Technical Working Groups and Technical Feedback Groups, are used within their Sustainable Pavements Program office.[5] The Sustainable Pavements Technical Working Group has been in existence for more than 10 years and is currently working on its third strategic plan. Through the Sustainable Pavements Program, resources have been developed for industry, including a pavement life-cycle assessment tool, webinars and technical presentations, technical documents, and funding to assist agencies in quantifying the emissions of sustainable pavements through the FHWA Climate Challenge.[6]

While not all of these resources are directly applicable to concrete bridges, many of them are. The remainder serve as models for bridge-specific resources that could be valuable to the industry in its quest to quantify and reduce the negative sustainability-related impacts of bridges.

The FHWA pavements office has two Technical Feedback Groups: one for asphalt and one for concrete. The CPM-TFG was formed

> *to discuss program-level challenges and opportunities concerning the performance and sustainability of concrete pavements. The CPM-TFG is a forum for discussion and for stakeholders to provide technical information to the FHWA.*[7]

Sustainability Focus

Although the mission of the CPM-TFG is not specific to sustainability, its first two workshops (held in May and November 2022) focused on achieving sustainability throughout the pavement life cycle while ensuring that pavements meet and exceed performance requirements. The following are key action items for FHWA from the May 2022 workshop:

- Advocate for easier, low- to no-cost substitutes for portland cement, such as portland-limestone cement.
- Provide education for various stakeholders related to improving the sustainability of concrete pavements.
- Focus on life-cycle-based methods for quantifying the sustainability of concrete pavements.
- Supply or supplement funding for demonstration projects related to more-sustainable pavement solutions.

These take-aways shaped the FHWA's objectives for the November workshop, which were as follows:

- Learn about ongoing efforts across stakeholder groups (agencies, academia, consultants, and industry).
- Communicate FHWA's posture and direction.
- Advance strategies across the pavement life cycle into quantifiable, practical, and implementation-ready approaches to reduce climate impacts.

The value of the CPM-TFG is in encouraging stakeholder groups to communicate how they can help FHWA meet its goals, while identifying barriers and requirements for implementation.

What about Bridges?

There is much to applaud in the pavement industry's efforts to improve its sustainability, and there is also much to learn. The Sustainable Pavements Program can serve as a model for the bridge community to create its own framework for quantifying environmental impacts and to develop practical and implementation-ready tools for all stakeholders.

This model for stakeholder engagement, technology and knowledge transfer, and partnership between FHWA and the concrete bridge industry is a perfect starting point for change. There are several challenges ahead, such as resistance to change and lack of data, but we have also been given a gift. The greatest implication for all NCBC members is that we do not have to re-create a program. The basics are already there, in the Sustainable Pavements Program.

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Cellulose Nanocrystals as an Additive for Prestressed Concrete Slab Girders

by Sivakumar Ramanathan, Krishna Siva Teja Chopperla, Taylor Washington, O. Burkan Isgor, and W. Jason Weiss, Oregon State University

Concrete is the most widely used artificial material in the world. This widespread use is undoubtedly due in part to its low cost and long-term performance and the availability of raw materials. However, there is a need to reduce the environmental impact of concrete materials and their production. It is therefore desirable to enhance the reactions of cement to provide a possible way to reduce the amount of cement needed in concrete.[1] At the same time, it is also beneficial to reduce amounts of materials that fuel forest fires; one way to achieve that goal is by finding alternative uses for small-diameter logs and even diseased wood that need to be removed from forests and are typically not viable for commercial use.[2] Toward this end, cellulose nanomaterials (CNMs), which are made using wood products, are being researched as a potential concrete additive.[3–5] Two commonly used CNMs are cellulose nanocrystals (CNCs) and cellulose nanofibers (CNFs).

CNCs are incredibly small: 3 to 20 nm wide and 50 to 500 nm long. They are not only much smaller than the conventional cellulose fibers used in concrete but also much smaller than cement particles themselves.[6] CNCs therefore act more like an additive than a conventional fiber that can bridge a crack. Research has shown that when CNCs are used at low dosages (0.2% by volume of cement), the flexural strength of cement pastes can increase in some systems by 20% to 30%, primarily due to an increase in degree of hydration of the cement.[5] CNCs are believed to be adsorbed by the cement grains, providing paths for water to migrate through the hydrated shell and resulting in increased cement hydration. When CNCs are used in low dosages (less than 0.2% by volume of the cementitious materials) in concrete mixtures, they act as water-reducing admixtures to reduce the yield stress—the minimum required shear stress to initiate flow of concrete or cement paste—and increase flow; however, at higher dosages, the CNCs begin to entangle and increase yield stress and viscosity. Properties of fresh concrete such as bleeding and proper filling of formwork depend on the yield stress of the paste.

A recent project evaluated the commercial use of CNCs in a prestressed concrete bridge constructed in Siskiyou County, Calif. The objective of the work was to assess whether there are any potential challenges in using CNCs in conventional concrete applications.

Table 1. Concrete mixture proportions used for the Moffett Creek Bridge girders

Material	Reference concrete	Concrete with 0.1% cellulose nanocrystals
Type III cement, lb/yd³	712	718
¾ to ½ in. aggregate, lb/yd³	592	602
½ in. to no. 4 aggregate, lb/yd³	1148	1135
Sand, lb/yd³	1212	1217
Water, lb/yd³	250	250
Cellulose nanocrystals, lb/yd³	0	3.6
Air-entraining admixture, oz/yd³	7	7
High-range water-reducing admixture, oz/yd³	42	42
Workability-retaining admixture, oz/yd³	21	21
Water-cement ratio	0.361	0.355

All Tables: Oregon State University.

Precast Concrete Bridge Girders in Siskiyou County

The project consisted of both trial batches of concrete and casting conventional prestressed concrete slab girders for use in the Moffett Creek Bridge project, which replaced an existing bridge in Yreka, Calif. The prestressed concrete girders were cast at the Knife River Prestress plant in Harrisburg, Ore. Each girder was 28 ft 11.5 in. long, 3 ft 5.25 in. wide, and 12 in. deep and weighed 18,000 lb. The concrete design compressive strength was 6000 psi, and the transfer strength was 4900 psi. Standard mixture proportions approved by the Oregon Department of Transportation were used for the reference concrete. A second concrete mixture was prepared with a low dosage level of CNCs (0.1% by volume of cement). While prior laboratory research has demonstrated that CNCs can enhance the hydration of cement at later ages and reduce the amount of cement needed, this work assessed the CNC as an additive for concrete in a full-scale demonstration; therefore, the amount of cement used in the mixture proportions was not reduced for this project. **Table 1** gives the mixture proportions for both concretes. A water-cement ratio of 0.36 was used with a Type III cement to achieve a high early strength for the transfer of prestress.

The CNCs used in this study were prepared by a pilot plant at the Forest Products Laboratory—a division of the U.S. Forest Service located in Madison, Wis.—using a sulfuric acid hydrolysis process (**Fig. 1**[7,8]) and supplied as a suspension in water.[9] The CNCs were strong, lightweight, colorless, and biodegradable.[10] Air-entraining and high-range water-reducing admixtures were added in similar proportions to both concrete mixtures to achieve the required fresh properties.

The concrete was batched using conventional procedures. The CNCs were added by hand to the pug-mill mixer, with the CNCs and water slurry being added to the concrete directly through the observation hatch after the tail water (**Fig. 2**). The CNC addition did not require specialized equipment or process modifications. **Figure 3** shows the fresh concrete containing CNCs being placed. The fresh properties of concrete were measured according to ASTM C1064/C1064M-17[11] (temperature), ASTM C143/C143M-20[12] (slump test), ASTM C231/C231M-17[13] (air content using the pressure method), and ASTM C138/C138M-17a[14] (unit weight) by the quality-control personnel at the precast concrete plant. In general, the fresh properties of the CNC concrete were similar to those of conventional concrete (**Table 2**).

Hardened properties of the concrete were measured, including compressive strength (ASTM C39/C39M-21[15]), splitting tensile strength (ASTM C496/C496M-17[16]), and electrical resistivity (AASHTO TP 119-15[17]). The reference concrete had a 28-day compressive strength of 8900 ± 286 psi, while the 0.1% CNC concrete had a strength of 9480 ± 488 psi.

The compressive strengths of both concretes exceeded the design strength of 6000 psi. The average compressive strength of the 0.1% CNC concrete was 8.8% higher at day 1 and 6.5% higher at 28 days than the average strength of the reference concrete. However, at 28 days, the compressive strengths of both types of concrete were statistically similar. The fact that the 0.1% CNC concrete was of similar strength, despite the higher air content in the CNC concrete (which could be expected to reduce the strength), is attributed to an increase in the degree of hydration of the cement. The 28-day splitting tensile strength of the 0.1% CNC concrete (1321 ± 80 psi) was similar to that of the reference concrete (1273 ± 46 psi).

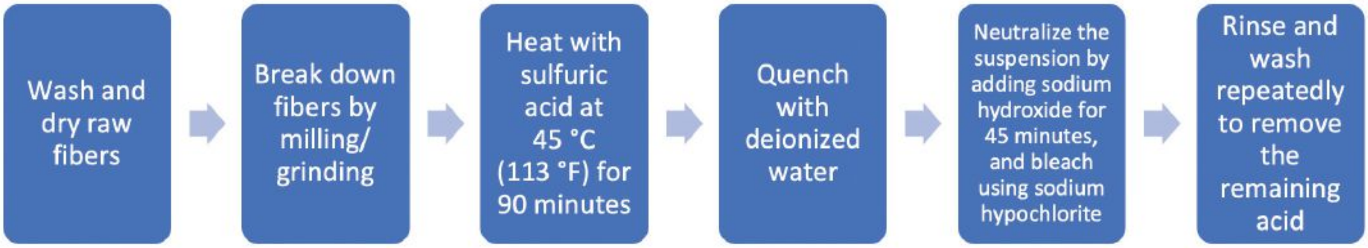

Figure 1. Flowchart describing the sulfuric acid hydrolysis process used to prepare cellulose nanocrystals for use in concrete mixtures.[7,8]

Figure 2. Addition of 0.1% cellulose nanocrystals through the observation hatch of the mixer as the concrete was being batched. Photo: Oregon State University.

Figure 3. Concrete with 0.1% cellulose nanocrystals being placed, vibrated, and finished in the prestressed concrete girder formwork. Photo: Oregon State University.

Table 2. Comparison of fresh properties of concrete with and without cellulose nanocrystals

Fresh property	Reference concrete	Concrete with 0.1% cellulose nanocrystals
Slump, in.	7.0	6.0
Air content, %	4.0	5.8
Density, lb/ft^3	143.84	141.16
Temperature, °F	72.0	72.0
Ambient temperature, °F	61.0	65.0

Table 3. Comparison of electrical resistivity of concrete with and without cellulose nanocrystals

	Reference concrete	Concrete with 0.1% cellulose nanocrystals
Resistivity, Ω-m	96.2	88.1
Standard deviation, Ω-m	2.2	1.7

In addition to compressive strength, the 28-day electrical resistivity of the samples was measured. Resistivity is increasingly being used as a potential alternative to the rapid chloride permeability test.[18] The bulk resistivities of both concretes (**Table 3**) were in the range of moderate chloride-ion permeability.

After meeting all specifications, the girders were transported to the project site in Yreka and installed by local county personnel (**Fig. 4**). The project successfully demonstrated that the addition of CNCs to concrete can result in similar or potentially improved performance. It also demonstrated the potential commercial use of these materials. Additional studies are underway to determine whether the improved hydration can be used to reduce cement content and improve the sustainability of these concretes.[1] Additionally, the use of CNCs is being tested for a wider range of cementitious materials.

Conclusion

CNCs were used as an additive to prestressed concrete used in slab girders for a bridge in Yreka, Calif. The addition of CNCs resulted in similar or slightly better concrete properties when compared with conventional concrete. While previous laboratory research has demonstrated that CNCs can enhance the hydration of cement at later ages, this work was the first full-scale demonstration of CNCs as an additive for concrete. The prestressed concrete girders cast using the CNC additive demonstrate that CNCs can be used in commercial concrete without delaying or affecting production.

Acknowledgments

The authors gratefully acknowledge the financial support from U.S. Endowment for Forestry and Communities.

Figure 4. Successful installation of the prestressed concrete slab girders. The installation was performed using county personnel. Photo: Inland Films.

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Ohio Pilot Projects Using Corrosion-Resistant Prestressing Strands

The Ohio Department of Transportation explores the use of stainless steel strand and carbon-fiber-reinforced polymer strand to resist corrosion in adjacent box-beam bridges

by Omar Abu-Hajar, Ohio Department of Transportation

Deteriorating structures continue to challenge the Ohio Department of Transportation (ODOT). As in many northern states, a large portion of ODOT's annual funding is spent repairing and rehabilitating its aging bridge inventory.

Thousands of prestressed concrete box-beam bridges were built in Ohio after 1975, with more than 300 erected in 1990 alone. With an average age of 30 years, these structures are approaching the end of their 50-year design life (**Fig. 1**). There are 7860 prestressed concrete box-beam bridges in the state, 119 of which have condition ratings of 4 (poor) or worse using the National Bridge Inventory ratings (**Fig. 2**). Based on these data, ODOT predicts that most of these structures are destined to be replaced.

In an effort to reverse this trend, ODOT initiated a study to determine whether revised design and construction practices could head off future maintenance issues and result in a 100-year service life for adjacent prestressed concrete box-beam bridges. ODOT explored several tactics, including increased concrete clear cover over reinforcement, high-strength concrete with a corrosion-inhibiting admixture, and alternative materials for reinforcement and prestressing strand.

High-Strength Stainless Steel Strand

Ohio's concrete bridges are exposed to road salts and freezing-and-thawing conditions. Among the many bridges in Ohio, the focus of the pilot projects was narrowed to adjacent prestressed concrete box beams because they are degrading faster than other bridge types. One potential solution to overcome the early deterioration of these bridges uses high-strength stainless steel (HSSS) strand. HSSS strand has high corrosion resistance and is an alternative to normal carbon steel strand in extremely aggressive environments.

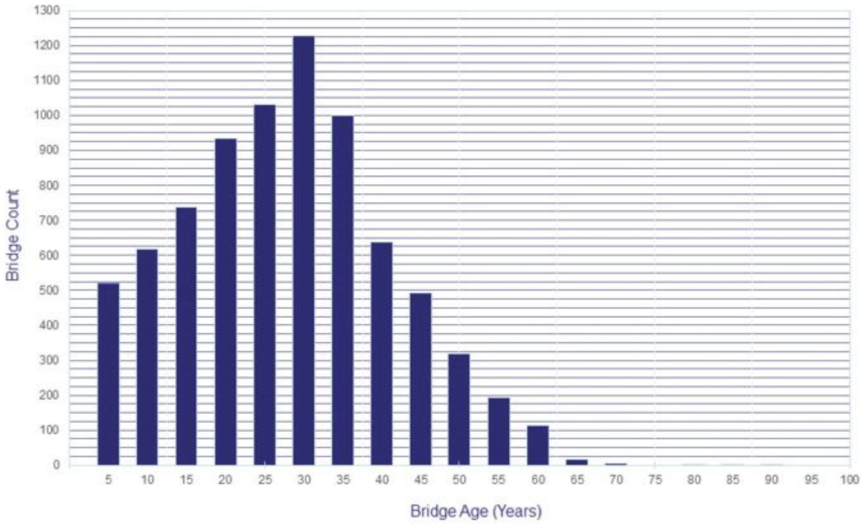

Figure 1. Age of in-service prestressed concrete box-beam bridges in Ohio based on 2019 data. All Photos and Figures: Ohio Department of Transportation.

When the ODOT program was launched in 2015, only limited relevant information was available. Several states had used HSSS strand in prestressed concrete piles, but not in beams. ASTM A1114/A1114M-20, *Standard Specification for Low-Relaxation, Seven-Wire, Grade 240, Stainless Steel Strand for Prestressed Concrete*,[1] published in 2020, was not yet available.

Compared with typical carbon or black steel, stainless steel is made from different alloys and the mechanical properties of stainless steel strand are fundamentally different (see "Structural Design Using Stainless Steel Strands" in the Spring 2018 issue of *ASPIRE®*). The most significant difference is in the ultimate strain: the minimum for stainless steel strand is 1.4%, compared with 3.5% for low-relaxation carbon steel strands.

The main concern when using HSSS strand in flexural components is its ductility. Because HSSS is a less-ductile material than carbon steel, the design must consider the strain capacity of the strand and must be balanced between flexural strength and ductility.

One of the benefits of using stainless steel strand as compared with carbon-fiber-reinforced polymer (CFRP) strand is that there are fewer constructability challenges with stainless steel strand. The prestressed concrete manufacturer can continue to use conventional tensioning methods and detensioning systems. Stainless steel strand is available domestically, but its use comes with some conditions that add to its premium price. For example, all mechanical connectors and other reinforcement should also be stainless steel. Stainless steel products should be stored and handled using tools that are not used on carbon steel, and stainless steel

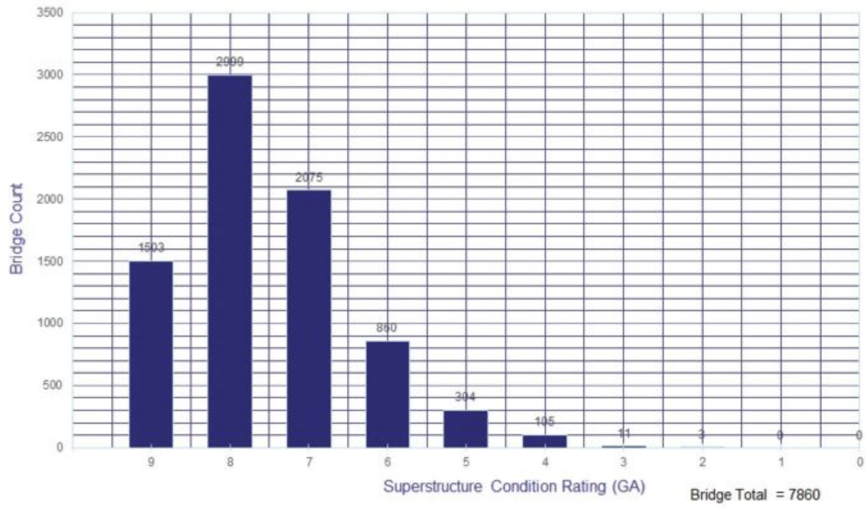

Figure 2. The superstructure condition ratings of prestressed concrete box-beam bridges in Ohio based on 2019 data.

products should not have direct contact with uncoated steel.

The first use of stainless steel prestressing and reinforcing steel in Ohio occurred in the SEN-19-14.34 bridge replacement project in Seneca County; this bridge opened to traffic on October 25, 2019. ODOT collaborated with precasters and consultants to design, fabricate, and construct the first prestressed concrete box beams using stainless steel prestressing strands in a bridge superstructure. Design software was also developed to streamline future ODOT projects with stainless steel strands in box beams.

At the time, commercial software did not allow the user to modify the strand elongation parameters. Carbon steel ruptures at a minimum of 3.5% strain, whereas stainless steel strands rupture at approximately 1.8% strain. The design value of strain rupture was set at 1.6% strain in the spreadsheet developed for stainless steel strands, so more strands were required. Additionally, commercial software did not allow the user to modify the initial stress to allow for compression-controlled or balanced-strain design methods.

The specifications for the project dictated 0.6-in.-diameter, 250 ksi stainless steel strands with an area of 0.216 in^2. According to data from the mill, the maximum elongation could range from 1.1% to 1.8%. The steel grade was 250 ksi, and the modulus of elasticity was 24,300 ksi. In the preliminary design, the jacking stress was set considering the maximum limit of 70% of the specified tensile strength of the stainless steel strand, but it was later lowered to 65% as recommended in the available literature.[2–4] The final design value was specified at 54% (29.2 kips per strand) to provide for a balanced-strain condition. ODOT set this limit to prevent strand from rupturing before reaching the ultimate compressive strain of the concrete. It was a balancing act, economizing the number of strands at an initial stress level while keeping stress limits in the beam at an acceptable level.

There was an approximate 13-week lead time for HSSS strand at the time of the project bid letting.

In addition to the stainless steel strands in the beams, stainless steel duplex alloy 2205 reinforcement with 75 ksi yield strength was used in the beams and in the composite concrete slab. Standard ODOT beam details were used for the strand layout and concrete cover to keep fabrication as typical as possible. Strands were placed 2 in. from the bottom of the beam, and beam shear reinforcement was placed below the strands for a concrete cover of 1.2 in. The Seneca County project also used transverse post-tensioning instead of the "snug-tight" tie rods that are standard in Ohio. To protect the 6-in.-thick, composite cast-in-place reinforced concrete deck, the specifications included using a 2½ in. concrete cover in the deck, sealing concrete surfaces, and installing a stainless steel drip strip at the slab's fascias.

Carbon-Fiber-Reinforced Polymer Strand

Testing data on flexural components using alternative prestressing strand materials were limited, so ODOT looked to other agencies for help with the alternative materials. Bridge engineers consulted with Michigan and Virginia Departments of Transportation as well as the American Association of State Highway and Transportation Officials' T-6 Committee on Fiber Reinforced Polymer Composites. At the time of design, AASHTO's *Guide Specifications for the Design of Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer (CFRP) Systems*[5] had not yet been published. Where there were no guidelines, sound engineering judgment was called on.

Examples of severe deterioration of prestressed concrete adjacent box-beam bridges built 35 to 45 years ago in Ohio.

Pilot project SEN-19-14.34 in Seneca County, Ohio, used stainless steel strand in a prestressed concrete adjacent box-beam bridge with a 6-in.-thick, composite cast-in-place reinforced concrete deck with stainless steel reinforcing bars. The completed structure is a 79-ft-long, 32-ft-wide single-span structure with a 30-degree skew.

When ODOT's CFRP pilot program began, CFRP strand was not available locally, and precast concrete producers were hesitant to use it. Unlike HSSS strand, CFRP strand does not closely mimic carbon steel strand when it comes to tensioning and detensioning. Whereas the process to cast beams with stainless steel strand required minimal changes from the standard process using carbon steel strand, accommodations and special procedures were necessary to cast beams with CFRP strands. For this project, ODOT used carbon-fiber composite cable (CFCC) strands that were 0.6 in. in diameter with an area of 0.179 in.^{2}, a modulus of elasticity of 22,481 ksi, and ultimate tensile strength of 337.2 ksi. The initial stress was set to 182.1 ksi with a tension force of 32.6 kips per strand.

Special equipment and procedures were needed at the precast concrete plant to install and tension the CFCC strands, a process that takes extra time and delays the turnover of the forms. Special couplers were rented from the CFCC manufacturer on a trial basis for this project. Additional protective gear was also required for fabricator personnel. Other differences in fabrication include preproduction planning, lifter and cage assembly, and strand tensioning. These processes differ from those performed for carbon steel strand. It typically takes a full workday to layout the CFRP strands and place the reinforcement. Beam fabrication is then finished by tensioning the strands and casting the concrete the following day. This essentially doubles the amount of time in the bed for beams with CFRP strands compared with traditional carbon or stainless steel strands.

Pilot project SEN-635-05.21 using CFCC was also located in Seneca County. The desirable features of CFRP strand include its noncorrosive qualities, high-tensile strength, and flexibility, and its light weight (CFRP strand is one-fifth the weight of steel strand). However, special care must be taken around the material

Pilot Project SEN-635-05.21 in Seneca County, Ohio, used carbon-fiber composite cable strands in a prestressed concrete adjacent box-beam bridge with a 6-in.-thick composite, cast-in-place reinforced concrete deck with stainless steel reinforcing bars. The completed bridge is a 54-ft-long, 32-ft-wide single-span structure with a 10-degree skew.

to avoid welding sparks and any sharp bending.

The two Seneca County pilot projects were simple spans of less than 80 ft. Both projects used 33-in.-deep and 48-in.-wide box beams. The total beam costs were $361,600 for eight 79-ft-span box beams using HSSS strand and $385,000 for eight 54-ft-span box beams using CFCC strand. Thus, the cost premiums for prestressed concrete box beams with HSSS and CFCC strand were 2.65 times and 6.25 times, respectively, the typical costs for box beams using carbon steel strand.

During the process, ODOT has evaluated whether the higher initial costs associated with these special materials are justified. Will the enhanced durability dramatically increase the service life? What are the long-term implications to maintenance and repair budgets? Economic comparisons of additional pilot projects are in the works as ODOT prepares final life-cycle cost analyses.

Future of Alternative Materials

ODOT will evaluate the use of innovative materials on a project-by-project basis. In particular, these materials may be considered along with more traditional materials for replacement projects of the high number of adjacent box-beam bridges built in the 1980s and 1990s, which account for one-half of the adjacent prestressed concrete box-beam bridge inventory in Ohio. ODOT's efforts with HSSS strand and CFRP strand on these pilot projects should prove to enhance both the durability and sustainability of these bridges. The new bridges in Seneca County are expected to provide safe access for northern Ohio communities for the next 100 years.

Although there was a significant premium in the initial cost of these pilot bridges, ODOT will continue to evaluate the life-cycle costs and look for potential savings as these materials become more mainstream. ODOT also intends to seek out improvements in conventional concrete construction methods for future projects.

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EDITOR'S NOTE

National Cooperative Highway Research Project 12-120, Stainless Steel Strands for Prestressed Concrete Bridge Elements, *is developing guidelines for the application of stainless steel strands for prestressed concrete bridge elements and proposing modifications to AASHTO design and construction specifications. The report is scheduled to publish in 2023.*

Whether carbon steel is at risk for galvanic corrosion when it is in contact with stainless steel has been debated. Research has indicated that even in the presence of chlorides, when carbon steel is coupled with stainless steel, galvanic coupling current density is very low and will not initiate the corrosion of the carbon steel. (See Qu, D., S. Y. Qian, and B. Baldock. 2003. "Effects of Galvanic Coupling between Carbon Steel and Stainless Steel Reinforcements." In Proceedings, NACE Northern Area 2003 Conference, Ottawa, Ontario, Sept. 14–17, 2003, 1-26. https://nrc-publications.canada.ca/eng/view/accepted/?id=73879711-a8c5-4ab6-a22e-80cd98919caa.)

Unique chucks are required to tension carbon-fiber composite cable strand, and the strand layout needed to accommodate the couplers wastes bed space. The couplers used for carbon-fiber composite cable strand require 11 pieces for strand preparation and assembly, compared with only three pieces for carbon steel or stainless steel strand.

CONCRETE BRIDGE TECHNOLOGY

Widening the Paudèze Bridges with Precast and Cast-in-Place Ultra-High-Performance Concrete

by Walter Waldis and Dimitrios Papastergiou,
Swiss Federal Roads Office

Built in the early 1970s, the concrete segmental box-girder bridges over the Paudèze River are a landmark of the Swiss federal highway network near Lausanne, carrying 55,000 vehicles daily. Photo: IngPhi SA, Lausanne.

In southwestern Switzerland, twin landmark bridges span the Paudèze River near the city of Lausanne and the Lavaux vineyard terraces—a UNESCO World Heritage site along the shoreline of Lake Geneva. When the federal highway bridges required retrofitting, the project team had to preserve their original form while minimizing traffic disruptions during construction.

Bridge Overview

The bridges were built between 1971 and 1973 as part of the Swiss federal highway network. Crossing the Paudèze River requires a long span: the bridges are 1325 and 1385 ft long with five spans between 150 and 340 ft. Each bridge was originally 39 ft wide and carried two traffic lanes plus an emergency lane. The concrete segmental box-girder design was erected using the balanced-cantilever method, which was the standard for 250- to 450-ft spans in Switzerland at the time. The box girders are approximately 7 ft tall at midspan and more than 18 ft tall over the piers. The box girders were designed with traditional post-tensioning in the longitudinal direction: draped tendons for every cantilever erection stage in the webs and continuous tendons in the deck (including the top flange) and the bottom flange. All tendons were grouted. There is no post-tensioning in the transverse direction.

The spans are supported by longitudinally oriented two-column piers that are up to 200 ft in height. The foundation uses drilled shafts and some anchorages to reduce horizontal movements from the sloping terrain.

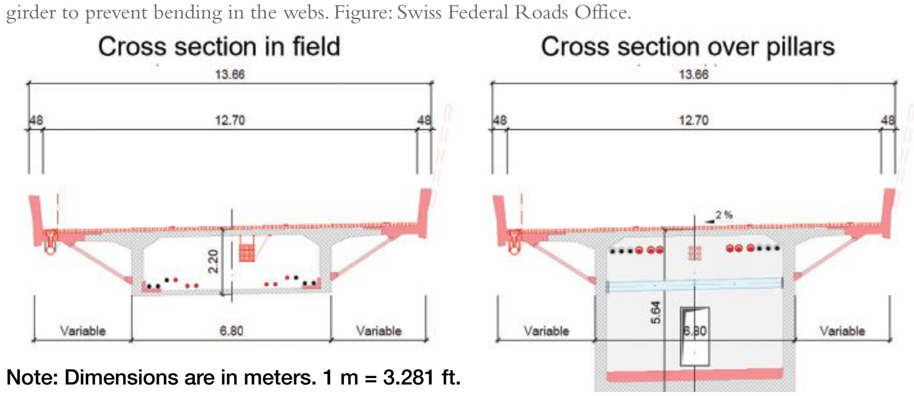
Bridge Condition

In 2002, some of the post-tensioning anchorages failed and were replaced. Deflection monitoring of the box girders began in 1988; in 2010, midspan deflections of up to 2 in. were measured on the longer spans. Tension force measurements on the continuous tendons showed losses of up to 30%, and cracks were evident in the bottom flange starting at the anchor heads. The cracking was similar to that found on the West Seattle Bridge in Washington state (see the Concrete Bridge Preservation article in the Summer 2022 issue of *ASPIRE*®). There were also a few localized shear cracks in the webs. A numerical analysis confirmed the crack pattern and that there was insufficient post-tensioning, a weak connection between the bottom flange and the webs, and insufficient flexural and shear reinforcement. An emergency repair was performed in 2010 with external post-tensioning tendons installed inside the box girders.

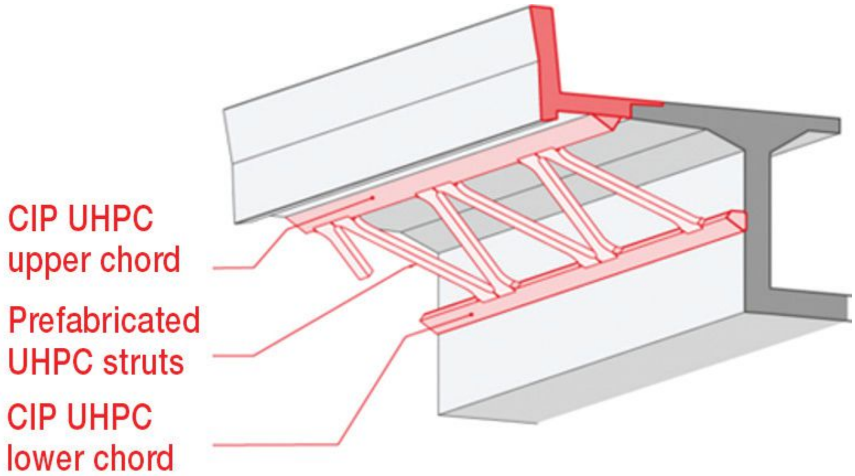
The resistance of the foundation against seismic actions and landslides was also found to be insufficient. Deicing salts combined with insufficient concrete cover and poor connections between the prefabricated concrete curbs and the slabs resulted in extensive corrosion of the reinforcing bars on the underside of the deck, as well as a lesser amount of corrosion on the top side. Joints, bearings, and abutments all needed to be replaced due to heavy chloride-induced corrosion.

The good news was that no signs of alkali-silica reaction were found in the concrete of the bridges, and there was no evidence of physical damage to the post-tensioning systems.

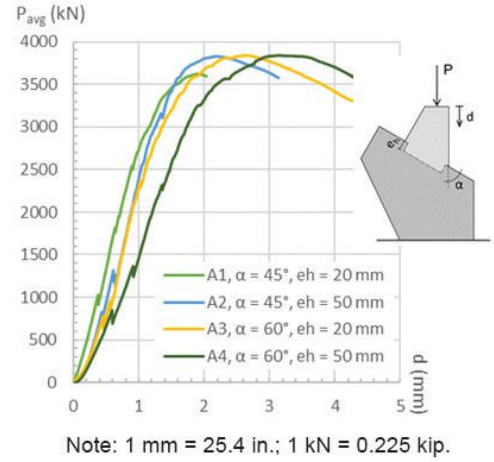
The cross section of each bridge showing the support for the widening. The location of the diagonally oriented Warren-truss style girder required reinforcement measures (shown in blue) inside the box girder to prevent bending in the webs. Figure: Swiss Federal Roads Office.



Note: Dimensions are in meters. 1 m = 3.281 ft.



The Warren girder deck support was constructed using ultra-high-performance concrete (UHPC). The struts were prefabricated, and the upper and lower chords were cast in place (CIP). Figure: Swiss Federal Roads Office.



Test results for connections between the lower chord and the box-girder web, and the upper support girder chord and the new deck extension. Figure: IngPhi SA, Lausanne.

Widening Concept

In addition to the noted deterioration, the original bridges were not wide enough according to the strategic guidelines of the Swiss Federal Roads Office, which require that each bridge be capable of carrying all traffic lanes (with reduced lane widths) during future rehabilitation measures. By approximately 2040, the Paudèze Bridges will also require additional width to enable the emergency lanes to become temporary third traffic lanes during rush hours. This change is needed because traffic volume is expected to increase beyond the current daily traffic volume of 55,000 vehicles.

The required widening for each bridge on each side was about 3 ft. The goal was to support the widened deck in a manner that would minimize the increase of bending moments in the deck. This support was achieved using a diagonally oriented girder modeled after a Warren truss. Additional longitudinal external post-tensioning tendons were installed to transfer the additional loads to the bearings.

Materials

The project team evaluated both steel and ultra-high-performance concrete (UHPC) for the Warren girder. UHPC was selected based on life-cycle cost analysis, appearance, and tolerances, and because it would eliminate the need for anchor bolts in the tendon-loaded webs.

Prefabricated UHPC struts were used to accelerate the construction schedule, achieve better quality, and produce a smooth, uniform appearance. The upper and lower chords were cast in place to allow for tolerances.

Struts are in their formwork at the precast concrete plant. Four types of forms were required. Photo: IngPhi SA, Lausanne.

The precast ultra-high-performance concrete (UHPC) struts in position before the upper and lower chords of the Warren girder are cast in place using UHPC. Photo: IngPhi SA, Lausanne.

The completed connection of the prefabricated strut to the cast-in-place upper chord shows the adjustability to the geometry that the innovative construction detail allowed. Photo: IngPhi SA, Lausanne.

The Swiss Federal Roads Office's temporary steel bridge (flyover) on the deck of the bridge resulted in a 12-ft-long work area across the entire width of the bridge that accommodated 40-mph traffic during construction activities. Photo: IngPhi SA, Lausanne.

Proof of Concept

The following full-scale laboratory tests were conducted to assess the performance of the new design concept:

- Testing of the connection between the lower chord and the web
- Testing of the connection between the top chord and new part of the deck
- Buckling tests on the struts

The test results for the connections showed large margins compared with the axial design load of around 170 kip.

Construction of the UHPC Warren Girder

The bridge required 816 struts, each weighing 500 lb and measuring 5 in. × 12 in. × 8 ft. The design of the struts was optimized for simple construction.

The 3 ft widening was constructed in 200-ft-long sections, except for one shorter section at one end. Each section was built in five stages as follows:

1. Scaffolding and installation of formwork for the lower and upper chords
2. Installation and adjustment of the prefabricated struts
3. Installation of reinforcement and placement of UHPC for the lower chord
4. Installation of reinforcement and placement of UHPC for the top chord
5. Finishing of deck formwork and reinforcement, placement of concrete for the deck

Each section required 2½ work weeks to complete.

The unique widening and rehabilitation scheme retained the bridges' clean lines and provided a modern aesthetic that preserves the area's cultural heritage landscape. Photo: IngPhi SA, Lausanne.

Accelerated Bridge Construction under Traffic

All lanes had to stay open to traffic except for short closures between 10:00 p.m. and 5:00 a.m. As a result, construction proceeded in three main stages:

- First year: foundation, external post-tensioning, abutments
- Second year: widening of one side per bridge
- Third year: widening of the remaining side and remaining bridge deck rehabilitation measures

During replacement of the abutments and joints, temporary steel bridges (flyovers) were used for two lanes to allow work to continue under them without affecting traffic.

Conclusion

Retrofitting an existing landmark bridge in a sensitive environment without interrupting traffic is a complex task. The Paudèze Bridges show that a motivated, skilled team of consultants, contractors, and owner can successfully complete such a project with the use of innovative materials and methods. This project successfully extends the service life of these bridges such that they are ready to use for the next two generations.

Walter Waldis is a senior bridge engineer and bridge specialist and Dimitrios Papastergiou is a researcher, senior bridge engineer, and head of bridges with the Swiss Federal Roads Office.

Study Shows Potential to Extend the Installation Season for Latex-Modified Concrete Overlays

by Chuck Fifelski, Trinseo

Latex-modified concrete (LMC) can be found across the United States and is typically used to rehabilitate old and worn-out concrete bridge deck overlays, parking decks, and other roadway surfaces. Known for its quality performance, LMC offers lower maintenance and total costs over a bridge's expected lifetime when compared with other concrete repair alternatives. In fact, LMC overlays provide more than 25 years of maintenance-free service life to a bridge deck.[1]

Like most concrete systems, the installation period for LMC is restrained by ambient-temperature variations. The specifications of most state departments of transportation (DOTs) only allow LMC bridge deck overlays to be installed and cured within a temperature range of 50°F to 85°F.

To challenge this constraint, a new study conducted by Trinseo, GTS Consulting, and Concrete Strategies sought to determine whether LMC can be installed and cured at lower-temperature conditions without compromising performance.[2]

Low-Temperature Curing

Using an LMC mixture containing a proprietary concrete modifier, the study examined the development of compressive strength, bond strength by slant-shear test, and chloride-ion penetration resistance over a 6-month period when LMC is cured at controlled temperatures of 35°F, 40°F, 45°F, 50°F, and 72°F.

To test for performance properties, three sets of LMC cylinders were cast and cured at the targeted temperatures for 180 days. Performance metrics were measured at 2-, 5-, 28-, 90-, and 180-day intervals for each temperature.

For all temperature conditions, the compressive strength increased from 2 to 180 days, with the LMC that was cured under lower-temperature conditions exhibiting increasing strength development over time (**Fig. 1**). After 5 days of curing, all systems achieved the 3000-psi minimum requirement typical for most state DOTs for opening a roadway to traffic.

When bond strength by slant shear was tested, the results showed that bond strength for each cure temperature increased over the test period of 28 to 180 days (**Fig. 2**). Samples maintained at lower temperatures developed higher bond strength compared with higher-temperature systems at every testing interval. In fact, the samples maintained at 40°F had higher bond strength at 28- and 180-day intervals than the other temperature systems.

Testing showed that even when cured at low temperatures, LMC improves chloride-ion penetration resistance over time (**Fig. 3**). Samples cured at lower temperatures began in the moderate range of penetrability and decreased to the low-permeability range based on the chloride-ion penetrability ratings shown in **Table 1**. Chloride-ion penetration resistance improves over time due to polymer coalescence and film formation; therefore, low-temperature curing is not expected to negatively affect the chloride-ion penetration resistance performance of LMC.

Conclusion

Overall, when LMC overlays are installed in lower-temperature curing conditions as compared with the temperature ranges in most existing DOT specifications, LMC develops excellent compressive strength, delivers excellent bond-strength performance, and generates expected chloride-ion penetration

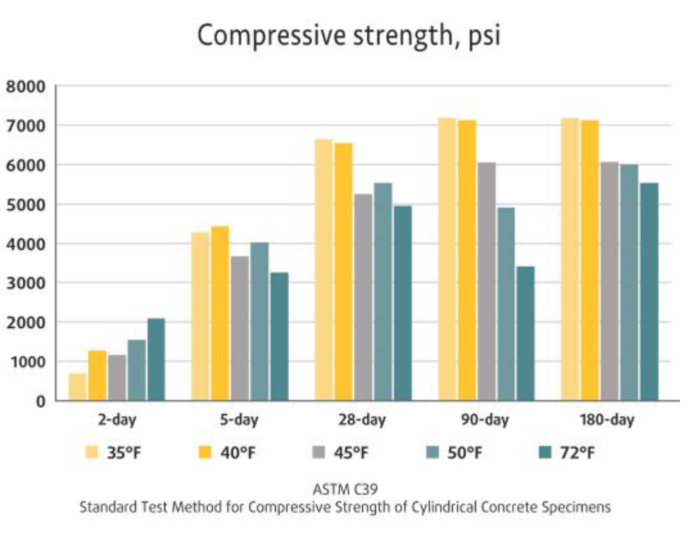


Figure 1. Compressive strength of latex-modified concrete cured under various temperature conditions. All Figures and Tables: Trinseo.[2]

Figure 2. Slant shear bond strength for latex-modified concrete cured under various temperature conditions.

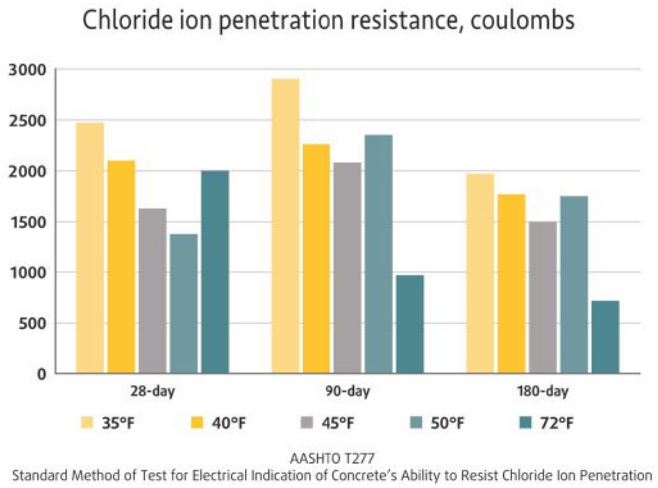


Figure 3. Rapid chloride-ion permeability test results for latex-modified concrete cured under various temperature conditions.

resistance. Thus, DOTs should reexamine temperature specifications and consider allowing the placement of LMC overlays in lower-temperature conditions, which would expand the installation season.

Table 1. Chloride-ion penetrability ratings

Charge passed, coulomb	Chloride-ion penetrability
> 4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very low
< 100	Negligible

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Precast Concrete Segmental Box Girders Arrive at the Chicago Transit Authority

by Carrie Wagener, Chicago Transit Authority

Over a decade ago, the Chicago Transit Authority (CTA) began in earnest to develop a massive construction program to replace aging infrastructure along the northern end of its busiest rail lines. Originally constructed in the early 1920s, the Red and Purple lines have seen nearly a century of use. Continuing to make costly repairs to stations, track, structures, traction power, and signaling systems was not only becoming increasingly inefficient but was also limiting CTA's ability to expand service to meet growing demand. The Red and Purple Modernization (RPM) program was developed to renew this infrastructure in several phases. In December 2018, CTA awarded a contract to Walsh-Fluor Design-Build Team (WFDBT) for design and construction work on the first phase of the program, RPM Phase 1. In this phase, a grade-separated bypass track is being constructed to eliminate the need for trains to stop and wait for other trains to cross at a flat junction and a four-track area, and support structures are being rebuilt to eliminate a series of speed-restrictive curves. In addition, four stations—Lawrence, Argyle, Berwyn, and Bryn Mawr—are being completely rebuilt along with the mile-long, four-track right-of-way and support structures adjacent to these stations.

The challenges associated with RPM Phase 1 are numerous. CTA train service operates 24 hours a day, 365 days a year, running through the construction zone as often as every 3 minutes during rush periods. The track structure runs through a city alley and is closely flanked by buildings on both sides, some of which touch the existing track structure, creating a very limited area for demolition and construction equipment. A densely populated neighborhood surrounds the project, and the effects of the project on schools, businesses, and large apartment buildings had to be considered. Consequently, when CTA issued the request for proposals for this design-build project, the goal was to find a team that could offer innovative solutions to maintain rail operations during construction, build within the extremely limited space, and maintain a safe working environment (see the Project article on page 12 of this issue).

View from the top of the gantry showing the proximity of in-service Chicago Transit Authority tracks and adjacent buildings to the new construction. Precast concrete segments are staged for erection on completed spans of the post-tensioned, precast concrete segmental box-girder structure. All Photos: Chicago Transit Authority.

Several precast concrete segments of the second span hang from the gantry as a new segment is hoisted from street level, all while a Chicago Transit Authority Red Line train proceeds unimpeded southbound past the work zone.

To encourage innovation, CTA included an alternative-technical-concept (ATC) process during procurement to enable teams to include creative approaches in their proposals, including any associated schedule and budget savings. This process enabled CTA to get the best-value proposal with the most-efficient solutions, means, and methods to build a transit infrastructure that will meet the demands of the next 100 years.

CTA's technical requirements were developed around a cast-in-place concrete substructure supporting a steel superstructure. Early in the procurement, WFDBT submitted an ATC for a post-tensioned precast concrete segmental box-girder superstructure. As CTA began its discussions, there were several key issues to be resolved: stray-current corrosion, erection means and methods, and CTA's lack of experience with the proposed structure type.

First and foremost, as an electric railroad, stray current is a huge concern for CTA. If the steel running rails and track fastening system are not adequately isolated, stray current can leak into the structure below, seeking the path of least resistance back to the substation. In a concrete structure, that path can be the steel reinforcement; in a post-tensioned structure, it can be post-tensioning tendons. Left uncontrolled, stray current can quickly corrode reinforcing bars and post-tensioning tendons. Consequently, CTA placed a variety of conditions on the approval of the ATC to ensure proper steps are taken to reduce and control

View from beneath a new segmental box-girder structure. The gantry enables top-down construction with very little lateral work zone and significantly reduces impacts to the neighborhood.

stray current as much as possible. CTA additionally required that WFDBT provide training and guided field assistance to the workforce responsible for ongoing stray-current monitoring.

Another concern was the gantry required for erecting a segmental box-girder structure. How would CTA train operators react when approaching a gantry over 280 ft long, towering above the adjacent in-service tracks? Furthermore, how would neighborhood residents react to a gantry right outside of the adjacent buildings, including schools and apartment buildings? After considering the benefits of an erection process using a gantry system, CTA ultimately decided that the challenges associated with the overwhelming size of the gantry could be overcome with the right amount of outreach. The gantry enables top-down construction with very little lateral work zone, making its use ideal for the narrow work area. Limiting swinging loads from cranes is also beneficial when work proceeds adjacent to active train service. Finally, the gantry significantly reduces impacts to the neighborhood in the form of street closures for crane staging.

The final hurdle for CTA was the simple fact that the structure would be concrete. CTA has a long history with steel, which began in the late 19th century with the first elevated open-deck track structures erected—such as the quintessential Chicago structures encircling the downtown Loop—and continues into the present. Steel is a known commodity for CTA, which has had over a century to refine design, construction, inspection, repair, and replacement techniques to ensure ongoing service as the infrastructure ages. CTA currently has few concrete structures and therefore little experience maintaining them. To overcome this hurdle, CTA added conditions to the ATC approval that the contractor provide not just classroom training on inspection processes but also field assistance to guide the CTA workforce through several rounds of inspection to ensure complete understanding.

Ultimately, CTA has realized many benefits from accepting the ATC for precast concrete segmental box girders. The segmental spans are longer and supported on fewer columns than the initially proposed steel superstructure, significantly reducing the number of foundations required, along with the associated construction risk and schedule impacts. Precasting at an off-site facility combined with top-down construction using gantries has greatly reduced the work-zone footprint in the tight confines surrounding the project. In addition, the overall duration of structural erection has been reduced. In fact, WFDBT completed the first of two segmental box-girder structures as 2022 drew to a close, and CTA looks forward to running the first trains over the structure in 2023.

Carrie Wagener is the Red and Purple Modernization program's deputy chief engineer for the Chicago Transit Authority in Chicago, Ill.

The gantry towers above the post-tensioned, precast concrete segmental box-girder structure that winds north through the city alley.

Precast Bridge Studio Advances Academia-Industry Connections

Preparing the Next Generation of Bridge Professionals

by Dr. Eric Matsumoto, California State University, Sacramento

What does innovation in the bridge industry look like? In the 2000s, when state departments of transportation began to implement self-propelled modular transporters for accelerated bridge construction to move bridges into place in mere hours, industry members and the public alike were stunned. People have similarly been surprised by recent advances in ultra-high-performance concrete, as new possibilities for bridge components and connections have emerged worldwide. Now, similarly bold innovations are needed in education to produce the next generation of bridge engineers as a tidal wave of baby boomers transitions into retirement.

In a Professor's Perspective in the Fall 2019 issue of *ASPIRE®*, I reported the initial results of a fresh approach—based on an academia-industry partnership—to prepare a new generation of bridge engineers, construction managers, and others for the transportation sector. In this article, I highlight advances and lessons learned during the past four years of the PCI Foundation–sponsored Precast Bridge Studio (PBS) at California State University, Sacramento, and call for the bridge industry to develop more partnerships with academia for the sake of the next generation.

PBS Objective and Synergy with Industry

The primary objective of PBS is to prepare a new generation of civil engineering (CE) and construction management (CM) bridge professionals through a challenging and innovative CE/CM "immersion" course project that requires student teams, under the mentorship of bridge industry members, to design a multispan precast concrete bridge and perform preconstruction services using actual bridge projects.

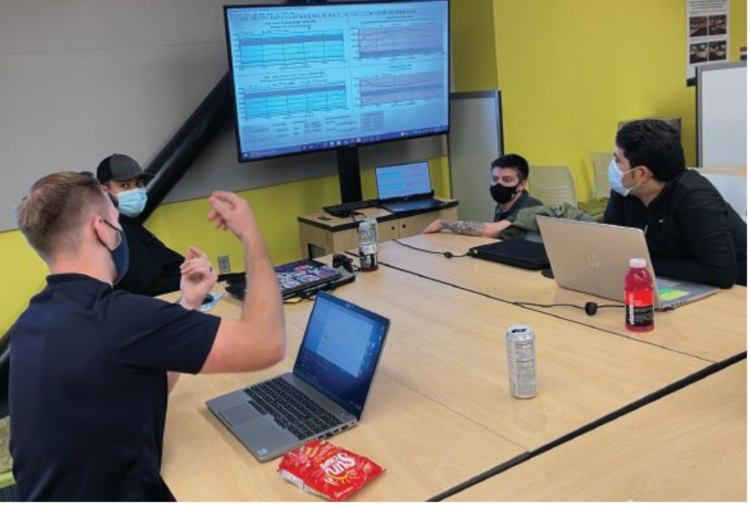
By developing close relationships between academia and industry, PBS has generated synergy not only among faculty, students, and a dedicated team of up to 20 bridge design and construction mentors but also among those who contribute to the immersion experience—precast concrete producers, bridge designers, fabricators, construction managers, contractors, suppliers, truckers, and others.

Advancements in Course Content

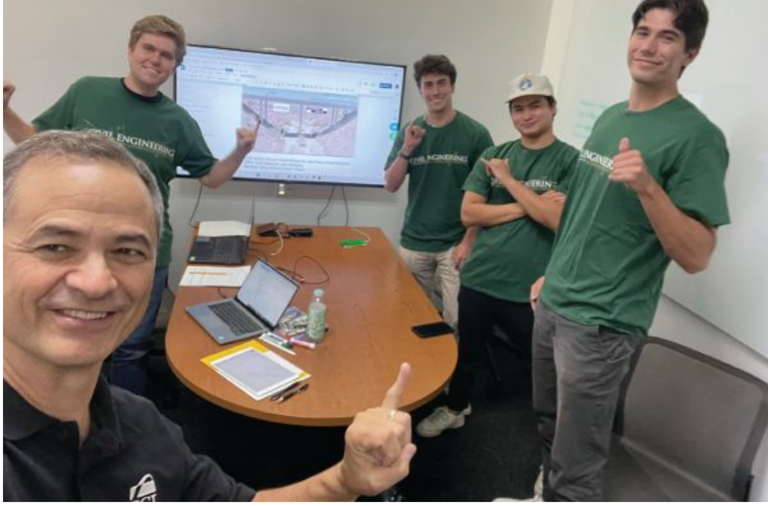
To reach the PBS goal, studio course content extends significantly beyond a typical prestressed concrete design class. Although the studio leverages important resources such as the *AASHTO LRFD Bridge Design Specifications*, the *PCI Bridge Design Manual*, PCI eLearning modules, and California Department of Transportation bridge references,

An engineering mentor leads a project introduction workshop. Photo: Eric Matsumoto.

A precaster's chief engineer explains prestressed concrete girder details to students during a tour of a precast concrete plant. Photo: Eric Matsumoto.



An assistant civil engineering mentor guides a student team during a workshop. Assistant mentors provide relatable experiences and fresh ideas. Photo: Eric Matsumoto.



Dr. Matsumoto, California State University, Sacramento, visits the student team at San Diego State University to mentor the students participating in a Precast Bridge Studio hybrid online course. Photo: Eric Matsumoto.

it also uses a wide range of additional resources, many of which were conceived and prepared through academia-industry collaboration. These resources support ambitious team deliverables. For CE students, the deliverables include type selection reports, precast concrete girder selection, superstructure design using professional software with the results then checked by hand calculations, and professional design drawings. Meanwhile, CM students tackle site logistics, project schedules, and cost estimates that integrate project specifications with local jurisdictions.

Unique PBS resources include specially designed workshops, lectures, and field trips with an emphasis on direct industry interaction and hands-on experiences. Offerings include a project introduction workshop (bridge project description, bridge layout, member proportioning, and girder-selection exercises guided by mentors); bridge design software training; a precast concrete plant tour; a prestressing strand plant tour; a precast concrete girder erection field trip; and a cast-in-place versus precast concrete bridge construction workshop. Resources also cover bridge construction materials, seismic precast concrete connections and research, estimating and specifications, and bridge foundations. These essential technical resources equip students and instill them with confidence as they prepare team deliverables and present those deliverables before a panel of industry and faculty judges and a large audience at the PBS finale.

Industry mentors who guide the teams through the projects serve a critical function in advancing course content with faculty. The most important lesson we have learned in developing course content has been to carefully consider industry recommendations, as these have led to key modifications such as the use of actual bridge projects from mentor firms, type selection reports, spreadsheet development for checking design software results, and joint CE/CM exercises in the interpretation of bridge drawings and identification of bridge components. Industry input also informed our decision to reduce course content so that teams can focus more on quality of deliverables.

Student Teams and Industry Mentors

Through five years of PBS, student teams and industry mentorship have changed to meet the needs of the program. In year 1, teams consisted solely of CE students (five per team). Combined CE/CM student teams were formed in years 2 to 5, typically with four CE and two CM students per team. This arrangement seems to be ideal for participation and CE/CM student interaction.

CE/CM interaction was established as a major program goal, yet such interaction had never occurred in the college's history before PBS. This interaction has been formative for students, improving communication and collaboration between disciplines.

Mentors play an indispensable role by helping teams accomplish technical objectives and learn professional practice. Most PBS students are graduating seniors and invariably "mature" into promising future industry professionals through the intense immersion experience under the guidance and supervision of industry mentors. Students quickly realize that mentors are rich resources of knowledge and experience but will not "hold students' hands." They expect students to do the work, come prepared, interact professionally, and produce quality deliverables on time.

Even in the bustling bridge industry within the Sacramento region, recruiting suitable mentors is a formidable challenge. However, recruitment has become easier over time as mentors have recognized the win-win opportunity that PBS provides: while helping students, mentors personally shape the future of the industry, influence the course content and the next generation, and observe first-hand the performance of prospective employees. Indeed, many students have been hired immediately upon (or before!) graduation. These new graduates bring their PBS experience to industry, and—in the words of Jim Voss, president of JVI and founder of the PCI Foundation—they "give precast a seat at the table."

Mentoring within the PBS paradigm requires considerable time and dedication. Encouragingly, the number of mentors has increased every year, from a single CE mentor per team in year 1 to an average of 2.6 CE mentors per team in year 5. This growth is a testament to the value the industry finds in this partnership and a recognition that each team needs multiple mentors.

The PBS has also carefully recruited assistant mentors, especially among program graduates. These younger mentors have shown great interest in serving, and they provide extraordinary value. They augment the work of

San Diego State University students get a close-up view of California wide-flange girder erection on Interstate 10 in Ontario, Calif. Photo: Con-Fab California.

Students get hands-on experience during a precast concrete plant tour. Photo: Eric Matsumoto.

senior mentors, provide increased and more relatable experience for students, propose fresh ideas, and help prepare new content. At the same time, they are trained under senior mentors to be part of the next generation. Assistant mentors have grown to represent over 40% of mentors during the past three years, with recent PBS graduates initiating requests to join their peers as assistant mentors.

The number of CM mentors has also grown, which is an important PBS goal. In the first four years, CE/CM teams had access to a small group of CM mentors with sufficient combined expertise to guide them. By year 5, an important objective was reached: two CM industry mentors were assigned to each team. This clearly facilitated CM student immersion, strengthened accountability, improved deliverables, and positively affected CE/CM student interaction.

Statewide Expansion

During the past three years, PBS encountered what might be called "COVID serendipity": an unexpected benefit from the pandemic. In fall 2020, PBS was conducted entirely online, as were most courses worldwide, and it became immediately apparent that course delivery was not bound by geography. This change in circumstances generated new PBS experiences and an opportunity to rethink possibilities for course delivery and collaboration. During spring 2022, I pioneered development of PBS as a hybrid online class to expand course access to students within other parts of California State University, the largest university system in the United States. In fall 2022, with strong encouragement from industry and support from the PCI West executive director, I introduced a new hybrid online PBS course with five CE students joining remotely from San Diego State University (SDSU) and California State University, Los Angeles (CSULA).

While this expansion meant that Southern California students would join a Northern California class online for lectures, all students needed a genuine PBS "industry-immersion" experience. We took four main steps to ensure an immersive experience:

- The four SDSU students were grouped into one team with two Sacramento State CM students and guided by mentors remotely. During the pandemic, online mentoring was found to be quite effective and became the preferred method by industry mentors; therefore, in fall 2022, all teams were primarily mentored remotely. In addition, I visited SDSU to assess each student's progress and bolster student learning through a small group session. The CSULA student, who was a more mature graduate student, was able to learn more independently and served as leader for another team.
- We mobilized the bridge industry in Southern California for student immersion. With the aid of PCI West, a local precast concrete producer welcomed the five of the students for a plant tour, and a Northern California precaster flew to Southern California to lead students on a California wide-flange girder erection field trip at Interstate 10 in Ontario, Calif.
- At semester's end, with PCI West support, SDSU students flew to Sacramento State to present in person with their CM teammates at the PBS finale.
- Finally, collaboration with the SDSU and CSULA professors laid a foundation for future development of this hybrid online approach, which promises to benefit the industry in California and beyond.

The effectiveness and long-term impact of PBS expansion statewide have yet to be fully determined. However, the SDSU team performed well, with team members unanimously reporting that the PBS class with its industry-immersion experiences and PBS finale solidified their interest in the precast concrete bridge industry. All SDSU team members were scheduled to attend the 2023 PCI Convention.

A Call to Action

Thanks to the vision, guidance, and support of the PCI Foundation as well as local and regional industry commitment over the past five years, PBS at Sacramento State has innovated in education, advanced new connections between industry and academia, and produced new graduates who are well equipped to become the promising next generation that the precast concrete bridge industry urgently needs. With this progress in view, I challenge the bridge industry to take definitive steps to partner with academia and secure a new generation of engineers, construction managers, and others who can serve the transportation sector throughout the United States.

Dr. Matsumoto gratefully acknowledges the contributions of Mikael Anderson, professor and Construction Management Program chair at Sacramento State University, as well as Jason Hickey from Mark Thomas.

Post-Tensioning Laboratory at the Concrete Bridge Engineering Institute

by Dr. Oguzhan Bayrak, Dennis Fillip, and Gregory Hunsicker, Concrete Bridge Engineering Institute

As part of a series of articles on the Concrete Bridge Engineering Institute (CBEI), an article in the Winter 2023 issue of *ASPIRE*® explored the institute's Concrete Materials for Bridges program. That article also presented CBEI's collaborative efforts with the National Concrete Bridge Council (NCBC) and the support provided by NCBC members. This article describes the Post-Tensioning Laboratory (PT Laboratory) program, one of CBEI's three "pillars of learning."

Program Scope

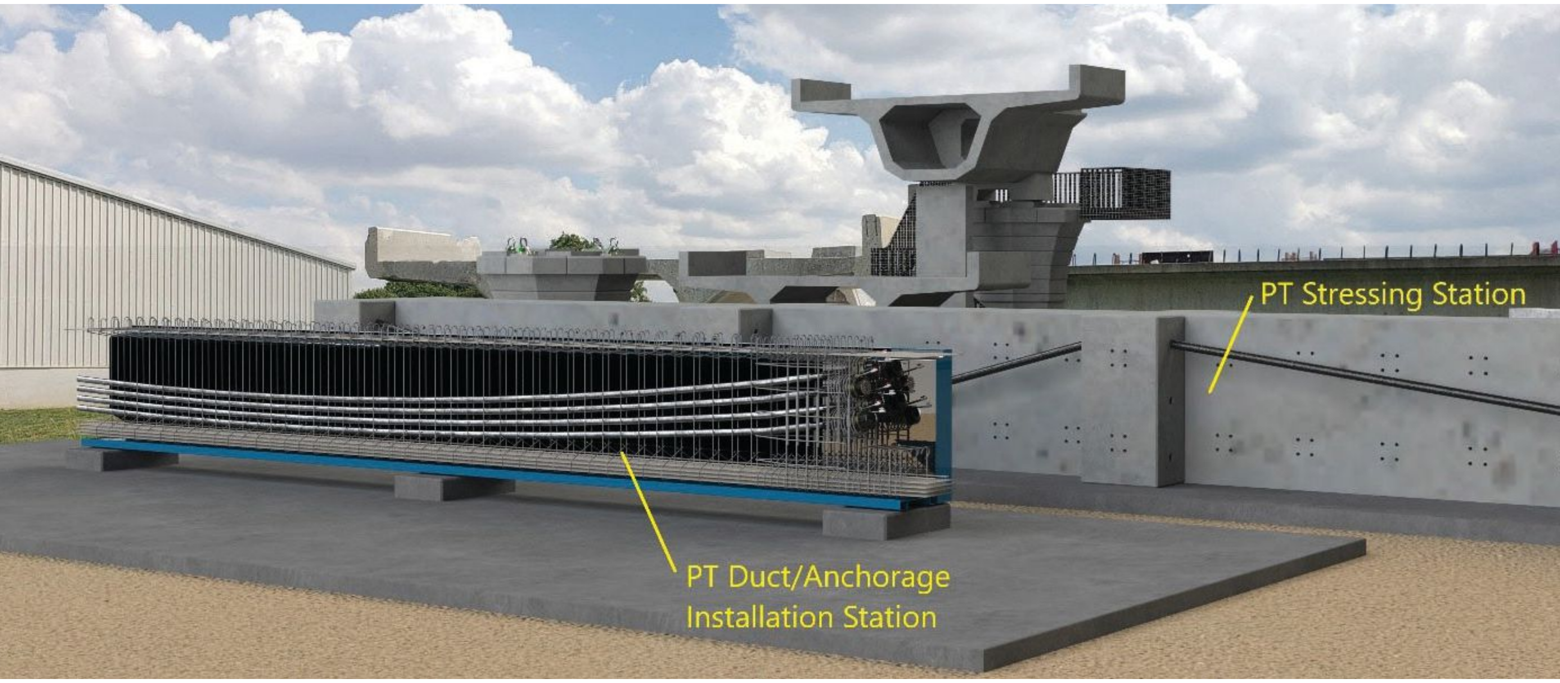
The PT Laboratory is scheduled to open in the fall of 2024. In addition to training and certification programs, it will offer technical services through formats ranging from workshops to one-on-one support for post-tensioning-related topics under the concrete solutions umbrella. The PT Laboratory, like the other CBEI programs, will be a hub for sharing information, standardizing procedures and relevant training programs, and facilitating implementation of new technologies.

Workforce-Development Goals

Many stakeholders in the construction industry have called for robust workforce-development programs that will attract workers and provide resources to train personnel in every facet of the industry. Additionally, it is recognized that post-tensioning installation in particular requires workers with a specialized technical skill set and a high standard of workmanship. To ensure that the intended durability of post-tensioned structures is achieved, it is crucial that workers who install and inspect post-tensioning receive intensive training informed by current industry standards and requirements.

In the United States, the need for qualified personnel and effective training programs has been recognized for decades. Programs such as those offered by the Post-Tensioning Institute (PTI) and the American Segmental Bridge Institute (ASBI) are required by owners around the country and have been instrumental in increasing the availablity of training offered in the industry. These robust programs have evolved with the changes in industry requirements over the last 20 years, and they have educated more than 2000 attendees.

Figure 1. Two of the Post-Tensioning Laboratory stations. All Figures and Photos: Concrete Bridge Engineering Institute.



Although the existing training programs have had a very positive impact, stakeholders have expressed that more hands-on training and "next-level" training for personnel would be an excellent complement to the existing programs and would further increase the effectiveness of training. The overarching goal for both existing training and the new offerings from the PT Laboratory is improved performance of post-tensioned structures. This goal can only be achieved if all individuals involved in planning, designing, and constructing post-tensioned structures can be uniformly educated and rigorously trained to address the expressed needs of the industry.

Target Audiences, Prerequisites, and Certification

The target audiences for the PT Laboratory training and certification programs are installation and inspection personnel directly involved in construction on project sites. Project managers, engineers, materials specifiers, and individuals who work in various other roles involved with bridge projects may also be interested in attending PT laboratory programs.

The post-tensioning courses at CBEI are intermediate and advanced courses. Most courses require the successful completion of the PTI Multistrand and Grouted PT Specialist Level 1 Certification workshop and the ASBI Grouting Certification training. These certifications and any other course-specific prerequisites are required so that attendees will already have a working understanding of post-tensioning concepts and will be prepared to focus primarily on hands-on exercises and demonstrations, while spending only a short time in the classroom.

The program will use demonstrations and hands-on exercises to teach the "whys" and "hows" of best practices. Attendees will participate in exercises on the correct approaches to post-tensioning, and they will examine lessons learned from scenarios in which things are done incorrectly. These experiences of "doing" and "seeing" are expected to accelerate the experience level of those involved in the program. By demonstrating a problem, such as a grout void, attendees will be exposed to a wide variety of situations that they may not otherwise encounter directly in the field for a substantial time. This program is designed to present as many of these problems as possible, show attendees how to avoid them, and provide troubleshooting information on how to approach them if encountered. For example, a failing pre-grout air test and the steps that are taken to remediate the issue before actual grouting of an element will be demonstrated.

Many of the PT Laboratory programs will include certification. The certification requirements of these programs will involve both written and hands-on practical exams. Demonstrating the ability to properly perform a given task or test is often a good indicator of competence.

To ensure that field personnel are equipped with an understanding of the latest industry requirements, owners may choose to establish requirements for certification, by this program or equivalent programs, in project specifications. Most certifications are valid for four years with renewal through a short program done either in-person or online, depending on the content. The renewals will primarily focus on any changes since the previous certification. Most of the certifications for the CBEI courses are anticipated to be part of the PTI and ASBI certifications, in addition to the programs PTI and ASBI currently deliver and administer.

Curriculum Development

The PT Laboratory courses are designed as modules that can be offered individually or grouped together in customized blocks. The overall curriculum includes both traditionally offered topics as well as new ones. While training will include some topics covered by existing PTI and ASBI certification courses, such as tensioning and grouting, the goal will be to complement the existing courses and avoid redundancy. Specific modules will be introduced for new procedures and materials as needed.

The following are a sampling of the initial certfification and learning modules planned:

- Installation
- Tensioning
- Grouting
- Finishing
- Protection Level 3 (PL3) monitorable tendons or electrically isolated tendons (EITs)
- Replaceable tendons
- Post-tensioning repairs
- Post-tensioning spliced-girder details
- Segmental post-tensioning details

A theme that will be emphasized throughout the modules is the importance of proper installation of the post-tensioning system for the overall durability of the structure. For example, the curriculum will emphasize that the initial installation of all materials—including the duct, anchorage, and grout vents—has a large impact on the success of the subsequent strand installation and tensioning, and duct-grouting operations. One module will be dedicated to finishing details, including the proper surface preparation and filling of blockouts, finishing of grout ports at the deck interface, proper installation of elastomeric coatings, and similar details that often represent a critical first line of protection for the post-tensioning system.

The initial modules for PL3 monitorable tendons or EITs and replaceable tendons will be one-day programs that will provide guidance for a visual and hands-on approach to the required details and equipment. The courses are designed to match the number of students with the available equipment and number of instructors to ensure appropriate access to the content.

The courses are planned to follow the guidance given in PTI/ASBI M50.3-19, *Specification for Multistrand and Grouted Post-Tensioning*,[1] and PTI M55.1-19, *Specification for Grouting of Post-Tensioned Structures*,[2] as well as manuals from the PTI certification programs.[3] (For detailed descriptions of PTI/ASBI M50.3-19 and PTI M55.1-19, see the Concrete Bridge Technology article in the Summer 2019 issue of *ASPIRE*.) The courses will also make use of references from owners and other industry groups, such as the Federal Highway Administration (FHWA)

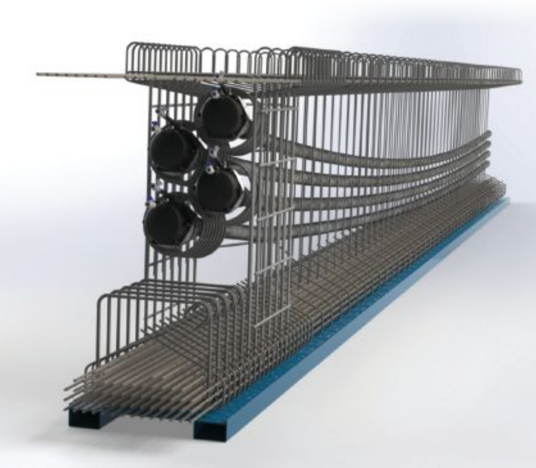


Figure 2. The Post-Tensioning Laboratory will have a duct/anchorage installation station with a "preconcrete" beam that has a reinforcing steel cage. Participants will witness demonstrations and experience hands-on activities such as installing post-tensioning components and learning proper placement of grout vents.

Figure 3 (above and on the right). Course participants in the Post-Tensioning Laboratory modules will be able to work with different types, brands, and sizes of post-tensioning systems, including both strand and post-tensioning bar systems.

publication *Replaceable Grouted External Post-Tensioned Tendons*.[4] Throughout the courses, the different tendon protection levels (PLs) will be referenced to acknowledge that different environments and structure types warrant different types of post-tensioning systems and procedures. PLs are a key concept presented in PTI/ASBI M50.3-19.

Two modules that are being developed based on input from stakeholders are the post-tensioning system inspector module and the grout testing module. The former module will provide inspector training and certification focused on understanding the requirements for certification and approval of a post-tensioning system per the PTI/ASBI M50.3-19 specification. The module will review the topics and issues encountered in the field, including defects, substitutions, material certifications, storage, and initial project qualification for a post-tensioning system. Upon completion, the attendee will be able to demonstrate through hands-on trials identification of conforming and nonconforming post-tensioning system components such as defects or substitutions. The module will also cover such topics as material certification quality control tests and traceability requirements, acceptance criteria for various components subject to corrosion or ultraviolet exposure, typical variances by type of structure and region, the various PLs, and a sample quarantine and disposition procedure for nonconforming parts.

The grout testing certification module will build on the information provided in the current ASBI Grouting Certification training. The CBEI certification will require the attendee to demonstrate, in the presence of a proctor with the testing equipment and grout, their competence in performing field grout quality control tests—such as wet density, modified flow cone, Schupack pressure bleed test, wick bleed test, sampling for a compressive-strength test, temperatures of mixed grout, ambient, water, and bag material, spot-checking bag weights and verifying expiration date, and chloride test—in accordance with the appropriate ASTM or PTI standards. The module will cover proper recording of the quality control information on a standard grout log. The module will also cover, primarily through demonstrations, potential causes of test values outside of the acceptable range and typical remediation measures.

Stations and Infrastructure

The PT Laboratory will be outfitted with infrastructure for efficient demonstrations and hands-on activities. Several stations will be arranged at the CBEI facility to focus on the various modules. The stations include an over-100-ft-long reaction beam for tendon-tensioning and duct-grouting operations (**Fig. 1**) and a companion "preconcrete" beam (**Fig. 2**) with a reinforcing steel cage for duct, anchorage, and grout vent placement operations. It will be possible to configure the reaction beam for different profiles and details, including replaceable tendons. The "preconcrete" beam at the duct/anchorage installation station will allow such activities as measuring support heights, viewing and remediating damaged ducts, maintaining proper angles and avoiding kinks at anchorage-to-duct transitions, proper placement of grout vents, and illustrating congestion at anchorage zones.

Stations specifically focused on grouting will include grout testing, grout inspection and remediation, and vacuum grouting. There will also be a station dedicated to finishing, including pourbacks, grout vent finishing, and elastomeric coatings; this station will be used for instruction focused on material installation, including proper surface preparation. Another station will be dedicated to inspection and nondestructive evaluation techniques. One station will be dedicated to post-tensioning systems and will include different types and sizes of post-tensioning systems, including both strand

Figure 4. Course participants will be required to identify conforming and nonconforming components of post-tensioning systems as part of the post-tensioning system inspector module.

and post-tensioning bar systems (**Fig. 3**). It will also include nonconforming and substituted parts that are used as part of the exercises during the post-tensioning system inspector module (**Fig. 4**).

While the PT Laboratory's infrastructure represents a significant tool, CBEI also aims to make as many of the modules as possible available in a mobile format. A train-the-trainer program is planned to disseminate the information as widely as possible. Other regional centers that could incorporate some of the larger infrastructure are being considered as part of strategy to expand the footprint of the training. Collectively, the training programs are intended to address the needs of the industry by educating and training all individuals vertically (from installers to engineers and designers) and horizontally (by establishing satellite training centers and opportunities all across the United States).

Conclusion

Plans for the PT Laboratory are ongoing under a current contract with FHWA. Articles in upcoming issues of *ASPIRE* will explore other CBEI technical programs, including the Bridge Deck Construction Inspection program, and provide status updates.

For more information about CBEI, please visit www.cbei.engr.utexas.edu.

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Approved Changes to the 9th Edition *AASHTO LRFD Bridge Design Specifications:* Use of 0.7-in.-Diameter Strands in Precast, Pretensioned Concrete Girders

by Dr. Oguzhan Bayrak, University of Texas at Austin

The forthcoming 10th edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] will include revisions to simplify designs, streamline specification language, clarify concepts and design expressions, and make allowances for new materials that have recently been introduced into the marketplace. This article focuses on the changes that involve the use of 0.7-in.-diameter strands in precast, pretensioned concrete girders. The benefits of using 0.7-in.-diameter strands are discussed in depth by Salazar et al.[2] In a nutshell, by using 0.7-in.-diameter strands in a 2-in. grid, we can lower the centroid of the prestressed reinforcement in a typical pretensioned girder and therefore increase the internal lever arm between the compressive and tensile resultants for flexural capacity. The increased internal lever arm can improve structural efficiency in cases where the flexural capacity check controls the superstructure design. A similar benefit exists for service-level stress checks. The concerns that stem from using larger strands carrying higher forces in a 2-in. grid have been addressed by several research groups at the University of Nebraska, the University of Florida, the University of Texas at Austin, and the University of Cincinnati. National Cooperative Highway Research Program (NCHRP) project 12-109 examined the body of knowledge and enhanced it by conducting additional tests and analyses to fill the gaps in our knowledge. NCHRP Research Report 994[3] includes recommendations stemming from that project, and those recommendations are the primary basis for the the changes to the AASHTO LRFD specifications[4] that will be made in the forthcoming 10th edition. The following changes to the specifications and additional specification language will all facilitate the addition of 0.7-in.-diameter strands to the bridge engineer's toolbox.

Table 5.9.4.1-1, which lists various strand sizes and minimum center-to-center spacings, will be modified to accommodate 0.7-in.- and 0.62-in.-diameter Grade 270 strands (**Table 1**). It should be noted that the 10th edition AASHTO LRFD specifications will retain the requirement that the clear distance between strands be not less than 1.33 times the maximum size of aggregate.

Article 5.9.4.3.3 item B will be revised to read as follows:

> *Debonding shall not be terminated for more than six strands in any given section or four strands for girders using 0.7-in.-diameter strand. When a total of ten or fewer strands are debonded, debonding shall not be terminated for more than four strands in any given section.*

In this way, abrupt changes made to the prestressing force and the cracking that may occur at sections where debonding begins and ends are controlled, and the potential adverse effects of debonding are minimized while the beneficial effects of strand debonding to control stresses are leveraged.

To provide additional clarification and guidance for structural detailing, new commentary (C5.9.4.4.2) will be added, as follows:

> *Several Owners have elected to provide No. 3 deformed bars beyond the end region due to past detailing practices and better performance of the girder if impacted by an over-height vehicle. The spacing varies by state, with 6 inches to 18 inches spacings being commonly noted. NCHRP Project 12-109 also noted better performance and ductility of girders with debonded strands if confinement reinforcement is extended to a location 1.5d past the end of the last debonded strands. Note the research showed the predicted girder ultimate capacity was achieved without the confinement steel.*

A new Article 5.9.4.4.3 providing guidance for horizontal transverse tension tie reinforcement will be added and will read as follows:

> *Horizontal transverse reinforcement provided to satisfy Articles 5.9.4.4.1 and 5.9.4.4.2 may also be used to satisfy this Article.*
>
> *Steel bearing plate with embedded shear studs at the girder ends may be used in lieu of the requirements of this article. Articles 5.9.4.4.1 and 5.9.4.4.2 shall still be applicable when a steel bearing plate is used.*
>
> *For all single-web beam sections with a bottom flange, horizontal transverse tension tie reinforcement shall be provided to resist potential longitudinal*

Table 1. Minimum center-to-center spacings for Grade 270 strand in the forthcoming *AASHTO LRFD Bridge Design Specifications,* 10th edition[1]

Strand size, in.	Spacing, in.
0.7 0.62 0.6 0.5625 special 0.5625	2.00
0.5000 0.4375 0.50 special	1.75
0.3750	1.50

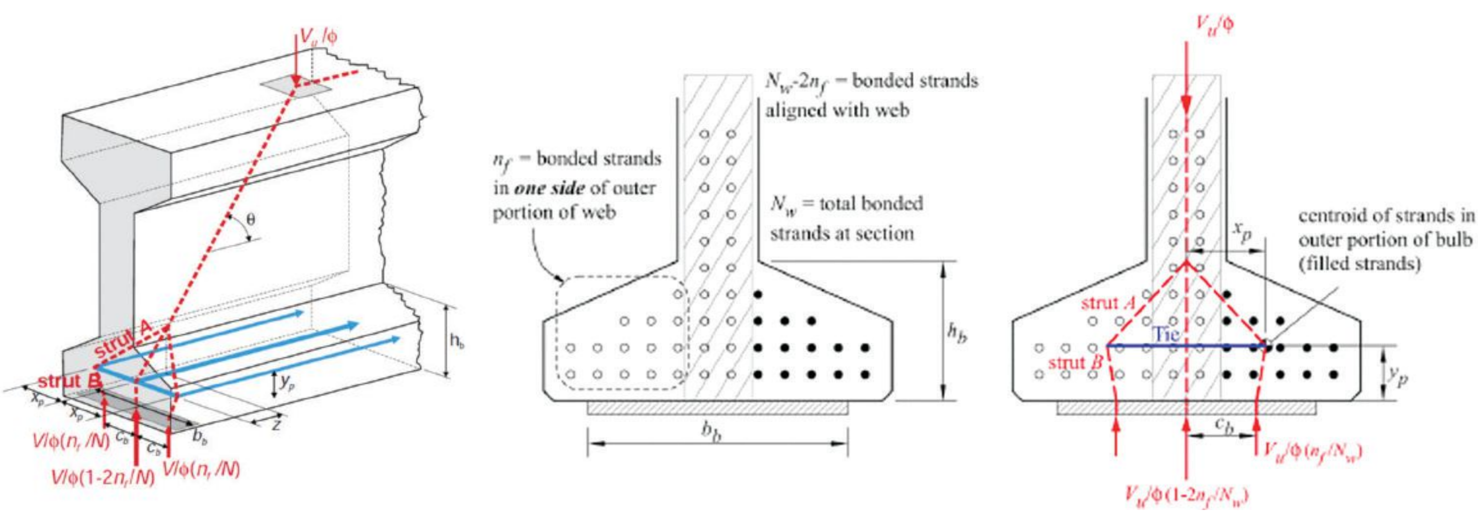

Figure 1. Strut-and-tie model for confinement reinforcement design that was developed by National Cooperative Highway Research Program (NCHRP) project 12-109. Provisions for the confinement reinforcement will be included in the new Article 5.9.4.4.3 in the forthcoming *AASHTO LRFD Bridge Design Specifications,* 10th edition.[1] Source: Fig. 2.10 in NCHRP Research Report 994.[3]

splitting cracks in the bottom flange. The strut-and-tie model and the associated Equation 5.9.4.4.3-1 shall be used to determine the required amount of horizontal transverse tie reinforcement.

The horizontal transverse tie reinforcement shall be uniformly distributed above the bearing from the end of the girder to a point h/4 beyond the bearing.

The horizontal transverse tie reinforcement shall be greater than:

$$A_s f_y = \left(\frac{n_f}{N_w}\right)\left[\frac{x_p}{h_b - y_p} + \frac{x_p - c_b}{y_p}\right]\left(\frac{V_u}{\phi}\right) \qquad (5.9.4.4.3\text{-}1)$$

where:

A_s = *area of tie reinforcement (in.*^{2}*)*

b_b = *width of bearing (in.)*

c_b = *distance from the bearing reaction force on either side of the girder to the girder center line (in.)*

= $(b_b/2)(1 - n_f)/N_w$

f_y = *yield strength of tie reinforcement (ksi)*

h_b = *depth of bottom bulb (in.)*

N_w = *total number of bonded strands at section*

n_f = *number of bonded strands in one side of outer portion of web*

V_u = *maximum factored reaction at bearing (kip)*

x_p = *horizontal distance from girder centerline to centroid of bonded strands in outer portion of bulb (in.)*

y_p = *vertical distance from girder soffit to centroid of bonded strands in outer portion of the bulb (in.)*

ϕ = *0.9 (resistance factor for tension in strut-and-tie models)*

A new commentary section (C5.9.4.4.3) will be added, as follows:

Tension forces, oriented transversely across the bottom bulb of single-web flanged sections, develop requiring tie reinforcement across the bottom flange to control longitudinal cracking at the Strength I limit state. The outcome of exceeding this limit, however, is related to transverse deformation and cracking of the flange and is likely to be a serviceability issue and not catastrophic in nature. Minimum confinement reinforcement satisfying Article 5.9.4.4.2 contributes to the tie capacity, and in many instances will be sufficient to fully resist the horizontal transverse tie force calculated using Article 5.9.4.4.3. The horizontal portion of splitting reinforcement required by Article 5.9.4.4.1, if present, contributes to the tie capacity force calculated using Article 5.9.4.4.3. This approach is consistent with the load transfer mechanism in Figure C5.8.2.2-5.

In some instances, these requirements may result in impractical horizontal transverse tie reinforcement details. An embedded bearing plate would likely be practical mitigation in such cases. Research recommends limiting the resistance of the bearing plate to 50 percent of the expected demand.

As the preceding design guidance shows, the aim of the new specification language is to allow the use of 0.7-in.-diameter strands in a rational manner by addressing the effects of larger tie forces that will be developed in 0.7-in.-diameter strands placed in a 2-in. grid spacing. The detailing requirements that apply to 0.7-in.-diameter strands apply to other strand sizes, albeit with a reduced tie force. With that stated, it is important to recognize that these requirements are substantiated with experimental data and explained by appropriate strut-and-tie models (**Fig. 1**).

References

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2. Salazar, J., H. Yousefpour, A. Katz, R. Abyaneh, H. Kim, D. Garber, T. Hrynyk, and O. Bayrak. 2017. "Benefits of Using 0.7 in. (18 mm) Diameter Strands in Precast, Pretensioned Girders: A Parametric Investigation." *PCI Journal* 62 (6): 59–75. https://doi.org/10.15554/pcij62.6-04.

3. Shahrooz, B. M., R. A. Miller, K. A. Harries, and R. W. Castrodale. 2022. *Use of 0.7-in. Diameter Strands in Precast Pretensioned Girders*. NCHRP Research Report 994. Washington, DC: The National Academies Press. https://doi.org/10.17226/26677.

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

IN THIS ISSUE

https://www.volusia.org/veteransmemorialbridge
WSP's global presence in bridge engineering is the topic of this issue's Focus article on page 6. This is a link to the Volusia County project website for the Tom Staed Veterans Memorial Bridge over the Halifax River in Daytona Beach, Fla. WSP led the design team for this bridge, which was the first precast concrete deck through-arch main span in the United States.

https://www.transitchicago.com/rpm
https://www.youtube.com/watch?v=RVsP9DjTYW4
The $1.2 billion Chicago Transit Authority (CTA) Red and Purple Modernization (RPM) Phase 1 design-build project is the subject of the Project article on page 12 and is also discussed in the Authority article on page 44. The first link is for CTA's landing page for information regarding the RPM program. The second link leads to a video rendering of the Lawrence to Bryn Mawr section of the project.

https://mdta.maryland.gov/NiceMiddletonBridge/Home
The new Nice-Middleton Bridge project is one of the Maryland Transportation Authority's (MDTA's) largest transportation initiatives to date. The $463 million design-build project to replace a 1.9-mile-long, two-lane bridge over the Potomac River between Maryland and Virginia is the subject of the Project article on page 18. The link leads to the MDTA website for the project, which includes videos of the finished bridge and the design approach.

https://www.dot.state.oh.us/OTEC/Documents/2021OTECPresentations/26/Carroll_26.pdf
The Concrete Bridge Technology article on page 34 discusses two pilot projects undertaken by the Ohio Department of Transportation to evaluate innovative materials for prestressing strands in adjacent prestressed concrete box-beam bridges. One bridge used high-strength stainless steel strands and one used carbon-fiber-reinforced polymer strands. This is a link to a presentation on the bridges from the 2021 Ohio Transportation Engineering Conference.

https://www.fhwa.dot.gov/pavement/sustainability/webinars.cfm
https://www.fhwa.dot.gov/pavement/sustainability/library
Strategies for incorporating sustainability into bridge design and construction are an ongoing topic of conversation in the concrete bridge industry. These two links lead to resources developed by the Federal Highway Administration (FHWA) to advance the sustainability of pavements. As discussed in the Concrete Bridge Stewardship article on page 28, the strategies developed for pavements may serve as a useful example for developing similar programs for bridges and structures.

https://youtu.be/FPyfZIDcM_E
The Concrete Bridge Technology article on page 30 explains how cellulose nanocrystals (CNCs) are being used as a concrete additive. This link leads to a U.S. Forest Service video that explains how diseased or damaged trees can be used as a renewable and nontoxic source for CNCs. The CNCs are then used as a supplementary cementitious material and may help decrease the amount of cement needed for concrete mixtures.

https://www.pci.org/ItemDetail?iProductCode=TR-9-22&Category=FIELD&WebsiteKey=5a7b2064-98c2-4c8e-9b4b-18c80973da1e
https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/22065/22065.pdf
Rehabilitation and widening of the twin bridges over the Paudèze River in southwestern Switzerland incorporated a unique ultra-high-performance concrete solution (see the Concrete Bridge Technology article on page 38). The first link can be used to acquire *Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete* (TR 9-22) from the PCI bookstore, and the second link accesses FHWA's *Design and Construction of UHPC-Based Bridge Preservation and Repair Solutions.*

https://www.fhwa.dot.gov/bridge/concrete/hif19067.pdf
FHWA's *Replaceable Grouted External Post-Tensioned Tendons*, available via this link, is one of the publications being used to develop content for the Concrete Bridge Engineering Institute's (CBEI's) Post-Tensioning Laboratory program. The Post-Tensioning Laboratory, which is one of CBEI's three "pillars of learning," is discussed in the article on page 51.

https://www.fhwa.dot.gov/bridge/lrfd/webinar.cfm
The FHWA article on page 58 presents a detailed discussion about concrete bridge shear load rating using the modified compression field theory. This link provides access to FHWA Webinar no. 35: *Application of the Modified Compression Field Theory in Concrete Bridge Shear Load Rating*.

https://doi.org/10.17226/26677
The LRFD article on page 55 describes provisions that will be published in the forthcoming 10th edition of American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* involving the use of 0.7-in.-diameter strands in precast, pretensioned concrete girders. Many of these provisions are based on the National Cooperative Highway Research Program Research Report 994, *Use of 0.7-in. Diameter Strands in Precast Pretensioned Girders*. The report can be downloaded from this link.

https://www.pci-foundation.org
The Professor's Perspective on page 48 discusses the Precast Bridge Studio program at California State University, Sacramento. This is a link to the PCI Foundation website, which offers information on precast bridge and architectural studios.

Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory

by Dr. Lubin Gao, Federal Highway Administration, and John Holt, Modjeski and Masters

Bridge engineers have faced technical challenges when applying the shear provisions in the American Association of State and Highway Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] to conduct shear load rating for existing concrete bridges designed to older standards. The *Concrete Bridge Shear Load Rating Synthesis Report* published in 2018 by the Federal Highway Administration (FHWA), documented the challenges.[2] The report found that bridge load-rating engineers needed more information on how the shear resistance is determined when the amount of either longitudinal tension or shear reinforcement is less than that specified in the current modified compression field theory (MCFT) design provisions for new design. In particular, example calculations were needed to demonstrate procedures to apply the MCFT. (For further information on the synthesis report, see the FHWA column in the Fall 2019 issue of *ASPIRE*®.)

Consequently, in April 2022, FHWA published FHWA-HIF-22-025, *Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory*.[3] The focus of this guide is the MCFT, which is not included in any editions of AASHTO's *Standard Specifications for Highway Bridges*. The guide comprises six chapters that can be grouped into three major sections:

- Technical procedures and validation against test data
- Application of the MCFT with the load and resistance factor rating (LRFR) method
- Examples that illustrate the application of the MCFT in shear load ratings of common bridge types

Technical Procedures and Validation

A comprehensive literature search and review was conducted to supplement the 2018 synthesis report. This review identified a 2019 paper by Caprani and Melhem,[4] which confirms that an iterative procedure is necessary to establish consistency between the load effects and capacities when estimating the shear capacity of existing girders with the MCFT. This paper also demonstrates the difference between design and load rating. For design, applied loads including design live load (HL-93) are known and unchanged. For load rating, the live load varies, and the peak resistance is to be determined through the load-rating analysis. Therefore, because the shear resistance is related to the applied loads, iteration will converge to the actual capacity for a particular type of live-load configuration (that is, axle weight [as a percentage of the gross vehicle weight] and spacings).

Choi et al.[5] further demonstrates the iterative procedure for assessment of shear capacity of concrete members. Because many old concrete bridges do not have the threshold amount

Table 1. History of the American Association of Highway and Transportation Officials' (AASHTO's) adoption of the modified compression field theory for shear

Year	Notable Change to Concrete Shear Design	Specifications
1994	• Modified compression field theory is introduced. • Tables and iterations are needed for θ and β. • Strain ε_s is calculated at middepth or at maximum strain location in the web. • Minimum shear reinforcement increased about 50% over the AASHTO *Standard Specifications for Highway Bridges* (2002).	*AASHTO LRFD Bridge Design Specifications*, 1st ed.
2007	• An alternate method called the simplified method is introduced. It requires the evaluation of two nominal concrete shear resistances: the shear resistance when inclined cracking results from combined shear and moment V_{ci}, and the shear resistance when inclined cracking results from excessive principal tensions in the web V_{cw}. • Load and resistance factor design (LRFD) is required for all federally funded bridge designs.	*AASHTO LRFD Bridge Design Specifications*, 4th ed.
2008	• Closed-form solution is provided (iteration is no longer needed). • Strain ε_s is calculated at tension reinforcement.	*AASHTO LRFD Bridge Design Specifications*, 4th ed. Interim Revisions
2010	• LRFD is required for all bridge designs.	
2017	• Alternate method (the simplified method) is removed.	*AASHTO LRFD Bridge Design Specifications*, 8th ed.

Source: Federal Highway Administration.

of reinforcement to use the MCFT procedure without reduction to compute the shear resistance, test data from University of Texas Prestressed Concrete Shear Database were used in the study to investigate size effect (the shear strength of reinforced and prestressed concrete members with insufficient web reinforcement typically decreases as the member depth increases) and the effect of shear reinforcement. The study showed the following:

- In areas of low strain where the section remains uncracked at the strength limit state (that is, where $M_u < M_{cr}$), the strain ε_s may be assumed to be zero; therefore, the angle of inclination of diagonal compressive stresses θ can be taken as 29 degrees.
- For reinforced concrete members with web reinforcement less than the minimum value, such that $A_v < A_{v,min}$, the β factor, which indicates the ability of diagonally cracked concrete to transmit tension and shear, should be adjusted for the size effect. For prestressed concrete beams, if f_{pc} / f'_c is greater than or equal to 0.02, regardless of the amount of shear reinforcement, the size effect may be neglected.

In load-rating analysis, it is important to use concurrent load effects to avoid being overly conservative, which may lead to undue load restriction. In addition, all possible combinations of load effects are to be addressed at a section under consideration. For example, maximum shear with concurrent moment, maximum moment with concurrent shear, minimum (or maximum negative) shear with concurrent moment, and minimum (or maximum negative) moment with concurrent shear should be considered.

Application of the MCFT with LRFR

Chapter 4 of the new FHWA guide concerns how to appropriately apply the MCFT in shear load rating of concrete bridges. It discusses major items that engineers should consider, for example, selection of critical sections, cross-section dimensions for shear, and load-rating expedients. It further illustrates the procedure developed in the first section. A flowchart is included to demonstrate the process to determine shear capacity by the MCFT method and as controlled by the amount of longitudinal reinforcement.

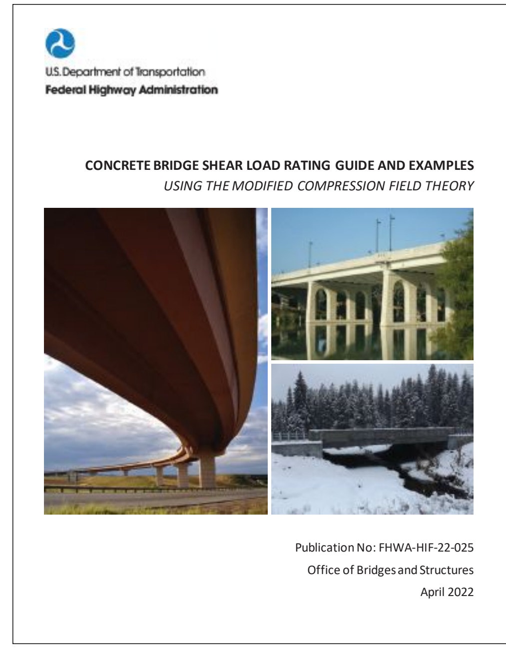
The guide also discusses a horizontal shear failure mode that has been observed at the ends of prestressed girders in laboratory tests.[6] This failure mode occurs at the flange-to-web interface, especially in modern cross sections with thin webs and large flanges that provide optimal cross-section efficiency for flexure but not necessarily for shear. It may also happen if deterioration exists at that interface. The guide also includes a flowchart that demonstrates the process to determine shear strength as controlled by horizontal shear.

Examples

The FHWA guide provides three complete shear load-rating examples:

- Example 1 is for an interior girder of a 47-ft simple-span bridge consisting of five prestressed concrete I-girders that was built in 1972.
- Example 2 is for an interior girder of a three-span (44 ft, 59 ft 6 in., 46 ft) continuous cast-in-place (CIP) reinforced concrete girder bridge. The girders were built integrally with their interior supports and with CIP full-depth diaphragms at end supports. The bridge consists of four T-beams spaced at 7 ft 10 in. and was built in 1969.
- Example 3 is for an interior web of a two-span (128 ft, 128 ft) continuous CIP post-tensioned concrete box-girder bridge. The box consists of four cells, each with a width of 9 ft 9 in. It was built in 1969.

For each example, critical sections are selected and rated for shear at design load-rating levels, both inventory and operating. These examples illustrate the shear load-rating procedure using the MCFT and LRFR developed and detailed in the earlier chapters of the guide.


U.S. Department of Transportation
Federal Highway Administration

CONCRETE BRIDGE SHEAR LOAD RATING GUIDE AND EXAMPLES
USING THE MODIFIED COMPRESSION FIELD THEORY

Publication No: FHWA-HIF-22-025
Office of Bridges and Structures
April 2022

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