ASPIRE®

THE CONCRETE BRIDGE MAGAZINE

SPRING 2022

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Global Firm with Local Perspective

CDM Smith offers broad diversity

SELMON WEST EXTENSION
Tampa, Florida

LAKE TILLERY BRIDGE REHABILITATION
Albemarle, North Carolina

CALIFORNIA STATE ROUTE 99 OVER 21ST AVENUE
Sacramento, California

Presorted Standard
Postage Paid
Lebanon Junction, KY
Permit No. 567

Photo: AECOM.

Photo: PCL Construction.

Photo: California Department of Transportation.

Features

Departments

Photo: CDM Smith.

Advertisers' Index

EDITORIAL

Photo: PCI.

Many Ways to Learn

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

I have a colleague who says, "In times of uncertainty, there's opportunity." Well, I seem to think that's exactly where we find ourselves right now—with opportunity!

It was hard not to notice the lack of attendees at this year's Transportation Research Board (TRB) annual meeting in Washington, D.C. The low turnout was understandable, given the COVID-19 pandemic and the virus's ability to morph. Still, those of us at the meeting had focused discussions in several sessions that highlighted the need to develop a strategy and programs to advance the engineering skills and abilities of the existing and upcoming engineering workforce. We continue to look for ways to surmount the age-old challenge of remaining up to date with the current and evolving (future) engineering environment. Time constraints continue to challenge most everyone I chatted with, but most concur that this is a topic we need to advance. As you may recall, Gregg Freeby and I discussed the National Concrete Bridge Council's areas of emphasis, which includes knowledge dissemination, in our Winter 2022 *ASPIRE*® editorial.

With the challenge of shaping our industry's future fresh in my mind, I returned to my PCI office to renew my focus on updating PCI's *Bridge Design Manual* (BDM). The BDM is a living document, and, as such, it needs a bit of TLC from time to time. Our bridge community has changed in the last few years, and we now have a broader array of strategies to address in areas such as design and construction methods, inspection criteria, maintenance, and preservation (extension of service life).

The TRB meeting and the BDM updating process got me thinking about how our bridge community can positively affect the educational challenges of our existing and future workforce. I've been exposed over the years to several educational delivery methods. In the past, most of us attended conferences and went to sessions to discover the latest thinking. Then along came webinars with limited audience questions and answers. Like you, I am most familiar with self-study, eLearning, distance learning, and instructor-led training (ILT) programs. I define these programs as follows:

- Self-study—increasing one's fundamental knowledge and proficiency through self-paced individual research and study.
- eLearning—computer-based educational programs with online interaction between the student and the preplanned experience.

On December 16, William Nickas gave the keynote speech at the Fall 2021 Sacramento State Precast Bridge Studio Finale at the Sacramento State Union after four integrated civil engineering and construction management student teams presented their design-build projects before a judging panel and other local and national bridge industry mentors and representatives. Photo: Courtesy of Dr. Eric Matsumoto.

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CDM Smith designed a 9-mile portion of Louisiana Highway One that uses a precast concrete two-lane elevated highway to provide reliable access to Port Fourchon, a major port on the Gulf of Mexico. The photo was taken shortly after completion and before the removal of existing moveable-span bridge.

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eLearning can be supplemented with embedded videos, animations, and embedded knowledge checks.
- Distance learning—computer-based educational programs with online interaction between the student and the presenters or faculty, who can answer questions in real time or via email. Distance learning can be supplemented with online videos, slideshows, homework or required assignments, and so on.
- ILT—an interactive, small-group program with real-time discussion, question and answer sessions, homework, and student-led assignments.

Which method gives us the best opportunity to keep our knowledge fresh? When evaluating the effectiveness (or even appropriateness/relevance) of each of these methods, one must consider the starting point and the desired outcome.

Recently, I had an opportunity to visit Dr. Eric Matsumoto's structural engineering program at California State University, Sacramento, College of Engineering & Computer Science, and was exposed to the exciting teaching and learning environment of an immersive precast concrete bridge studio.

The purpose of this studio program is to provide students with immersive, experiential exposure to precast concrete bridge design, construction, and delivery. Further, the program offers a unique environment for students in the engineering and construction management programs to partner throughout the program life. The studio draws its strength from its partnerships with precast concrete fabricators, consulting engineering firms, contractors, specialty partners, a bridge software company, and Caltrans. Students must address many key questions: Why are concrete bridges the best solution? What conditions make this solution the most advantageous? How does the choice of precast, prestressed concrete affect bridge design, materials, and construction? How is a prestressed concrete bridge designed, from inception to final detailed design? What supplementary elements such as seismic conditions, site limitations, or innovative materials need consideration?

The final phase of this program requires students to defend their prestressed concrete bridge solution to industry experts. This reminded me of an exit interview from a value engineering proposal or process team report to the upper management at a department of transportation. You could see how well the students understood the needs of the project and the desired outcomes through their recommendations. Students who successfully navigate this rigorous studio program will enter your fabrication facility, consulting firm, or department of transportation with a level of knowledge that will elevate your programs. Well done, Dr. Matsumoto! (See the Professor's Perspective in the Fall 2019 issue of *ASPIRE* to learn more about the Cal State design studio, and the Winter 2022 issue to learn about the precast concrete studio at Idaho State University.)

With this inspiration, I say let's take ILT up a notch, incorporate a hands-on component, and call it ILT+. Everyone—engineers in the making, seasoned engineers, project managers, construction workers, inspectors—can benefit from hands-on training. Overall, the hands-on experience is valuable and develops a better qualified workforce. We, as individuals, can foster informal ILT+. For example, arrange a field trip for a local university group or your employees, bring hands-on activities to the office, or take a recently hired engineer with you to a jobsite. It's an eye-opener to see an ironworker struggle to install reinforcement that looked so pretty on your computer screen.

I honestly believe ILT is the most effective and impactful educational delivery system—at least for me and these soon-to-be engineers. If I were left to my own self-study or distance learning efforts, I'd soon be overcome by a condition known as OTTD ("Other Things to Do"). This condition—which often comes on slowly, but rapidly becomes debilitating—is characterized by letting anything and everything get in the way of getting something done. I am extremely envious of those of you who are accomplished with self-study and distance learning, and I acknowledge that those platforms are highly successful and very popular with many.

Now I had better put my head down and work with all these subject matter experts to keep this PCI BDM update project moving ahead for the Fall 2022 release date.

It's never too late to educate!

CONTRIBUTING AUTHORS

Dr. Oguzhan Bayrak is a professor at the University of Texas at Austin and was inducted into the university's Academy of Distinguished Teachers in 2014.

Scott Campbell is senior vice president, structures and codes, for the National Ready Mixed Concrete Association.

Brian Killingsworth is executive vice president and department head for local paving for the National Ready Mixed Concrete Association.

Dr. Tyler Ley is the Gilbert, Cooper, W&W Chair at Oklahoma State University. His research interest is in improving the constructability, economy, durability, and sustainability of concrete. He is a self-proclaimed concrete freak!

Thomas Saad is a senior structural engineer at the Federal Highway Administration Resource Center, where he provides technical support to engineers across the country in the design and analysis of bridges and other structures.

Linh Warren is a structural engineer at the Federal Highway Administration, where she provides technical support to national structural engineering program areas, including load rating, inspection, design, construction, and security of bridges and structures.

CONCRETE CALENDAR FOR SPRING 2022

The events, dates, and locations listed were accurate at the time of publication but may change as local guidelines for gatherings continue to evolve. Please check the website of the sponsoring organization.

April 11, 2022
ASBI Grouting Certification Training
Commons Conference Center
J. J. Pickle Research Campus
Austin, Tex.

April 19–22, 2022
PCI Level I/II Quality Control School
Online

April 24–27, 2022
PTI Convention
Hilton La Jolla Torrey Pines
La Jolla, Calif.

May 4–6, 2022
PTI Certification Training: All Levels
Westin Baltimore Washington – BWI
Baltimore, Md.

June 12–16, 2022
fib ***International Congress 2022***
Clarion Hotel The Hub
Oslo, Norway

June 20–23, 2022
AASHTO Committee on Bridges and Structures Annual Meeting
Omni William Penn Hotel
Pittsburgh, Pa.

June 20–23, 2022
PCI Level I–III Quality Control School
Chicago, Ill.

July 17–20, 2022
International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, Pa.

July 31–August 4, 2022
AASHTO Committee on Materials and Pavements Annual Meeting
Miami, Fla.

September 13–15, 2022
PTI Certification Training: All Levels
Phoenix, Ariz.

September 20–24, 2022
PCI Committee Days Conference
Loews Chicago O'Hare Hotel
Rosemont, Ill.

October 4, 2022
Repair of Structural Concrete
ACI Monthly Online Webinar Series

October 4–7, 2022
PTI Committee Days
JW Marriott Cancun Resort & Spa
Cancun, Mexico

October 23–27, 2022
ACI Fall Convention
Hyatt Regency Dallas
Dallas, Tex.

October 31–November 2, 2022
ASBI Annual Convention and Committee Meetings
Hyatt Regency
Austin, Tex.

December 7–9, 2022
International ABC Conference
Miami, Fla.

January 8–12, 2023
Transportation Research Board Annual Meeting
Walter E. Washington Convention Center
Washington, D.C.

January 16–19, 2023
World of Concrete
Las Vegas Convention Center
Las Vegas, Nev.

February 21–25, 2023
PCI Convention at The Precast Show
Hyatt Regency & Convention Center
Columbus, Ohio

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

Editor's Note:

The *ASPIRE*® team welcomes and values all reader comments. Recently, we received an email requesting a hard copy of a back issue. In the follow-up correspondence, the reader remarked, "*ASPIRE* is an excellent magazine. It is one of the few engineering/construction publications I typically read cover to cover."

We strive to deliver a high-quality publication with relevant content for the concrete bridge industry and are gratified to hear from readers that we are hitting that mark.

Global Firm with Local Perspective

Civil engineering firm CDM Smith is broadly diverse with in-house professionals who specialize in transportation, facilities, energy, environmental, and water industries

by Monica Schultes

CDM Smith worked with Sverdrup to perform preliminary design for the South Carolina Department of Transportation's Ravenel Bridge near Charleston. At the time of design, the bridge was the largest cable-stayed bridge in the United States. This photo was taken shortly after completion of the new bridge in 2005, but before the truss bridges that it replaced were demolished. All Photos: CDM Smith.

CDM Smith is a consulting engineering firm that specializes in the transportation, facilities, environmental, energy, and water industries. On separate trajectories in the civil and infrastructure design world, Camp Dresser McKee (CDM) and Wilbur Smith Associates (WSA) pursued parallel markets for many years. The two professional engineering companies joined forces in 2011, consolidating their efforts and offices across the United States and around the world.

Established 75 years ago, CDM specialized in water treatment and civil design, whereas WSA, which was established in 1952, specialized in transportation and planning. Today, CDM Smith employs more than 5000 professionals across more than 100 offices worldwide, enabling the firm to take on a wide range of projects with in-house resources. In the bridge sector alone, the firm has designed almost 1000 new or rehabilitated bridges, performed maintenance inspection on tens of thousands of structures as part of the National Bridge Inspection Program, and performed construction inspection of bridges for more than 50 years.

Frank Bale, principal structural engineer and leader of the bridge discipline at CDM Smith, believes that their involvement in all aspects of bridge design, construction, inspection, and asset management gives them a unique perspective—not just for their clients, but for employees as well.

Nurturing Talent

"The most difficult aspect of a successful service industry is finding and keeping good employees," says Bale. Before the COVID-19 pandemic, there was a sense that employees could easily change jobs across the engineering field, but they were tethered to a regional or corporate office. "Now if we find a talented employee, we can offer them a position wherever they may be," he adds.

"The most difficult aspect of a successful service industry is finding and keeping good employees."

Take summer internships, for example. A candidate may reside in a city where there is no CDM Smith office, but that is no longer a significant barrier to employment. CDM Smith nurtures a healthy intern program that has been very successful in providing a steady stream of talent from engineering campuses. "Most of our interns become full-time employees," says Bale. Despite COVID-19 restrictions, that invaluable influx of talent has continued.

Leveraging Technology

Young professionals are more tech savvy than ever before and are more likely to use technology to overcome project challenges. At CDM Smith, the use of cloud-based platforms has improved productivity and enables the firm to allocate staff and resources to reflect market conditions.

Bill Huffstetler, senior engineer, transportation structures, and previous bridge discipline leader, says that CDM Smith was ready to shift to remote collaboration when the pandemic hit. They had previously invested in mobile devices, and the firm's established inter- and intra-office communication systems and work-share technologies were already in place.

"If there is an upside to COVID-19, it is that we were better positioned than many other firms," says Huffstetler. "We had already begun to modernize our infrastructure and internal communication and had set up networking between offices. When the lockdown was enforced, it was a much easier transition to work from home," he adds.

Like most engineering companies, CDM Smith is trying to decide how to move forward with balancing work at the office and at home. "I don't think we will return to an office-based company like before," predicts Huffstetler. "The professional service industry will never be the same."

While younger staff enjoy the remote work and are amenable to working from home, some of the senior staff feel differently. "I miss the casual hallway conversations," says Huffstetler. Bale agrees that there is less chance for office comradery and fewer group interactions when communication is virtual.

Professional Associations

CDM Smith's leadership believes that engineers have a fundamental responsibility to advance the practice of engineering. The company encourages participation in technical associations such as the American Association of State Highway and Transportation Officials (AASHTO), the American Society of Civil Engineers, or the Transportation Research Board. Huffstetler has had a front-row seat to many changes over the years. "I have attended many AASHTO bridge subcommittee meetings and witnessed the evolution of our industry," he recalls. "It is invaluable to pass on those technical developments and industry contacts."

"The AASHTO bridge specifications have grown from a few hundred pages to over a thousand pages during my career. While I don't endorse using a slide rule, it seems that the pendulum has swung too far in the other direction, and we tend to overcomplicate our standard code practices," Huffstetler says. However, staying abreast of both technical advancements and changes to the LRFD Design Specifications is essential to keep the firm on the leading edge of design.

Everyday Innovations

Most bridges in the United States have short to medium span lengths. Many of those structures are classified as being in "poor" condition. CDM Smith specializes in just those types of structures. "Those small- to medium-span bridges are where we do most of our work in the bridge market. That is our bread and butter," Huffstetler says.

"Those small- to medium-span bridges are where we do most of our work in the bridge market. That is our bread and butter."

Not every transportation project graces the cover of a magazine, but what did capture the industry's attention was a new way to integrate bridge superstructure and substructure. The use of an integral post-tensioned concrete pier cap was developed by WSA in 1978. Their design of the Interstate 75/Interstate 640 interchange in Knoxville, Tenn., first pioneered this innovative concept. Since then, the post-tensioned concrete pier cap system has proven popular in the construction of interchanges where there is insufficient headroom for conventional pier caps or where road profiles need to be lowered.

Local Bridge Centers

In its early years, WSA had a strong centralized bridge design division. As bridge owners increased their use of consultants, the firm decided that the marketplace was best served by independent bridge groups and decentralized operations. Their bridge centers now operate autonomously, similar to the state departments of transportation (DOTs) that they serve. "State agencies have become more proprietary, which can make it difficult to share work across offices," explains Huffstetler. However, there is still work-sharing across the bridge production offices using their cloud-based network.

CDM Smith is frequently found in the state capitals where the DOTs are located. Working on open-ended contracts with the New York State DOT, CDM Smith is providing bridge maintenance inspection services from their Albany, N.Y., office. In its Pennsylvania locations, CDM Smith

The Louisiana Department of Transportation and Development tasked CDM Smith with the design of a 9-mile portion of Louisiana Highway 1 that uses a precast concrete two-lane elevated highway to provide reliable access to Port Fourchon, a major port on the Gulf of Mexico. The new alignment and high-level structure provided a fixed-span crossing of Bayou Lafourche with 73 ft vertical clearance. The photo on the left was taken shortly after completion and before the existing moveable-span bridge was removed.

CDM Smith field personnel inspect the placement of concrete for a bridge deck.

has been awarded numerous bridge design projects. Farther south, the North Carolina DOT has outsourced many of their bridge design and construction inspection projects to CDM Smith.

Cross-Training

In addition to bridge design, CDM Smith supports a large bridge inspection practice in the Northeast and construction engineering services in the Southeast. The firm tries to cycle their people through all disciplines. "That cross-training has been consistent, and we use it to bolster our design staff," says Bale. Bridge construction inspection and inspection for maintenance have become important parts of their business. "With today's focus on finding and keeping valued employees, training across several disciplines enables them to customize a career path," adds Huffstetler.

"The cross-training of bridge design and construction inspection is helpful. You are a better design engineer when you have been in the field," observes Huffstetler. Inspecting aging bridges provides insights that are invaluable to a designer. The fact that the company has a balanced staff helps them recruit and retain young engineers.

Technology for Asset Management

In bridge inspection, CDM Smith stays abreast of advancing technologies and sometimes uses their own unmanned aerial vehicles. Currently, they use drones as a tool, although that does not supplant the need for bridge inspectors in the field. "Typically, drones have not been used to identify defects, but to provide supporting data and documentation of the work," explains Bale. "We will continue to utilize and promote that

CDM Smith provided emergency design services for a critical substructure repair of the historic Ashley River Bridge located near downtown Charleston, S.C.

Wilbur S. Smith, Innovator in Modern Transportation Systems

World-renowned transportation designer and engineer Wilbur S. Smith was the chair and president of Wilbur Smith & Associates, the engineering consulting firm based in Columbia, S.C., that he founded in 1952.

Smith began his career by working for the South Carolina Department of Highways, where he became the first state traffic engineer. He left to study traffic engineering at Harvard and Yale and founded Wilbur Smith & Associates while he was a faculty member at Yale and serving as the associate director of the Bureau of Highway Traffic.

An innovator in modern transportation systems, Smith helped design and develop major parts of the Interstate Highway System, the New Jersey Turnpike, the Chesapeake Bay Bridge-Tunnel, and the mass transit system in Washington, D.C.

Bill Huffstetler, a senior engineer with CDM Smith, says Smith is referred to as "one of the fathers of traffic engineering." This moniker stems from Smith's background in electrical engineering that he translated into traffic-signal design. The signal coordination we rely on today was untested then, but with its implementation, the improvement to traffic flow was so dramatic that he was sought after by agencies around the world. That concept and similar innovations in traffic and transportation engineering were the impetus to start his own company. "I was fortunate to work with him, and his energy was infectious," recalls Huffstetler.

The firm expanded rapidly with the growing interstate system and developed expertise in designing roads, bridges, airports, railroads, waterways, subways, and urban redevelopment, and in performing transportation-systems planning and feasibility analyses. Smith's company covered everything related to transportation, as CDM Smith continues to do today.

Throughout his illustrious career, Smith was active in and recognized by many trade organizations. He received honors from the National Society of Professional Engineers and the Transportation Research Board. The Highway Division of the American Society of Civil Engineers honored him with an annual award that bears his name, and the Institute of Transportation Engineers presented him with an award for distinguished service.

CDM Smith provided design and construction documents for several miles of new roadway and seven new bridges that serve as part of the final link into Natchez, Miss. The designs maintain the aesthetics desired by the National Park Service.

technology as we see broader use of it across all states," he adds.

While CDM Smith envisions wider use of drones for asset management, it will take some time before drone use is widely adopted. "There is a disparity across the states, which makes it a challenge for consultants. We are cautious as to how drone images and models will be utilized," Bale says.

Nothing compares to boots on the ground to evaluate structures and provide feedback on structural conditions, especially in emergencies. The U.S. Route 17/Ashley River Memorial Bridge in Charleston, S.C., was such a project. The bridge was eligible for the historic register when significant foundation deficiencies were discovered. When the South Carolina DOT determined that the concrete foundations had delaminated and deteriorated, CDM Smith assisted with the immediate partial closure. "We went to emergency design mode and in a few weeks designed a post-tensioned transfer beam cap replacement method to repair the foundation without total replacement," Huffstetler recalls. The result was a successful pier replacement that was achieved while maintaining traffic on the bridge and maintaining the structure's historic appearance.

As U.S. bridges age, the emphasis on preservation and maintenance has increased. CDM Smith has kept pace with new testing methods. Along with drones, other nondestructive evaluation methods and technologies such as ground-penetrating radar are useful for assessing bridge conditions. These methods allow CDM Smith engineers to identify problems earlier and more cost effectively while prioritizing employee and public safety.

As a global engineering firm with a broad perspective, CDM Smith has its sights on new opportunities, looking to grow while dealing with the challenges that come with today's evolving workspace. A

Infrastructure Resilience and Functional Recovery

by Scott Campbell and Brian Killingsworth, National Ready Mixed Concrete Association

Infrastructure investment is commonly discussed in the public forum, with some people decrying the current state of said infrastructure. The Infrastructure Investment and Jobs Act, which was passed by Congress and signed into law by President Biden in November 2021, has placed a renewed focus on the topic as $550 billion will be invested in hard infrastructure over the next decade. If this money is to be spent wisely, it is necessary to ensure that resilience is considered as part of the design and decision-making process for all projects.

To properly consider resilience, it is important to understand what is meant by the term. In a building industry statement,[1] based on work by the National Research Council and signed by more than 50 organizations, "resilience" is defined as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. Preparing for, planning for, and absorbing adverse events are typical parts of the design process, even if considering enhanced resilience requires some changes to how those steps are performed. However, the concept of recovering from an adverse event is seldom considered. That is, the time and funding required to bring infrastructure back into service are often overlooked in the decision process.

Identifying the need for recovery after earthquakes, the National Institute of Standards and Technology and the Federal Emergency Management Agency[2] created a definition for "functional recovery":

> *A post-earthquake performance state in which a building or lifeline infrastructure system is maintained, or restored, to safely and adequately support the basic intended functions associated with the pre-earthquake use or occupancy of a building, or the pre-earthquake service level of a lifeline infrastructure system.*

This concept can just as easily be applied to non-earthquake types of adverse events, and to types of structures other than buildings. To have true resilience, the structure must be able to return to functionality within a reasonable time frame, and the cost for doing so must be considered in the planning and design processes.

An example of the "cost" of not fully considering functional recovery is the aftermath of Hurricane Katrina in New Orleans, La. The city's population dropped by more than 50% after the hurricane struck in 2005 and has not fully recovered to date. Moreover, the most vulnerable members of the community have been the most affected. The fact that functional recovery of the infrastructure, including homes, offices, and industry, took so long was a major factor in peoples' decisions not to return—they had settled in other places.

Although the definition of functional recovery seems straightforward, the idea of what constitutes the "basic intended functions" of infrastructure can vary depending on the type of project and the goals of the owner and community. One possibility is that the basic intended functions are all the functions that were in place before the adverse event. This is the ultimate goal—but are all pre-event functions needed immediately after an adverse event? Is 50% capacity at a water treatment plant acceptable for a short period (days or weeks)? What about one open lane on a major bridge? These scenarios provide some functionality, and it is up to the community to decide if that is acceptable, and for how long.

The concept of resilience is often raised in terms of events that can cause physical damage to a system, but that is not the only time when resilience is relevant. For example, the shutdown of Interstate 95 in Virginia from January 3 to January 4, 2022, was not due to the roadway, bridges, or exits being physically damaged, but rather the state's winter storm response resources becoming overwhelmed. As a result, hundreds of travelers were left stranded in their vehicles, some for more than 24 hours, in freezing temperatures and often with no food or water. This was not a matter of design, but rather preparedness. Truck accidents that blocked traffic could not be cleared because allocated resources were simply overwhelmed by the severity of the storm. Note that this does not mean that the state should have had sufficient capacity to prevent any shutdown; however, there must be adequate resources or a plan to limit the downtime to a duration that is deemed acceptable.

It is possible to design, build, and operate infrastructure to achieve enhanced resilience. Along with concepts such as life-cycle analysis, functional recovery provides a way to quantify performance and therefore to measure whether the project goals are achieved. However, to implement these ideas, the levels of functionality required for various scenarios and different time frames must be developed. Once we have a firm scope of the desired performance, designs can be adjusted to provide the appropriate level of infrastructure resilience for each project.

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2. Federal Emergency Management Agency (FEMA) and National Institute of Standards and Technology (NIST). 2021. *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time.* FEMA P-2090/NIST SP-1254. https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1254.pdf.

Selmon West Extension Improves Regional Connectivity

by Bob Anderson and Drew Miller, AECOM, and Russel Dingman, Kiewit

The recently completed $235 million Selmon West Extension in Tampa, Fla., is a 1.6-mile-long toll road consisting primarily of a viaduct above the median of Gandy Boulevard. The current configuration of the extension is generally one 15-ft-wide lane with two 6-ft-wide shoulders in each direction. This width is sufficient to allow for four lanes of traffic during an evacuation event or a future capacity increase with lane reconfiguration by restriping.

By separating commuter traffic from local trips, the Selmon West Extension provides safer and smarter regional connectivity while alleviating traffic congestion on Gandy Boulevard and creating greater capacity and access for neighborhood businesses and residents.The trip time through the corridor can now be cut from 20 minutes to 2 minutes.

Integration of Design and Construction in an Urban Environment

The design-build team understood the importance of maintaining traffic on Gandy Boulevard and was tasked to provide a "best value" solution to the Tampa Hillsborough Expressway

The Selmon West Extension in Tampa, Fla., is a 1.6-mile-long toll road consisting primarily of a viaduct above the median of Gandy Boulevard. Travelers now have direct connections between the Lee Roy Selmon Expressway, Dale Mabry Highway, and the Gandy Bridge to St. Petersburg. Figure: Tampa Hillsborough Expressway Authority.

profile

SELMON WEST EXTENSION / **TAMPA, FLORIDA**

BRIDGE DESIGN ENGINEER: AECOM, Tampa, Fla.

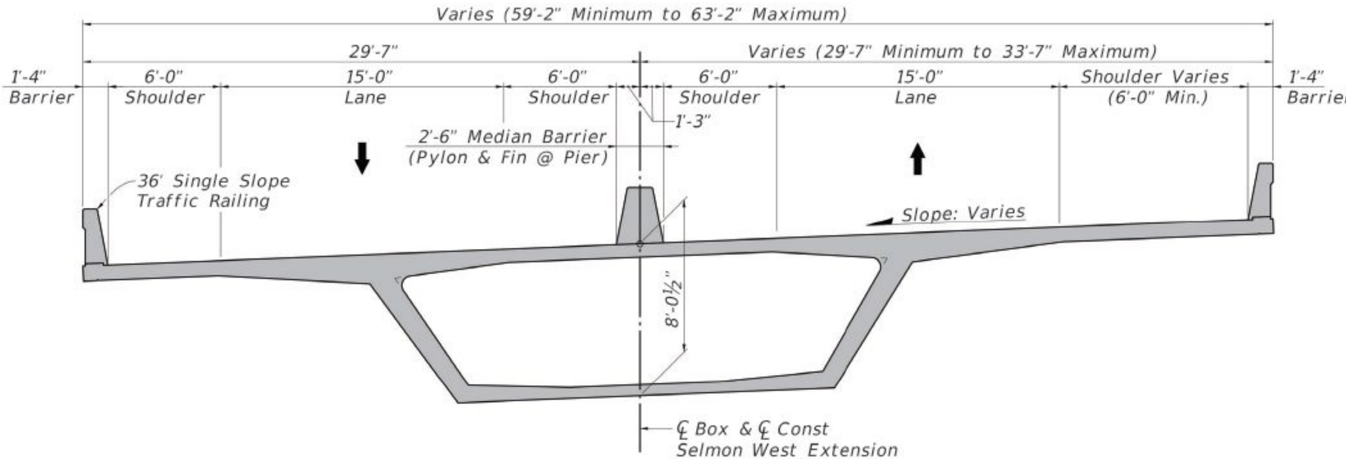
OTHER CONSULTANTS: Owner's engineer: HNTB, Tampa, Fla.; construction engineering services: McElhanney, Tampa, Fla.; Kiewit Infrastructure Engineers, Denver, Colo.; independent peer reviewer: SYSTRA–International Bridge Technologies, San Diego, Calif.; construction engineering inspection: Atkins, Tampa, Fla.

PRIME CONTRACTOR: Kiewit — Kiewit Infrastructure South Co., Tampa, Fla.

CONCRETE SUPPLIERS: Drilled shafts: Titan America, Tampa, Fla.; all other concrete: CEMEX USA, Tampa, Fla.

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

OTHER MATERIAL SUPPLIERS: Formwork for precast concrete segments, erection girders, straddle carrier, and swivel crane: DEAL, Bay Harbor Islands, Fla.; form travelers for cast-in-place segments: Kiewit Engineering Group Inc., Tampa, Fla.; bearings: R. J. Watson Inc., Alden, N.Y.; expansion joints: D. S. Brown, North Baltimore, Ohio; epoxy and prepackaged grout supplier: Pilgrim Permocoat Inc., Tampa, Fla.; flexible filler for post-tensioning tendons: Fuchs Lubricant Company, West Palm Beach, Fla.



The typical section of the Selmon West Extension is generally configured with one 15-ft-wide lane and a 6-ft-wide shoulder in each direction. This width is sufficient to allow for four lanes of traffic during an evacuation event or a future capacity increase with lane reconfiguration by restriping. Figure: AECOM.

Completed elevated viaduct with street traffic below on the West Gandy corridor. Photo: AECOM.

Authority (THEA) with scoring criteria that included the total weighted sum of the letter of interest score (20%), design (15%), construction (15%), maintenance of traffic (10%), schedule (20%), and price (20%). The chosen design-build team fulfilled this challenge by submitting the most innovative, constructable, and cost-competitive design that met the goals established by THEA. (see the Authority article on THEA on page 58).

The highlight of the Selmon West Extension project is clearly the elevated concrete segmental viaduct structure. THEA required it to be supported entirely within the narrow (typically 10-ft-wide) median of the four-lane urban Gandy Boulevard, and prescribed an aesthetically pleasing, single box-girder superstructure with 30 ft of vertical clearance to allow open sightlines for businesses on opposite sides of the road and to minimize the tunnel effect below the elevated structure. Long span lengths and slender cantilever piers were also required to

TAMPA HILLSBOROUGH EXPRESSWAY AUTHORITY, OWNER

BRIDGE DESCRIPTION: The signature element is an eight-unit, 35-span, 7060-ft-long concrete segmental box-girder viaduct with spans up to 260 ft

STRUCTURAL COMPONENTS: 744 precast concrete box-girder segments, each weighing approximately 72 tons; cast-in-place finbacks that encase large post-tensioning tendons; cast-in-place cantilever piers with vertical and horizontal post-tensioning bars; and cast-in-place concrete footings and drilled shafts

PROJECT COST: $235 million

2021 AWARDS: *Roads & Bridges* Top 10 Bridges in America; International Bridge, Tunnel and Turnpike Association Toll Excellence Award; Florida Transportation Builders Association Best in Construction, Expressway Project of the Year; Construction Management Association of America Florida Project Achievement Award in Transportation; American Segmental Bridge Institute Bridge of Excellence Award; Hillsborough Planning Commission Planning & Design Award; American Council of Engineering Companies of Florida Grand Engineering Excellence Award; Greater Tampa Section Institute of Transportation Engineers Project of the Year

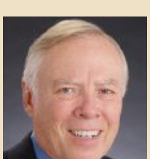
An innovative progressive span-by-span viaduct construction method was used to meet the project's constructability challenges. Using this method, the concrete segments were erected with self-launching underslung erection girders supported by temporary towers in the median. Photo: Kiewit.

provide for proper left-turn sight distance at all intersections and median openings. Spans over intersections are generally 230 ft, with the longest spanning 260 ft. Spans over left-turn movements into driveways are between 200 and 220 ft. The 59-ft 2-in.-wide viaduct overhangs most of the four lanes of Gandy Boulevard below. THEA required that the boulevard remain open during construction, with only single-lane overnight closures and rolling stops permitted.

Given the potential for restrictive impacts to the businesses, residents, and commuters during construction, the request for proposal stipulated the use of top-down construction techniques, an aggressive 1000-day design and construction schedule, and redundant support of the erection equipment and concrete segments during construction for the entire 7060-ft-long structure. There were also significant penalties written into the contract if all lanes along Gandy Boulevard were not open by 6:00 a.m. each day. THEA proactively managed constructability and redundancy concerns by requiring the submittal of an erection plan and protection plan for overhead construction detailing each design-builder's approach to construction before bid, which was included in the "best value" scoring.

Conventional Approaches Proved Inefficient

The conventional design for a viaduct with 230- to 260-ft spans requires a top-down construction method with a precast concrete segmental box girder built using the balanced-cantilever method with an overhead gantry. Using this method, one segment is set at a time on alternating ends of the cantilever, and the segment hangs from the gantry until post-tensioned to the cantilever. The gantry, in turn, is supported by the cantilever and temporary shoring may be required to stabilize the cantilever, especially for redundancy. The design-build team determined that this method of construction was not practical because it would require two headings, each having its own overhead gantry to complete erection within THEA's required time frame. In addition, for this project with this construction method, the overhead gantries would need to be supported on the final foundations, and that would often control the permanent substructure and foundation design. The resulting heavily loaded eccentric columns and foundations would not fit in the narrow median without long-term lane closures. Lastly, this gantry style does not afford a redundant means of supporting segments; thus, traffic would not be allowed to travel beneath construction the next morning if post-tensioning operations were not complete.



AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

The design decisions that were most important in making this bridge beautiful were not made for aesthetic reasons—they were made for engineering or urban impact reasons. Many were made by the owner before design even started. Limiting the width of the substructure to the width of the median, requiring adequate left-turn sight distance at all intersections, and, related to both, requiring that the superstructure be a single box girder with wide overhangs, were all decisions made for the safety and convenience of the users of Gandy Boulevard. Setting the vertical clearance under the bridge at 30 ft, roughly twice the legal minimum, was done to maintain the viability of the Gandy Boulevard businesses. Taken together, these technical decisions produced the bright, open spaces under the bridge that make it so attractive.

The designers responded to the project's challenges with engineering decisions that both met the constructability requirements and improved the bridge's appearance. The finback design solved the constructability challenges and also lengthened the spans, reduced the depth of the girder, and gave travelers on the viaduct visual features to enjoy. Post-tensioning the piers improved the performance of the piers and reduced their thickness and visual mass.

Then there are the decisions that were made for solely aesthetic reasons. The vertical blue stripes on the columns and on the sides of the finback towers and the diagonal blue stripes on the fins themselves divide these massive forms longitudinally and make them appear thinner, as does the blue "racing stripe" on the face of the parapet. The "estuary" motif on the piers and towers works well in this landscaped commercial environment. Overall, these visual features perfectly complement the aesthetic qualities of the structural elements.

So, let's sum it up. Users of Gandy Boulevard can see along and through the structure from all angles. The signs and frontages of adjoining businesses are fully visible. Daylight penetrates across the whole width under the bridge, making the space bright and inviting. The aesthetic motifs complement the structural elements and the neighborhood. There is no dark forest of massive columns here, nor any pigeons lurking overhead in the shadowy spaces between I-girders. Compare the attractiveness and usability of the space under this viaduct to the spaces under any viaduct in your town. Where would you prefer to be?

New Construction Method and Structural System

Constructability was the primary focus of the innovative erection method that was developed for the Selmon West Extension project. Many segments would have to be erected at once, supported redundantly from below, and delivered to the heading from the completed bridge. The long-span structural system would need to be light and efficient while accommodating the new erection method. These challenging and unique requirements are what led the design-build team to create an innovative progressive span-by-span viaduct construction method and complementary extradosed post-tensioned finback structural system (see details of this system in the Concrete Bridge Technology article on page 44).

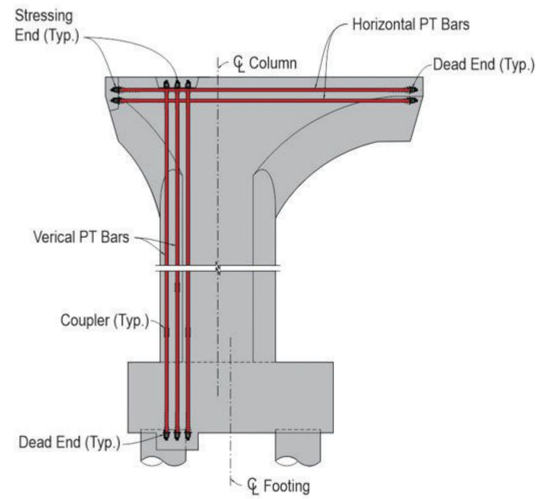
Using the progressive span-by-span scheme, the concrete segments were erected with self-launching underslung erection girders, which are not usually practical with spans longer than 180 ft. The erection girders were supported by three temporary towers in the median and did not load the permanent foundations. To accommodate the longer spans with reasonably sized erection girders, each span was erected in three sections: two 130-ft-long pier sections that were centered over adjacent interior piers, and a drop-in section that was placed to fill the gap between pier sections. For both types of sections, the segments, which were typically 10 ft long, were placed on the erection girders and moved into position. Then, joints were epoxied, temporary post-tensioning was applied, and the closure pours were placed. Finally, continuity post-tensioning tendons were installed, tensioned, and ducts were injected with flexible filler.

The progressive span-by-span erection method allowed segments to be delivered to the construction heading and staged along the recently completed spans without lane closures below. This method also eliminated lane reopening delays because the segments were always redundantly supported by the erection girders, allowing travel lanes below to be reopened before post-tensioning operations were completed. The only operations that could not be completed over traffic were erection girder launching and segment placement, which were completed at night. Erection using the progressive span-by-span method was 50% faster than the conventional balanced-cantilever method would have been for this project. Because the project needed only one construction heading and one set of erection equipment to meet the aggressive schedule, the cost of construction was significantly reduced.

Segment Fabrication and Materials

The property where the precast concrete segmental units were fabricated had been used for precasting operations on previous THEA projects and is located approximately 7 miles away from the jobsite. The fabrication site and the delivery route were selected to accommodate easy transportation to Gandy Boulevard.

Because the viaduct is located within 2500 ft of salt water, its environmental classification is "Extremely Aggressive" as defined by the Florida Department of Transportation's (FDOT's) *Structures Design Guidelines*.[1] This environmental classification dictates the concrete class for each bridge component, which then specifies the mixture proportions and cover requirements for the structure to ensure durability.



Post-tensioning bar layout in cantilever piers. Vertical and horizontal post-tensioned bars were used to avoid tensile stresses in the concrete under permanent loads by using post-tensioning forces to balance permanent loads. Controlled cracking was allowed under transient loading conditions. Figure: AECOM.

Table 1 summarizes the types of concrete used to construct components of the expressway, in accordance with Section 346 of the July 2017 edition of FDOT's *Florida Standard Specifications for Road and Bridge Construction*.[2]

Flexible wax fillers were used for all internal and external tendons per FDOT's *Structures Design Guidelines,* with the exception of the longitudinal cantilever tendons and the transverse tendons in the deck slab, for which cementitious grout was used.

Resiliency

The finback tendons are encased in post-tensioning ducts that deviate through the pier towers and are protected by

Table 1. Specified 28-day compressive strengths for concrete elements based on Section 346 of the Florida Department of Transportation (FDOT) *Standard Specifications for Road and Bridge Construction*[2]

FDOT class	Location in structure	Concrete strength, psi
V (mass)	Precast concrete superstructure, expansion joint segments	8500
V	Segmental box-girder superstructure (precast and cast-in-place concrete)	8500
V	Fin arms, finback tower, and median barrier at fin arms	6500
IV and IV (mass)	Cast-in-place substructure	5500
IV (drilled shafts)	Drilled shafts, ¾-in.-maximum aggregate size	4000
IV (drilled shafts, special)	Drilled shafts, ¾-in.-maximum aggregate size	5000

Tall cantilever piers with complementary aesthetics accommodated superstructure offsets at left-turn lanes and provided open sight lines beneath the structure between the two sides of Gandy Boulevard. Photo: AECOM.

a 30-in.-wide concrete fin encasement that fits within the viaduct median. The fin is integral with the median barrier at the pier and is designed to resist an equivalent static force of 600 kip, in accordance with Article 3.6.5.1, Vehicular Collision Force, in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[3]

Additional redundancy is provided by the finback structural system. Longitudinal load is carried by a combination of the girder and strut-and-tie system comprising the girder, finback arms, and tower, with the latter creating a direct load path up the finback arms and down to the foundation.

Based on its proximity to the Gulf Coast, the bridge was also designed to withstand 150 mph, hurricane-strength wind loads with appropriate gust factors and drag coefficients. To accurately account for the height and thickness of the finback, Figure 7.23 from Eurocode EN1991-1-4:2005[4] was used to determine its drag coefficient.

Use of Post-Tensioning in the Viaduct

Post-tensioning was used in four primary components on the concrete viaduct: cast-in-place cantilever piers (C-piers), precast concrete segmental box-girder longitudinal design, precast concrete box-girder deck transverse design, and cast-in-place concrete extradosed fins that extend above the deck level.

The multistrand longitudinal tendons in the box girder provide strength and a zero-tension design under service loads, as required by FDOT guidelines.[1] The longitudinal tendons used 0.6-in.-diameter strands with 12- to 19-strand internal tendons for the bottom and top slab cantilever tendons, and 23 to 31 strands for the finback and external continuity tendons.

The anchorages for all post-tensioning tendons, with the exception of the cantilever tendons, are located inside the enclosed box-girder section, which provides an additional layer of corrosion protection and makes the tendons easily accessible for tensioning, inspection, and retensioning (if necessary). The transverse post-tensioning allows for a shallow deck with 15-ft-long overhangs and provides strength to the delta frames that anchor the extradosed finback tendons. The extradosed post-tensioning fully prestresses the concrete fin arms and is designed to carry half of the span weight to the finback tower and pier. The post-tensioned finbacks make the progressive span-by-span erection method and the light and shallow superstructure possible. Longitudinal post-tensioning systems for the girder and finback are further described in the companion Concrete Bridge Technology article on page 44.

Partial Prestressed Design for C-Piers

As previously stated, most of the substructure elements located within the 10-ft-wide median of Gandy Boulevard were C-piers used to accommodate superstructure offsets at left-turn lanes. The eccentricity of the superstructure produces significant shear and overturning moment in the pier cantilever and the column, respectively. To avoid tensile stresses in the concrete under permanent loads, vertical and horizontal post-tensioned bars were used so that the post-tensioning forces can balance permanent loads. The prescribed post-tensioning allowed controlled cracking under transient loading conditions. The limiting crack widths required by THEA for the service limit state were more stringent than those specified in the AASHTO LRFD specifications.

Advantages of post-tensioning the C-piers included the following:

- More efficient use of reinforcing steel, less congestion, and improved constructability
- Superior geometry control because the use of post-tensioning limits the deflection and reduces long-term creep deformations and live-load deflections
- Mitigated cracking at service limit state for better corrosion protection of main reinforcing steel and enhanced durability
- Extended service life with less maintenance as a more sustainable solution

Conclusion

The innovative design and construction methods used for the Selmon West Extension enabled the design-build team to construct an elevated facility incorporating complementary aesthetics within a congested urban corridor while limiting the project's impact on the traveling public and local businesses. The completed project benefits both commuters and local residents by improving mobility within the region.

References

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2. FDOT. 2017. *Standard Specifications for Road and Bridge Construction*. Tallahassee, FL: FDOT. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/programmanagement/implemented/specbooks/july2017/files/717ebook.pdf?sfvrsn=e0b7d16b_0.
3. American Association of State Highway and Transportation Officials (AASHTO). 2014. *AASHTO LRFD Bridge Design Specifications*, 7th ed. with 2015 and 2016 interim revisions. Washington, DC: AASHTO.
4. European Committee for Standardization (CEN). 2010. *Eurocode 1: Actions on Structures—Part 1-4: General Actions—Wind Actions*. EN 1991-1-4:2005 with 2010 Amendment. Brussels, Belgium: CEN.

Bob Anderson and Drew Miller are senior bridge engineers specializing in complex bridges at AECOM in Tampa, Fla. Russel Dingman is a project sponsor at Kiewit in Tampa, Fla.

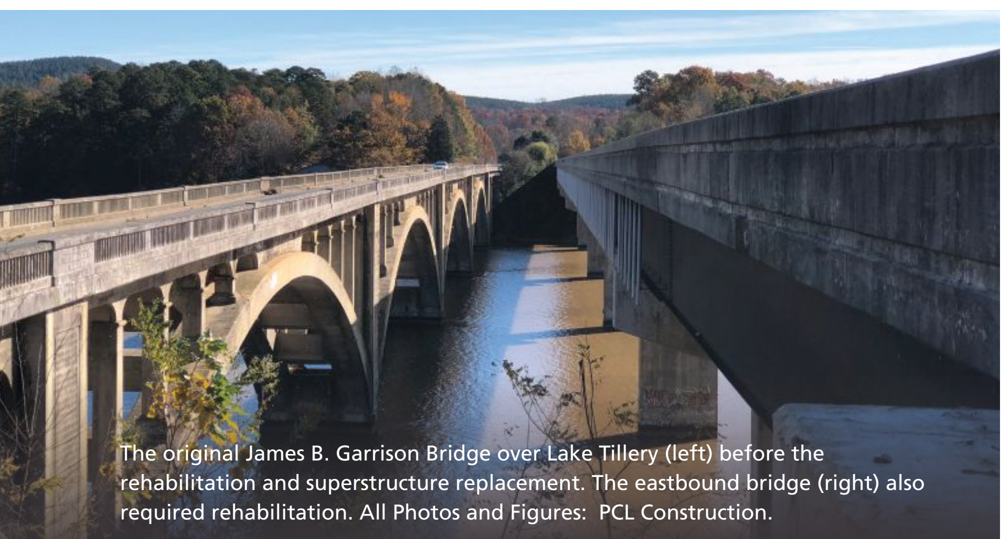
Preserving a Landmark: Lake Tillery Bridge Rehabilitation

With innovative construction techniques, a historic concrete arch bridge in a North Carolina National Forest was preserved

by Eric Chavez and Colin McCabe, PCL Construction

The Lake Tillery Bridge in the Uwharrie National Forest has been a landmark for North Carolina residents for almost a century. When the superstructure for this historic open-spandrel concrete arch bridge with four arch spans, originally built in 1927, needed to be replaced, the project also needed to accommodate a widened roadway cross section on the west end of the bridge.

Although the bridge was in need of rehabilitation, the City of Albemarle wanted to preserve its unique features. The original arches—an architectural design that was popular in the early 1900s—made the bridge instantly recognizable. So, when the North Carolina Department of Transportation (NCDOT) hired the contractor to rehabilitate the beloved bridge, the contractor knew the project would require a high level of care and attention to detail. The project team needed to rehabilitate the structure to modern standards while still maintaining the original aesthetics and preserving the bridge's importance to the community.



The original James B. Garrison Bridge over Lake Tillery (left) before the rehabilitation and superstructure replacement. The eastbound bridge (right) also required rehabilitation. All Photos and Figures: PCL Construction.

Demolishing the Structure

This project involved two adjacent bridges: the westbound historic concrete arch bridge and the eastbound bridge, which is a newer, steel-girder bridge. For the eastbound bridge, replacement of bearings, expansion joints, approach slab, and a deck overlay was required.

Although the superstructure of the westbound bridge had to be replaced, the original concrete arches of the substructure were in great condition. To replace the structure above the arch while preserving the aesthetics of the iconic piece of infrastructure, the design would need to re-create or preserve the arch ribs so that the final appearance would emulate the characteristics of the original bridge. NCDOT hired an engineer of record for the project to develop this unique design. However, NCDOT and the engineer of record concluded that contractor input was critical to ensuring the the success of the project, so NCDOT let the contract as design-build.

profile

JAMES B. GARRISON BRIDGE (WESTBOUND) / ALBEMARLE, NORTH CAROLINA.

OWNER'S BRIDGE DESIGN ENGINEER: AECOM, Raleigh, N.C.

CONTRACTOR'S SPECIALTY ENGINEER: Modjeski & Masters Inc., Mechanicsburg, Pa.

PRIME CONTRACTOR: PCL Construction Inc., Tampa, Fla.

CONCRETE SUPPLIER: Troy Ready Mix Inc., Troy, N.C.

PRECASTERS: Prestressed concrete box beams and deck panels: Eastern Vault Company Inc., Princeton, W.Va.; Precast concrete fascia panels: Ross Prestressed Concrete LLC, Knoxville, Tenn.—both PCI-certified producers

Revised June 2022

A section of the original bridge deck is removed from span C. Twenty strain gauges were installed in the existing arches to monitor stress and movement during demolition.

Cast-in-place concrete cap construction.

The design-build team began by evaluating the existing concrete arch bridge and original demolition sequence. The team proposed a new demolition sequence that kept the bridge in balance, removed leading-edge safety hazards (that is, worker fall hazards), and eliminated longitudinal saw cutting to prevent concrete slurry from entering the lake. The team collaborated with NCDOT and the engineer of record to come up with a new demolition sequence. The contractor then proceeded with removal of the concrete superstructure while leaving the four arch spans and the original piers intact. Because the original bridge arches were to remain and become the foundation of the new bridge, it was imperative to closely monitor the structure for movement after every step to ensure that the substructure and arches did not exceed allowable stress levels. Twenty strain gauges were installed in the existing arches to monitor the stress and movement during demolition.

The contractor essentially took the structure apart piece by piece, using a 60-in. saw to cut transversely through the concrete sections, while avoiding longitudinal cuts. Taking the complicated geometry and stability of the existing bridge into consideration, the team developed and implemented key alternative construction sequences that maintained the stability of the structure throughout all stages of construction. The strain gauge measurements were diligently and continuously monitored and recorded. The revised sequence and precise demolition methods resulted in stress and movement levels of the arches well below the allowable limits.

Water Work

While taking apart the existing bridge superstructure, the contractor had three floating crane barges on the water and used tugboats to move the barges to facilitate the removal of each piece. The process took about six months from the start of saw cutting the concrete until all

A protective layer of concrete was installed at all existing piers of the arch bridge to protect and reinforce the area most susceptible to erosion from the fluctuating water levels. The cofferdam system provided access for crews to apply the shotcrete protection. The left photo shows the shotcrete application, and the right photo shows the finished product.

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION, OWNER

OTHER MATERIAL SUPPLIERS: Formwork: Doka GmbH Amstetten, Austria; reinforcing steel: Harris Rebar, Stoney Creek, ON, Canada; access systems for work on the concrete arches: Safespan Platform Systems, Tonawanda, N.Y.; bearings: D.S. Brown, North Baltimore, Ohio; specialty fabric formwork: TrapBag, Fort Meyers, Fla.

BRIDGE DESCRIPTION (FOR WESTBOUND BRIDGE): 1060-ft-long, four-arch, open-spandrel, reinforced cast-in-place concrete bridge

STRUCTURAL COMPONENTS: 104 cast-in-place vertical columns, 52 cast-in-place concrete caps, 4154 linear ft of precast concrete spandrel box beams, 21,060 ft^2 of prestressed concrete deck panels, cast-in-place concrete deck slab, 96 architectural precast concrete fascia panels

BRIDGE CONSTRUCTION COST: $21.3 million

AWARDS: Engineering News-Record Southeast: Best Highway/Bridge 2021; Slag Cement Association's 2020 Slag Cement Project of the Year in innovative applications

New precast concrete box beams are erected in span F. Note the continuity reinforcement detail at the beam end, the common bearing under the continuity diaphragm, and the epoxy-coated reinforcement that will be cast into the composite deck.

Prestressed concrete box beams are placed and await the cast-in-place concrete continuity diaphragms.

the pieces were ready to be disassembled. During demolition, NCDOT required that one river channel be left open because Lake Tillery is heavily trafficked by boaters and jet skiers. Maintaining access was a priority throughout the project because it allowed safe boating in the channel.

With tight constraints for accessing the lake, a new bulkhead was identified as the solution for loading the barges with heavy equipment. The bulkhead structure retained fill material so a flat working area could be constructed to load heavy equipment onto the barges. Determining the location of the bulkhead was tricky because it could not encroach into the lake. The contractor worked closely with NCDOT and other stakeholders to develop a solution that would meet permit requirements. The excavation, forming, reinforcement installation, concrete placement, and drilling earth anchors for the bulkhead construction were all performed in an environmentally sensitive area without leaving any environmental impacts.

Both bridges required underwater structural encasements of the existing substructure to extend the life of the piers. A protective layer of concrete was installed on all existing arch bridge piers from the base of new construction to 4 ft below the normal pool waterline to protect and reinforce the area most susceptible to erosion from the fluctuating water levels. This effort required placing concrete 6 ft underwater.

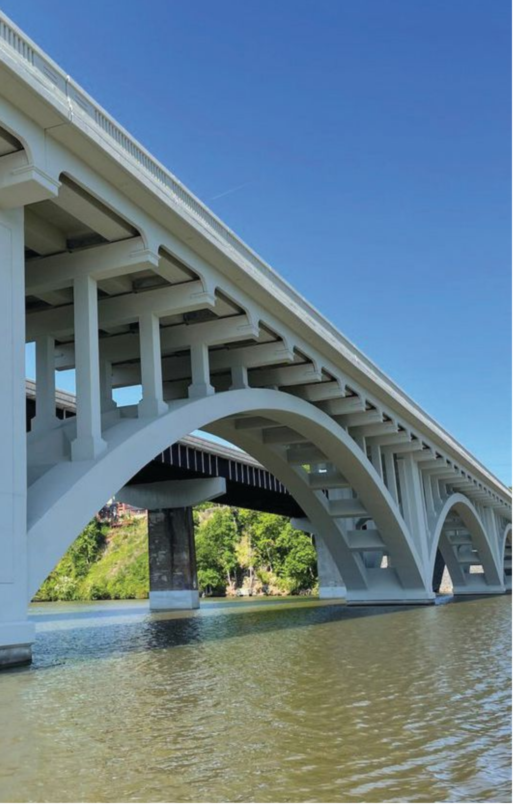
The project team worked together to find an effective installation procedure that would minimize the impact to the waterway. The contractor designed a steel cofferdam that was attached to each pier on both bridges and could be lowered to a level below the area that needed repairs. The cofferdam was sized to allow workers room to install the protection after dewatering. This operation was performed instead of a challenging underwater grouting operation, which would have been difficult to vent adequately given the site's constraints. This revision provided a safer work environment and resulted in a better product when completed. Instead of using traditional concrete formwork, a diving crew used injection ports to construct a sacrificial shotcrete layer within the cofferdam. After pumping out the cofferdam, the crew could work in that space to apply the final shotcrete protection to the piers in the dry.

Slag concrete was used for the substructure repairs below the waterline. Slag cement is a durable solution for protecting the structural integrity of the original bridge arches that is less susceptible to an alkali-silica reaction, which results in flakes falling off into the water over time. Slag cement also held the slump longer, made the mixture more workable, and was easier to place using long boom lines.

Conquering the Unexpected

One significant owner-directed change extended the scope for the concrete repair and epoxy injections. The engineers inspected both bridges during the preconstruction phase to map out all the spalls, areas of delamination, and cracks in the concrete substructure. Once on site, the contractor and its specialty subcontractor performed an independent inspection to verify the project requirements. This uncovered additional

Precast concrete fascia panels were used to preserve the historic aesthetics of the original arch structure.



The completed project maintains the historic character of the original structure while extending the service life of the bridge for many more years.

The parallel bridge required a protective layer of 2-ft-thick reinforced concrete to be cast in place around one pier footing more than 20 ft below the waterline. More than 200 yd^3 of concrete were placed underwater by tremie for this repair—a process that took 16 hours of continuous pumping from the deck of the bridge.

repair areas that were not originally identified due to limited access during the original inspection. NCDOT then approved additional repairs to ensure the structure's integrity.

A 2-ft-thick protective layer of reinforced concrete was designed to be cast in place around the pier footing more than 20 ft below the waterline to address cracking from alkali-silica reactive concrete that was improperly used during the original construction. An innovative solution to accomplish the repair was developed using reinforced geotextile fabric for the formwork; this solution ensured that the project schedule was maintained and access in the waterway was provided (see the Creative Concrete Construction article on page 53 for details).

More than 200 yd^3 of concrete were placed at the pier—a process that took 16 hours of continuous pumping to complete. The sheer quantity of concrete placed, plus the logistics of bringing in all the trucks and pumping the concrete, made this a unique aspect of the project.

Maintaining Architectural Features

The existing superstructure was replaced with prestressed concrete spandrel box beams that were 3 ft × 3 ft and 20-ft 7-in. or 14-ft 10-in. long, depending on the cap spacing. Each beam contained reinforcement that extended from the beam ends, which allowed the beams to be set and connected with a cast-in-place diaphragm to create a continuous beam across the span.

Partial-depth prestressed concrete deck panels were placed to span transversely between the beams. The 3.5-in.-thick panels were 4 ft × 6 ft 8 in. and served as a work surface and formwork for the cast-in-place concrete bridge deck.

Another unique feature of the bridge was the barrier railing, which was designed to preserve the architectural intricacy of the existing structure. The concrete barrier was cast in place using custom barrier wall forms to achieve the exact spacing and appearance of the "church windows" that span the length of the bridge. Because NCDOT specified a Class II surface finish on the concrete barrier, full-time grinding and patching crews were required to ensure the final product met expectations. This surface finish extends the service life and enhances the aesthetics of the bridge, and will minimize required maintenance and patch work in the future.

Continuing the Legacy

Everyone involved in the design and construction of the project is extremely proud of the results for many reasons. The rehabilitation project has won multiple awards, including the 2020 Slag Cement Project of the Year award in innovative applications from the Slag Cement Association, and the *Engineering News-Record* Southeast Best Project in the Bridge and Highway category. The project also demonstrated that the design-build team was willing to go above and beyond for its client, finding innovative solutions for the unexpected challenges that arose. The construction team is incredibly proud that it played a part in preserving the original aesthetics of a bridge that has significant value to the surrounding community. This concrete arch bridge is a great example of what makes concrete structures so remarkable, and this rehabilitation ensures the structure will remain an iconic landmark far into the future.

Eric Chavez is a construction manager and Colin McCabe is an engineer with PCL Construction in Tampa, Fla.

PROJECT

California State Route 99 over 21st Avenue in Sacramento

by Dave Carlin, California Department of Transportation

California State Route 99 (SR 99), a remnant of what was once U.S. Route 99, spans more than 400 miles from the infamous Los Angeles "Grapevine" in the south to the city of Red Bluff, two hours north of Sacramento. In tandem with Interstate 5, it links the agricultural and industrial complexes of the Central Valley to commercial hubs including the Port of Stockton and Sacramento. Traffic studies conducted in 2019 indicated an average volume of 220,000 vehicles per day along the segment between Elk Grove and Sacramento, making that segment one of the most heavily traveled portions of SR 99 and a critical component of the region's transportation infrastructure.

Originally designed to expressway standards, the section of SR 99 within Sacramento County supports both heavy industrial and high-density commuter traffic, subjecting its bridges to a combination of impact and prolonged peak-hour static loading. The 21st Avenue undercrossing, located within this segment, was constructed in 1959 and consisted of two parallel cast-in-place (CIP) bridges spanning 21st Avenue between the Oak Ridge and North City Farms neighborhoods.

The structures were composed of traditionally reinforced voided slabs bearing on strutted abutments with spread footings. Subsequent retrofits in 1974 and 1983 filled the gap between the two bridges with a CIP post-tensioned voided slab deck on cantilever abutments, increasing overall capacity to five lanes in each direction. Updated barriers and soundwalls were also added.

Project Need

California Department of Transportation (Caltrans) Structure Maintenance and Investigations (SM&I) records for the SR 99 bridge over 21st Avenue (which date back to 1962) detail typical deck surface wear throughout the 1970s and 1980s, with maintenance operations ranging from minor crack and spall patching to joint and seal replacements. Noted deficiencies increased significantly in the early 2000s, necessitating a 2011 contract to remove and replace unsound deck material and place a polyester concrete overlay.

Subsequent monitoring identified a more significant structural issue evidenced by delamination of the polyester overlay and soffit crack propagation. An initial recommendation for placement of a reinforced 4-in.-thick deck-on-deck slab was made, and more in-depth analyses of the structure commenced.

Originally constructed in 1959, the 21st Avenue undercrossing on State Route 99 is the primary vehicle and pedestrian route linking the Oak Ridge and North City Farms neighborhoods of Sacramento, Calif. Although the abutments and substructure were sound, delamination of a previous overlay, soffit cracking, and other deterioration led to the decision to replace the superstructure. All Photos: California Department of Transportation.

profile

21ST AVENUE UNDERCROSSING, STATE ROUTE 99 / **SACRAMENTO, CALIFORNIA**

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

CONSTRUCTION ENGINEER: California Department of Transportation, Unit 3665, Shingle Springs, Calif.

PRIME CONTRACTOR: Bridgeway Civil Constructors, Inc., Vacaville, Calif.

ULTRA-HIGH-PERFORMANCE CONCRETE SUPPLIER: LafargeHolcim, Chicago, Ill.

PRECASTER: Con-Fab California LLC, Lathrop, Calif.—a PCI-certified producer

Several on-site outreach meetings were conducted to educate the surrounding community and provide an open forum for discussion of project impacts and concerns.

SM&I determined that although the abutments and substructure were sound, the original and retrofit deck slabs had deteriorated to such an extent that a supplemental deck slab was not applicable and superstructure replacement was required. A project development team was assembled, and impacts on the surrounding community and traveling public were quickly identified as the driving forces in the design selection process.

Structure Selection

Given the anticipated construction duration and the safety implications of working immediately adjacent to live traffic lanes, traditional multistage construction was ruled out and the focus shifted toward the application of accelerated bridge construction (ABC) techniques.

As the project development team continued down the ABC path, several design alternatives were reviewed, and each was critiqued with respect to the unique aspects of the site. Early on, the lack of adequate space adjacent to the site precluded the lateral deck-slide option. Input from regional precast concrete vendors eliminated the potential for larger deck panels because the complexity of casting and transporting panels increased exponentially with panel width. This feedback resulted in the selection of 4-ft-wide prestressed concrete box beams, which were readily constructable and afforded flexibility in transportation, staging, and erection.

Historical data related to adjacent precast concrete box-beam bridges using traditional grouted keyways, with and without transverse post-tensioning, indicated a tendency for differential shear to result in longitudinal deck cracking and degradation of CIP deck components, whether reinforced or polyester concrete. To address this issue, and based heavily on experience gained during the highly successful Echo Summit Sidehill Viaduct Replacement Project (7 miles west of the city of South Lake Tahoe on U.S. Route 50) in 2020, ultra-high-performance concrete (UHPC) was selected as the mechanism by which the beams would be connected, with a polyester concrete overlay provided as the finished driving surface.

Contract Development

With the project design solidified as a single-stage, precast concrete box-beam bridge using UHPC connections, the project development team continued working to address concerns raised by the project stakeholders. Key items incorporated into the bid documents included the following:

- Mandatory prebid meeting—The high-consequence nature of the contract, along with a bid process occurring under newly established COVID-19 pandemic guidelines, made it critical that all bidders were clear on the requirements of the contract, conditions at the site, the working-day allotment, and the penalties associated with delay.
- Incentivized closure duration of 100 hours—The project team used input from a variety of sources to develop a closure schedule. A total project duration was selected based on a cost-benefit analysis weighing impacts on the community, return on investment, and the safety of all parties throughout the construction phase. A multitiered monetary incentive program for early reopening was included via a bid-period addendum.
- Allowable work window—Based on historical traffic data, regional event schedules, and desired conditions for the placement of UHPC, the relevant lane closure authorizations were restricted to the period from June 9 to August 11.
- UHPC prequalification and beam test fit—Lessons learned from Echo Summit and other projects using

CALIFORNIA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: A 51-ft-long, single-span, precast, prestressed concrete box-beam replacement superstructure supporting 10 traveled lanes and shoulders, with a total width of 140 ft

STRUCTURAL COMPONENTS: 35 precast, prestressed concrete box beams (48 in. × 27 in. × 51 ft), with ultra-high-performance concrete-filled keyways and a cast-in-place polyester concrete overlay driving surface

BRIDGE CONSTRUCTION COST: $3.92 million ($550/ft^2)

Preassembly of the completed beams at the precaster's facility allowed verification of cumulative casting tolerances and fit-up.

The tight window for installation of the prestressed concrete box beams required simultaneous setting operations on both sides of the bridge centerline. The 35 beams were set in less than five hours.

UHPC and precast concrete deck elements were incorporated directly into the project specifications, including enhanced UHPC quality-control requirements and mandatory off-site preassembly of the completed beams to verify accumulated casting and fit tolerances.

- Delayed start clause—With 25 working days allotted to complete the work, a 120-day delayed start clause was included to provide sufficient time for the selected contractor and subcontractors to complete the relevant submittal, procurement, and casting processes.

Bidding for the project opened on October 29, 2020, with the award and contract approval following on November 16 and December 17, respectively.

Construction

The project schedule centered on executing the 100-hour full closure on June 11, as early as possible within the allowable work window, to ensure favorable temperatures for UHPC placement and curing. The contractor mobilized several weeks in advance of this date and used allowable lane closures to complete all possible preparatory work, including barrier demolition and installation of the temporary abutment lateral-bracing corbels and brackets.

On the night of June 11, all traveled lanes, including those on 21st Avenue, were sequentially closed per the traffic management plan, and the remainder of the lateral-bracing system was installed. Crews welded full-span horizontal struts between the preinstalled corbels, maintaining the full width of 21st Avenue for equipment and material movement. Demolition of the existing superstructure, one of the most challenging aspects of the work, was completed in 15 hours. The existing abutments were cleared of debris, and a CIP seat extension was placed to the grades required to match the adjacent roadway.

Demolition of the southbound portion of the bridge has been completed and the temporary lateral-bracing system for the abutments has been installed. The existing northbound slab deck (foreground) has been slotted along the interior voids to create manageable panels that are ready for removal.

As this work took place, the beams were delivered and staged for installation on the morning of June 13. Installation of the 35 precast concrete units, completed in under five hours, was immediately followed by sealing and water-testing the beam joints to ensure mortar tightness and achieve a uniform saturated-surface dry condition for the UHPC placement operation.

Placement of UHPC began that afternoon and was completed in approximately seven hours. Multiple crews, working outward from the bridge centerline, used motorized buggies to transport and place the UHPC while project engineers oversaw installation of temperature-monitoring embeds throughout the project. As the UHPC was placed in each joint, cover plates with gravity-fed ports were installed. A separate crew monitored and maintained positive head pressure during the initial setup, ensuring that the self-consolidating UHPC completely filled the keyways. A heated cure tent was constructed to maintain optimum conditions, and the entire structure was isolated from vibration throughout the time required to achieve a compressive strength of 12.0 ksi.

Upon reaching the 12.0-ksi threshold in under 18 hours, the UHPC joints were stripped and ground flush, and the complete deck was media-blasted and prepared for placement of a 1-in.-thick

Immediately following installation of the box beams, crews installed joint caps and seals and performed the required surface saturation and leak testing before placing ultra-high-performance concrete in the joints.

As each successive joint was filled with ultra-high-performance concrete, secondary crews installed cover plates, positive head-pressure ports, and temperature-monitoring embeds.

polyester concrete overlay. Backfill of the abutments, approach and departure paving, and traffic striping were performed in sequence, and the completed structure reopened to traffic in both directions on Tuesday, June 15, at 10:00 p.m.—94 hours after the full closure of SR 99.

Takeaways

Moving forward, Caltrans is actively pursuing opportunities to refine and apply its expanding ABC skill set to reduce the impacts of projects throughout the state. Key elements of the 21st Avenue project that are being incorporated into future projects include the following:

- Community outreach. A comprehensive campaign, spearheaded by the Caltrans Public Information Office, used a variety of media to educate and prepare the public for the impacts of the project. Multilingual radio broadcasts, streaming geofence messaging, community open house events, and door knocking were all used to gather public input as well as maximize the effectiveness of planned mitigation strategies. These strategies ranged from free light-rail access to temporary suspension of adjacent projects, extensive highway patrol support, and a traffic management plan spanning four counties.
- On-site preconstruction meetings. Both the development and review of the proposed 100-hour closure schedule involved real-time input provided by key parties during on-site meetings and walk-throughs. Optimum sequencing, activity durations, scope isolation, and identification of time-saving alternatives were all derived from these meetings.
- UHPC prequalification and mock-up. Caltrans's past successes with UHPC played a key role in the design selection process, and lessons learned on previous projects were reflected throughout the contract documents. Site-specific UHPC mixture prequalification, date restrictions, a required mock-up, and preconstruction strength verification were all used to ensure that the many variables associated with this application were accounted for in the contractor's work plan.

The success of the 21st Avenue project can be directly tied to the collaborative efforts put forth throughout the development and construction phases. From design, analysis, and selection, to community outreach and partnering, the project team sought and incorporated stakeholder input to produce a comprehensive design and contract that positioned the contractor to both succeed and deliver a high-quality product to the state.

Dave Carlin is a structure representative of Unit 3665 for the California Department of Transportation in Shingle Springs, Calif.

Batching, placing, and finishing processes for the ultra-high-performance concrete were all prequalified using the contract-specified mock-up assembly.

Returned to service in 94 hours and with no permanent impacts on the surrounding homes and businesses, the 21st Avenue undercrossing proved to be an ideal application of the accelerated bridge construction methodology.

Understanding Segmental Bridge Defects and Effective Repair Solutions

by Chris Davis and Scott Greenhaus, Structural Technologies; Craig Finley and Jerry Pfuntner, Finley Engineering Group

The previous article in this series (see the Winter 2022 issue of *ASPIRE*®) introduced the topic of preservation of concrete segmental bridges in the United States. It discussed the performance challenges for these unique structures and the lessons learned over the last several decades. Better understanding of investigation and inspection techniques—nondestructive and exploratory—and implementation of the holistic analysis methodology described in the article provide the industry with the tools and confidence to ensure that rehabilitation and service-life extension are achievable for concrete segmental bridges. This article explores defects that may be found in concrete segmental bridges and outlines some of the engineering implications. It presents repair solutions and processes, including project delivery methods conducive to optimizing outcomes.

Defects

Spalling and Reinforcement Corrosion

Segmental bridges experience concrete deterioration mechanisms similar to traditional bridges, albeit at a much-reduced pace due to the benefits of prestressed concrete elements and high-quality concrete materials.

Reinforcing steel corrosion is a primary cause of concrete deterioration. Corrosion is an electrochemical process requiring an anode, a cathode, and an electrolyte. These elements combine to form a corrosion cell. The corrosion process causes the steel to rust, creating expansive forces that ultimately lead to the delamination and spalling of concrete (**Fig. 1**).

Reinforcing steel in concrete is typically protected by a passivating layer formed on the steel in an environment with a high pH level, which is found within concrete. Disruptions to passivation can be caused by chlorides or by carbonation of the surrounding concrete.

Exposure to chlorides dissolved in water, such as saltwater spray in coastal environments or highway deicing salts, accelerates the corrosion process. Cracks and joints may allow water and contaminants to reach embedded metals more quickly.

Carbonation is a process where carbon dioxide in the air is absorbed into the concrete and lowers the concrete's pH. A pH below 10 promotes corrosion. Carbonation is typically a slow-moving process that occurs in environments where structures experience wetting and drying cycles.

Grouting Issues and Post-Tensioning Tendon Deterioration

Over the past 20 years, corrosion of post-tensioning strands in segmental bridge construction has been investigated, the causes determined, and solutions developed. Corrosion and potential failure of tendons is an ongoing concern. It is important to understand the causes of corrosion before developing repair and strengthening solutions, should it be determined that repairs are necessary.

Corrosion of segmental bridge tendons in the United States was first discovered in the early 2000s. A variety of issues

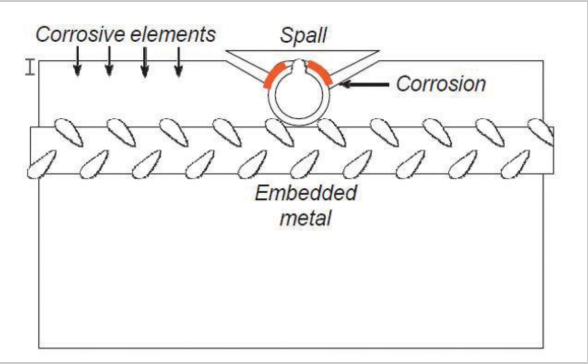


Figure 1. Corrosion is an electrochemical process requiring an anode, a cathode, and an electrolyte. If all of these elements are present, they can combine to form a corrosion cell that causes the steel to rust, creating expansive forces that ultimately lead to the delamination and spalling of concrete. Figure: Structural Technologies.

primarily involving the materials, detailing, and installation techniques related to tendon grouting were determined to be the root causes. The earliest post-tensioning tendon grouts consisted of cement and water as the basic constituents, which at times were augmented with grouting aids such as expansive admixtures. Grout was injected into galvanized, spirally wound metal ducts, which were found to provide poor protection in a corrosive environment in some situations.

Grout-related issues uncovered in these early bridges include segregation of grout materials; voids in grouted ducts; porous, soft grout that remained pasty and permeable; poorly protected tendon anchorage systems; and poor detailing at closure pours (**Fig. 2** and **3**). These issues are discussed in more detail in the previous article in the Winter 2022 issue of *ASPIRE*.

To remedy these issues, the industry made several advancements in grouting details and technology, which are also discussed in detail in the Winter 2022 article, as well as articles in the Winter 2017 and Summer 2019 issues of *ASPIRE*.

Figure 2. Corrosion of individual post-tensioning strands in an external tendon at a location where the duct was not completely grouted, leaving strands unprotected. Photo: Structural Technologies.

Figure 3. Corrosion of an external post-tensioned tendon at a location of soft, moist grout. Photo: Structural Technologies.

Engineering Considerations

Long-Term Post-Tensioning Losses

Our body of knowledge on creep and shrinkage of concrete has been enhanced over the years. Early methods often just applied a factor to the initial forces to account for these phenomena. This approach does not capture the redistribution of the imposed deformations from creep and shrinkage and sometimes provides an inaccurate representation of the actual variation in stresses with time in these bridges and can lead to premature cracking. Modern codes such as the *fib* (International Federation for Structural Concrete) *Model Code for Concrete Structures 2010*,[1] as well as modern software, have greatly improved the accuracy of predictions about creep and shrinkage behavior. Modern design approaches also ensure that predictions of creep and shrinkage are sufficiently bracketed by considering high and low predictions to better account for long-term effects.

Live-Loading Changes

Since the advent of complex post-tensioned bridges, live loading has progressed well beyond the original HS20-44 design truck developed in 1944. Truck sizes and traffic volumes have increased significantly. The HL-93 notional loading reflects these contemporary demands and is a significant increase over the original HS20 highway loading, particularly for spans greater than 150 ft. The loads for spans of that size were found to be underestimated by the older method, which is unfortunate because spans greater than 150 ft are where post-tensioned girders begin to be considered. Older bridges, and older segmental bridges in particular, are subjected to more live-load demand than they were originally designed for, which may lead to structural cracking and potential deterioration.

Principal Stresses

Early design codes did not require designers to check principal shear stresses. This stress check, which is required in current design codes, is particularly critical for webs to ensure that web shear cracking does not initiate under service-load conditions. Earlier design codes placed some limits on the concrete contribution for shear under factored loads, but no checks were required at the service limit state. In addition, critical detail areas such as anchor blocks and diaphragms may be subject to large tensile stresses from restraint and stress concentrations such as reentrant corners that were not considered in the original simplified analysis and may result in cracking. Today, finite element analysis software can analyze these critical areas and identify the need for additional reinforcement for high principal stresses. Earlier bridge designs did not benefit from modern analysis methods, and thus locations of high principal stresses are sometimes subject to cracking and spalling.

Casting Geometry

In the casting yard, proper match casting of segments is critical to ensure that the compressive stresses due to post-tensioning can be transferred across the segment joints through uniform bearing. The bearing surface can be interrupted by several different issues. Improper repairs made to segments before erection may result in localized bearing "hot spots" that cause an internal redistribution of stress across the joint. Improper shimming of segment joints can also create the same effect. Over the service life of the structure, these localized hot spots create stress concentrations that can lead to cracking and/or spalling and may lead to the beginning of local deterioration in the segment. Older segmental bridges with dry joints (no epoxy) are particularly sensitive to localized bearing points. Epoxy-coated joints help provide a uniform bearing surface to compensate for shims, repairs, and any irregularities.

Cracking

Issues that cause unintended stresses may eventually lead to cracks in segmental bridges. Although prestressed concrete is designed to limit concrete service stresses in the precompressed tensile zone, unintended concrete tensile stresses can lead to cracks in segmental concrete bridges. Given that service-level design stresses are based on the full design section contribution, cracking may create a local section loss within the concrete cross section. Over time, this section loss can be progressive and result in higher localized tensile stresses and changes in the flow of stress around these local section-loss regions, which may contribute to additional unintended tensile stresses.

Repair Solutions

Segmental bridges are durable structures by design. With careful monitoring, inspection, repair, and rehabilitation, the intended function of these bridges can be maintained to provide the full, if not extended, service life.

The successful repair of corrosion-damaged concrete requires a clear understanding of the causes of the deterioration and the careful selection of repair materials and application techniques.

Material Selection

Selection of concrete repair material is focused on ensuring that the material is appropriate for environmental and structural loads and is compatible with the substrate material. The following are important properties to consider when selecting materials:

- Compressive strength similar to the underlying substrate.
- Low drying shrinkage of repair materials—suppliers should be asked to provide shrinkage data. Drying shrinkage can be controlled by minimizing water demand (low cement content consistent with design strength and maximum aggregate distribution), water-reducing admixtures, and proper curing.
- Compatibility with placement techniques (pumping, pouring, and pressure placement into forms) to ensure proper filling of the repair cavity.

Repair Process

The following procedures are necessary for the successful repair and extended service life of concrete members:

- Ensure the safety and stability of the structure by removing loads and/or shoring and bracing as determined by a licensed design professional.
- Remove corrosion. This is critical to the long-term success of surface repairs. Repairs have failed because reinforcing steel corrosion was not properly removed.
- Remove concrete around a corroded reinforcing bar that has lost bond with the existing concrete. This removal is critical for the repair to be successful and will allow the new material to fully encapsulate the

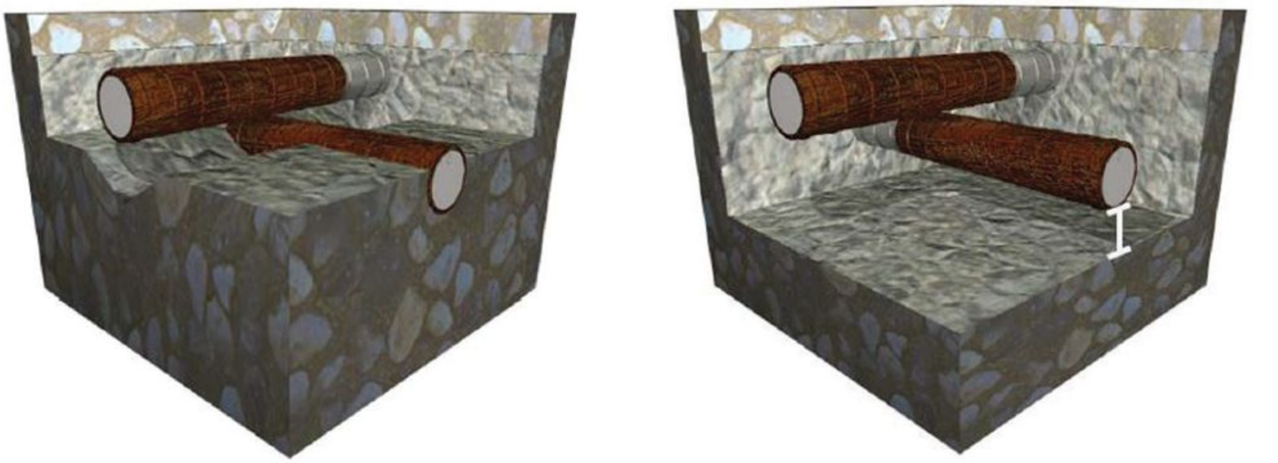


Figure 4. When multiple reinforcing bars are corroded, concrete must be removed around the bar and where the bar has lost bond with the existing concrete, as shown in the right image. This ensures future protection of the bar. Figure: Structural Technologies.

bar to provide a protective, high-pH environment (**Fig. 4**).
- Apply the appropriate repair geometry (rectangular areas without reentrant corners). Sawcut edges to ensure a surface with no feathered edges.
- Repair or replace reinforcing bars as required.
- Clean the surface of concrete and reinforcing steel by abrasive blasting, high-pressure water, or mechanical methods to ensure that corrosion is removed from reinforcing steel and concrete pores are open (that is, there is no dust or debris that might inhibit bond).
- Moisture condition the substrate to accept new repair material.
- Use application techniques that create an intimate bond of the new material to the substrate (pumping pressure, vibration, hand and/or mechanical pressure).
- Maintain surface moisture and/or apply curing compound after repair is completed.

Consistent implementation of these requirements will significantly extend life of the concrete members.

Crack Repair by Adhesive Injection

Concrete cracks can be repaired to restore load transfer or for waterproofing purposes by using adhesive (generally epoxy) injection. To ensure crack repair efficacy, it is important to understand the cause of the crack as well as the amount of movement to be expected. Cracks with excessive movement will reopen in the same or an adjacent location. If cracks are caused by reinforcing bar corrosion, they cannot be repaired by injection because the corrosion process will continue after treatment. Concrete removal, thorough cleaning of the reinforcement to remove all existing corrosion, and replacement of the concrete is the proper solution for cracks caused by reinforcement corrosion.

Crack repair by adhesive injection is accomplished by pressure injection of a low-viscosity fluid into ports along a surface-sealed crack (**Fig. 5**). The injection proceeds in a port-to-port basis (ports spaced approximately the width of the element) until the crack is filled. The efficacy of this method is verified by core removal or nondestructive testing techniques.

Strengthening Methods

Composites

One effective repair method for strengthening concrete bridges involves using externally bonded composite material such as carbon-fiber-reinforced polymer (CFRP). Favorable characteristics of CFRP materials include their tensile strength-to-weight ratio and noncorrosive nature. This strengthening technique provides an alternative load path for the structure and is effective for restoring flexural or shear capacity to various types of concrete bridge elements. On segmental bridges, CFRP sheets can be applied to either the inside or outside faces of web walls and slabs of box girders, as well as around columns or on pier components (**Fig. 6**). The workability of the material facilitates its effective use in a diverse range of geometric configurations. When encountering time-dependent effects such as creep and shrinkage, externally bonded CFRP can help stabilize a structure by slowing the spread of cracking at distressed locations.

Proper design and detailing of a CFRP strengthening system are crucial, and a solid understanding of the structure's stiffness and CFRP material properties is necessary for proper application of this solution. Sound workmanship and adherence to proper quality assurance and quality control practices are also imperative to ensure effective bonding and long-term performance. Top-coat finish options are also available for ultraviolet protection and the desired aesthetic. (See the Concrete Bridge Preservation article on externally applied fiber-reinforced-polymer composites in the Winter 2021 issue of *ASPIRE*.)

Figure 5. A cracked concrete element being prepared for repair with epoxy injection by installing grout ports and sealing the surface. Photo: Structural Technologies.

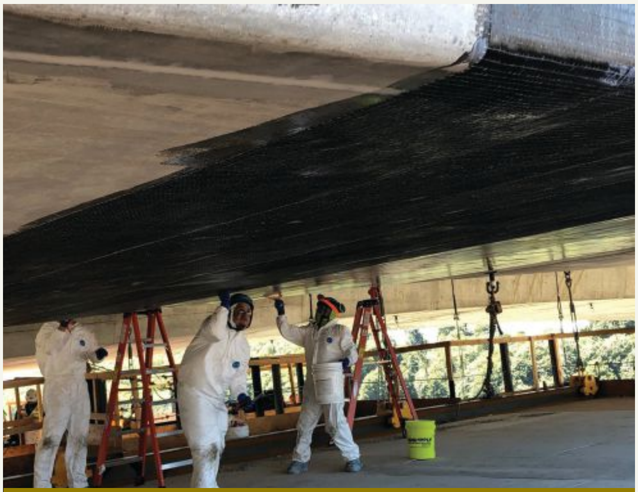


Figure 6. Carbon-fiber-reinforced polymer (CFRP) being installed to strengthen a concrete segmental bridge. Proper design, detailing, and installation is required for a CFRP strengthening system. Photo: Structural Technologies.

Post-tensioning

Post-tensioning is a strengthening technique used to counteract tensile stresses and deflections due to damage and deterioration to the structure, or from increased load demand. Unlike mild steel reinforcement, post-tensioning provides active reinforcement, which is accomplished by introducing a prescribed magnitude and distribution of internal forces using bar or strand systems.

Information related to loads, geometry, boundary conditions, mild reinforcement, and material properties of the existing structure should be gathered before starting analysis and design of the post-tensioning strengthening system. The two primary engineering considerations are strength and serviceability. While sufficient post-tensioning should be provided to strengthen the member for factored load combinations, care should be taken not to overstress the member at the service limit state, including the combination of post-tensioning and dead load only.

The design should ensure an effective connection between the structure and the post-tensioning system. Jacking forces can be large and can generate critical bearing, tensile, and bursting stresses within the existing concrete member and/or new concrete anchorage block. Deflections, crack control, and reinforcing steel stresses at service loads should be checked for both the strengthened member(s) and any other affected members to provide the expected serviceability.

External post-tensioning—such as placing the tendons within the void of the segment—has been successfully used on numerous segmental structures (**Fig. 7**). New tendons are added and tensioned at discrete locations along the length of the existing members. Fabricated steel or concrete deviators are typically placed at midspan, third points, or quarter points along the span to create a draped tendon profile.

Protection is required for all post-tensioning systems. Multiple strand tendons are typically encapsulated in corrosion-resistant, high-density polyethylene ducts. Low-bleed cementitious grout or flexible filler is used to further encapsulate and protect the strands.

Figure 7. External post-tensioning tendons being installed to strengthen an existing concrete segmental bridge. Photo: Seattle Department of Transportation.

Project Delivery Options

Specialized experience and efficiency in the project delivery process are often of particular importance when it comes to structural assessment, solution development, and rehabilitation of segmental bridges. To successfully navigate the challenges that we have described, and to fully leverage the important lessons that have been learned, two things are crucial: establishing a strong team and facilitating effective collaboration within that team.

Project delivery models that have proven effective at bringing together all key project partners (owner, designer, construction engineering and inspection, and contractor) to achieve shared project goals include construction manager/general contractor, construction manager at risk, and progressive design-build. In our opinion, these contracting methods are most effective at delivering the greatest value to owners for the types of repair projects discussed here. These project delivery options involve the right people earlier in the process, which facilitates:

- identifying and understanding true root issues,
- generating the best solution,
- collaborative budget and schedule development, and
- risk mitigation.

Conclusion

Concrete bridges in general, and particularly those with segmental construction, can and should be preserved to fulfill and possibly exceed service-life expectations. A sound approach to obtaining successful results includes understanding root causes of deterioration, developing a holistic assessment and repair strategy, and adhering to best practices using a qualified and effective project team while making the repairs. Experience gained by the industry over the past few decades is summarized in this article and the article in the Winter 2022 issue of *ASPIRE.* These lessons should be implemented to efficiently and effectively maintain these bridges, which make up some of our nation's most critical transportation infrastructure. The concluding article in this series will demonstrate the effective implementation of these concepts through case studies.

Reference

1. *fib* (International Federation for Structural Concrete). 2013. fib *Model Code for Concrete Structures 2010*. Berlin, Germany: Ernst & Sohn.

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Rubber-Tired Gantry Cranes for Bridge Construction

From precast concrete production facilities to bridge construction sites, gantry cranes are routinely used to perform the heavy lifting

by Monica Schultes

The first thing you see on many jobsites is the boom of a crane. Cranes have been used throughout the history of construction, and a wide variety are used on today's projects, each handling a specific task. The sheer variety of crane types, each with its own advantages and disadvantages, makes it challenging to select the right machine. Each project is unique and may require a combination of different types of equipment.

Picking the right crane for a bridge project involves understanding the jobsite, the surrounding terrain, and the weight and length of the materials or components to be handled. Weather conditions, as well as project schedule and duration, also come into play. Project teams therefore consider which types of cranes to select and how many will be needed from the earliest planning stage.

Replacing a bridge while minimizing the project's impact on both the surroundings and the traveling public necessitates creative thinking. The rubber-tired gantry crane, often referred to as an RTG, is a unique combination of an overhead lifting device and a mobile crane, making it a good fit for tight sites. The big differences between a gantry crane and a boom or counterbalance device are the gantry crane's stable platform and its minimal space requirements.

Rubber-tired gantries are popular with precast concrete fabricators for work at precasting facilities. They have also become popular with contractors, who use them to erect bridge beams and to move and install deck panels and other components on the construction site.

"Although Mi-Jack Travelift rubber-tired gantry cranes may not replace all types of cranes nor service every project," says Jerry Studer, Southeast regional sales manager for MI Jack Products' Travelift division. "They do offer material handling versatility that some contractors may not have considered."

Limited Space

Where space is limited, such as an infill project where a new structure is placed in the gap between two parallel bridge decks, RTGs come into their own. An RTG can be driven with two legs on each of the existing structures or roadways, straddling the gap to be filled (**Fig. 1**).

In some cases, such as high-traffic areas, departments of transportation specify the use of RTGs to avoid lane closures.

The RTGs require a limited drive aisle to operate, typically a 5-ft runway on each side (**Fig. 2**). They can be used for many facets of the job that require only

Figure 1. With the ability to straddle the gap between the existing structures, a rubber-tired gantry crane allowed work to progress on the Interstate 65 bridge over the Alabama River without lane closures. It also eliminated the need to transport cranes to other areas of the project. All Photos: Mi-Jack Products.

Figure 2. The rubber-tired gantry crane requires just 5 ft of aisle way on either side to handle loads.

a narrow lane for crane access and where the entire work envelope is underneath the gantry.

Some RTGs have a 16-wheel design to reduce ground load pressure over the traditional 8-wheel design. While rubber tires are most frequently used because of their cost, mobility, and flexibility advantages, some projects dictate the use of gantry cranes with rail wheels.

A gantry fitted on a rail system could be used to distribute the load to a specific area or where transporting materials is limited to certain fixed dimensions. In a situation with extremely narrow access, stationary rails are appropriate. However, as GPS steering technology has become more accurate, it has replaced the need for rails in some applications.

Caloosahatchee River Project

For certain projects such as the widening of Interstate 75 (I-75) in Fort Myers, Fla., a gantry or straddle crane is the only solution. Two RTGs with clear spans of 84 ft were able to span the median gap between the existing twin-span bridges (**Fig. 3**). The operators tried to steer the large cranes themselves, but they had a difficult time keeping the cranes on the allocated path because the bridge had a slight continuous curve. The solution was an auto-steering system based on GPS technology that guided the twin RTGs so the operators could concentrate exclusively on maneuvering the loads into position. Use of the GPS system is growing, and has taken the place of corrective steering and rail systems in some situations. While keeping the crane on the straight and narrow is a challenge, automated self-centering technology to avoid overcorrections has also progressed. Using the GPS system for the Caloosahatchee River project made the large machines easy to direct and kept the cranes from bumping into barrier walls, allowing the operators to concentrate on their picks as well as other conditions. The GPS steering guided the cranes through the new bridge's 1-degree horizontal curve and up and down the 3.5% slope, as well as delivering materials 50 ft below the bridge deck.

Tandem Lifts

RTG capacity ranges from 30 to 300 tons. "We haven't met a beam we can't lift," says Studer. Although a single RTG may be able to lift a large beam, tandem lifts are becoming more popular because they distribute the load of both the beam and gantry over more wheels and a larger area, often providing a more practical and economical solution (**Fig. 4**). "Tandem lifting with two Travelifts can be more practical than one larger crane with heavier capacity," says Studer.

Tandem lifts may seem more challenging, but the RTG setup and rigging is forgiving if, for instance, one operator is driving

Figure 3. For the widening of Interstate 75 in Fort Myers, Fla., a gantry or straddle crane was the only solution. RTGs with clear spans of 84 ft cleared the median gap between the existing twin-span bridges. Two gantry cranes controlled by GPS, each having one set of tires on the west span and the other on the east span, minimized lane closures and lessened environmental encroachments.

Figure 4. Expanding the lanes of an interstate bridge that services thousands of cars per day poses right-of-way and traffic flow challenges. Gantry cranes can provide a practical and economical solution where access is limited.

slightly faster than the other. There is additional leeway in the rigging to allow time to avoid a critical situation.

Tandem lifting has been around in precast concrete yards for decades. On a jobsite, the bridge layout is often straight or on a slight curve, making the tandem pick easy to achieve.

Handling an extremely long beam with one RTG typically requires a large spreader bar nearly the length of the beam, which adds a significant amount of weight and cost. In that case, the solution that makes the most sense is a tandem lift. Two smaller spreader bars also make twisting or bending of the long beam less likely during handling.

Plan Your Lift

When the crane supplier gets involved early in a project to assist contractors, estimators, and engineers, they can recommend the correct crane size and type and provide wheel loads depending on the beam weights that need to be lifted. There are three critical dimensions required when specifying an RTG: the inside clear width (span), hook height, and wheelbase. Because those dimensions are project specific, RTGs are usually custom built. Boom-type cranes typically require a counterbalance machine with weights or outriggers. A boom-type machine takes up a lot of space, and the farther it has to reach, the less weight it can lift. In contrast, a gantry crane can always lift and travel with its maximum capacity. Lifting a 100-ft-long bridge beam and positioning it might require a 250- to 300-ton boom crane, as opposed to a 50- to 70-ton RTG.

There is often a mix-and-match approach to crane selection, because gantry cranes can't do it all. For example, other equipment is still needed to drive piles and perform some of the foundation work.

RTGs were first used in the bridge market in the late 1990s to place heavy bridge beams. Recognized for their functionality and versatility, now they are the workhorses shuttling materials around the jobsite. "You could use an RTG that is one-third the size of a boom crane to reach across the site. It all comes down to the job, the site specifics, and the budget," Studer says.

Contractors want to be as cost competitive as possible and use their own fleet first. When acquiring new assets, they often look at what they have used in the past. More contractors are becoming comfortable with RTGs. Minimizing lane closures might be the initial reason, but eliminating the time and trouble to reposition a large boom crane is an added bonus.

Setup and Operation

While a small, 25-ton, rough-terrain crane can be hauled on one truck and quickly assembled, most projects require larger cranes that take multiple loads and several days to set up. Transporting an RTG requires between three and six trailers. For most projects, the components arrive on Monday and by Friday the cranes are up and ready to go. Because there are almost always boom-type cranes on site for other purposes, they can assist with the assembly of the RTGs.

There was a time when operators trained on load charts, but now electronic instrumentation has automated the use of such information for operators. For gantries, operators don't have to worry about outriggers, tail swing, and boom radius, which simplifies the ability to operate them and eases the requirements.

Even though the machines look big and bulky, 90-degree rear-pivot steering is standard. Like forklifts, RTGs can pivot on a zero inside-turning radius, and lead-wheel steering allows the operator to drive sideways, spin like a carousel, crab steer on an angle, or pivot steer.

Conclusion

While gantry cranes will likely never completely replace standard crawler or boom cranes, they can be another tool in the general contractor's toolbox. Gantry crane technology is improving, making it possible to deliver safer, faster, and more efficient cranes. RTGs are a common sight at prestressed concrete facilities and are being used with increasing frequency on bridge construction sites.

EDITOR'S NOTE

The ASPIRE® *team has published multiple articles covering jobsite techniques for accelerated bridge construction (ABC). This article is based on an interview with a supplier of a technology that is being more frequently used in ABC. Another example is the Creative Concrete Construction article on self-propelled modular transporter–gantries used to install girders for a project in Mississippi in the Summer 2021 issue of* ASPIRE. *The team invites other construction industry experts to share relevant jobsite topics like this with our readers.*

Temporary Top Strands in Prestressed Concrete Girders

by Dr. Krista M. Brown

Extending spans using taller girders, high-performance concrete, and more strands packed into the bottom flange leads to prestressed concrete girders with increased compressive stresses in the bottom fibers and increased tensile stresses in the top fibers at the ends of the girder, as well as the potential for large cambers. In addition, these aspects of current designs can make it challenging to achieve girder stability during handling, shipping, and erection; necessitate debonding of some bottom strands; or require higher concrete strengths at transfer or additional prestressing. Addressing these challenges can become a vicious cycle, which may not have a good solution. In an effort to temper the adverse effects of an increased prestressing force, some designers and precasters make use of temporary strands in the top flange.

What Are Temporary Top Strands?

Temporary top strands are fully tensioned strands that are installed in the top flange of a prestressed concrete girder and are typically only intended to function until the girder is erected and braced. They can be either pretensioned or post-tensioned. If pretensioned, the temporary strands are tensioned at the same time as all other strands, before the concrete is placed. If post-tensioned, the temporary strands are typically post-tensioned after the transfer of prestress of the permanent strands, either while the girder is still on the casting bed or shortly thereafter while the girder is still in the precaster's yard. If pretensioned, the strands are generally bonded for about 10 to 15 ft at each end, and the remaining portion of the strands in the midsection of the girder is debonded, typically with a sleeve. Post-tensioned temporary strands may be unbonded for their full length or bonded at one end.

With either pretensioning or post-tensioning, the temporary top strands are detensioned after the girders are erected and temporarily braced, but before the permanent diaphragms are installed. Pretensioned strands are detensioned using the same process that is used in the plant for permanent strands: One at a time and working in a symmetrical pattern, a strand is heated with a flame to relax (yield) the strand and gradually release the force before individual wires break. The strand is not "cut," even though that term is commonly used.

Post-tensioned temporary strands are used less frequently than pretensioned temporary strands, and the detensioning processes for the post-tensioned strands vary. Sometimes, the force in each post-tensioned temporary strand is backed off using a jack, one at a time in a symmetrical pattern. Because the post-tensioned temporary strands are not bonded, extra care should be given to this process. Another detensioning technique for post-tensioned strands is to provide a slot in the live-end bearing plate and place material behind the plate to create a small void; then, an acetylene torch can be used to relax the strand just ahead of the anchor. Care must be taken to ensure all personnel are clear of both ends of the girder during the detensioning process.[1]

Occasionally, external temporary strands are used to control stresses in girders. This article does not address that option.

What Is the Function of Temporary Top Strands?

The benefits of placing strands in the top flange have been documented.[2–4] They include controlling tensile stresses in the top fiber and compressive stresses in the bottom fiber near girder ends; improving lateral stability of the girder during handling, shipping, and erection; and reducing camber. Secondary benefits can include the ability to use a lower concrete design strength at transfer and reducing the need to debond as many strands in the bottom flange. The downside is that permanent top strands partially offset the desirable effect of compression in the bottom flange for in-service conditions. The best of both worlds is to take advantage of top strands before the bridge deck is placed and have the full advantage of bottom-flange strands and/or harped strands thereafter.

Guidance and Design

Top temporary strands may be included in the engineer of record's original design or added by a precaster at the shop drawing stage (with the approval of the engineer of record) to enhance lateral stability of the girder and/or reduce the concrete stresses or the required concrete strength at transfer.

For temporary top strands, typical design requirements may not apply or may be absent altogether. Article 5.9.4.5 of the *AASHTO LRFD Bridge Design Specifications*[5] briefly addresses temporary top strands. The following items are noteworthy:

- Detensioning shall be shown in the construction sequence.
- The development length of the pretensioned strands shall be determined per Article 5.9.4.3.3 (κ = 2.0), but no other provisions of debonded strands (Article 5.9.3.3) shall apply to temporary strands.
- The effects of temporary strands must be considered when determining camber and loss of prestress, both before and after the temporary top strands are detensioned.

The first item ensures that the proper instructions will be conveyed to everyone involved in girder fabrication and construction. The second points out that the restrictions on the number of debonded strands in a row and the length of debonding do not apply to temporary top strands. The last item directs the engineer to take the temporary strands into account when determining prestress losses and camber. Also, the commentary recommends that the inside diameter of the debonding sleeve should be 0.18 to

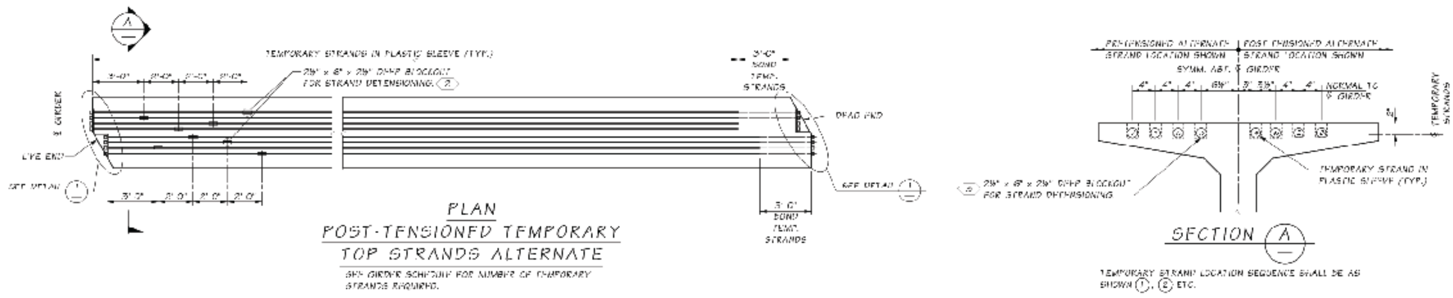

Figure 1. Excerpt from Washington State Department of Transportation standard details for pretensioned and post-tensioned temporary top strands. All Figures: Washington State Department of Transportation.

0.25 in. larger than the strand diameter; timing of detensioning (after bracing but before permanent diaphragms); and treatment of access pockets to prevent water accumulation and subsequent freezing.

While some state departments of transportation may mention in their bridge design manuals or specifications that temporary top strands are either allowed or not permitted, Washington State Department of Transportation (WSDOT) gives specific directions, details, and example calculations for temporary top strands.[6,7] **Figure 1** shows WSDOT standard details for pretensioned and post-tensioned temporary top strands, and **Fig. 2** illustrates the change in camber that occurs when the temporary strands are detensioned after erection. The WSDOT *Bridge Design Manual (LRFD)*[6] includes a prestressed concrete girder design example that shows calculations for prestress loss, camber, and camber growth associated with temporary top strands. The WSDOT bridge design software *PGSuper*™ also has the ability to make these calculations. For construction, WSDOT requires that the detensioning process be included in the construction sequence. WSDOT also specifies that temporary top strands be tensioned to $0.75f_{pu}$, where f_{pu} is the specified ultimate tensile strength of the prestressing strand. For other agencies and owners, the temporary strands are tensioned to the stress that is required for the specific design application, up to the $0.75f_{pu}$ maximum.

The reduction in camber due to temporary top strands is not fully regained after detensioning those strands because additional prestress losses have occurred and the concrete has gained strength. Furthermore, if the initial camber is smaller, so is the camber growth. However, if the temporary top strands were not considered in the original design and the camber is less than originally predicted, the reduced camber could lead to changes in material quantities or vertical profile for a bridge. An increase in the haunch depth (the concrete between the top of the girder and the bottom of the deck), especially for girders with wide top flanges, would increase the dead load, which would affect the demand at service and strength limit states. If a prestresser recognizes the need for temporary top strands early in the project, the contractor can be notified of the expected change in camber so adjustments can be made to bearing seat elevations to accommodate the reduced camber.

Why Is There Reluctance to Use Temporary Top Strands?

Temporary top strands in prestressed concrete girders have been used for at least 10 years. As mentioned earlier, they reduce concrete stresses at the ends of girders and also camber. Their use can allow the precaster or designer to move lifting points inward to improve girder stability during handling, shipping, and erection, and they may help reduce design concrete strength at transfer.[1] With all of these benefits, why aren't temporary top strands used more often? Reluctance by some contractors, precasters, engineers, and owners may be explained by a lack of experience, misconceptions about detensioning the strands, limits on prestressing bed capacity, the need for additional planning, or the possible shift of design responsibility when temporary top strands are not included in the original design.

A common misconception is that detensioning in the field is unsafe. Tensioning or detensioning of strands should never be taken lightly, but with proper training and procedures, the process for detensioning pretensioned strands is no different on a jobsite than in a precaster's yard. As mentioned earlier, the strand is not "cut"; rather, an access pocket is provided for each temporary strand and each strand is detensioned gradually by heating with a flame (torch). Remember, each strand is in a sleeve that is encased by concrete; it is unlikely that a detensioned strand could harm a worker.

Another misconception is that upon detensioning, the strand will "buck" the worker off the girder. However, there have been no such reported cases, the mass of a girder makes this highly unlikely, and the typical safety measures would protect a worker from such a scenario.

In a few cases, cracking of the top flange has occurred during the post-tensioning process or during the detensioning process for pretensioned strands. Documented cases are not available, but such damage is likely the result of poor detensioning practices or insufficient pretensioning or post-tensioning anchorage reinforcement (see the AASHTO LRFD specifications, Articles 5.9.4.4 and 5.9.5.6, respectively). Cracking in the top flange can also be caused by ice forming in the access pocket or along the unbonded length of strand. Precautions to protect the pocket from accumulating water and freezing, and patching the void immediately after detensioning should suffice. For this reason, WSDOT prefers to place the pocket toward the end of the girder on the downhill side and to leave the foam in the access pocket to prevent water entry until detensioning. Some agencies prefer to place the pocket at the center of the beam.

Some say that the change in camber upon detensioning temporary top strands cannot be adequately predicted. This

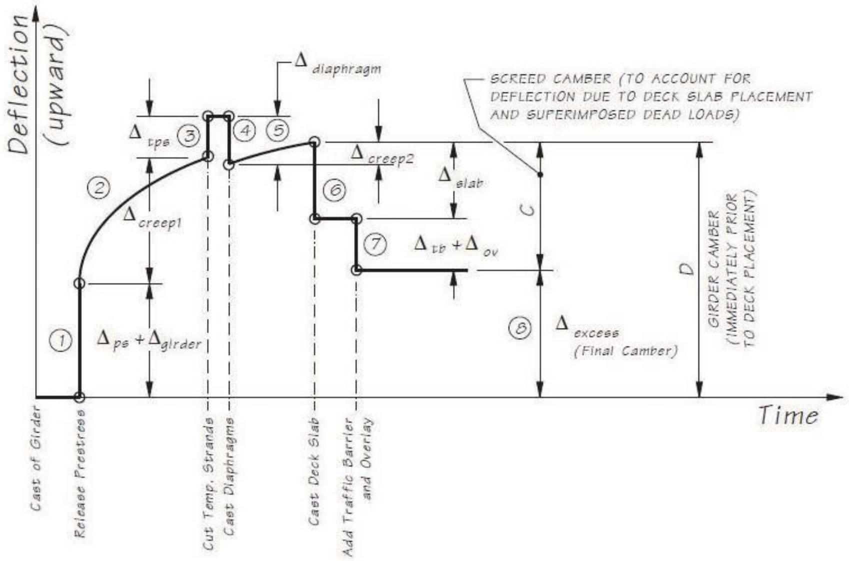

Figure 2. Schematic midspan deflection diagram from Washington Department of Transportation's *Bridge Design Manual (LRFD)*.[6] Step 3 shows the upward change in deflection due to detensioning of temporary top strands, Δ_{tps}. Step 4 is the downward deflection due to the placement of diaphragms. Camber growth between steps 3 and 4 is not obvious, but it must be considered during girder design.

is a basic calculation, and all camber predictions have variability. However, it is important, and often required, to determine the prestress losses both before and after detensioning of the temporary top strands so that camber and camber growth due to creep are appropriately considered.

One item that could prevent installation of pretensioned temporary top strands is a precaster's equipment. Some girders are very tall, and a precaster might not have the casting bed capacity to tension at that height, or the bed might not be long enough to redirect the strands to a lower tensioning height.

Conclusion

Installing temporary top strands in a prestressed concrete girder is not a panacea, but it is certainly a useful tool to control stresses and camber, and to improve girder stability during handling, shipping, and erection. Although the concept is simple, appropriate procedures must be used for each step in design, fabrication, and detensioning. Even if the strands are only installed to gain time to allow additional prestress losses to occur or concrete strength to increase, thus moderating concrete stresses, there may be implications for the final girder design. As always, communication among all parties—the owner, engineer of record, contractor, and precaster—is the key.

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External temporary top strands ensured the lateral stability needed to safely ship and erect a 203 ft girder in Utah (for details, see the Creative Concrete Constuction article in the Summer 2019 issue of *ASPIRE*®). Photo: Forterra Structural Precast.

Comparison of Methods to Estimate Long-Term Deflections for a Precast, Prestressed Concrete Bridge Beam with a Cast-in-Place Composite Deck

by JP Binard, Precast Systems Engineering, and Al Patel, Clark Nexsen

Estimating camber and deflection in precast, prestressed concrete bridge elements is a common topic of confusion and disagreement among design engineers, contractors, fabricators, and other stakeholders. In many design provisions and specifications, a net-positive design camber is required after all dead loads are placed. In other words, the girder is not supposed to sag under dead loads: self-weight, deck weight, and superimposed dead loads (barriers, diaphragms, and future wearing surface). Some agencies require a very specific net-positive design camber, such as ½ in. minimum.

Given that camber estimates in design may vary by 50%, how is this accuracy achieved in the final design? Is this an elastic requirement, or is it a time-dependent requirement at 20,000 days or greater based on service life? If the latter, how does a design engineer forecast the effects of creep, shrinkage, and relaxation on the deflection of the system? Can prestress losses really be determined accurately enough or with any level of precision for this final requirement?

Section 8.7 of the *PCI Bridge Design Manual*[1] presents an approximate method for estimating camber that uses a simple constant multiplier method originally proposed by Martin[2] in 1977. However, the basis of these multipliers, shown in Table 8.7.1-1, was never intended for bridge members made composite with a cast-in-place deck. This point is noted in Section 8.7:

> *This method gives reasonable estimates for cambers at the time of erection. The method does not, however, properly account for the significant effects of a large cast-in-place deck. The presence of a deck, once cured, drastically changes the stiffness of a typical bridge member. This has the effect of restraining the beam creep strains that are the result of prestressing, member self weight, and the dead load of the deck itself. Also, differential creep and shrinkage between the precast beam and the cast-in-place concrete can produce changes in member deformation. The multipliers for long-term deflection suggested by this method, therefore, should not be used for bridge beams with structurally composite cast-in-place decks.*
>
> *In addition, it is not recommended that prestressing levels be increased in order to reduce or eliminate long-term downward deflection that might be predicted if the multipliers in Table 8.7.1-1 are used.*

Table 8.7.1-1 Suggested multipliers to be used as a guide in estimating long-term cambers and deflections for typical members

		Without Composite Topping	With Composite Topping
	At erection:		
(1)	Deflection (↓) component – apply to the elastic deflection due to the member weight at transfer of prestress	1.85	1.85
(2)	Camber (↑) component – apply to the elastic camber due to prestress at the time of transfer of prestress	1.80	1.80
	Final:		
(3)	Deflection (↓) component – apply to the elastic deflection due to the member weight at transfer of prestress	2.70	2.40
(4)	Camber (↑) component – apply to the elastic camber due to prestress at the time of transfer of prestress	2.45	2.20
(5)	Deflection (↓) component – apply to elastic deflection due to superimposed dead load only	3.00	3.00
(6)	Deflection (↓) component – apply to elastic deflection caused by the composite topping	---	2.30

Source: Reproduced by permission from *PCI Bridge Design Manual*, 3rd ed.

The Washington State Department of Transportation's *Bridge Design Manual (LRFD)*[3] further explains field observations of long-term camber in Section 5.2.4.B.8:

> *It might be expected that the above deck slab dead load deflection would be accompanied by a continuing downward deflection due to creep. However, many measurements of actual structure deflections have shown that once the deck slab is poured, the girder tends to act as though it is locked in position.*

Nevertheless, most design software programs use the long-term or "final" multipliers given in Table 8.7.1-1 of the *PCI Bridge Design Manual* as default multipliers for estimating final deflections.

Design Impact

Engineers who add strands to girder designs to achieve net-positive camber under all dead loads and after all losses by using the PCI deflection multipliers may find their designs can be conservative in terms of service stresses in the bottom fiber—that is, there may be more precompression in the bottom fiber than is required—because this method overestimates the time-dependent dead load deflection after the deck has cured. However, adding prestress to induce a net-positive camber can cause excessive tension in the top fiber near the ends, and addressing that issue may require a revised design with debonded or harped strands. Such a conservative design for the service limit state may also make lifting, handling, and transportation of the beam more difficult because of elevated tension in the top flange. Furthermore, adding strands to avoid a negative final camber can cause excessive camber in storage and at erection, which may cause issues in the field.

Materials

The constituents of today's high-performance concrete accompanied by higher transfer strengths, low water-cement ratios, and requirements on some projects for precast concrete beams to have a minimum age before casting the deck, all reduce creep effects on the deformation of the composite system. The original PCI multipliers were formulated using an ultimate creep coefficient of 2.0 in accordance with the 1971 edition of the American Concrete Institute's *Building Code Requirements for Reinforced Concrete* (ACI 318-71)[4] and considering the recommendations in *Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete* (ACI 209)[5] for concrete elements without compressive reinforcement and approximations for creep and shrinkage in a precast concrete element. Since that time, significant material advancements, such as implementation of ultra-high-performance concrete and improved curing methods, have further reduced long-term creep effects.

Alternative Design Method and Results

Analysis methods that are more rigorous than the simple constant multiplier method are now available to more accurately estimate the long-term deflection of a bridge system. These alternative methods are commonly employed in complex projects such as concrete segmental construction.

For the standard bridge with a cast-in-place concrete deck, Section 8.13.2.2 of the *PCI Bridge Design Manual* describes a time-dependent method based on information published in several books and articles such as the 1982 article by Dilger.[6] This method is a sectional analysis using creep, transformed section properties, and curvature for each time step and loading condition.[7,8] The basic time steps are as follows:

1. Transfer of prestress (instantaneous)
2. From transfer of prestress to deck placement (time dependent)
3. Placement of deck and superimposed dead load (instantaneous)
4. From placement of deck and superimposed dead load to final (time dependent)

The instantaneous stresses and strains are computed using transformed section properties with the material properties at the time of each analysis step. The time-dependent stresses and strains within a particular time step are computed as follows:

1. Calculate the age-adjusted effective modulus and corresponding modular ratio for the steel and the transformed composite section properties.
2. Determine the free strains that develop during the time interval being considered due to shrinkage, and those due to creep resulting from stresses applied during previous time steps.
3. Determine the artificial restraint of stresses and curvatures and the resultant normal force and moment at the centroid of the transformed section to prevent occurrence of the free strains in the previous step.
4. Apply these forces in the reverse direction to the centroid of the age-adjusted transformed section and calculate the time-dependent strains and stresses in the section.
5. Sum the results of steps 2 and 4 to provide net strains and stresses at each element corresponding to the restraining effect of the prestressing steel.
6. Determine deflections using standard formulas and the time-dependent curvatures computed as outlined in step 4 for the beam end and midspan.

This method of analysis was used to compute multipliers for various depths and selected spacings of precast concrete bulb-tee shapes common to the Mid-Atlantic and Northeast regions (**Fig. 1**).

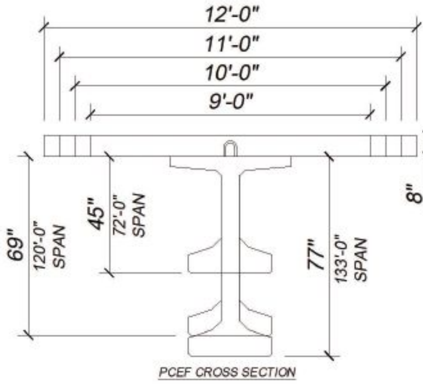

Figure 1. Precast concrete economical fabrication (PCEF) bulb-tee cross sections analyzed in this study. All Figures: JP Binard and Al Patel.

The effective deck thicknesses used in the analysis were 8 in. for 9- and 10-ft beam spacings and 8.5 in. for 10- and 11-ft spacings. The concrete design compressive strengths were 6.4 ksi at transfer, 8 ksi at 28 days, and a 4-ksi deck concrete compressive strength. The deck placement was assumed to take place at 56 days and the final period was 27,000 days or about 75 years.

We also investigated a historical example of an AASHTO Type III beam (62 ft 0 in. span) and Type IV beam (85 ft 0 in. span) using, respectively, a concrete compressive strength at transfer of 4 ksi and a design compressive strength at 28-days of 5 ksi, and a concrete compressive strength at transfer of 4.8 ksi and a design compressive strength at 28-days of 6 ksi. Such material strengths were common in the 1980s and might more closely resemble the conditions for which the PCI multipliers were developed. The deck concrete strength was assumed to be 4 ksi for these cases, and the deck placement was assumed to take place at 56 days with the final period of 27,000 days or about 75 years.

Lastly, we included a stretched span-to-depth design using a shallow 37-in.-deep bulb tee with a spacing of 9 ft 0 in. and a span length of 90 ft 0 in.

Figures 2 and **3** compare the results of the calculated long-term prestress multiplier (upward camber) and self-weight multiplier (downward), respectively, for the different scenarios investigated.

The prestress and self-weight multipliers calculated with a lower compressive strength at transfer and the smaller cross

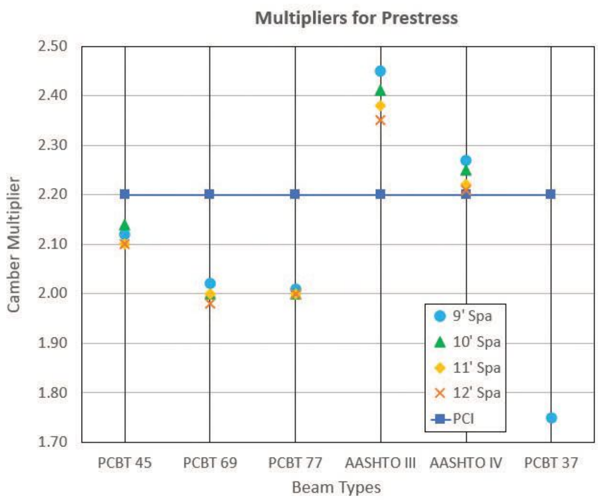

Figure 2. Long-term multiplier to be applied to elastic camber at time of transfer due to prestress for several girder configurations computed using PCI multipliers and a more refined method from the *PCI Bridge Design Manual.*

Figure 3. Long-term multiplier to be applied to elastic self-weight deflection at time of transfer for several girder depths and spacings computed using PCI multipliers and a more refined method from *PCI Bridge Design Manual.*

section (AASHTO Type III) more closely follow the PCI multipliers, whereas the longer-span bulb tees with higher transfer strengths do not.

A key variable in this analysis is the magnitude of deck shrinkage to be considered. Section 8.6.7.3 of the *PCI Bridge Design Manual* recommends that only 50% of the deck shrinkage be applied, but the *AASHTO LRFD Bridge Design Specifications*[9] do not specify a percentage. Therefore, we compared results of calculations made with the PCI multipliers using both 100% and 50% of the deck shrinkage along with the deck weight up to the final time step (**Fig. 4** and **5**). In general, for the cases based on 100% of the deck shrinkage, the calculated multipliers were slightly lower than the PCI multiplier. The 45-in.-deep precast concrete bulb-tee (PCBT 45) beams were the exception, which is likely due to two main factors: the lower span-to-depth ratio as compared with the other beams, and the computed deck deflections with respect to span length. However, for the cases that used 50% of the deck shrinkage, the calculated multipliers were notably lower.

Fig. 6 compares superimposed dead-load multipliers for final conditions (after deck placement). In this case, all calculated multipliers are lower than the PCI multiplier.

As previously mentioned, we investigated a case with a shallow 37-in.-deep bulb-tee beam and a stretched span to study the long-term camber behavior for a high span-to-depth ratio. The estimated long-term deflection using PCI multipliers is a sag of 0.1 in. When using 50% of the deck shrinkage and the age-adjusted transformed properties, the result is a positive camber of 1.5 in. **Table 1** compares the calculated camber using the time-step method and the PCI multipliers.

Topics for Further Study

Direction from industry on the required percentage of deck shrinkage to apply when estimating long-term deflection in conventional bridge construction is important for greater accuracy in those estimates. Furthermore, current practice in some states is to design bridges as continuous for live loads with the continuity connection between spans made at a minimum specified time after transfer of prestress. Changing the system behavior from a simple span to a continuous span after the continuity connection has been made may result in smaller long-term deflection values than determined in this article.[10] Future study is required to refine the multipliers for a continuous system for the period after deck placement, which is when the

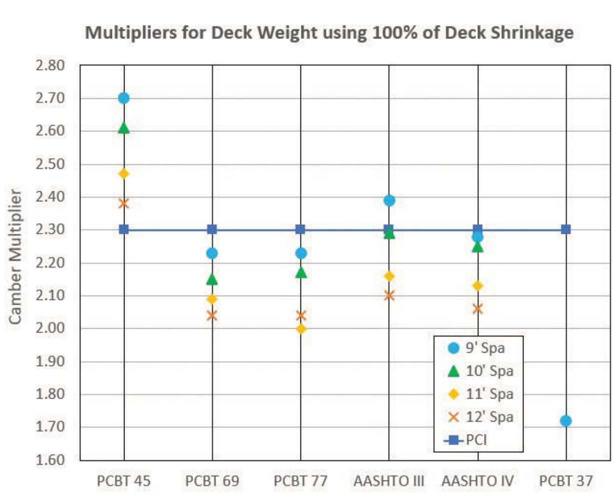

Figure 4. Long-term multiplier to be applied to elastic deck weight deflection, considering 100% of deck shrinkage at final for various girder depths and spacings computed using PCI multipliers and a more refined method from the *PCI Bridge Design Manual.*

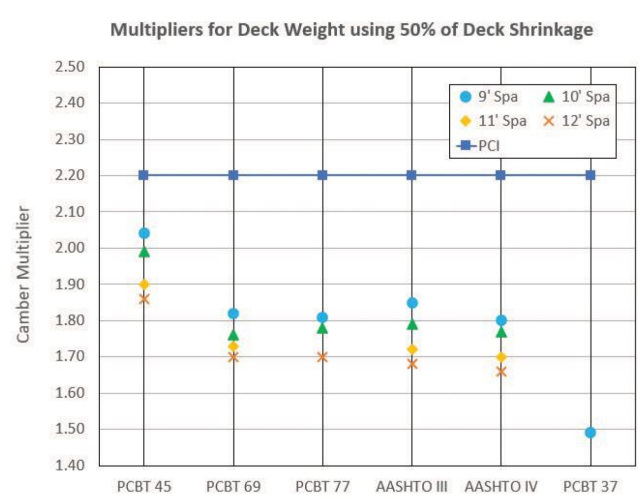

Figure 5. Long-term multiplier to be applied to elastic deck weight deflection, considering 50% of deck shrinkage at final for various girder depths and spacings computed using PCI multipliers and a more refined method from the *PCI Bridge Design Manual.*

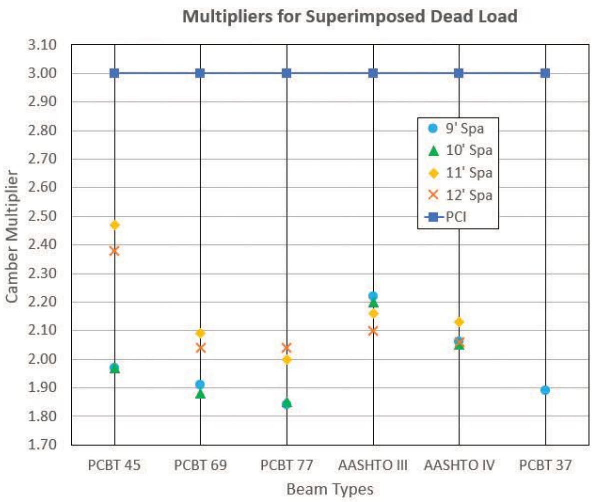

Figure 6. Superimposed dead-load multiplier for several girder depths and spacings computed using PCI multipliers and a more refined method from the *PCI Bridge Design Manual*.

Table 1. Comparison of long-term multipliers and computed design deflections using 50% of deck shrinkage for a 37-in.-deep bulb-tee girder spanning 90 ft 0 in. with a 9 ft 0 in. girder spacing

Long-term multiplier comparison					
Parameter	Elastic deflection, in.	Detailed analysis		PCI multipliers	
		Multiplier	Total deflection, in.	Multiplier	Total deflection, in.
Prestress	5.70	1.74	9.90	2.20	12.50
Self-weight	-1.80	1.78	-3.20	2.40	-4.40
Deck, 50%	-3.30	1.48	-4.90	2.30	-7.60
Super-imposed dead load	-0.18	1.89	-0.34	3.00	-0.60
			1.46		-0.10

continuity connection is made. Additional time steps for the time-dependent effects between deck placement and continuity connection may be necessary to determine appropriate multipliers for final deformation.

Conclusion and Recommendations

Wide-flange bulb-tee beams, used in conjunction with increased concrete strengths and larger-diameter strands, have allowed efficient designs with increased span-to-depth ratios and beam spacings in bridges with cast-in-place decks. Furthermore, the advancement of material technologies such as ultra-high-performance concrete may require further refinement in analyzing deformations beyond common design assumptions based on tabulated multipliers. Therefore, because the accuracy of the long-term deflection estimates is important to most owners, a program using regional field data to create region-specific multipliers based on beam types used by local prestressed concrete producers, design and construction practices, and bridge history may be beneficial. Until those data are available or analyzed, multipliers may be computed for commonly produced prestressed concrete beams using the method presented in this article for both 50% and 100% of deck shrinkage to provide a reasonable range of values (Table 2).

The multiplier values developed in this study apply to a limited set of beam types, specific conditions, and certain assumptions. Although these multipliers, which are lower than standard PCI multipliers, may provide more accurate estimates of long-term camber that can possibly lead to more efficient designs, bridge engineers should only use them with a full understanding of their derivations, assumptions, and implications.

Table 2. Average multipliers for long-term effects and comparisons using 50% and 100% of deck shrinkage

Deck cast at 56 days using 50% of deck shrinkage					
	PCBT	AASHTO types	All beams	PCI	Recommended
Prestress	2.02	2.32	2.14	2.20	2.10
Member self-weight	1.93	2.08	1.99	2.40	2.00
Deck weight	1.81	1.75	1.79	2.30	1.90
Superimposed dead load	1.93	2.12	2.00	3.00	2.00

Deck cast at 56 days using 100% of deck shrinkage					
	PCBT	AASHTO types	All beams	PCI	Recommended
Prestress	2.02	2.32	2.14	2.20	2.10
Member self-weight	1.93	2.08	1.99	2.40	2.00
Deck weight	2.25	2.21	2.23	2.30	2.25
Superimposed dead load	1.93	2.12	2.00	3.00	2.00

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Extradosed Finback Design and Progressive Span-by-Span Erection for the Selmon West Extension Project

by Bob Anderson and Trevor Kirkpatrick, AECOM, and Russel Dingman, Kiewit

For the Selmon West Extension in Tampa, Fla., a creative and prototypical post-tensioned structural system was conceived to accommodate the progressive span-by-span segmental erection method needed to meet project constraints. As an enhancement to existing conventional techniques for segmental construction, the extradosed finback solution was used for its ability to efficiently reduce the depth, weight, and cost of the superstructure, and to provide structurally functional aesthetic elements in the form of finbacks at interior piers.

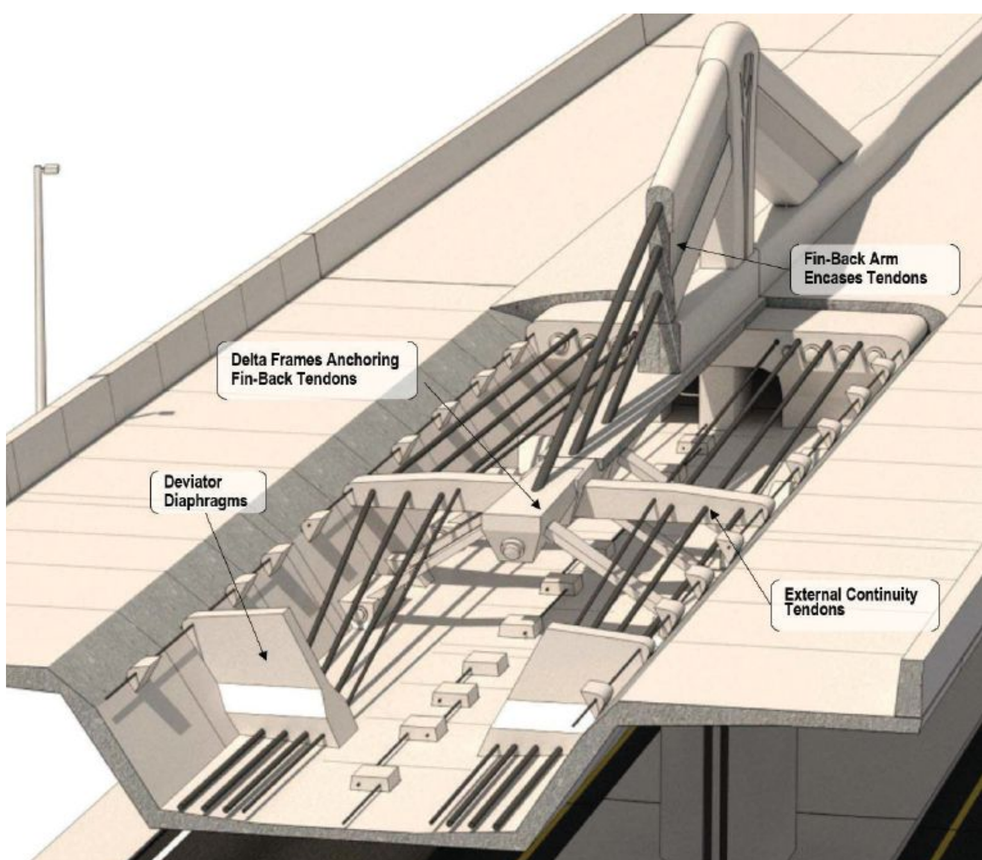
Extradosed Finback Design

Extradosed finback design combines a segmental post-tensioned box-girder bridge with many of the advantages of cable-stayed bridges without the complications and requirements of a typical cable-stayed structure. The extradosed tendons (tendons exterior to the superstructure cross section) in the finback replace several of the typical internal or external tendons normally contained within the concrete box-girder cross section. These extradosed tendons have shallow trajectories from the finback tendon anchorages just below the deck surface on each side of the pier and are deviated over short towers at each interior pier. The shallow angles of these tendons result in the transmission of a large compression force into the bridge deck, allowing the tendons to function in a similar manner to conventional flexural bridge prestressing. The cast-in-place finback behaves as a frame and allows direct transmission of load via tension through the precompressed finback arms down through the short tower and then to the foundations, providing robust and efficient load paths.

The geometric design of the finback accommodates vertical and horizontal curves, as well as superelevations associated with the project. For curved horizontal alignments, the fin arms were angled to intersect the box girder at the centerline of the structure and the finback tendons were deviated slightly within the fin arms and tower. Additional reinforcement to accommodate tendon deviation loads was incorporated into the finback design. Superelevation is addressed with the finbacks being normal to the deck as opposed to vertical and plumb.

A single-plane extradosed finback is located within the 130 ft pier section (negative moment region) along the centerline of the bridge. Unlike conventional extradosed bridges, the extradosed tendons are completely encased in a cast-in-place concrete fin. This design protects the tendons from vehicular impact; significantly increases the stiffness of the overall structural system; and allows for the use of conventional post-tensioning hardware, ducts, and flexible wax filler instead of expensive cable-stay systems. Three large, multistrand extradosed tendons (up to thirty-one 0.6-in.-diameter strands) anchored at interior delta frames fully prestress the concrete fins and provide a significant portion of the negative moment capacity for the span. The extradosed finback tendons are designed as unbonded tendons and

Cutaway view of a finback and segmental box girder system showing post-tensioning tendons, delta frame finback tendon anchorages, and continuity tendon deviator locations. All Figures: Kiewit/AECOM.



Photograph showing stages of construction of finback structure of the Selmon West Extension. Temporary shoring towers to allow erection of the next section of the bridge using the progressive span-by-span method are shown in the foreground. Several spans with their finbacks are visible in the background. Photo: Tampa Hillsborough Expressway Authority.

are detailed to be fully replaceable, in accordance with the Florida Department of Transportation's post-tensioning requirements.

The box-girder segments making up the pier section are post-tensioned with multistrand top- and bottom-slab tendons before the concrete fin is constructed. The fins are monolithic with the box girder and median barrier at the approximate quarter points of the pier section, and the tower is cast integrally over the pier diaphragm. Thus, the pier section behaves similarly to a stiffened king-post truss and tends to rotate as a rigid body under unbalanced loading.

Between the fins and at the end spans, the drop-in section is composed of multiple precast concrete segments and configured like a typical box girder, which spans continuously from fin to fin and from fin to pier. Six external post-tensioning tendons are anchored at each pier diaphragm and run high through the pier section, then deviate down at the second finback anchor segment toward deviator diaphragms as the tendons approach midspan. Several internal bottom-slab tendons run through the drop-in section and are anchored in bottom-slab blisters. The external and internal post-tensioning create continuity between the pier sections and drop-in sections and provide the positive moment strength required at midspan. The described design allows for a shallower and lighter superstructure than could be achieved with conventional segmental construction. Where a conventional segmental box girder would generally require a depth of 10 ft for a 260 ft span, the extradosed finback design only requires an 8-ft-deep section, for a total span-to-depth ratio of 32.5 for the 260-ft maximum span.

When compared with a conventional balanced-cantilever erection design, this creative use of post-tensioned concrete for the superstructure reduced the concrete quantity (and weight) by 13%, and reduced the post-tensioning quantity by 16%. The reduced superstructure weight and associated construction loading on the permanent foundations also led to reductions in substructure size and quantities. The combination of quantity reduction and the single-heading construction scheme achieved significant cost savings and schedule compression over the concept design provided in the request for proposal.

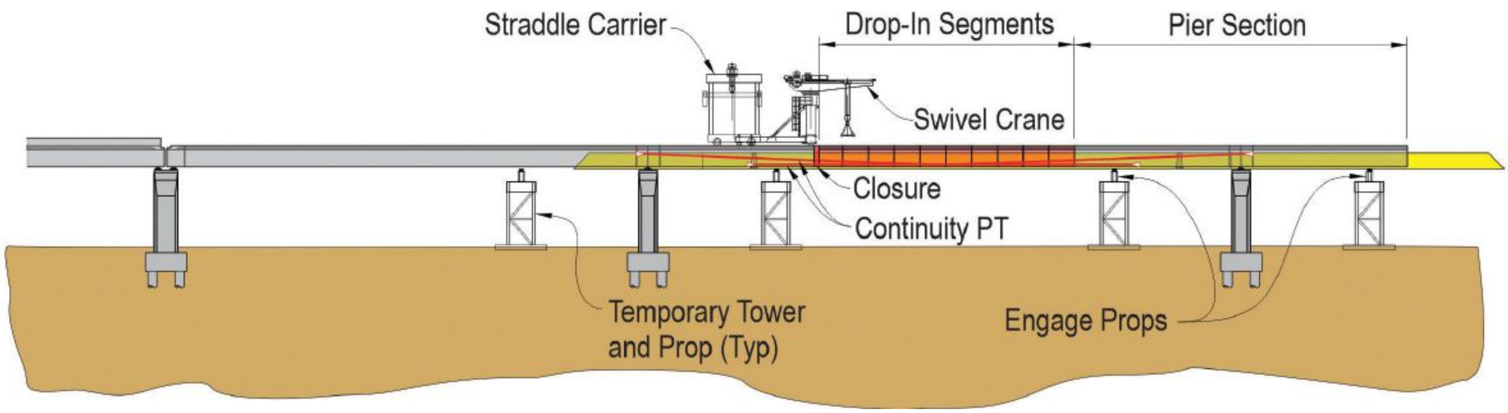
Extradosed Finback Construction Sequence

Construction of a finback bridge is a hybrid solution that combines balanced-cantilever and span-by-span techniques, referred to as progressive span-by-span erection. Use of underslung erection girders resulted in a top-down construction approach that created an elevated work zone. Segments were delivered from the casting yard to the project site and placed from atop the completed portions of the viaduct.

As spans were completed, temporary towers were advanced. Segment installation, post-tensioning, and erection girder advancement activities were performed at night when the inside lanes next to the median could be closed.

The following steps describe the construction sequence for each unit:

- Construct temporary towers adjacent to piers. Launch erection girders (supported by three towers).
- Deliver precast concrete segments via completed bridge. Place pier-section segments on erection girders with swivel crane.
- Roll cantilever-section segments into position over pier on erection girders. Epoxy joints, and tension top and bottom cantilever-section tendons.
- Engage jacks at towers supporting pier section. Lower erection girders and adjust for drop-in segments. Place segments with swivel crane. Roll segments into position, epoxy joints, and cast closure pour. Tension continuity tendons. Inject flexible filler to protect the tendons shortly after all continuity tendons are tensioned, within 14 days of tendon placement at most.
- Advance erection girders, straddle carrier, and swivel crane. Construct next pier section using the previously described steps.
- Construct drop-in section between completed pier sections.
- Advance erection girders, straddle carrier, and swivel crane. Cast finback at previous pier. Tension finback tendons, which run continuous from one delta-frame anchor in the box girder over the tower, with the appropriate deviation radii, and back down to the other delta-frame anchor.



Schematic of progressive span-by-span erection with drop-in segments (orange) in place. Launching girders are shown in yellow. Finbacks are not shown because they were not installed until the construction operation moved to the next span.

- Continue previously described steps to complete unit. Construct remaining barriers (that is, the barriers that are not part of the median barrier in the finback assembly).

Conclusion

As the Selmon West Extension shows, the combination of the extradosed finback design and the progressive span-by-span erection method offers the following advantages:

- A constant-depth single-cell concrete box girder that is 20% shallower than a conventional segmental design
- Improved redundancy by providing an additional load path
- Reduced foundation loads
- Smaller footprint in the median to avoid turning-lane impacts on surface-street traffic
- Reduction in substructure and post-tensioning quantities
- Spans of up to 260 ft

Bob Anderson and Trevor Kirkpatrick are senior bridge engineers specializing in complex bridges at AECOM in Tampa, Fla. Russel Dingman is a project sponsor at Kiewit in Tampa, Fla.

Precast Concrete Structures for Fish-Passage Culverts

by Dr. Bijan Khaleghi, Washington State Department of Transportation

Washington State Department of Transportation (WSDOT) is working to improve fish passage and reconnect streams to help keep our waterways healthy. Statewide, there are 3965 highway crossings over fish-bearing waters. Of these, 2073 are documented fish-passage barriers, including 2040 culverts, of which 1531 block a significant amount of upstream habitat. Consequently, WSDOT created a dedicated program to identify and correct barriers that restrict or completely block fish access to historic spawning and rearing habitat. With this program, WSDOT can identify high-priority barriers and correct them with dedicated fish-passage funds through planned transportation projects.

Structure Types and Selection

Buried structures and bridges are the two types of concrete structures used for fish-passage program delivery.

Buried structures are used:

- for smaller hydraulic openings that do not require bridges,
- where debris potential is tolerable, and
- when a buried structure is a more economical option than a bridge.

Bridges are used:

- where culverts are impractical,
- when a bridge is a more economical option than a culvert,
- to mitigate environmental harm caused by culvert construction,
- where stream migration and floodway encroachments are issues, and
- where large debris is an issue.

Precast concrete buried structures or bridges are commonly used for both new and replacement structures because of their advantages compared with other structure types and materials. The following are advantages of precast concrete for WSDOT's buried structures:

- Superior strength. Precast concrete can be manufactured and designed to support highway, pedestrian, seismic, and other loads.
- High quality. Precast concrete made in a controlled facility ensures good quality control during casting.
- Installation benefits. Precast concrete structures can be installed in both wet conditions and cold temperatures.
- Cost effectiveness and other benefits. Precast concrete structures are more economical, require less jobsite work, meet the requirements for environmental fish window times, accelerate construction, and ensure minimal impact on the environment.

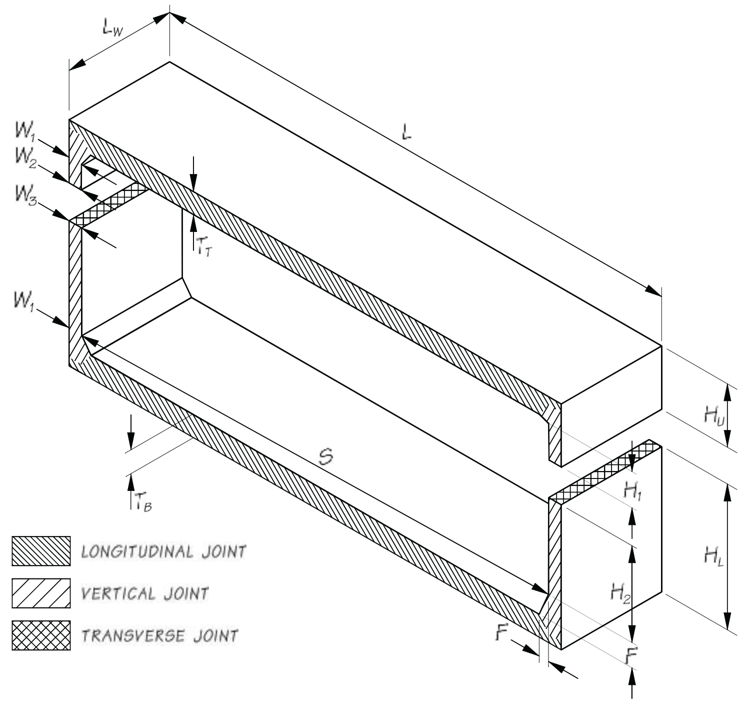


Figure 1. Details of the Washington State Department of Transportation standard precast concrete split-box unit. Joints are designed to carry the applied horizontal and vertical forces, and they are formed so that they can be assembled to transmit those forces and provide joint tightness. All Photos and Figures: Washington State Department of Transportation.

While WSDOT uses both bridges and buried structures for fish-passage culvert replacement projects, only buried structures are discussed in detail in this article.

WSDOT Buried Structures

The WSDOT Bridge and Structures Office has developed standard designs and drawings for precast reinforced concrete buried structures.[1,2] The two types of precast concrete buried structures are split boxes and three-sided structures. With either type, multiple units are joined to achieve the desired crossing width.

Precast Concrete Split Boxes

Concrete boxes are four-sided rigid frame structures. Split boxes consist of the upper unit, which is either a three-sided rigid frame lid or a flat top slab, and a three-sided rigid frame base that is the lower unit. In the precast concrete industry, the typical steel formwork used for three-sided rigid frame units of split boxes has span lengths that vary from 8 to 35 ft, in 1-ft increments. **Figure 1** shows the details of precast concrete split boxes.

The thicknesses of the top and bottom slabs can vary between 10 and 24-in., in 2-in. increments. The heights of the upper-

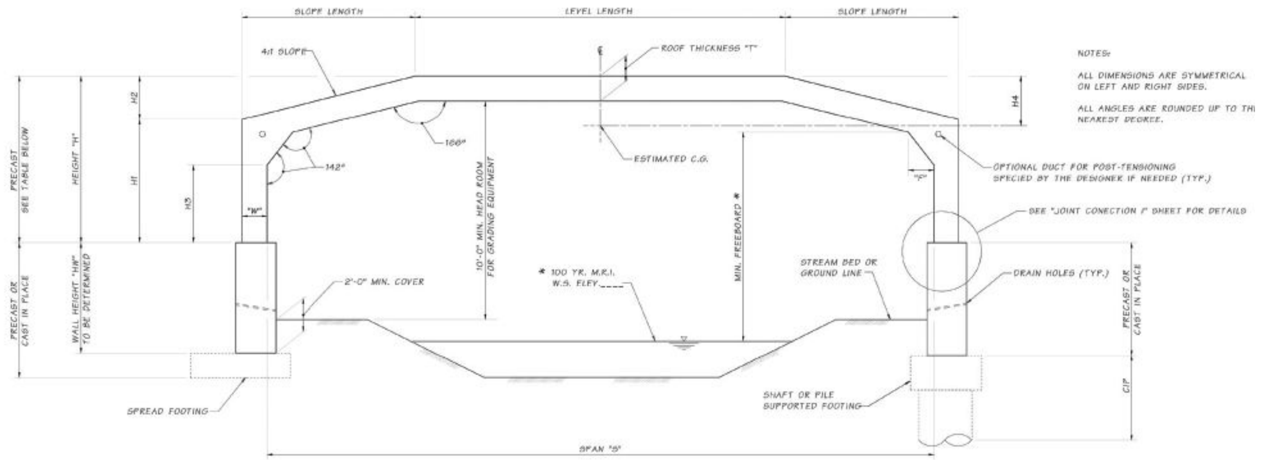


Figure 2. Details of the Washington State Department of Transportation standard precast concrete three-sided structure. The precast concrete unit is supported by either cast-in-place or precast concrete foundation units.

and lower-unit walls can vary between 0 ft (creating a three-sided base with a flat top slab) and 10 ft, in 1-ft increments. The wall thickness at the fillet is typically either 10 or 12 in., and tapers at 1 to 12 to accommodate removal from the form. The height limit is determined by shipping requirements and manufacturer's form capabilities. The widths of individual segments vary between 4 and 10 ft, in 1-ft increments. The fillets at the slab-to-wall junctures are 17.0 × 17.0 in. Skewed units are limited to skew angles of 45 degrees or less, in 1-degree increments.

Precast Concrete Three-Sided Structures

Three-sided structures are rigid frames, which may have open inverts and are supported by either cast-in-place or precast concrete foundation units consisting of a footing and possibly a stem wall.

Rigid three-sided structures have span lengths ranging from 8 to 35 ft, measured along the centerline of the roadway, and are constrained by the same geometric limitations that should be considered when establishing any structure's geometry. Wall heights are limited to a maximum of 10 ft. **Figure 2** shows the details of precast concrete three-sided structures.

Materials for Precast Concrete Buried Structures

Concrete Classes 5000 through 7000 (28-day design compressive strength being equal to the class of concrete) are commonly used for precast concrete buried structures. Self-consolidating concrete can be used for the fabrication of precast concrete units. Concrete cover is 2.0 in. minimum at all faces.

Welded wire reinforcement can be used to replace steel reinforcing bars in buried structures. Welded wire reinforcement is deformed and conforms to the requirements of AASHTO M 336.[3] The specified minimum yield strength for design is limited to a maximum of 80 ksi for reinforcing bars and 75 ksi for welded wire reinforcement.

When the fill depth of the buried structure is less than 2 ft at any point, all reinforcement in the top slab is required to be corrosion resistant, except reinforcement in the top slab need not be corrosion resistant when there is a 5.0-in. minimum composite cast-in-place concrete topping that meets the requirements for a Type 4 deck protection system.[1] (The Concrete Bridge Preservation article in the Fall 2020 issue of *ASPIRE®* presented details of WSDOT bridge protection systems.)

Consideration is given to the degradation of buried structure materials resulting from corrosive conditions. Corrosion-resistant reinforcement is used in both marine and nonmarine corrosive environments, and additional concrete cover may also be provided. The minimum cover requirements for direct exposure to salt water and coastal situations are in accordance with the *AASHTO LRFD Bridge Design Specifications*.[4]

Design of Buried Structures

The service limit state is used to determine stress limits, deflection, and control of cracking requirements, where applicable. Buried structures with span lengths greater than 20 ft are designed to accommodate the effects resulting from two types of seismic loading: ground shaking (transient ground displacement) and ground failure (permanent ground displacement).

For concrete structures where the top slab is less than 2 ft from the roadway surface, the design equalizes deflections by incorporating a structural connection capable of transferring the imposed shear between the top slabs of adjacent units. The structural connection includes cast-in-place reinforced concrete closures or grouted shear keys.

Joints are designed to carry the applied horizontal and vertical forces, and they are detailed to transmit those forces and provide joint tightness consistent with the required tolerances. Vertical joints between adjacent units and horizontal transverse joints between the upper units and foundation units are designed for the applied lateral forces by employing a shear key, block restrainer, or dowel bars.

When the top of a concrete buried structure is directly exposed to vehicular traffic, bridge approach slabs and a concrete or hot-mix asphalt (HMA) overlay or reinforced concrete deck are provided. When a HMA overlay is used, the minimum concrete cover for the top of the buried structure is 2.5 in. For a concrete overlay or reinforced concrete deck, the minimum concrete cover is 2.0 in.

Fish-Passage Culverts

About 60% of fish-passage projects are accomplished using buried structures. These precast concrete structures are an economical solution for removing fish-passage barriers and reconnecting streams to help keep our waterways healthy. The following are two examples of culverts replaced to provide fish passage:

- State Route 6 over Salmon Creek, a tributary to Rock Creek. A 24.3-ft-span concrete box culvert with 10.1-ft-high walls was used as a fish passage (**Fig 3**).
- Church Creek, tributary to the Stillaguamish River (**Fig. 4**). Because the old crossing, a 6-ft-wide, 8-ft-tall concrete box, was undersized for the channel, water velocities were excessive and the channel depth was insufficient

Figure 3. A new culvert was provided under State Route 6 at Salmon Creek to allow fish passage.

Figure 4. Church Creek, tributary to the Stillaguamish River. The old crossing (left) was replaced with a larger structure (right) to reduce channel velocities and increase depth for migrating salmon.

for migrating salmon. The new crossing is a 34.7-ft-wide, 14.8-ft-tall, three-sided precast concrete structure that provides access to 12.7 miles of potential habitat for chum and coho salmon, as well as trout.

Conclusion

WSDOT is efficiently using standardized precast concrete buried structures to meet the fish-passage program schedule and commitments. Precast concrete split boxes and three-sided buried structures are designed per applicable loads, seismic design requirements, and service life. WSDOT buried structures of various sizes are used to accommodate challenging stream conditions as well as shipping and handling constraints.

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Welded Wire Reinforcement: A Primer for the Bridge Designer, Part 2

by Paul Aubee, Artisan Structural PLLC

In part 1 of this two-part series, published in the Winter 2022 issue of *ASPIRE®*, we discussed welded wire reinforcement (WWR) manufacture, material characteristics and benefits, design compatibility, and use in bridge elements. This article shifts the focus to the implementation of WWR in contract drawings and the critical role played by the manufacturer's WWR detailing staff in preparing shop and placement submittals for engineer and contractor reviews.

Specification Options

The extent to which WWR is included as a structural reinforcement option in bridge elements is a function of state agency acceptance. Just as each state's department of transportation (DOT) establishes and maintains its own unique set of roadway and bridge design and detailing standards, the degree to which WWR is included in those standards varies as well.

Generally speaking, for bridge girders, WWR is largely used as steel reinforcement in the form of vertical stem, top flange, and bottom flange confinement applications. The inclusion of WWR in the American Association of State Highway and Transportation Officials' bridge design and construction specifications[1,2] as mild steel reinforcement for use in flexural, shear, torsional, and axial sectional strength calculations will generally be enough to allow a state to authorize use of the material.

With state acceptance, the use of WWR is typically deployed by one of two methods. The first and perhaps most common approach is for the DOT's standard drawings or specifications to allow WWR as a preapproved substitution for reinforcing bars that are typically detailed as the "default solution." Example language could be, "WWR may be substituted for reinforcing bars." In some cases, such as with the Texas DOT,[3] the area of WWR for some bars may be reduced in proportion to the increase in reinforcement yield strength over 60 ksi. However, WWR yield strength is limited to 75 ksi in the AASHTO specifications. Different states may have different limits.

When the state's standard specifications or drawings allow WWR as a preapproved substitution, both the designer and the contractor have the latitude to use WWR on a case-by-case basis to suit project-specific design challenges and site and schedule logistics, without altering the basic reinforcing bar detailing. A key attribute of this solution is that the WWR manufacturer is afforded the flexibility of using combinations of welded wire size and spacing (and sometimes strength) that are acceptable as long as a structurally equivalent design is achieved, considering the cross-sectional area and, when allowed, the increased yield strength of the wire reinforcement.

The second approach is for WWR to be directly specified in the standard drawing, with explicit details showing the required WWR size, spacing, and geometry. This is the approach used by the Florida DOT,[4] which typically has two sheets showing standard reinforcement details for each girder size. One sheet presents reinforcing bar details and the second has the alternate WWR details. Similar to the previously mentioned preapproved substitution method, the direct specification method uses WWR as an alternative to the default reinforcing bar arrangement. The difference between this approach and the preapproved substitution method is that the alternate standard detail approach is less flexible because the wire size, spacing, and positioning are specified in the alternate girder details.

It is worth noting that some state DOTs may not use either of the aforementioned acceptance methods, and will instead present standard details with no reference to WWR usage. In these situations, the designer can initiate communication with the state agency to seek a project-specific (or application-specific) approval. The material's acceptance throughout AASHTO standards would be the most obvious basis for such a request, but the argument for WWR usage can be strengthened by presenting examples of previously completed projects in which WWR was successfully implemented. It is the author's experience that the strongest cases made are typically those in which the designer collaborates with both a contractor and manufacturer to present a holistic view of a proposed WWR option for a project. This is an upfront effort that can yield significant downstream benefit.

The Role of the WWR Manufacturer

Regardless of the method used by a state to incorporate WWR into its bridge design standards, the WWR manufacturer is tasked with producing a project-specific reinforcement submittal package that conforms to the state DOT's requirements while accurately capturing a specific project's material placement and quantity demands.

To be clear, WWR use in cast-in-place or precast concrete bridge girders is not a commodity pursuit. There is no construction material distributor in the supply chain, which is different than some building applications where standard rectangular WWR mats may be specified.

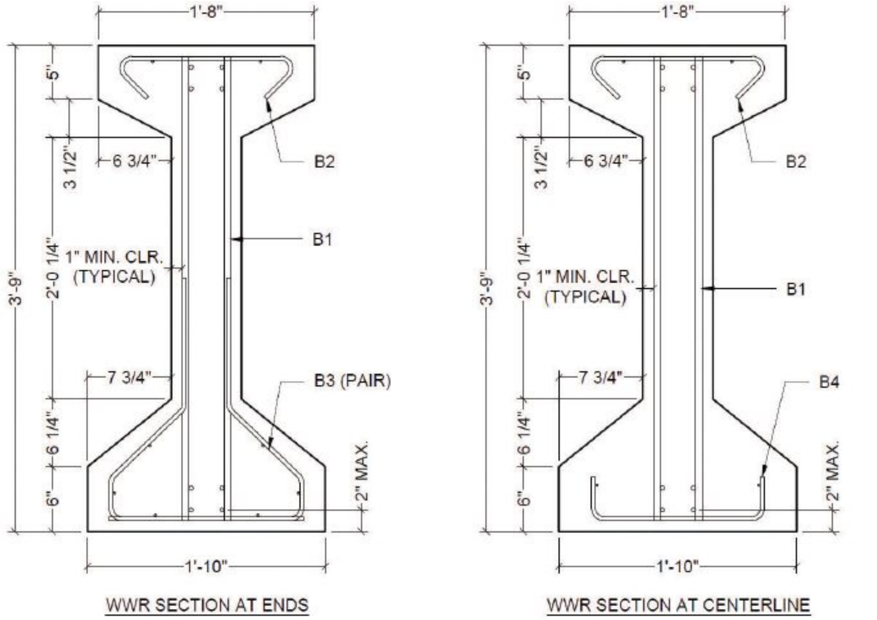

Figure 1. In a typical WWR submittal, there are two cross-section views—end and middle—for a given bridge girder. All Figures: The Wire Reinforcement Institute.

Manufacturers employ technical staffs who are tasked with generating submittal packages for project-specific WWR use. These technical staff members have the appropriate level of familiarity with the governing design and detailing standards, and they are able to generate WWR information that aligns with the manufacturer's own production capabilities. To that end, each WWR submittal contains WWR mat geometries, quantities, and placement requirements specific to a given project.

The manufacturer's detailing effort will vary depending on the method by which WWR is presented in the contract documents. If the state DOT allows WWR as a preapproved substitution, the WWR solution developed by the manufacturer might offer savings and efficiencies, as there is leeway to achieve the specifier's intended design by pulling from a broader range of wire size, spacing, and strength combinations. Deriving a reinforcement solution that satisfies the specifier's design intent and, at the same time, best leverages a manufacturer's inventory allocation and minimizes welding equipment changeover times is the real sweet spot for WWR. While direct specification is a viable and proven method for implementing WWR on bridge projects, the WWR as shown on the project drawings does not necessarily allow the manufacturer's detailer to select a solution favorable to in-house WWR fabrication capabilities. WWR manufacturers won't shy away from using what is explicitly specified in the plans, but there is some merit to a more general definition of reinforcement areas and spacing limits on design drawings to unlock some additional efficiency.

In the end, regardless of the method by which WWR is presented as an option on a bridge project, the Wire Reinforcement Institute's manufacturer members are staffed to produce detailed submittals that conform to the specifier's original design intent.

The Deliverable

A typical WWR submittal, which serves as the deliverable intended for the contractor's, girder producer's, and specifier's reviews and approvals, includes the following information:

- Beam section views—There are typically two cross-section views for a given bridge girder. The first view is cut through the end region of the beam, and the second view is cut through an intermediate or middle region of the beam. While these regions are often similar to each other when it comes to the reinforcement assembly that populates the beam cross section, the end sections are usually more heavily reinforced. Therefore, differences in configuration are best illustrated through separate cross-section views (**Fig. 1**).
- WWR mat diagrams—For the WWR mats that populate the aforementioned sections of the beam, diagrams are provided to show WWR sectional geometry, wire size, and bend arrangement, as applicable (**Fig. 2**).
- WWR mat summary—The mat summary outlines the WWR mat item description and quantity for the beam or beam project. The item description helps the reviewer spot-check sizes and spacings of the reinforcing wires, and it is critical for in-house use by the WWR manufacturer's workers on the plant floor who are tasked with actually producing the mats. The combination of item description and WWR mat diagram is mandatory for the production of WWR (**Fig. 3**).
- Beam elevation view—WWR mats shown in cross-section view and summarized in item descriptions with accompanying mat diagrams ultimately must be identified in an elevation view to show the girder producer the precise placement of mats in the forms or beds. Elevation views illustrate the distribution of mat types along the length of a given beam (**Fig. 4**).

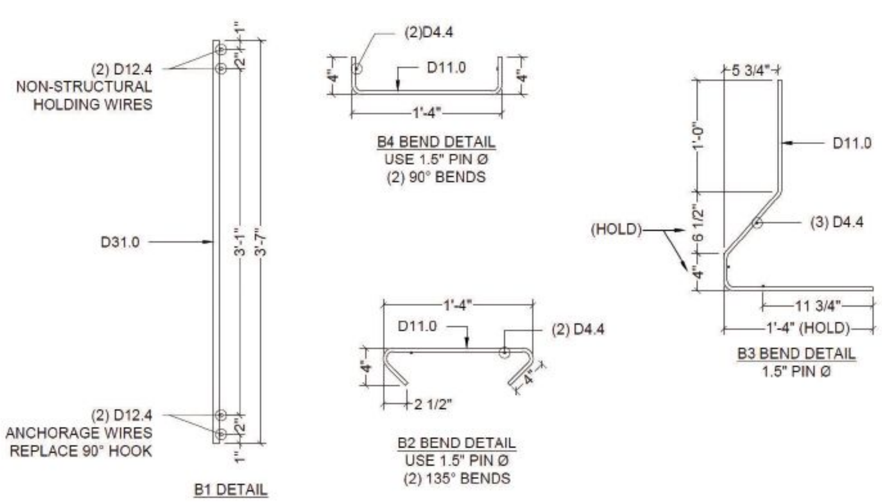

Figure 2. A mat diagram in a typical WWR submittal shows welded wire reinforcement sectional geometry, wire size, and bend arrangement.

SUMMARY OF WELDED WIRE REINFORCEMENT:

B1 END/MID1:	V1xV2	D12.4xD31.0	41"(+1",+1")	x	13'-0"(1",1")	72 REQ'D
B1 MID2:	V1x18	D12.4xD31.0	41"(+1",+1")	x	15'-2"(1",1")	72 REQ'D
B2 END/MID1:	10xV2	D4.4xD11.0	10"(+7",+7")	x	13'-0"(1",1")	36 REQ'D
B2 MID2:	10x18	D4.4xD11.0	10"(+7",+7")	x	15'-2"(1",1")	36 REQ'D
B3 END-L:	6xV3	D4.4xD11.0	12"(+16",+11.75")	x	7'-0"(1",1")	36 REQ'D
B3 END-R:	6xV4	D4.4xD11.0	12"(+16",+11.75")	x	7'-0"(1",1")	36 REQ'D
B4 MID1:	20x12	D4.4xD11.0	20"(+1.25",+1.25")	x	5'-2"(1",1")	36 REQ'D
B4 MID2:	20x18	D4.4xD11.0	20"(+1.25",+1.25")	x	15'-2"(1",1")	36 REQ'D

V1 = 1"oh - 2" - 37" - 2" - 1"oh
V2 = 1"oh - 8@3" - 4" - 9@6" - 6@12" - 1"oh
V3 = 1"oh - 8@3" - 4" - 9@6" - 1"oh
V4 = 1"oh - 9@6" - 4" - 8@3" - 1"oh

Figure 3. The mat summary in a typical WWR submittal includes the welded wire reinforcement mat item descriptions and quantities for the beam or beam project.

- Manufacturer notes—The manufacturer will include a list of notes that is relevant to both the reviewing contractor and the specifier. These notes often reiterate the material's conformance with the AASHTO M 336M or ASTM A1064 standards for WWR,[5,6] describe the WWR material equivalency to the originally specified reinforcing bar (when applicable), and distinguish between the reinforcement items that were "converted" to WWR and those that remained in reinforcing bar form (**Fig. 5**).

Conclusion

To meet the increasing demand for construction efficiency in the face of skilled labor shortages, manufacturers continue to work alongside specifiers, contractors, and girder producers in an effort to derive WWR solutions tailor-made for concrete bridge applications. Both the specifier and manufacturer play central roles in the communication of WWR use in bridge beams and how that reinforcement is ultimately produced and placed to achieve a successful end result.

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Paul Aubee is the technical consultant for the Wire Reinforcement Institute and is the principal engineer and owner of Artisan Structural PLLC, a consulting structural engineering firm.

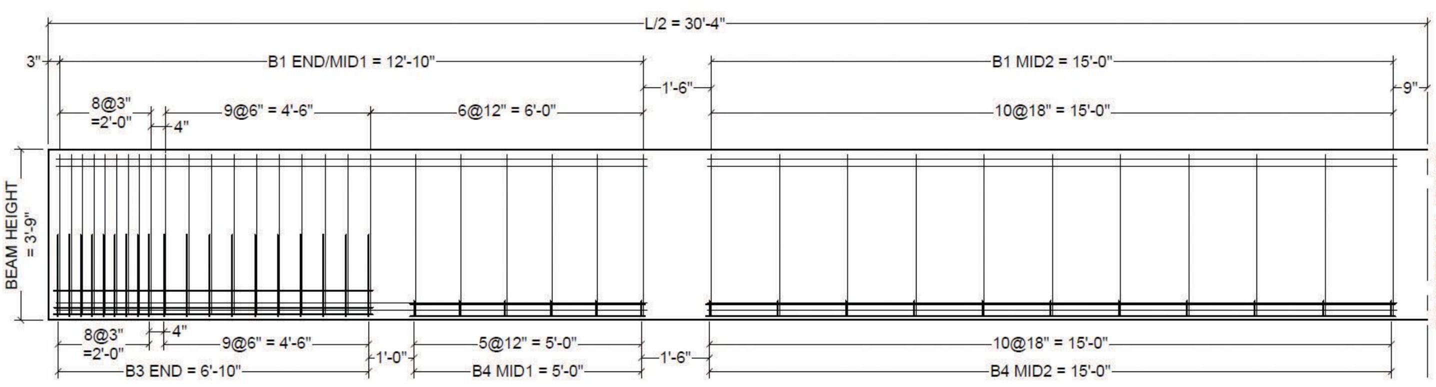


Figure 4. Beam elevation view in a typical WWR submittal showing the required placement of specified welded wire reinforcement mats.

NOTES:
- ALL MATERIAL CONFORMS TO ASTM A1064 FOR GRADE 70 DEFORMED WIRE.
- WELDED WIRE CONFIGURATIONS SHOWN ARE BASED ON EQUAL AREA CONVERSION FOR REBAR SHOWN IN DRAWINGS PROVIDED BY CUSTOMER.
- ONLY B1, B2, B3 AND B4 BARS WERE CONVERTED TO WELDED WIRE, ALL OTHER REINFORCEMENT REMAINS REBAR PROVIDED BY OTHERS.

Figure 5. The WWR manufacturer typically includes a list of notes that is relevant to both the reviewing contractor and the specifier.

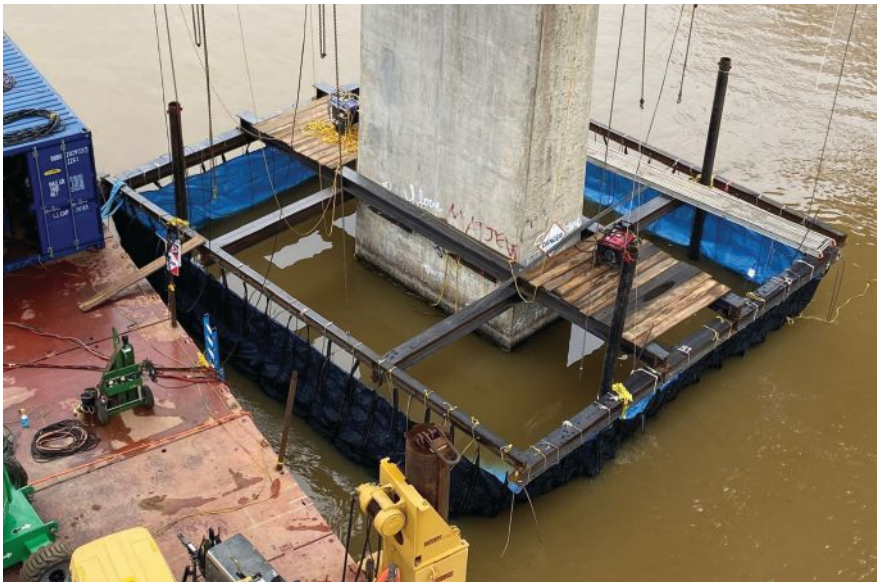
Innovative Geotextile Fabric Formwork

by Nick Fasano, TrapBag

When PCL Construction reached out to TrapBag Barrier Systems, a leading manufacturer of geotextile fabric forming products and other patented geotextile products, about the Lake Tillery Bridge rehabilitation project in North Carolina, we were presented with a unique situation (see the Project article on page 18 for additional details). The project involved placing concrete underwater to encase an existing bridge pier footing that was cracked due to alkali-silica reactivity. After reviewing the original plans and scope for the required underwater footing encasement on this bridge, the contractor realized that the means and methods could be improved. There were safety concerns about installing standard forming systems on the uneven surfaces at 35 ft of water depth and zero visibility, as well as containing the concrete silica plume.

The bridge that needed pier repairs required a 2-ft-thick reinforced concrete protective layer to be cast around the pier footing more than 30 ft below the surface of the water. A cofferdam was ruled out as unfeasible at this challenging location, and conventional forming was impractical due to irregularities below the footing, congested reinforcing steel in the encasement layer, zero visibility in the water, and concerns about silica being introduced to the water. To address this challenging situation, the PCL and TrapBag teams worked together for months to design a reinforced-fabric forming system that would satisfy the requirements of the contract drawings and structurally withstand the anticipated loadings. Ultimately, they designed a custom 170 × 40 ft forming system that used multiple layers of reinforced proprietary geotextile fabric as the concrete formwork material to encase the entire pier footing and extend out of the water. The fabric forming system was constructed with three layers of fabric and vertical webbing as well as vertical fabric channels for suspension cables. The fabric and cables were anchored to the uneven pier footing base and then suspended from a frame that was supported from the pier shaft. Hoists suspended from the bridge above were used to support and move the tremie tubes for placing concrete under water. This facilitated a safer and faster installation, accommodated the uneven surfaces to be repaired, and provided excellent containment for the underwater concrete silica plume. Upon completion, the fabric form was easily removed.

Nick Fasano is the business development director for TrapBag in Fort Myers, Fla.



The North Carolina Department of Transportation approved the fabric concrete forming system using multiple layers of reinforced proprietary geotextile fabric developed by TrapBag Barrier Systems for the repair of a footing for the Lake Tillery Bridge rehabilitation project. All Photos: PCL Construction.

Innovative concrete formwork was developed for the footing repair on the Lake Tillery Bridge rehabilitation project. The 170 × 40 ft custom reinforced-fabric forming system encased the entire pier footing and extended out of the water. The fabric and cables were anchored to the uneven pier footing base and suspended from an I-beam frame above the water surface. Tremie pipes with attached funnels that were used for placing concrete under water are visible near each corner of the forming system.

Construction Safety Awareness

by Angela Tremblay

Construction work can be a challenging occupation with the potential for many jobsite hazards. In any job, we all want to get home safely at the end of the workday. In a construction project, everyone—owners, design engineers, worksite supervisors, and workers—can help ensure that workers stay safe by being aware of safety hazards and taking appropriate steps to mitigate risk on the construction site. To promote safety and enhance workforce development, the American Association of State Highway and Transportation Officials' (AASHTO) Transportation Curriculum Coordination Council (TC3) offers low-cost or no-cost web-based training courses on construction safety awareness.[1]

TC3 Courses

AASHTO TC3 offers training on a broad variety of transportation topics such as concrete materials, bridge maintenance, and structural inspection. The courses, along with other training resources, are available through the TC3 website (https://tc3.transportation.org) via the Training Resources tab. TC3 courses are organized into six main categories: construction, materials, maintenance, traffic and safety, pavement preservation, and employee development. Within each category, additional filters are available to narrow the choices based on subcategory, discipline, career level, cost, and whether professional development hours are offered.

The TC3 website describes the training initiative and directs the user to the AASHTO Learning Management System platform where construction safety courses can be found under the Traffic and Safety listings. There are more construction safety courses listed under the general Traffic and Safety category than are found when using the Construction Safety filter. As courses are updated and added, there may be differences in the naming conventions depending on the path by which the courses are accessed.

This article focuses on the offerings in the construction safety series, a subset of the traffic and safety category. This series provides an opportunity for everyone in the concrete bridge industry to easily enhance their knowledge of safety issues. This awareness can allow engineers to improve designs and construction methods to avoid potential hazards where possible. The courses typically range from 30 to 60 minutes and offer a basic overview of topics such as recognition and avoidance of unsafe conditions, confined spaces, and demolition of structures. To make it even easier for agency workers to upgrade their safety knowledge, the Federal Highway Administration (FHWA) has purchased access to the TC3 courses to

AASHTO TC3 Construction Safety Series

- Barges
- Concrete and Masonry Construction
- Confined Spaces
- Crane Safety
- Demolition of Structures
- Earthmoving Equipment and Motor Vehicles
- Electrical Safety
- Excavation and Trenching
- Fall Protection
- Hazardous Materials
- Material and Personnel Hoists
- Personal Protective Equipment
- Recognition and Avoidance of Unsafe Conditions
- Scaffolding Safety
- Working Safely in Work Zones

Construction safety awareness courses available from the American Association of State Highway and Transportation Officials' Technical Curriculum Coordination Council (TC3). TC3 offers these and other web-based courses at no or minimal cost. The courses listed here can be found under the Traffic and Safety category without applying the Construction Safety filter. Figure: Angela Tremblay.

Personal protective equipment provides another level of safety after engineering controls have been established to remove or reduce jobsite safety hazards. Photo: Angela Tremblay.

Heavy equipment and working at heights are some of the safety hazards that may be present on a bridge construction site. Photos: LJB Inc.

provide free training for local and tribal agencies.[2] Many state departments of transportation also provide free access to the courses through Local Technical Assistance Programs.

Safety Basics

The TC3 courses present best practices from various agencies, FHWA training rules, and relevant laws and regulations. State, local, and company-specific requirements must be followed as well, but the construction awareness series training gives a good starting point for basic safety knowledge. Planning ahead is a key part of any safety program. The goal is to identify potential hazards and have a procedure in place for how to handle problems before they develop.

Bridge construction often involves potentially hazardous equipment and materials that could lead to serious injuries, in addition to the obvious dangers of working near traffic. The first step in safety protocols should be to eliminate or control as many hazards as possible through engineering measures such as standard operating procedures that minimize exposure to specific hazards, machine guards, and effective traffic control. Once proper procedures and engineering controls are established, personal protective equipment (PPE)—safety glasses, hard hats, work gloves, and ear protection—provides the next level of protection from jobsite hazards.

Safety Is Everyone's Responsibility

Awareness of safety protocols and the proper use of PPE is just as important for engineers and project managers visiting a construction site as it is for workers. When everyone involved in the planning and construction of a bridge is aware of safety hazards, these hazards can be more effectively avoided and controlled. The AASHTO TC3 courses make it easy for consultants and contractors to join owner agencies in taking advantage of low-cost safety resources that can offer their staff valuable and even life-saving training. We don't need to know how to solve every safety problem, but by recognizing the potential dangers, we can know when to ask for specialized help. Ultimately, safety awareness improves the likelihood that all workers make it home safely at the end of the day.

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Purple Epoxy-Coated Reinforcement: Does Color Make a Difference?

by Peter Fosnough, Epoxy Interest Group of the Concrete Reinforcing Steel Institute

Although ASTM A775[1] (green) reinforcement is the most commonly specified epoxy-coated reinforcement (ECR), there has recently been a slight uptick in the specification of ASTM A934[2] (purple) ECR, which begs the question: "What's the difference?" Most engineering school programs do not even introduce epoxy coating as a method of mitigating the corrosion of reinforcing steel, let alone discuss the different methods used for coating the reinforcement. As a result, several myths have developed over the decades regarding the differences between the two products. In this article, I hope to clarify these differences and dispel any myths.

The first recorded use of ECR was in the Interstate 476 bridge over the Schuylkill River in Conshohocken, Pa., in 1973. In 1981, the first product standard for ECR was approved as ASTM A775, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*; today, this product type is known as the "green" bar. Because the epoxy coating material often cracked during bar fabrication, a new process was developed by pipe coaters to apply the epoxy coating (which contained additional filler) after fabrication. As the chemistry of the powder evolved, the ASTM A934, *Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars*, was developed and approved in 1995 as a second standard for ECR (for the "purple" bar). Meanwhile, the original coating material was also improved to prevent cracking during fabrication. Now ASTM A775 material is coated as a straight bar (typically in 20- to 64-ft lengths) and is then fabricated (cut and bent) after coating, whereas ASTM A934 material is prefabricated and then coated. Pigmentation is used to differentiate between the two products.

So, let's dispel some myths.

Different processes are used for coating ASTM A775 and ASTM A934 bars

False. The ASTM A775 and ASTM A934 standard specifications both require the following processes:

1. Blast cleaning, which removes mill scale and creates an anchor profile to increase surface area to enhance adhesion of the epoxy to the steel
2. Heating, which brings the steel to 375°F to 475°F so that the epoxy powder "melts/fuses" upon contact with the steel
3. Powder application, which applies the epoxy powder in a contained environment with dust collection and recycling of unadhered powder
4. Curing, which allows the epoxy powder (once it has contacted the hot steel in the powder application) to gel and begin to cross link
5. Cooling, which allows the epoxy coating to harden to the point that it will not be damaged when the reinforcing bar is handled appropriately

The only difference in processing is the method by which the material is conveyed as the coating is applied and the size of the equipment used. ASTM A934 uses a chain conveyor from which the fabricated material hangs (on hooks) as it travels through the coating processes. The larger the items are that are being coated, the larger the equipment must be. ASTM A775 material is simply conveyed on rollers, regardless of the length of the material.

A934 material is "harder" than A775 material; therefore, A934 ECR is less susceptible to jobsite damage

False. To qualify as an epoxy powder to meet the respective standards, both powders undergo the same tests: chemical resistance, cathodic disbondment, salt spray resistance, chloride permeability, coating flexibility, relative bond strength in concrete, abrasion resistance, and impact. The two specifications have identical setup and acceptance criteria, with the exception of impact testing. ASTM A934 requires the test be performed with an impact of 40 in.-lb, whereas ASTM A775 requires an impact of 80 in.-lb. Therefore, ASTM A775 ECR is designed to withstand harder impacts.

Testing of the products is the same

True (partially). Almost all of the same tests are run, but the acceptance criteria are different (**Table 1**). The epoxy powders are qualified separately from the finished product after coating. Therefore, the epoxy powders undergo the same testing as previously described; however, some of the finished product

Craney Island Fuel Depot, Portsmouth, Va. Photo: Lane Enterprises.

Table 1. Comparison of ASTM A934 and ASTM A775 epoxy-coated reinforcing steel acceptance criteria		
Attribute	ASTM acceptance criteria	
	A934, *Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars*	A775, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*
Anchor profile	1.5 to 4 mil	1.5 to 4 mil
Flexibility	No. 3 to 5: 9-degree bend in 5 seconds No. 6 to 18: 6-degree bend in 5 seconds	180-degree bend in 15 seconds
Continuity (holiday*)	Sampling offline—Random bars are selected for the testing, which is conducted by hand after the process is completed.	100% online—Every bar goes through the testing while traveling down the line before it is discharged from the coating line.
Coating thickness	No. 3 to 11: 7 to 12 mil (up to 16 mil permitted in bend sections)	No. 3 to 5: 7 to 12 mil No. 6 to 18: 7 to 16 mil
Adhesion (cathodic disbondment)	Less than 0.25 in.	No test required

*A holiday is a small, pinhole-size discontinuity in the coating that is not discernible to a person with normal, corrected vision.

testing varies slightly between the A934 (purple) and A775 (green) ECRs. For example, the finished purple bars must have a cathodic disbondment test performed, whereas the finished green bars do not require the test.

A934 powder can only be applied on custom lines

False. The confusion here is probably because fabricated bars (that are bent) cannot be coated on a straight bar line. They can only be coated on a custom line. Straight bars, however, can be coated on either type of line. Both custom and straight lines can produce A934 and A775 material. The challenge is meeting the testing requirements.

When A934 material is used in straight line production, the accelerated cathodic disbondment tests will need to be performed unless these tests are waived. When A775 material is used in custom lines, 100% holiday testing is required and the additional 4 mil of thickness on the bent sections will not be permitted.

A934 has better corrosion protection than A775

False. Both types provide the same level of protection. Epoxy is epoxy. Both materials provide an equivalent barrier to prevent corrosion of the steel.

Conclusion

When specifying the use of ASTM A934 material, the physical constraints of the coater need to be taken into consideration in the design and detailing of the project. Custom coaters will be restricted by the conveyance and size of their equipment. Epoxy Interest Group members only have five custom coating lines in North America: one each in Nevada, Ohio, and Pennsylvania, and two in Illinois.

Additionally, the current edition of ASTM A934 does not specify any product performance requirements for patching material; therefore, when specifying A934 for use, it is recommended to add to the specification that patching material shall meet the requirements of ASTM A775 Annex A2 (Requirements for Patching Material Used to Repair Organic Coatings for Steel Reinforcing Bars), which should prevent substandard materials from being used.

So, why the different colors? The colors were established primarily so that inspectors would know what criteria to use when performing testing. Over time, the greatest benefactor of the different colors is the jobsite personnel. ASTM A934 material is not intended for projects where jobsite fabrication or modification may be required. Therefore, it is necessary for ironworkers, detailers, and engineers to understand that "purple bars must be placed perfectly" because they cannot be bent or cut later.

In the end, "Does color make a difference?" When it comes to highly effective, low-cost corrosion resistance, no, it doesn't. Epoxy is colorblind.

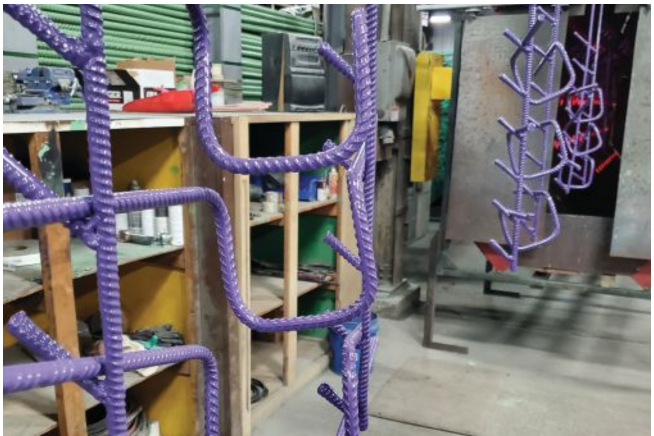
References

1. ASTM International. 2019. *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*. ASTM A775/A775M-19. West Conshohocken, PA: ASTM International.
2. ASTM International. 2019. *Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars*. ASTM A934/A934M-19. West Conshohocken, PA: ASTM International.

Peter Fosnough is the managing director of the Epoxy Interest Group of the Concrete Reinforcing Steel Institute in Schaumburg, Ill.

Epoxy-coated steel reinforcement conforming to ASTM A934 must be cut and fabricated before coating. It should not be bent or cut at the jobsite. It is necessary for ironworkers, detailers, and engineers to understand that "purple bars must be placed perfectly" because they cannot be modified. Photo: Lane Enterprises.

The only differences in processing ASTM A934 and ASTM A775 material are the method by which the material is conveyed as the coating is applied and the size of the equipment used. ASTM A934 material uses a chain conveyor from which the fabricated material hangs (on hooks) as it travels through the coating processes. Photo: Simcote Inc.



AUTHORITY

Tampa Hillsborough Expressway Authority

Building innovative and iconic concrete bridges to serve the community

by Brian Pickard, Tampa Hillsborough Expressway Authority, and James E. Drapp, HNTB Corporation

View of the underside of the Lee Roy Selmon Expressway Reversible Express Lanes (REL) elevated structure, which was the world's first fully operational all-electronic tolling facility when the REL opened. The REL provides an additional three lanes, westbound during the morning commute from Brandon to Tampa and eastbound during the evening commute and on weekends. All Photos: Tampa Hillsborough Expressway Authority.

Since its establishment in 1963, the Tampa Hillsborough Expressway Authority (THEA) in Florida has led the charge in state-of-the-art transportation options at the local, national, and international levels. As an independent agency of the state, THEA owns, maintains, and operates four facilities within Hillsborough County: the Selmon Expressway, the Brandon Parkway, Meridian Avenue, and the Selmon Greenway. The agency is focused on driving innovation and improving mobility and safety throughout the Tampa Bay region, and it is committed to the progress and future of the region.

THEA partners with community organizations on everything from beautification to economic development to education; among its priorities are enhancing the community and activating urban spaces. THEA constructed the Selmon Greenway, a 1.7-mile-long multiuse trail that runs east-west under the Selmon Expressway through downtown Tampa and connects with Tampa's Riverwalk and the Meridian Trail. Along the Selmon Greenway, THEA has built a series of pocket parks with landscaping, benches, and artwork that enhance downtown Tampa's aesthetics. One of these parks is the award-winning Deputy Kotfila Memorial Dog Park.

THEA owns and maintains 15 miles of concrete bridges totaling more than 4 million ft^2 of bridge deck area. The estimated value of all THEA concrete structures is $775 million. The vast majority of the 71 THEA-owned bridges are conventional prestressed concrete, multigirder superstructures, but four concrete segmental box-girder superstructures comprise more than half of the bridge inventory by deck area. These four bridges—State Route (SR) 618A from 12th Street to 26th Street, SR 618A from 39th Street to 78th Street, SR 618A over Interstate 75, and the recently completed Selmon West Extension (SR 618B over U.S. 92)—form the most recognizable aspect of THEA's system and are icons in the Greater Tampa community. The first three bridges, collectively known as the Selmon Expressway Reversible Express Lane bridges, were built as separate projects beginning in 2004 (see the article on the project in the Fall 2007 issue of *ASPIRE*®). Unique features of these bridges include:

- They were constructed almost entirely in the limited median of an existing four-lane limited-access expressway.
- All existing travel lanes remained open during daily peak hours.
- The slender precast concrete superstructures were built on piers that are only 6 ft wide.

The aesthetics inherent in the concrete segmental box-girder superstructure and the concrete piers and columns provide an

View of the Selmon Expressway crossing the Hillsborough River as it passes south of downtown Tampa.

opportunity to enhance the experience for the driver and community. THEA has built on these features by installing aesthetic lighting with unique color schemes for both the piers and bridge spans. These amenities have enabled THEA to celebrate community events such as holidays, sporting events, and the local Gasparilla Pirate Fest.

These robust concrete bridges have handled the demands of high traffic counts and Florida's coastal environment while delivering the ride experience THEA's customers expect. The long-term performance of these structures has helped THEA achieve consistently high bond ratings, thereby reducing long-term financing costs. To better capture the value of the long-term performance of concrete bridges and all bridges across its system, THEA will take over bridge inspection responsibilities from the Florida Department of Transportation in July 2022.

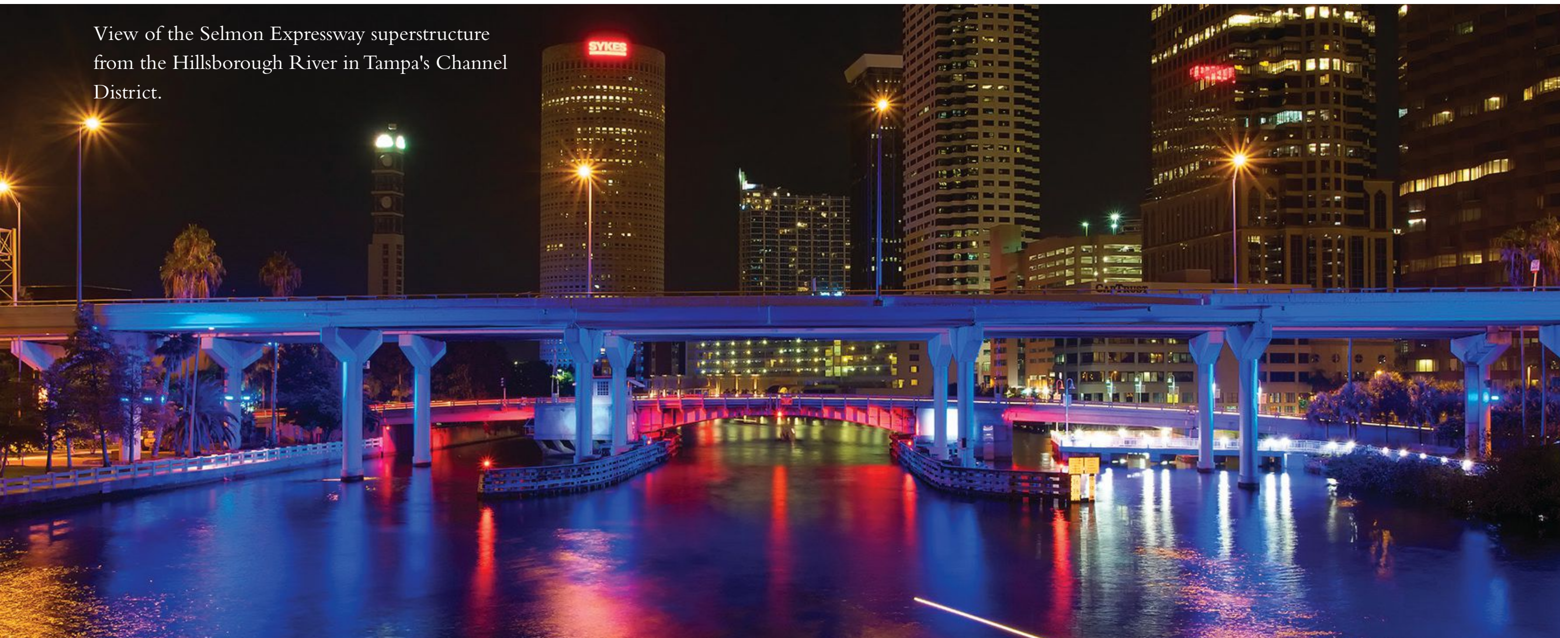
As Tampa's facilities and community evolve, THEA's state-of-the-art system will continue to be resilient, efficient, and responsive to changing demands, thanks to the versatility and economy of concrete bridges.

***Brian Pickard** is the Tampa Hillsborough Expressway Authority's director of Operations and Engineering and **James E. Drapp** is a senior vice president for HNTB Corporation in Tampa, Fla.*

EDITOR'S NOTE

The most recent addition to THEA facilities is the Selmon West Extension, described in the Project article on page 12 and the Concrete Bridge Technology article on page 44.

View of the Selmon Expressway superstructure from the Hillsborough River in Tampa's Channel District.



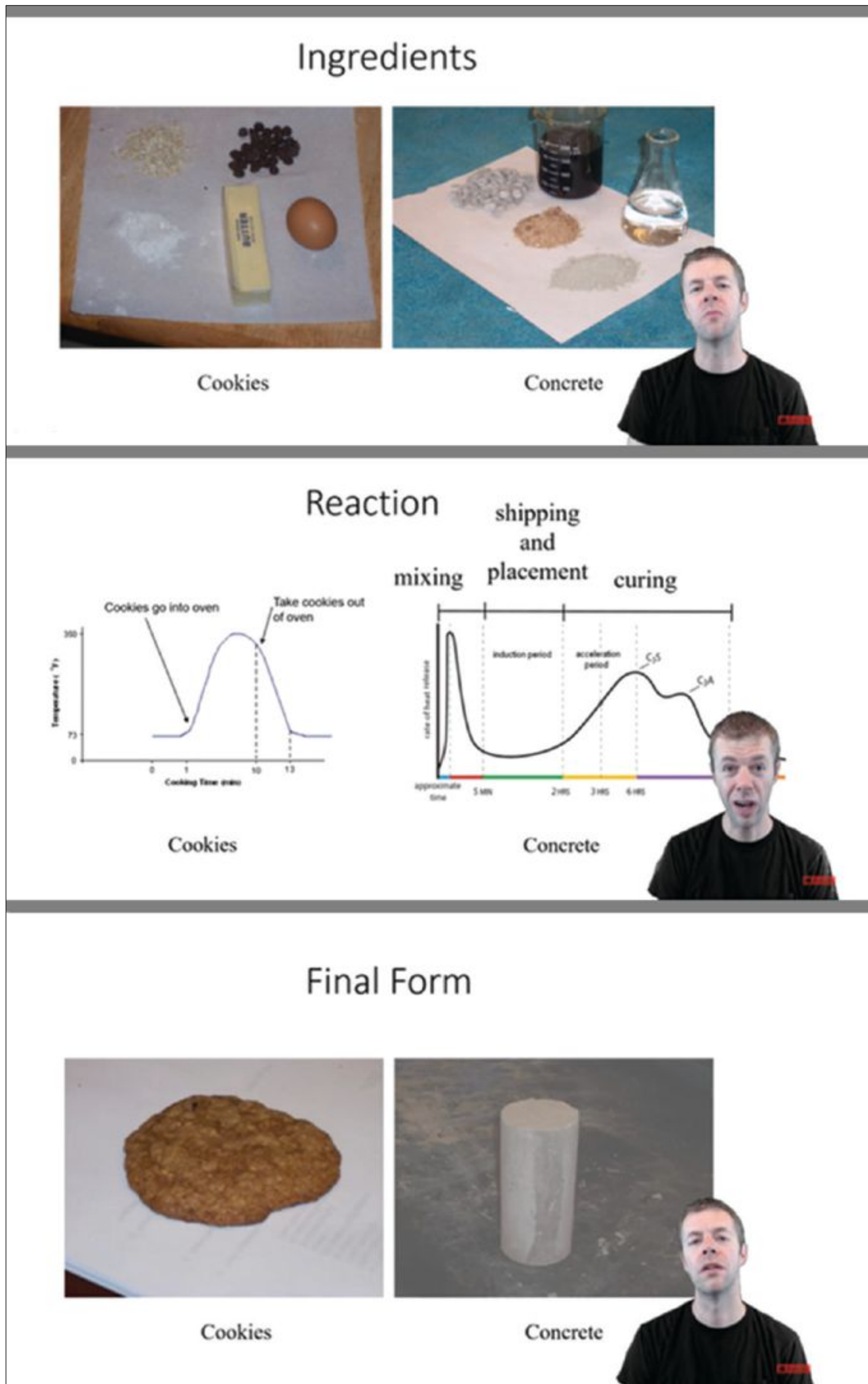
Educating the Future Workforce: Sharing Knowledge on YouTube

by Dr. Tyler Ley, Oklahoma State University

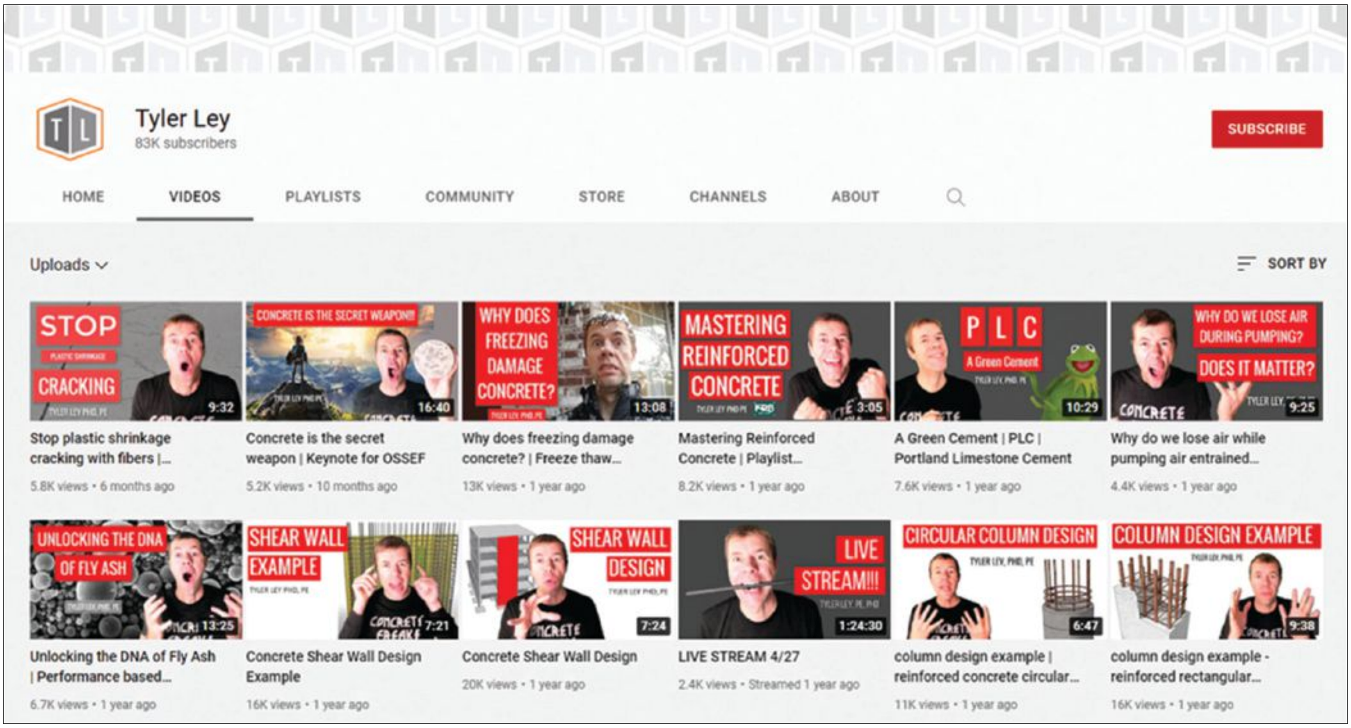
Our industry faces a major education challenge. Our most experienced engineers and builders are retiring, and the new workforce is being asked to accomplish more with fewer resources. This workforce will need to integrate knowledge and tools from the past with technology that is actively being developed. If we have a poorly educated workforce, we will repeat mistakes from the past and will not successfully implement the latest advancements. This lack of education will create unneeded costs, increase waste, and potentially put lives in danger. We need to have trusted educational resources that are timely, easy to locate, and engaging. I believe this need can be met by creating video content for technical topics and making that content freely available on YouTube.

YouTube has become a ubiquitous resource to learn how to create, build, or fix almost anything. YouTube offers a number of functions to facilitate creating and sharing videos. It allows you to upload videos for free, provides simple editing tools, and will also create closed captioning so that the video can be watched without sound. The videos are searchable and can be organized into playlists, which helps people find them. When you upload a video, YouTube will alert your subscribers or followers to the new content. In addition, YouTube provides detailed information about how viewers rated your video, how long they watched, what they watched next, and where they are from. This is all useful information to help you bring your ideas and messages to more people and learn how to be a better communicator and engage your audience.

About three years ago, I started making YouTube videos regularly to share my conference presentations, research papers, classroom lectures, worked example problems, and even partially developed ideas. My channel,



As part of his Concrete Materials playlist, Dr. Tyler Ley compares cookies with concrete. Everyone knows and loves cookies, so the comparison helps students understand some basic concepts about concrete materials. All Photos: Dr. Tyler Ley.



Dr. Tyler Ley uses his YouTube channel to educate everyone from absolute beginners and students to industry colleagues about concrete, which he calls "the greatest material in the world." The videos are typically short—15 minutes or less—and cover a range of topics, including reinforced concrete design, fly ash, admixtures, and mixture proportions.

www.youtube.com/tylerley, receives approximately 170 hours of watch time every day, and my videos have been watched more than 6 million times! This is an amazing amount of return for posting videos on YouTube.

For my classes, I create short videos, typically 15 minutes or less, that explain the fundamentals about a topic, and I ask the students to watch them before class. In a week, the students may be asked to watch five or six videos. I find that my students perform better on quizzes and exams when they are introduced to a concept by video, followed by more complex in-class discussions about how to apply the principles. I have made videos that cover every major topic in reinforced concrete design, structural steel design, concrete mixture proportioning, and concrete durability. These videos are organized into playlists and they are available on YouTube to anyone.

I also use YouTube to share my research findings. These videos give me a concise way to explain the importance of the research and how it can be applied in practice. This allows me to bring my research papers to life and gives me another use for my conference presentations. The videos are easy to share, and they can lead someone to a paper or a report where they can find more information. This helps share my research, makes it easier for people to implement the work, and thereby makes an impact on our industry.

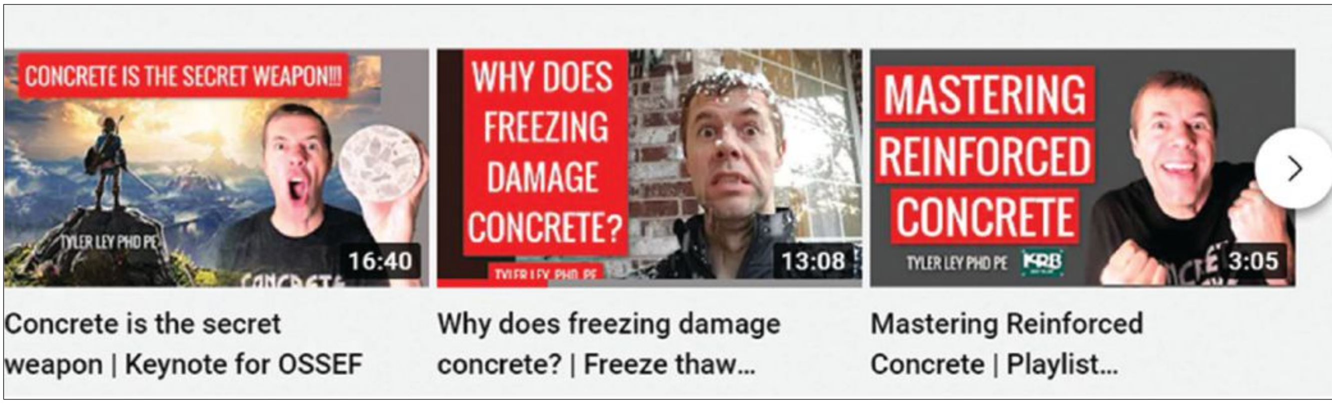
I have been asked by other engineers and professors whether my YouTube channel will hurt my career because I am "giving my intellectual property away for free." On the contrary, my YouTube channel creates opportunities for me by helping to establish me as an expert. It creates awareness about who I am and the research I am doing. This makes it easier to find graduate students who want to work with me and funding agencies that want to support me. The channel also creates more opportunities for me to speak at conferences. All of these opportunities have helped advance my career.

Others question whether professors will still be needed once their lectures are available online. I have not found this to be an issue. I think our students and our industry will always need trusted guides to help solve their problems. In my opinion, freely available online video content makes everyone's job easier. These videos help everyone to start at the same level of understanding. They provide a way to remove the monotonous aspects of explaining a subject for the 100th time, and they will always be available for someone to rewatch. This gives us more time to focus on creating solutions and discussing complex issues where there is no clear solution. Ultimately, I feel that these videos bring more value to both our students and the profession. They also help spread knowledge and ideas while highlighting what we don't understand.

The best-selling author, marketing genius, and engineer Seth Godin says, "Ideas that spread, win." I believe that for our profession to win, we need more professors and experts in our community to share their knowledge and ideas via online video content. I have found YouTube to be an amazing way to do this, and the platform has been very valuable to me.

I encourage both academics and practicing engineers to start their own YouTube channels. Being on YouTube gives you a chance to establish yourself as an expert. It also allows you to give back and bring more value to our industry. Furthermore, starting a YouTube channel can help you improve your public speaking skills and make you a better technical communicator. It is also a creative and fun way to share your ideas.

I encourage you to start simply. You could record your screen while giving



Dr. Tyler Ley is passionate about concrete. His engaging technical YouTube videos are an accessible way to transfer knowledge in the concrete bridge industry.

an online presentation. You could have your students film a presentation from their class. You could film yourself in your office, in the laboratory, or, with permission, at a jobsite. I think using a simple camera like the one on your cell phone or a webcam is best because these types of cameras are so easy to use and the quality is suitable for YouTube. Developing YouTube videos is no different than any other skill: you have to practice to improve. So, start making videos and try to improve with each one.

Many online resources are available to help you learn more about making videos. One of my favorite YouTube channels that focuses on making YouTube videos is www.youtube.com/primalvideo. Feel free to reach out to me at tyler.ley@okstate.edu, and of course, visit www.youtube.com/tylerley and like, subscribe, and leave me a comment.

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

IN THIS ISSUE

https://www.asbi-assoc.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=E2F39410-0485-4BC0-84D3AD9157EA9ED1
The Selmon West Extension in Tampa, Fla., is the focus of the Project article on page 12 and the Concrete Bridge Technology article on page 44. The segmental concrete structure is creative in its style and used a progressive span-by-span erection technique. This link provides access to a presentation on the project given at the American Segmental Bridge Institute's (ASBI's) Fall 2021 Convention. The video presentation includes an animation of the erection of the precast concrete box segments using specialized equipment.

https://twitter.com/CaltransDist3/status/1403937276044877824
The Project article on page 22 features the replacement of the superstructure of the California State Route 99 over 21st Avenue Bridge in Sacramento County. The bridge could only be closed for a short period due to heavy commuter and industrial traffic, so the demolition and removal of the superstructure was completed in 18 hours. This is a link to a video of the removal of the last girder. The new bridge was reconstructed with 35 precast, prestressed concrete box girders.

https://www.slagcement.org/casestudies/id/102/lake-tillery-bridge.aspx#prettyPhoto
Slag cement was a key component in the rehabilitation of the Lake Tillery Bridge, a historic arch bridge in North Carolina featured in both a Project article (page 18) and a Creative Concrete Construction article (page 53). This is a link to a web page with details of the slag cement mixture and the rehabilitation, as well as additional photos.

https://www.fhwa.dot.gov/bridge/pubs/hif21031.pdf
The FHWA article on page 68 discusses the use and standardization of building information modeling in the transportation industry. This is a link to download the publication *Demonstration of Bridge Project Delivery Using BIM* (FHWA-HIF-21-031), the basis of the article.

https://www.youtube.com/c/TylerLey
In the Professor's Perspective article on page 60, Dr. Tyler Ley of Oklahoma State University shares his vision for educating the future workforce through YouTube. This is a link to his YouTube channel, which offers numerous videos on concrete materials and design.

https://www.asbi-assoc.org/index.cfm/events/MonthlyWebinars
This is a link to the ASBI archive of their monthly webinar series on topics such as "An Introduction to Today's Concrete Segmental Bridge Technology." The Selmon West Extension is a concrete segmental bridge and is featured in both a Project article on page 12 and a Concrete Bridge Technology article on page 44.

http://www.aspirebridge.com/magazine/2022Winter/ProfessorsPerspective-MakePrecastConcretePartOfTheCoreCurriclum.pdf
The precast concrete bridge studio program at California State University, Sacramento, is showcased in the Editorial on page 2. A similar program at Idaho State University was the subject of the Professor's Perspective in the Winter 2022 issue of *ASPIRE*®. This is a link to a pdf of that article.

https://content.aia.org/sites/default/files/2021-01/Preparing-to-Thrive_Resilience-Building-Coalition_5-year.pdf
The Perspective on page 11 discusses functional recovery and resilience. This is a link to Preparing to Thrive: Resilience Building Coalition 5-year Progress Report, which includes the industry statement on resilience mentioned in the article.

OTHER INFORMATION

https://www.fhwa.dot.gov/publications/ltbpnews/21063.cfm
This is a link to the newsletter for the Federal Highway Administration's Long-Term Bridge Performance Program. The newsletter program, which contains brief updates on the program's progress and activities, including data collection, releases, and analysis, as well as new products and publications.

https://store.transportation.org/Item/CollectionDetail?ID=226&Asp
The American Association of State Highway and Transportation Officials (AASHTO) has released a *Guide Specifications for Bridges Subject to Tsunami Effects*. With these guide specifications, designers now have a means to quantify forces associated with a tsunami event. This is a link to the AASHTO online store, which provides the publication's table of contents and introduction in addition to purchasing information.

https://www.nap.edu/catalog/25913/proposed-aashto-guidelines-for-performance-based-seismic-bridge-design
This is a link to National Cooperative Highway Research Program Report 949, *Proposed AASHTO Guidelines for Performance-Based Seismic Bridge Design*. The report presents a methodology for analyzing and determining the seismic capacity requirements of bridge elements in terms of service and damage levels. Ground motion maps and detailed design examples illustrate the application of the proposed guidelines.

https://www.nap.edu/login.php?record_id=26495
The report for the National Cooperative Highway Research Program Synthesis 571 Load Rating of Bridges and Culverts with Missing or Incomplete As-Built Information is available at this link. The report presents the current state of practice and techniques (such as nondestructive evaluation, load testing, and engineering judgment) used by state departments of transportation for load rating of bridges and culverts with missing or incomplete as-built information.

Washington, D.C.

by Yvonne Thelwell, District Department of Transportation

Washington, D.C., is a city steeped in history, of which the transportation network is an integral part. City planner Pierre L'Enfant's 18th-century vision of carefully laid-out streets, avenues, and circles has evolved into the current network of roads, bridges, bikeways, and transit that ably serves hundreds of thousands of users daily. Within the city's 68-square-mile footprint, the District Department of Transportation's (DDOT's) bridge inventory includes 235 city-owned bridges, 39 National Park Service bridges, 38 railroad-owned bridges, and 15 tunnels. Averaging 3.5 city-owned bridges per square mile, this far exceeds the bridge density of any state in the nation. Challenges faced by DDOT when making the decision to replace or rehabilitate a bridge include maintenance and protection of vehicular, pedestrian, and bicycle traffic, the structure's historical significance, aging infrastructure, extensive utilities, and high construction costs. Rehabilitation of our historic bridges faces an additional challenge: extensive coordination with and approval by the State Historic Preservation Office (SHPO) for the District of Columbia.

Concrete Arch Bridges

The city has numerous concrete arch bridges that, through robust engineering and good materials selection, have withstood more than 100 years of service life. Cyclical maintenance on these bridges includes the removal of pigeon debris, cleaning and flushing drains, cleaning joints, sealing cracks, sealing concrete, and repairing damage from accidents and storm events. It is also important to perform maintenance-based activities to address deficiencies identified during the inspections; these activities may include repairing or replacing drains, replacing joints, patching or repairing concrete spalls, and performing scour countermeasures. With routine maintenance, the concrete arch bridges will be in service for many years to come. These bridges are a tribute to the long-term durability of concrete and demonstrate that with good detailing, longevity for our bridges can be achieved.

Pennsylvania Avenue Bridge

Pennsylvania Avenue Bridge spans Rock Creek, Rock Creek Parkway, and Rock Creek Park Trail. The original 1858 bridge—constructed of 48-in.-diameter cast iron water mains as the load-bearing arch members—carried both water and vehicular traffic, including a horse-drawn streetcar from 1863 to 1872.[1] With a length of 200 ft and a width of 40 ft, the bridge was one of the largest single-span iron pipe arch structures in the world. In 1913, the District of Columbia (DC) Board of Commissioners chose to erect a 276-ft-long, 73-ft-wide concrete arch bridge around the original bridge rather than build a new bridge, at a cost of $121,032.[2]

The bridge underwent reconstruction of the superstructure in 1979. In 2018, rehabilitation of the arch and superstructure to extend the service life was completed. This rehabilitation required a thorough knowledge of the bridge, its history, and the needs of the local community to achieve an efficient and durable design that met both the project's technical requirements and the aesthetic and historic preservation demands. The goal to extend the life of the bridge without compromising its aesthetic appeal or character was achieved.

To preserve the uniqueness of the bridge, composed of pre–Civil War cast iron water mains and concrete arches from the early 20th century, advanced modeling and structural engineering techniques were required to "reconstruct" the history of the bridge. This design analysis provided an understanding of the existing stresses in the arch system and the effects of the proposed rehabilitation on the bridge's load-carrying capacity. The analysts used a combination of hand calculations and finite element analysis that modeled all aspects of the structure in three dimensions, including time-dependent loadings such as creep and shrinkage, effects of load removal and replacement, and settlement of supports. Furthermore, maintaining and protecting vehicular and pedestrian traffic was a major

Pennsylvania Avenue Bridge over Rock Creek Parkway. Originally constructed in 1858 of 48-in.-diameter cast iron water mains as the load-bearing arch members, the bridge was one of the largest single-span iron pipe arch structures in the world. In 1913 a concrete arch bridge was constructed around the original bridge. The concrete superstructure was reconstructed in 1979, and the arch and superstructure were rehabilitated in 2018 to extend the bridge's service life. Photos: District Department of Transportation.

The Francis Scott Key Bridge crossing the Potomac River is a reinforced concrete open-spandrel, ribbed-arch bridge, which was completed in 1923. Designed in the Classical Revival style by Nathan C. Wyeth, the bridge was added to the National Register of Historic Places in 1996. Photo: District Department of Transportation.

concern of the public. By developing details to accommodate staged construction, the project team was able to reduce the detour time to be 30% less than originally scheduled. The rehabilitation received an American Council of Engineering Companies of Metropolitan Washington Honor Award.

Francis Scott Key Bridge

Francis Scott Key Bridge, often referred to as the Key Bridge, spans the George Washington Memorial Parkway, the Potomac River, the Whitehurst Freeway, and the Chesapeake and Ohio Canal. It is the oldest surviving Potomac River bridge and was added to the National Register of Historic Places in 1996.

A congressional charter was obtained in 1830 to construct an aqueduct to extend the Chesapeake and Ohio Canal across the Potomac River. "The Aqueduct" was the first river crossing constructed at this site, consisting of a large wooden trough supported by stone piers. The bridge consisted of two large Howe trusses strengthened by timber arches. The wooden construction soon began to rot and leak, so it was abandoned as a link in the canal system. When the Civil War broke out, the government seized the bridge for military use until 1866, after which a company took custody under a 99-year lease.[1] A wagon bridge was erected on the stone piers, but high tolls were charged. Under pressure from enraged residents, Congress passed the Riddleberger Bill, which authorized $125,000 to purchase the bridge or erect a new bridge at Three Sisters Island.[2] In the late 19th century, construction of a new superstructure on the old piers began. The substructure began to deteriorate, requiring three of the eight piers to be reconstructed between 1897 and 1907. Increased deterioration required a 4-ton load limit and closure during periods of heavy ice flow, and eventual replacement.[2] The original structure was designed and constructed by the U.S. Army Corps of Engineers and constructed by day labor under the supervision of the Corps of Engineers at an approximate cost of $2.5 million.

Despite material and labor shortages caused by World War I, a new bridge with seven reinforced concrete open-spandrel, ribbed-arch spans was completed in 1923 and dedicated to the author of the Star Spangled Banner, Francis Scott Key. The bridge includes solid concrete piers resting on footings founded on a rock bed. An eighth span was later added on the Virginia side.

The Key Bridge was designed in the Classical Revival style by Nathan C. Wyeth, a prominent architect who designed several other landmark structures, including the White House's West Wing. The 1781-ft-long bridge has an out-to-out width of 90 ft and a curb width of 66 ft. In 1955, trolley tracks across the bridge were eliminated and the deck was widened from 70 to 80 ft. In 1987, the deck was replaced and widened further to 90 ft (although the width of the roadway remained unchanged), followed by a major repair in 2019. It currently carries 60,000 vehicles and 8000 pedestrians and bicyclists per day.

William Howard Taft Bridge

The William Howard Taft Bridge carries four lanes of Connecticut Avenue traffic over Rock Creek, Beach Drive, and Cathedral Avenue. This 1841-ft-long, five-span, unreinforced concrete, open- and closed-spandrel arch structure with

William Howard Taft Bridge, which carries four lanes of Connecticut Avenue traffic over Rock Creek, Beach Drive, and Cathedral Avenue, is an 1841-ft-long, five-span, unreinforced concrete, open- and closed-spandrel arch structure with a reinforced concrete deck. Completed in 1907, it was one of the first and largest unreinforced concrete bridges in the world. Photo: District Department of Transportation.

Q Street Bridge is on a 12-degree horizontal curve. The color of the bridge's stone evokes the warm tones of Spain and Italy. In 1973, the bridge was added to the National Register of Historic Places. Photo: District Department of Transportation.

a reinforced concrete deck was one of the first and largest unreinforced concrete bridges built in the world.

Although three steel arches were proposed in an 1890s competition, the progressive concrete arch was selected. The winning design used cast-in-place concrete with bush-hammered surfaces to emulate granite. Arch ring stones, brackets, moldings, railings, and other trim are all precast concrete. Concrete blocks were used as permanent forms as well as for the finished surface. All arches are hingeless and without reinforcement. Lions at each end of the bridge, sculpted by R. Hinton Perry, were not completed until six months after the bridge opened because it was feared that the project would run out of money, in which case the sculptures would have been eliminated. The lions were restored in 1965 and then fully replaced in 2000.[1]

The plans for the bridge were prepared by the DC Bridge Division in consultation with George S. Morrison, engineer, and Edward Pearce Casey, architect. The bridge was built in 1907 at a cost of $846,331.[2] In 1931, the bridge was renamed in honor of President William Howard Taft.

The Q Street Bridge

Also known as the Dumbarton Bridge or the Buffalo Bridge, the Q Street Bridge is a five-span, reinforced concrete closed-spandrel arch structure on a 12-degree horizontal curve. It spans Rock Creek Valley between the DuPont Circle and Georgetown neighborhoods. Acquiring a used bridge for the site was originally considered, but a structure of the same caliber as the Taft Bridge was chosen instead. The majestic bridge was completed in 1915 at a cost of $223,553 with input from architect Glenn Brown, engineer Daniel B. Luten, and public planning bodies that included the city's newly formed Commission of Fine Arts.[1] The bridge is 342 ft long, with a 33-ft-wide roadway and 7-ft-wide sidewalks on each side.

Flanking both ends of the bridge are four large bronze buffalo sculptures by sculptor Alexander Phimister Proctor.[2] The arches are decorated with sculptures of Native American heads designed by Glenn Brown based on a life mask of the Sioux chief Kicking Bear. The color of the bridge's stone was intended to evoke the warm tones of Spain and Italy. In 1973, the Dumbarton Bridge was added to the National Register of Historic Places.

16th Street over Piney Branch Parkway

The 16th Street over Piney Parkway Bridge is a 272-ft-long, single-span concrete arch, and was the first parabolic arch bridge erected in the United States. It consists of two large parallel arches and a platform supported by spandrel beams, encased by a concrete facing, giving it a very solid, simple appearance. The unreinforced concrete bridge was built one side at a time. Architectural features include appliques and an exposed pebble aggregate covering the surface with a triple arch ring and coping of smooth concrete. The abutments are smooth pilasters flanking the arch. Tigers, sculpted by Alexander Phimister Proctor, adorn the ends of the bridges. It was designed by the DC Division of Bridges and was constructed in 1906 at a cost of $135,000.[1] Its rehabilitation, which began in 2022, includes concrete repairs, slope improvements, light and signal upgrades, sculpture restoration, addition of stormwater management biofiltration planters, and replacement of the pedestrian fence.

State-of-the-Art Bridges

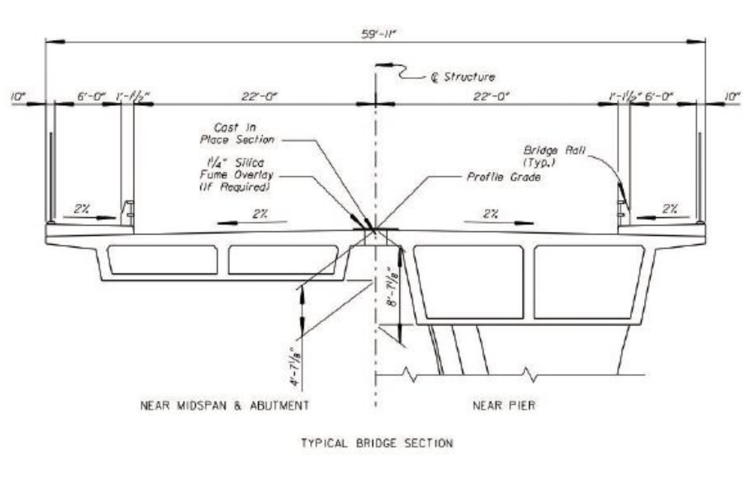
During the 21st century, DDOT has added state-of-the-art bridges to its inventory, including the Southern Avenue over Suitland Parkway Bridge and the Frederick Douglass Memorial Bridge, both under design-build contracts.

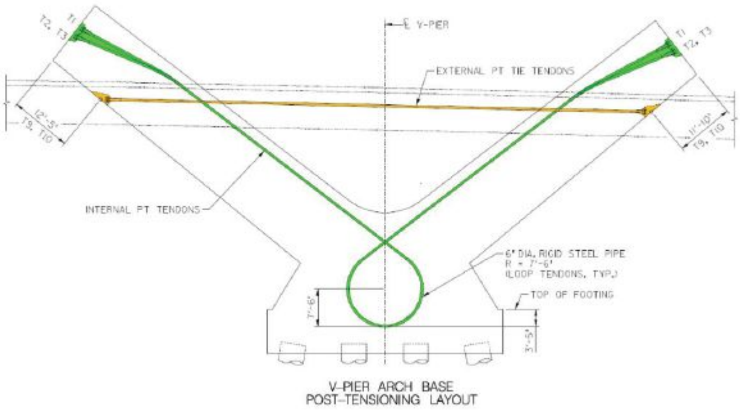
Southern Avenue over Suitland Parkway Bridge Replacement

The Southern Avenue over Suitland Parkway Bridge replaced a 390-ft-long steel structure

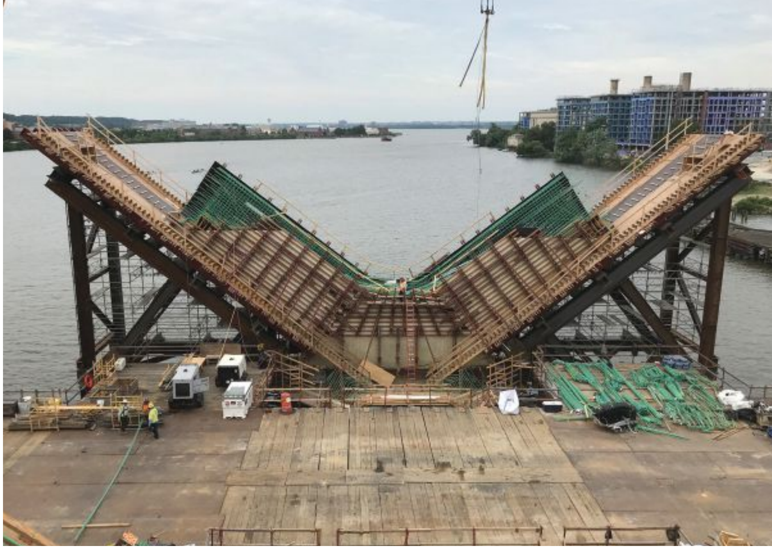
The Southern Avenue Bridge over Suitland Parkway is a three-span, 413-ft-long cast-in-place concrete, post-tensioned, haunched box-girder structure. Photo: CDM Smith.

Typical cross sections for the Southern Avenue Bridge. Figure: CDM Smith.





Cast-in-place concrete V-piers for the Frederick Douglass Memorial Bridge are both internally and externally post-tensioned. The V-piers use very-low-permeability concrete to meet strict corrosion-protection requirements. Figure: HNTB.



Each V-pier of the Frederick Douglass Memorial Bridge required 950 yd³ of concrete, completed in four mass placements with cooling tubes. Photo: District Department of Transportation and HNTB.

with a three-span, 413-ft-long, cast-in-place concrete, post-tensioned, haunched box-girder bridge structure, under a design-build contract with Federal Highway Administration, Eastern Federal Lands Highway Division.

Two lanes of traffic were maintained during construction and demolition of the previous bridge. Scaffolding and falsework structures were required to support the box-girder superstructure during construction of the cast-in-place bottom slabs, walls, and top slabs. The design included installation of a total of 342 longitudinal post-tensioning strands through ducts in the box-girder walls. The multistrand tendons were tensioned until they elongated more than 34 in., giving the structure the strength it needed to span the 164 ft across Suitland Parkway.

The project was completed in 2007. It was the recipient of the 2007 ABC Excellence in Construction Award in the Heavy/Industrial/Transportation Construction category for the Washington, D.C.. metro region.

Frederick Douglass Memorial Bridge over the Anacostia River

The Frederick Douglass Memorial Bridge replaced a 70-year-old swing structure spanning the Anacostia River. The old bridge had required frequent and costly maintenance and repairs, was functionally obsolete with substandard sidewalks, and was structurally deficient with truck traffic prohibited in the curb lanes due to load-rating restrictions. The new bridge is an iconic, 1445-ft-long, three-arch structure (452 ft 6 in., 540 ft, and 452 ft 6 in.), with all components designed and detailed for a 100-year service life.

The cast-in-place concrete V-piers use internal post-tensioning (eight tendons with twenty-seven 0.6-in.-diameter strands in corrugated plastic ducts, stressed at both ends then grouted) and external post-tensioning (27-strand, 0.6-in.-diameter, coextruded high-density polyethylene [HDPE] sheathed strand, with wax-filled HDPE external ducts) to resist the ultimate demand loads. The concrete mixture proportions were specifically developed with high slag content to obtain a very low permeability to meet the strict corrosion-protection requirements for the bridge (nonreplaceable components required a 100-year minimum service life, and replaceable components required a minimum 30- to 75-year service life). Concrete crossbeams built integrally with the V-piers extend out transversely beneath the bridge deck to support the superstructure's longitudinal edge girders on elastically restrained bearings.

The 10-in.-thick precast concrete deck panels (5000-psi 28-day design strength) required a 180-day cure, necessitating intense coordination with the suppliers. Durability features include a 1-in.-thick polyester polymer concrete overlay with a high-molecular-weight methacrylate sealer prime coat, 6500-psi portland cement concrete closure pours, stainless steel reinforcement across construction joints, and epoxy-coated longitudinal and transverse reinforcing steel.

Another major component of this design-build project is the reconstruction of the Interstate 295 (I-295)/Suitland Parkway Interchange, which had many deficiencies. The existing bridges were structurally deficient and functionally obsolete, the existing interstate did not meet current design standards, and the interchange ramps did not meet current design standards for speed, shoulder width, and sight distance. The new bridges include the I-295 bridges over Firth Sterling Avenue and CSX railroad tracks, Suitland Parkway and Howard Road, Ramp A over Suitland Parkway, and Ramp F over Howard Road. All bridges use precast, prestressed concrete bulb-tee girders that were selected for durability and cost advantages. The design using prestressed concrete girders was the most economical option even though the profile of I-295 over Suitland Parkway had to be raised to meet the vertical clearance requirements with the deeper girders.

The Frederick Douglass Memorial Bridge opened to traffic in 2021. The approaches are scheduled for completion in 2022.

Conclusion

DDOT continues to overcome many challenges while honoring the District of Columbia's history by keeping our historic bridges in a state of good repair and constructing new state-of-the-art structures for an extended service life. Performing routine, cyclical, and condition-based maintenance activities on our historic concrete arch bridges involves a relatively minor investment and can ensure longevity for future generations. Meanwhile, new bridges are designed and constructed for an extended service life by using durable materials and systems, details that provide easy access for performing maintenance activities, and details that allow easy replacement of components that have a service life shorter than the service life of the full bridge.

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1. Myer, D. B. 1974, reprinted in 1983 and 1992. *Bridges and the City of Washington*. Washington, DC: U.S. Commission of Fine Arts.
2. Robertson, J. N. 1956. *Washington Bridges*. Washington, DC: Department of Highways, Office of Planning, Design and Engineering.

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Building Information Modeling for Highway Bridge Projects

by Linh Warren and Thomas Saad, Federal Highway Administration

Building information modeling (BIM) is a technology used to deliver infrastructure projects with digital media, known as digital delivery. As the architecture and building construction industries have made extensive use of BIM in project delivery for many years, the transportation industry now recognizes its many benefits. As a result, the application of BIM to highway infrastructure is growing in prominence both in the United States and internationally.

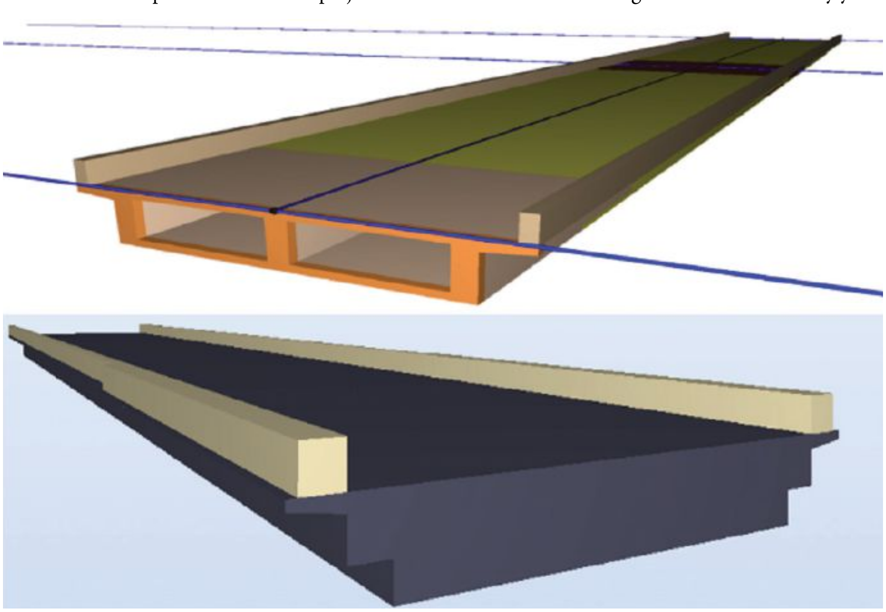
BIM can greatly improve collaboration among bridge designers, fabricators, and construction staff and is envisioned to improve data and design-model management throughout the life cycle of each bridge asset. The Federal Highway Administration (FHWA) conducted a research project to address two specific challenges related to digital delivery: technical needs to manage the new digital processes and media, and standardizing the content and format of the digital data. A case study of a bridge project delivered digitally using BIM-based media for the contract document was also conducted as part of this research project. The information presented in this article is from the project's final report, *Demonstration of Bridge Project Delivery Using BIM* (FHWA-HIF-21-031).[1]

Background

For the past century, information flow has been through the use of two-dimensional (2-D) plans, which were usually developed using drafting standards to ensure a consistent, predictable, repeatable, and reliable presentation of the design specifications for construction. One of the primary industry goals of nonbinding and voluntary data standards is to be able to use BIM to replace 2-D plans with three-dimensional (3-D) digital information that has the same standards of accessibility, repeatability, and universal accessibility.

BIM has matured in the architecture and buildings domain and has been adopted widely following a series of major standardization milestones. Data standards for buildings are based on the Industry Foundation Class (IFC) data schema and exchange file format. For many years the lack of data standards for transportation assets limited the application of BIM. In 2019, the American Association of State Highway and Transportation Officials (AASHTO) passed a resolution titled "Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data,"[2] which recognized IFC schema as the national standard for transportation projects.

The objectives of the FHWA research project described here were to support the state highway agencies that are advancing digital delivery for bridges and to apply and document the effectiveness of the "IFC Bridge Design to Construction Information Exchange (U.S.),"[3] which is a model view definition that expresses the bridge information necessary for construction.



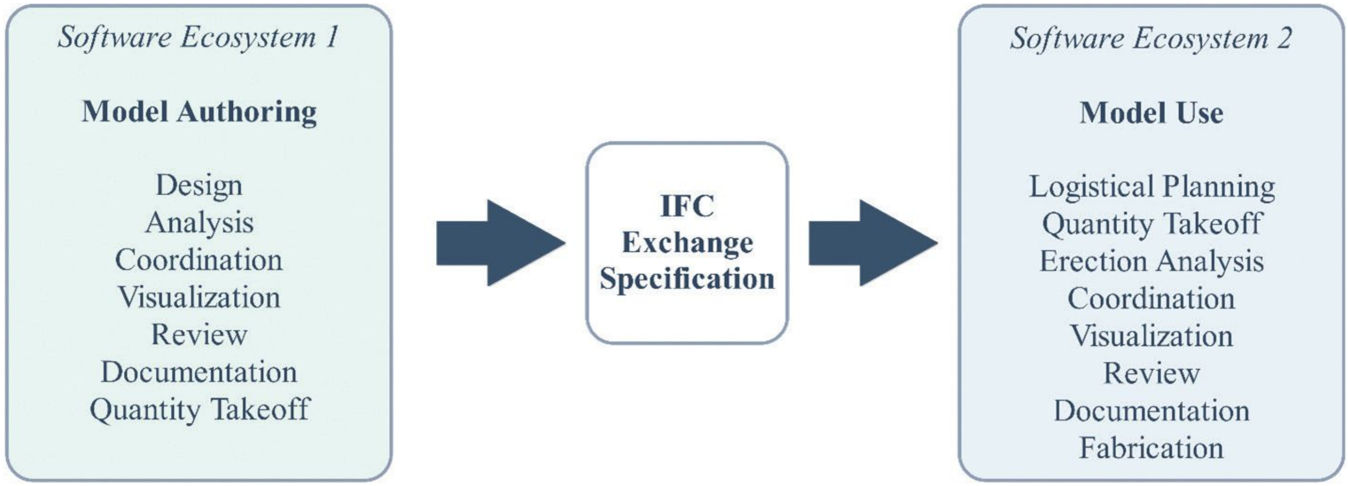
Digital rendering of section and abutment elevation of multicell box-girder bridge. All Figures: Federal Highway Administration.

Case Study

A Utah Department of Transportation (UDOT) project was chosen as the case study for this research. The project, known as the Blackrock project, involved replacing three steel bridges: two parallel bridges that carry Interstate 80 (I-80) over the Union Pacific Railroad, and a bridge that carries State Route 36 over I-80, which was replaced with a prestressed concrete superstructure. UDOT allowed the research team to develop a case study using the project data set to test the IFC exchange specification that had been developed for FHWA.

A utility application was developed in this research that provides access to data stored in AASHTOWare Bridge databases, which can be leveraged by users exporting to design applications and can also accelerate bridge data interoperability with other design, fabrication, and construction software.

Before modeling the case study bridges, data exchange format verification and testing were performed using common industry tools. For the research project, the team used a utility application and accompanying software components that have been created to convert data from AASHTOWare Bridge Design (BrD) and Bridge Rating (BrR) software into IFC format.



Digital construction information flow. For construction, the owner has more control of how construction information is created and delivered, as represented by the authoring activities on the left. The owner can also influence the way information is exchanged from one software ecosystem to the next (middle). However, the owner cannot control how the contractor and fabricator consume information, which is part of the contractor's means and methods (right).

The Alaska Department of Transportation and Public Facilities and Wisconsin Department of Transportation provided a sample of bridges from their AASHTOWare BrD inventory. These bridges were batch converted to IFC using the exchange utility. By converting these sample bridge models to IFC format, dozens of software viewing applications and toolkits can render the information in three dimensions.

IFC Model of Case Study Bridges

The three new bridges from the UDOT case study were used to further test the IFC exchange specification. The research team used the proprietary 3-D models developed for the bridges as a data set and compared the quality and quantity of information generated by the IFC and proprietary data exchanges. The extent of functionality with IFC-compliant models was investigated. To model the Blackrock project bridges, IFC 4.1 was necessary to capture geometry with dimensions used relative to alignment curves. Custom software functionality was adapted from internal software tools to support modeling of the test bridges using the design information.

BIM Technical Specifications for Bridges

Providing information for consideration when agencies are drafting BIM technical specifications for highway bridges was an additional objective of this research project. The following items should be considered in implementing BIM for bridges:

- Technical specifications for BIM-based design should include determination of BIM-related roles and responsibilities (model/BIM manager, model authors, and third-party users), BIM template files, the construction schedule, details of the information exchanges, and overall BIM data structure.
- Construction specifications should include partnering in BIM projects, which is a structured approach to collaboration and teamwork between contracting parties on a construction project, including the owner, designer, fabricator, and construction engineers; the use of electronic documents with digital signatures; and scope validation such as exchange of information and communication, including BIM-related products, and establishing precedents of the BIM documents among the entire set of bid documents for resolving claims and disputes.

Key Findings and Suggestions

This research project provides resources for state transportation agencies implementing digital delivery of bridge projects by including sample technical specifications, a test of an implementation of the "IFC Bridge Design to Construction Information Exchange (U.S.)" model view definition that provides feedback to national and international efforts, and an AASHTOWare BrD to IFC Exchange Utility, which can be used to convert current BrD files into IFC.

The key findings and suggestions include the following:

- It is currently possible to use digital delivery to construct and fabricate complex workhorse bridges using an approach with proprietary software and user-defined detail annotations and attachments for work-around as needed.
- The AASHTOWare bridge models share a well-designed data model that can be mapped to IFC format for most workhorse bridges.
- The bridges tested for IFC exchange in this research were comprehensively described by the IFC data structures. However, it would be beneficial to refine the "IFC Bridge Design to Construction Information Exchange (U.S.)" model view definition to provide direction on representing provisional data and to provide information for capturing multiple representations of the same component for different uses.
- A BIM object template, which provides a structured approach to providing input to describe and expand digital description and associated software standards, is suggested for further study and development.

Moving Forward with BIM

With today's advanced technology and tools, the traditional practice of sharing project documents via hard-copy plan sets and by PDF and word-processing files from silo to silo through the life cycle of a bridge project is inefficient. With BIM, all project data from planning to decommissioning will be digitally accessible for all involved in planning, building, and maintaining bridges, thereby providing seamless data exchange. State departments of transportation are increasingly recognizing the advantages of implementing BIM to improve efficiency and advance our industry.

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Details on Two Upcoming Changes to the *AASHTO LRFD Bridge Design Specifications*: Strut-and-Tie Modeling versus Sectional Design, and Struts Crossing Cold Joints

by Dr. Oguzhan Bayrak, University of Texas at Austin

My article in the Fall 2021 issue of *ASPIRE*® summarized 11 working agenda items that were approved by the American Association of State Highway and Transportation Officials' (AASHTO's) Committee on Bridges and Structures (COBS) at its summer 2021 meeting. That article provides sufficient explanations for the adopted revisions to the *AASHTO LRFD Bridge Design Specifications*[1] that are limited in scope, but others warrant additional discussion. To that end, my article in the Winter 2022 issue and this article each focus on two of the items in greater detail.

Working Agenda Item 206: Strut-and-Tie Modeling versus Sectional Design

Working agenda item 206 provides clarification to Article 5.7.3.2 regarding what types of loads impose additional demands on stirrups near the supports, and what types of loads directly flow into the supports via the formation of direct struts. Sections near supports are subjected to a complex state of stress influenced by the location (that is, the distance from the support) and the type (concentrated or distributed) of loads. In the absence of a concentrated load within the effective shear depth d_v, and where the reaction force in the direction of the applied shear introduces compression into the end region of a member, the location of the critical section for shear is to be taken at a distance d_v from the internal face of the support, and the shear reinforcement required at the critical section shall be extended to the support. This is because the externally applied uniform loads and the self-weight of the member in the immediate vicinity of the support are directly transferred into the support by a compression strut and do not impose an additional demand on stirrups located within d_v of the support. Loads away from supports create a compression field, and the vertical component of the forces generated in the compression field does introduce an additional demand on stirrups (see Fig. C5.7.3.2-1b in the AASHTO LRFD specifications).

It is important to recognize that loads both near and away from supports introduce stresses in the compression-compression-tension node that forms above the supports, and those stresses should be checked in accordance with the requirements of Article 5.8.2 of the AASHTO LRFD specifications. Alternatively, the complex state of stress that results from the presence of a concentrated force near a support may be accounted for using sectional design models by making conservative assumptions for shear design. In the context of sectional design, calculating capacity and demand at the face of the support conservatively considers the complex state of stress that results from the load introduction into the member near a support.

If there is a concentrated load within d_v of the support, or the reaction force in the direction of the applied shear introduces tension into the end region of a member, the location of the critical section should be at the internal face of the subject support. Accordingly, the design section shear load and shear resistance are to be calculated at the internal face of the support. Furthermore, if the beam-type structural member extends to both sides of the reaction area, the design section on each side of the reaction shall be determined separately based on the loads on each side of the reaction and whether their respective contribution to the total reaction introduces tension or compression into the end region.

Working Agenda Item 215: Struts Crossing Cold Joints

Working agenda item 215 provides new requirements for struts crossing cold joints when designs use the strut-and-tie method. These requirements will avoid unconservative capacity predictions for this situation and bring the AASHTO LRFD specifications into better alignment with international design guidance. Accelerated bridge construction, repair and retrofit of existing bridge structures, foundation retrofits, segmentally constructed bridges, and spliced-girder bridges, as well as other innovative bridge solutions involving complex geometries, result in structural details that contain cold joints. Furthermore, recent events have highlighted the importance of properly checking and detailing cold joints.[2] This technical item was initially discussed in a Concrete Bridge Technology article in the Fall 2020 issue of *ASPIRE*.

Recent events have highlighted the importance of properly checking and detailing cold joints.

Article 5.8.2.2 of the current AASHTO LRFD specifications does not explicitly require that struts crossing cold joints must be checked for shear-friction at that interface. With the upcoming changes to the specifications, this check will become mandatory. This modification will ensure that such cases are checked in design or assessment, or both, and it will help prevent unconservative capacity predictions.

According to the forthcoming AASHTO LRFD specifications, if a D-region is built in stages, the forces imposed by each stage of construction on previously completed portions of the structure are to be carried through appropriate strut-and-tie models. Where a strut passes through a cold joint in the member, the joint shall be investigated to verify that it has sufficient shear-friction capacity. The strut force may be resolved into a normal and shear force at the interface, and the capacity of the interface shall be calculated in accordance with the interface shear resistance requirements of Articles 5.7.4.3 and 5.7.4.4.

In this context, the reader's attention is directed to the discussion in the current commentary to Article 5.7.4.1:

> *Shear displacement along an interface plane may be resisted by cohesion, aggregate interlock, and shear-friction developed by the force in the reinforcement crossing the plane of the interface. Roughness of the shear plane causes interface separation in a direction perpendicular to the interface plane. This separation induces tension in the reinforcement balanced by compressive stresses on the interface surfaces.*
>
> *Any reinforcement crossing the interface is subject to the same strain as the designed interface reinforcement. Insufficient anchorage of any reinforcement crossing the interface could result in localized fracture of the surrounding concrete.*

Proportioning, detailing, and anchorage of the reinforcement crossing cold joints are all important to mobilizing the calculated capacity at the cold joint. It is also important to recognize that the cohesion and friction factors listed in Article 5.7.4.4 vary substantially depending on the type and condition of the cold joint interfaces.

Future articles will keep our readership informed about additional upcoming changes to the next edition of the AASHTO LRFD specifications, which is to be published in 2023.

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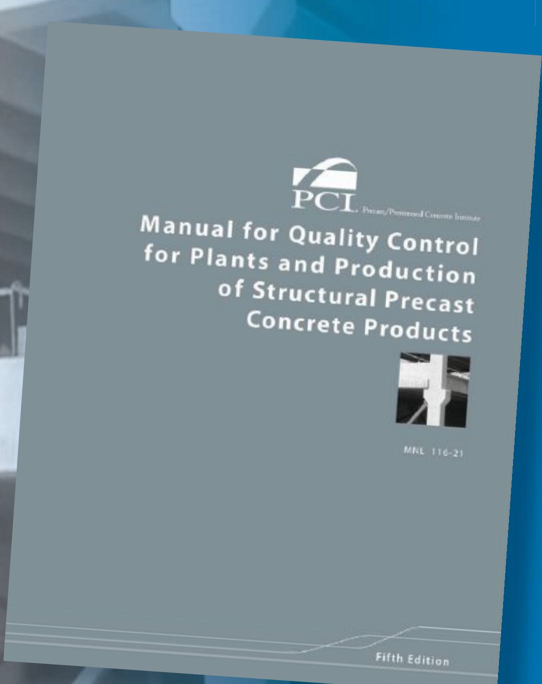
2. National Transportation Safety Board (NTSB). 2019. *Pedestrian Bridge Collapse Over SW 8th Street, Miami, Florida, March 15, 2018.* Highway Accident Report NTSB/HAR-19/02 PB2019-101363. Washington, DC: NTSB. https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1902.pdf.



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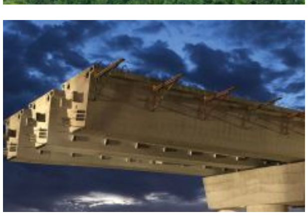
Transportation AWARDS








JURY

Jim Fabinski

VICE PRESIDENT/GENERAL MANAGER, ENCON UNITED, DENVER, COLO.

Jim Fabinski works for EnCon United in Denver, Colo. Despite a distaste for committee work, Fabinski finds himself serving as chair of the Transportation Activities Council and as a member of the PCI Board of Directors, as well as the R&D, Bridge, and Bridge Producers committees. He also helps with various odd tasks for the institute. Fabinski has been involved with PCI since 2004 and barely completed the Leadership PCI program. He has worked in the prestress business in Colorado since 1994. He has an MBA from the University of Colorado Denver and an engineering degree from Michigan State University. Fabinski is a licensed engineer in several states, and a registered contractor in too many. He and his wife, Sterling, share four crazy kids and two obnoxious dogs. In what passes for free time Fabinski likes to road bike, ski, and wrench on motorcycles and old cars. His commitment to PCI is founded on the belief that this organization is essential for advancing the industry we all love so much. He has yet to visit a prestress plant anywhere in the world that is not in the flight path of an airport.

ZhengZheng (Jenny) Fu

BRIDGE DESIGN ENGINEER ADMINISTRATOR, LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT, BATON ROUGE, LA.

ZhengZheng "Jenny" Fu received a bachelor of science degree in mechanical engineering from Huazhong University of Science and Technology in China in 1984 and earned a master of science degree in civil engineering from Purdue University in 1991. Fu is the bridge design administrator in Louisiana Department of Transportation and Development, where she is responsible for bridge design–related activities. Fu is Louisiana's voting member on the American Association of State Highway and Transportation Officials' Committee on Bridges and Structures (COBS) and a member of the COBS executive committee. She serves as the chair for COBS Technical Committee T-8 (Movable Bridges) and is a member of the T-10 (Concrete) and T-11 (Research) committees. She also serves on the Long-Term Infrastructure Program Expert Task Group on Bridges.

Derek Soden

STRUCTURAL ENGINEER, FHWA OFFICE OF BRIDGES AND STRUCTURES TEAM LEADER, FHWA

Derek Soden is the structural engineering team leader in the Federal Highway Administration (FHWA) Office of Bridges and Structures and FHWA's principal structural engineer. Soden is responsible for planning and managing national-level programs targeted at improving the state of practice of structural engineering as applied to the planning, design, construction, and evaluation of highway bridges and structures. He leads a staff of highly qualified engineers who provide technical leadership and guidance to state departments of transportation, industry, and other FHWA offices.

Soden has worked for FHWA since 2009. He was the assistant division bridge engineer for FHWA's Florida and Puerto Rico divisions from 2009 to 2012 and a senior structural engineer with the FHWA Resource Center, where he provided technical assistance and training in the areas of bridge design, construction, and inspection, from 2012 to 2020. Before joining FHWA, he was a bridge design engineer from 1998 to 2009 for the Alaska Department of Transportation and Public Facilities, where he developed designs for new bridges and bridge repair, rehabilitation, and seismic-retrofit projects throughout the state. He received his bachelor of science degree in civil engineering in 1997 from the University of Alaska in Fairbanks (where he was born and raised) and his master of science degree in structural engineering in 1998 from the University of California, Berkeley.

2022 PCI DESIGN AWARDS

Bridge with a Main Span Up to 75 Feet

Middlebury Bridge and Rail Project

MIDDLEBURY, VERMONT

Every bridge project is affected by timing. Communities need these vital routes to be built or rehabilitated as quickly as possible to minimize traffic disruptions. For the town of Middlebury, Vt., the need for speed was especially critical, as the bridges and railroad in need of upgrades ran right through the middle of town.

The 20-ft-deep rail corridor, which was built in the 19th century, cuts through the center of Middlebury, with two bridges offering the only way for traffic to pass over it. In 2013, when the bridge design phase began, the railroad was plagued with drainage issues, clearance restrictions, and poor track conditions, which had contributed to a train derailment. The two bridges were also deteriorating.

The hazardous situation spurred the city to invest in the $80 million bridge and rail improvement project, which included replacing both bridges, updating the rail corridor, and increasing the overall vertical clearance for the railroad by more than 3 ft. The project would be difficult because of its location and the constant road and rail traffic.

"We knew that working around the railroad schedule was going to be a challenge," says Aaron Guyette, transportation lead for VHB. "Accelerated bridge construction [ABC] using precast concrete was the perfect solution to keep the project on schedule."

Even with the ABC approach, the project would still create traffic problems for everyone involved. The railroad ultimately agreed to a 10-week extended track closure, and the city agreed to a 10-week closure of all downtown streets. "The

KEY PROJECT ATTRIBUTES

- **The sealed precast concrete structure created a watertight tunnel.**
- **Galvanized reinforcing steel protects against deterioration and provides a 100-year service life.**
- **Each tunnel U-shape was cast monolithically and weighs over 30 tons.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Build two bridges and update a deteriorating rail corridor.**
- **The project included 295 U-wall sections and 127 upper wall units.**
- **The project was completed during a 10-week rail and road closure period.**

decision to close all downtown streets essentially cut the downtown community in half," says Craig Rypkema, sales engineer for the Fort Miller Company. However, it was the most efficient solution for all stakeholders involved.

The choice of a precast concrete made the 10-week timeline possible, says Jon Griffin, project manager for the Vermont Agency of Transportation. "Fabricating each component prior to the bridge closure period saved an immense amount of time compared to traditional cast-in-place methods."

WATERTIGHT SYSTEM

One of the critical elements for the precast concrete producer on this project was ensuring that the pieces for the rail corridor could meet the tight tolerances necessary to make the system watertight. Each joint had to be within a specific range for the joint waterproofing materials to work properly.

The owner, designer, precast concrete producer, and contractor worked collaboratively to find a balance of fabrication tolerances, construction tolerances, costs, and functionality. They ultimately came up with the perfect design. "The constant collaboration helped make this project a success," Rypkema says.

The team used a precast concrete box structure that would permanently retain surrounding soils and support the existing roadways. The sealed structure was designed to keep groundwater out and convey stormwater from tunnel approaches.

The 345-ft-long concrete box section consists of a series of bottom U-shapes and top U-shapes that join with a keyway to form a clear opening. The tunnel was fabricated with tops and bottoms that could easily be placed together at the jobsite, with U-walls needed to extend upward more than 20 ft.

"It was a challenge to design elements that would be able to be transported to the jobsite and that would easily fit together in the field," Guyette says. To accomplish this, the design team post-tensioned the precast concrete panels to the U-shaped wall bases at the project site. Individual pieces were then connected longitudinally using galvanized "dogbone" hardware that could be quickly inserted and tensioned before the next piece was installed. As an added advantage, the box structures could be extended between the two existing bridge locations to create a tunnel and reconnect the historic town green.

"Precast concrete helped us achieve a project that was constructable within the project constraints," Guyette says. "This means that precast concrete made the schedule achievable, made the project affordable, and helped to achieve the 100-year design life." And for the first time in nearly 180 years, the town green—now a focal point of the downtown area—has been reconnected and developed into a beautiful community space.

Photos: VHB.

"This has been a transformational project that will have a lasting impact in Middlebury for generations to come."
— Aaron Guyette, VHB

PROJECT TEAM:

Owner: Vermont Agency of Transportation, Barre, Vt.
PCI-Certified Precast Concrete Producer: The Fort Miller Co., Inc., Schuylerville, N.Y.
Engineer of Record: VHB, South Burlington, Vt.
General Contractor: Kubricky Construction Corp, Wilton, N.Y.
Project Cost: $80 million

2022 PCI DESIGN AWARDS

Bridge with a Main Span From 76–200 Feet

Eisenhower Bridge of Valor

RED WING, MINNESOTA

The Eisenhower Bridge of Valor is a vital new piece of infrastructure spanning the Mississippi River between Wisconsin and Minnesota. The project fully replaced a cantilever bridge, which opened in 1960 and was recently determined to be "fracture critical."

The old bridge was the only river crossing for 30 miles and accommodated more than 13,000 vehicles every day, so the replacement process had to be minimally disruptive and cost effective. Those priorities drew the design team to precast concrete.

"Precast concrete I-girders are the bread-and-butter superstructure that MnDOT uses for a variety of reasons largely related to cost, simplicity in construction, durability, and low maintenance," says Ben Jilk, complex analysis and modeling engineer for the Minnesota Department of Transportation (MnDOT) Bridge Office. Additionally, the use of prestressed concrete helped the project meet federal environmental assessment standards, which required that the project not significantly affect the local environment.

KEY PROJECT ATTRIBUTES

- **Girders were erected during 45-minute windows.**
- **The 174-ft-long concrete girders were the largest in Minnesota at that time.**
- **Construction crews worked from barges to overcome staging obstacles.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Replace an aging bridge over the Mississippi River between Wisconsin and Minnesota.**
- **The project included four 174-ft-long prestressed spans.**
- **Precast concrete erection was completed in two months, with five-hour road closures per span.**

The design features a seven-span precast concrete bridge composed of four spans of 174 ft 82 in., and 202,000-lb prestressed girders. At the time of production, the 174-ft-long concrete girders were the longest in the state. Their massive size and high-performance strength outmatched alternative materials and proved ideal for this substantial project, Jilk says. "The newer shapes allow us to span longer distances with our precast concrete bridges and help reduce the number of piers needed."

FROM JANESVILLE TO RED WING

To produce the long spans, crews had to perform production activities from elevated work surfaces, which required specialized scaffolds and lifts. Once cast, the precast concrete producer safely hauled the massive bridge girders 280 miles from Janesville, Wisc., to Red Wing, Minn. "The total length of loads reached 220 ft, combining the girder, truck, and six-axle rear-steer trailer," says Gary Courneya, plant operations manager for County Materials Corporation.

To minimize disruption to traffic, the new bridge was constructed next to the existing structure over a busy rail corridor and waterway. A 1000-ft-long causeway and 43-ft-deep cofferdam were created to access the site.

The spans were installed above the land leading up to the river, with three spans of steel tub girders, measuring 218, 432, and 292 ft, spanning the river. Crews worked from barges and performed frequent critical crane lifts to overcome staging obstacles.

To keep the project on schedule, two cranes were used to set prestressed girders during 45-minute windows, which dramatically minimized the need for road closures.

After two years of construction, the bridge opened for traffic in 2019. It features two travel lanes, wide shoulders, a shared-use biking and walking path, and 1640-ft-long spans. "This was a special project because it was built in an iconic town, and it provided a unique opportunity for MnDOT and the Wisconsin Department of Transportation to collaborate," Jilk says.

PROJECT TEAM:

Owner and Engineer of Record: Minnesota Department of Transportation, Winona, Minn.

PCI-Certified Precast Concrete Producer: County Materials Corporation, Janesville, Wisc.

General Contractor: Zenith Tech, Waukesha, Wisc.

Project Cost: $63.4 million

Project Length: 1640 ft

"Prestressed concrete bridge girders were specified because of their unmatched life-cycle costs, longevity, and installation efficiency."
— Gary Courneya, County Materials Corporation

Photos: *County Materials Corporation.*

2022 PCI DESIGN AWARDS

Bridge with a Main Span More Than 201 Feet

70th Ave. E. Over I-5

FIFE, WASHINGTON

The 70th Avenue East Bridge project in Fife, Wash., replaced an outdated bridge that was delaying future construction on State Route 167. It was the first of six projects to support the Puget Sound Gateway Program, which will provide essential connections between the ports of Tacoma and Seattle, Wash., ensuring people and goods can move reliably through the region.

The Washington State Department of Transportation (WSDOT) chose precast concrete for this project because the material is durable and cost effective, and accelerates construction. During the design phase, WSDOT worked closely with the design-build contractors to make the final design even more efficient.

The original plan included prestressed concrete girders with intermediate piers, including one placed in the median of the heavily used Interstate 5 (I-5). However, the team at Guy F. Atkinson Construction offered an alternative technical concept that would adjust the bridge alignment and lengthen the girders to span I-5 without the need for intermediate bridge piers.

UNEXPECTED CURVATURE

The final design features 10 of the longest precast concrete girders ever used in bridge construction. The 222-ft, 3-in.-long girders were manufactured just a few miles from the bridge site by Concrete Technology Corporation, using a high-

KEY PROJECT ATTRIBUTES

- **The project features some of the longest girders used in any bridge project.**
- **Unexpected curvature in the girders due to the lightweight concrete mixture was corrected with adjustable braces.**
- **WSDOT adapted its standard girder plans to offset flexibility issues on future projects.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Build a replacement bridge in Fife, Wash.**
- **The project included ten 222-ft, 3-in.-long girders**
- **The girders were placed during two overnight closures in August 2020.**

strength, lightweight concrete mixture, which allowed the transport loads to stay within the maximum allowable vehicle vertical forces. This design choice was necessary to ensure that transportation to the bridge site would be possible on specialized variable-axle trucks.

"The choice of single long-span girders was made to meet the site's geometric conditions and to eliminate the need for a pier in the freeway median," explains Kevin Dusenberry, senior project manager at Jacobs. "Using WF100G girders eliminated the need for falsework of any kind over the freeway and greatly reduced the amount of freeway and lane closures required." The elimination of a pier in the median also significantly reduced the project's carbon footprint and its environmental impact on the adjacent wetlands.

This long-span approach saved months of construction time and eliminated the need for multiple disruptive closures and realignment of I-5 during construction. "The bridge spans five lanes in each direction and accommodates the ultimate build-out of the freeway in the future," Dusenberry says.

Early in the project, the team had to adapt to an unexpected acceleration of the timeline to meet the fabrication schedule for the girders. "Jacobs worked closely with WSDOT for special 'over-the-shoulder' reviews and with Atkinson Construction and Concrete Technology to complete the girder design in record time and girder fabrication on schedule," Dusenberry says.

In August 2020, the ten girders were hoisted across I-5 to form the foundation of the new bridge during two overnight I-5 closures. After the girders were erected, the team discovered that nine of them had picked up a horizontal curvature, causing them to be out of plumb at the bearings. "The lightweight concrete girders were more flexible than anticipated, which allowed them to curve and twist more than standard-weight girders would have," Dusenberry explains.

The girders had been braced into this configuration, and most of a false deck had been placed between the bottom flanges of the girders. To fix the problem, the contractor replaced all the bracing with adjustable braces and incrementally moved individual girders while adjusting the bracing into the final configuration. "All the girders were adjusted to be well within tolerance, and there was no damage to the girders as a result of the adjustments made," says Dusenberry.

Most importantly, the girder adjustments were safely completed over live traffic on I-5, and no lane closures were necessary to resolve this issue. WSDOT has since made a change to Washington State's standard girder plans to implement a 5-ft-1-in.- wide top flange to offset the flexibility issue on future projects using lightweight concrete.

"The biggest benefit of using the long girders was the elimination of impacts to the traveling public. "
— Kevin Dusenberry, Jacobs

Photos: Washington State Department of Transportation Bridge & Structures Office.

PROJECT TEAM:

Owner: Washington State Department of Transportation, Olympia, Wash.

PCI-Certified Precast Concrete Producer: Concrete Technology Corp., Tacoma, Wash.

CPCI-Certified Precast Concrete Producer: MSE Precast Ltd., Qualicum Beach, BC, Canada

Engineer of Record: Jacobs, Bellevue, Wash.

General Contractor: Guy F. Atkinson Construction, Renton, Wash.

Project Cost: $40.9 million

Project Length: 225 ft

2022 PCI DESIGN AWARDS

International Transportation Structure

Lambor Bridge Crossing the Perak River

PERAK, MALAYSIA

The new Lambor Bridge connects two communities across the Perak River in one of the key districts in the state of Perak, Malaysia. One of the original goals for this project was to elevate the bridge over the 100-year flood level without creating an unacceptable grade of 9.25% in the approach road.

"Under normal circumstances, the Malaysia Department of Irrigation and Drainage requires all permanent structures crossing rivers to have a minimum 1 m [3 ft] of freeboard between the 100-year highest flood level and the soffit level," explains Dr. Fairul Abas, senior bridge engineer, Malaysia Public Works Department.

In this case, the 100-year highest flood level was more than 18 m (59 ft). Therefore, the bridge and road would have to be built at an elevation of more than 21.25 m (70 ft) to meet the grade requirements. However, the road was at an elevation of just 12 m (39 ft).

The designer considered extending the bridge back to a local interchange, but this plan was too costly and would have required additional land acquisition, which could have taken up to two years to secure. Another concern was the aggressive heat and humidity, which limited the types of construction materials that could be used. To address the grade and climate challenges, the design team determined that an ultra-high-performance concrete (UHPC) was the best option.

KEY PROJECT ATTRIBUTES

- **Ultra-high-performance concrete increased durability, lowered costs, and made the bridge resilient to 100-year flooding.**
- **Spans were erected without launching girders, using a temporary bridge and scaffold system.**
- **This is Malaysia's first submersible bridge design.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Build a bridge across the Perak River that addresses 100-year flood levels.**
- **The project included eight 166-ft-long spans.**
- **The project began March 5, 2018, and was completed September 4, 2020.**

"Lambor Bridge is Malaysia's first submersible bridge design, and probably also the first in the world."
— Dr. Fairul Abas, Malaysia Public Works Department

The use of UHPC meant the bridge did not have to be elevated; instead, it could be submerged in the event of extreme flooding because the impervious nature of UHPC would prevent intrusion of moisture and salt. Also, the near total elimination of reinforcing bar would significantly reduce the risk of corrosion and related maintenance costs.

"UHPC offered unparalleled benefits," says Yen Lei Voo, executive director and CEO of Dura Technology. It meant the final road finished level could be set to 16.3 m (53.5 ft), so that the gradient of the approach road from the junction is less than 5%. "Lambor Bridge is the first submersible bridge using UHPC where the bridge will be fully covered with water in the event of extreme flood," Abas says.

FULLY SUBMERSIBLE

The bridge surface is designed in a "boat" shape to optimize the hydraulics of water passing through it. The surface is completely smooth, which will accelerate water flow and reduce drag forces. "The boat-shaped bridge girder not only meets the technical criteria of the bridge functionality but also improves the aesthetics compared to normal T-beam or U-beam designs," Abas says. The extremely low porosity of UHPC increases the structure's impact resistance and durability in the instance of flooding.

The erection of the bridge presented some unique challenges. Because Malaysia does not have access to expensive launching girders that allow span-by-span construction of segmental bridges, the contractor chose a more practical approach. The first three spans were erected on a temporary steel bridge erected between permanent pier and abutment supports. The remaining five spans were erected on the ground using a scaffold system. In both cases, no span moving was required, and each span took about 13 working days to erect.

"The selected system is believed to be the first of its kind in the world," Lei Voo says. "Precast concrete is taken to a higher level while still being cost competitive and providing a long, maintenance-free life that is expected to exceed 300 years."

Photos: *Courtesy of Dura Technology Sdn Bhd.*

PROJECT TEAM:

Owner and Engineer of Record: Malaysia Public Works Department, Kuala Lumpur, Malaysia

PCI-Certified Precast Concrete Producer: Dura Technology Sdn Bhd, Chemor, Perak, Malaysia

Engineer of Record: Perak Public Works Department, Perak, Malaysia

General Contractor: Everfine Resources Sdn Bhd, Petaling Jaya, Selangor, Malaysia

Project Cost: $13.9 million

Project Length: 1326 ft

2022 PCI DESIGN AWARDS

Non-Highway Bridge Cowinner

Phoenix Sky Train Stage 2

PHOENIX, ARIZONA

Phoenix Sky Train Stage 2 is an extension project to connect the Phoenix Sky Harbor International Airport's existing elevated train to its consolidated rental car center and new ground transportation center. The goal of the extension was to streamline transportation for passengers and to support growth of the Arizona airport, which is expected to serve 58 million travelers by 2024. It also helped meet the airport's sustainability goals by reducing the daily vehicle count by 20,000.

The project included construction of more than 2.2 miles of elevated bridge, along with two aircraft taxiway bridges that will carry future airplanes over the below-grade portions of the guideway. Precast concrete was selected as the original design material for all of the bridge superstructures because the designers knew its use was the best way to meet the aggressive delivery schedule required for the 2022 opening.

"Precast concrete was cost effective, and it met the aesthetic goal of matching earlier sections of the project," says Mark M. Pilwallis, vice president at Gannett Fleming. "Most importantly, the speed at which precast concrete could be constructed was a big factor since we were working in a constrained airport environment where maintaining operations was critical."

KEY PROJECT ATTRIBUTES

- **The precast concrete producer modified its forms to cast a 78-in.-deep U-girder section.**
- **Two spans erected over an existing building required lengths up to 197 ft 8 in.**
- **Embedded steel corbels allowed for vertical adjustment with shim plates and a simple field connection.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Build a 2.2-mile-long addition to the Phoenix Sky Harbor International Airport's elevated train and two taxiway bridges.**
- **The project included 296 precast concrete elements.**
- **Construction was completed between April 2018 and June 2020.**

"The prestressed girders made it easy to meet the limited live-load deflection criteria of the system for passenger comfort."
— Mark M. Pilwallis, Gannett Fleming

CORBEL BRACKETS AND DROP-IN GIRDERS

To support the new guideway bridge superstructure, precast concrete U-girders were placed on cast-in-place columns and caps. The taxiway bridges were designed using precast concrete voided rectangular box girders. A facilities access road bridge was also constructed using precast concrete voided slab girders.

The U-girders maintain the overall aesthetic of the guideway structure while meeting all of the structural and serviceability requirements, Pilwallis explains. The precast concrete producer modified its forms to accommodate a deeper U-girder section, allowing for continuous spans up to 197 ft 8 in., and to maintain the standard web slope with filler forms to increase the versatility of the forming system.

Erecting the post-tensioned U-girder was the biggest obstacle the project team faced, as the unit spanned over an active airport terminal building during construction. "The challenging site constraints and the operational need to have small- to medium-size aircrafts taxi below our guideway led us to use longer-than-typical bridge spans for precast concrete," Pilwallis says. "We used spliced precast concrete girders to extend the spans and fit the site."

The tight site conditions did not allow the team to use temporary falsework supports in the span adjacent to the terminal building, so the precast concrete specialty engineer designed embedded corbel brackets to support the drop-in girders from the adjacent pier girders. The corbels allowed for vertical adjustment with shim plates and a simple field connection of two bolts per corbel. With this accelerated construction method, the girders could be erected in the four-hour time slots allotted for the work.

Given the splice location and pier geometry, several of the post-tensioned pier girders did not have a large enough factor of safety against overturning during intermediate stages of construction prior to casting splices and applying the post-tensioning. To ensure the girders remained stable and to maintain worker safety, the precast concrete producer and precast concrete specialty engineer worked together to design and cast temporary ballast blocks to sit inside of the U-girders during the intermediate construction stages. The girders were erected with the ballast in place to ensure stability when the cranes were disengaged from the girders. After the cast-in-place splices were cast and the girder stability was ensured, the ballast blocks were removed.

To further accelerate delivery, the precast concrete producer installed electrical conduits on the exterior girder webs at the precast concrete plant before girders were shipped. This allowed for easier access with the girders at ground level and saved the contractor weeks of field installation. It also created a safer work environment by eliminating the need to install thousands of feet of conduit, which would have required laborers tied off in man lifts to work in an active traffic zone at an airport.

"The project is the latest segment of a multiphase transit system that creates significantly more landslide capacity at the airport, while reducing congestion and greenhouse gases," Pilwallis says. The train is scheduled to open to the public in early 2022.

Photos: Modjeski and Masters.

PROJECT TEAM:

PCI-Certified Precast Concrete Producer: TPAC, Phoenix, Ariz.
Precast Concrete Specialty Engineer: Modjeski and Masters, Littleton, Colo.
Engineer of Record: Gannett Fleming, Phoenix, Ariz.
General Contractor: Hensel Phelps, Phoenix, Ariz.
Project Cost: $320 million
Project Length: 2.2 miles

2022 PCI DESIGN AWARDS

Non-Highway Bridge Cowinner

UC San Diego Mesa Housing Pedestrian and Bicycle Bridge SAN DIEGO, CALIFORNIA

The University of California San Diego is set in a breathtaking location, nestled on 1200 acres of coastal woodland near the ocean. However, at the university's center is a canyon that separates the main campus from student housing and the East Campus Medical Center, and historically, this separation created long travel times for pedestrians and bikers. The new $10 million Mesa Housing Pedestrian and Bicycle Bridge solves this problem, improving access between the neighborhood and campus.

"The bridge design is inspired by the canyon it spans and the long-standing San Diego tradition of pedestrian and bike bridges that span from one mesa to the next," says Eric Naslund, project architect for Studio E Architects. "The simple and elegant spans of the concrete beams make a perfect foil for an organically shaped deck that morphs as it arrives at either landing."

Several bridge types were considered for this project, including steel truss, steel girder, precast concrete girder, and stress ribbon. The designers ultimately settled on a three-span, precast concrete spliced-girder bridge with a 190-ft-long middle span. The design was selected for its combined aesthetics, durability, and cost effectiveness.

"Use of precast concrete was the option with the highest cost savings, resilience, and durability, and the least maintenance," says Sami Megally, project engineer for Kleinfelder. "Use of precast concrete girders allowed the addition of all aesthetics features that make this bridge an architectural icon of the UC San Diego campus."

KEY PROJECT ATTRIBUTES

- **Long span girders were spliced in-air to avoid use of temporary supports.**
- **The bridge's serpentine design and curved overhangs mimic the canyon below.**
- **Two-tone glass-seeded Lithocrete finish distinguishes paths for pedestrians and bicycles.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Build a pedestrian and bike bridge over a protected canyon.**
- **The project included eight California wide-flange girders (6 ft deep).**
- **Total time to erect all bridge girders was five working days.**

An extensive analysis of the precast concrete design demonstrated its constructability amid adjacent project construction and steep grades, and proved that it could accommodate environmental restrictions in the canyon, which is home to a protected wetland and coastal sage scrub and gnatcatcher habitats. "Permanent and temporary supports could not be used within the canyon," says Keith Gazaway, project manager for Kleinfelder. "The 190-ft span length was the minimum feasible length to avoid encroaching into the environmental 'no-touch' zone."

SPLICED IN THE AIR

Each line of girders in the bridge consists of three segments: two segments over the bents and end spans, and a middle drop-in segment. To accommodate the limiting site requirements, the precast concrete girders for the end spans were designed to be erected before the main span, and to span over the bents and into the main span. Partial construction of the deck slab was then completed, so that the main span girders could be spliced in the air—an arrangement that avoided the need for temporary supports. To further minimize the project's impact on the environmentally sensitive area, the team located bridge supports outside of the wetlands' limits during and after construction.

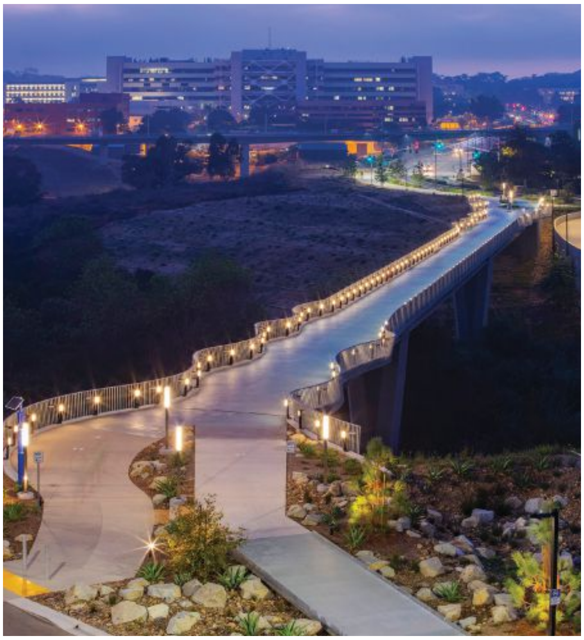
During construction, a survey error resulted in the bridge being 6 ft longer than originally planned. "This was a challenging situation, especially when using precast concrete," Gazaway says. His team solved the problem with a rapidly deployed abutment retrofit scheme, keeping the project on schedule.

The finished design features significant curvatures in the edge of the deck, with varying inclination of metal railings along the length of the bridge to create a more compelling visual experience. Shallow precast concrete girders were used to reduce crane-lifting requirements and to accommodate architectural features. To enhance the experience of bridge users, paths for pedestrians and bicyclists were distinguished from each other through the innovative use of a two-tone glass-seeded Lithocrete finish with two different colors.

By bringing innovative ideas and solutions to the bridge design and construction process, the project team achieved a balance of safety, functionality, environmental sensitivity, community value, aesthetics, and cost savings. The bridge enhances access and connectivity between the university and the surrounding community, and it encourages walking and biking by providing a significantly shorter, safer route to almost every part of the campus.

Gazaway believes this project demonstrates how a precast concrete girder bridge project can evoke a positive image of engineering excellence in terms of architectural design and structural feasibility. "The project also is a testimony to the fact that precast concrete girders with extended span limit can be used for architecturally innovative bridge crossings over areas where conventional formwork is not feasible or too costly."

***Photos:** Jesse Marquez, John Durant, and Keith Gazaway.*



"The voluptuous edges allow for lingering and viewing of the canyon along the way without impeding the flow of traffic."
— Eric Naslund, Studio Architects

PROJECT TEAM:

Owner: University of California San Diego, La Jolla, Calif.
PCI-Certified Precast Concrete Producer: Oldcastle Infrastructure, Perris, Calif.
Architect: Studio Architects, San Diego, Calif.
Engineer of Record: Kleinfelder, San Diego, Calif.
General Contractor: Granite Construction Company, Carlsbad, Calif.
Project Cost: $10 million
Project Length: 465 ft

2022 PCI DESIGN AWARDS

Rehabilitated Bridge

The Arlington Memorial Bridge Rehabilitation

WASHINGTON, D.C.

The Arlington Memorial Bridge is not just another transportation route for locals and tourists. It is an iconic element of the entrance to the nation's capital. The neoclassical bridge spans the Potomac River, linking the Lincoln Memorial in the District of Columbia to the Arlington National Cemetery in northern Virginia and serving an estimated 68,000 vehicles daily.

After nearly nine decades of dedicated service, the bridge needed a major rehabilitation to extend its service life. In 2017, the National Park Service (NPS), in coordination with the Federal Highway Administration (FHWA), solicited proposals for the rehabilitation project through a two-phase, design-build process. The project was awarded to Kiewit Infrastructure Company in partnership with AECOM.

The goal of the project was to restore the bridge's structural integrity while protecting and preserving its memorial character and significant design elements. The designers used precast concrete bridge elements in the design to help meet all of the project goals.

"The use of precast concrete deck panels was a requirement and essential to the success of this project," says Stephen Matty, project manager in the bridge

KEY PROJECT ATTRIBUTES

- **The use of precast concrete will extend the life of the bridge for another 75 years.**
- **Closure pours used UHPC with a minimum 28-day compressive strength of 21,000 psi.**
- **HPC was used in the sidewalks, approach slabs, cross walls, beams, caps, columns, and precast concrete deck panels.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Rehabilitate a historic 70-year-old bridge between the District of Columbia and northern Virginia.**
- **The project included 450 deck panels and 82 precast concrete beams.**
- **The project began in March 2018 and was completed in December 2020.**

"The rehabilitation kept this bridge in service for the local community and for visitors from all over the world."
— Joseph Fabis, FHWA

design group for AECOM. The use of precast concrete deck panels facilitated rapid construction while minimizing disruptions to the traveling public, and it provided a cost-effective approach to achieving the durability and service life requirements in the contract.

In addition, the use of ultra-high-performance concrete (UHPC) closure joints with a minimum 28-day compressive strength of 21,000 psi minimized the number of expansion joints required for the project.

HIGH PERFORMANCE, LOWER COST

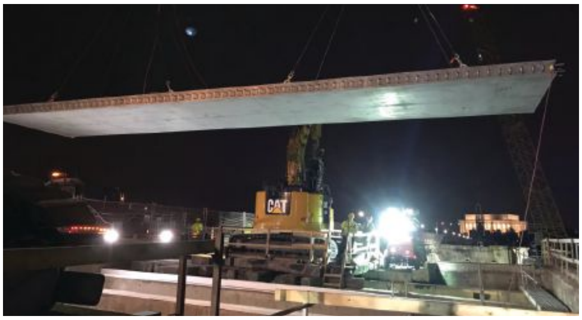
The project involved the rehabilitation of the concrete arch approach spans, including replacement of the existing cast-in-place reinforced concrete deck, and design and construction of the replacement of the moveable bascule span with a fixed steel girder span.

For the first phases of the project, designers used 450 precast concrete deck panels and replaced all of the internal concrete beams and columns on top of the piers. The later phase included replacement of the existing cast-in-place deck with precast concrete deck panels and link slabs to minimize open joints. Ten reinforced concrete arch approach spans and a multigirder steel center span were placed over the navigable channel, with eight arches spanning directly over the Potomac River.

The precast concrete deck panels were about 10 ft long and 42 to 44 ft wide, and were connected at each cross wall using 5-in.-wide UHPC closure joints. The 82 precast concrete beams were about 44 ft long and 2.5 ft deep. Each precast concrete beam was connected together along the center of the bridge using 8-in.-wide UHPC closure joints to form a continuous transverse floor beam.

High-performance concrete (HPC) was used in the sidewalks, approach slabs, cross walls, beams, caps, columns, and precast concrete deck panels, with 28-day compressive strengths ranging from 4500 to 6000 psi.

"The precast concrete deck panels with HPC, UHPC closures, and stainless-steel reinforcement provide a level of protection to the supporting structure that will extend the life of the bridge for another 75 years," Matty says. "The partnership between the FHWA and NPS was key to the success of this project," adds George Choubah, FHWA lead structural engineer. "Everyone on the team worked very hard to make sure that the fast-paced design and construction schedules were met without jeopardizing the quality of the final product," he notes.



Photos: FHWA.

PROJECT TEAM:

Owner: National Park Service, McClean, Va.

PCI-Certified Precast Concrete Producer: Pennstress, Roaring Spring, Pa.

Engineers of Record: AECOM, Glen Allen, Va., and FHWA, Ashburn, Va.

General Contractor: Kiewit Infrastructure Co., Hanover, Md.

Project Cost: $201 million

Project Length: 2162 ft

2022 PCI DESIGN AWARDS

Transportation Special Solution and Harry H. Edwards Industry Advancement Award Honorable Mention

Veterans Drive Seawall

ST. THOMAS, U.S. VIRGIN ISLANDS

Veterans Drive in St. Thomas, U.S. Virgin Islands, is a 2-mile-long seaside road that offers breathtaking views of the harbor and sea and serves as an anchor point for the city of St. Thomas.

In 2017, American Bridge Company contacted WSP USA to provide value-engineering design services to improve a half-mile seawall portion of the road, which was badly in need of repair. The project included road widening, pavement reconstruction, seawall construction, and related work as part of a larger revitalization of the St. Thomas Waterfront and Downtown Charlotte Amalie.

The owner originally proposed a stacked, precast concrete block design, but the team determined that such a structure would be too risky and too expensive. Also, the supply of materials at the time was undependable. After considering several alternative options, the team selected a precast concrete counterfort wall design that could be produced and transported from Coastal Precast Systems in Virginia.

"The precast concrete counterfort gravity wall design incorporated all of the benefits of the design-build process by tailoring a unique design to meet the owner's requirements, the contractor's abilities, and the budget," says Justin Berglund, project manager for American Bridge Company.

KEY PROJECT ATTRIBUTES

- **Production of full-height units reduced crane picks from 6600 to 251.**
- **Underwater GPS attached to an excavator was used to guide the precast concrete pieces into place.**
- **Some excavations extended 15 ft deep before seawall footings were placed.**

PROJECT AND PRECAST CONCRETE SCOPE

- **Replace an aging seawall using a precast concrete counterfort wall design.**
- **Precast concrete modular wall units were made out of marine-grade concrete.**
- **The precast concrete design solution cut nine months from the project timeline.**

GPS REPLACES DIVERS

The design features individual, standard precast concrete wall units composed of a tapered base slab, a wall stem, and single or double counterforts based on height of soil retained; some counterforts were as tall as 16 ft. The precast concrete producer developed the piece-wise layout of the units in the plant to ensure they would fit the exact alignment of the project site.

"The overall design and fabrication of the pieces allowed some flexibility in trimming portions of top of the precast concrete modules to fit the site conditions," Berglund says.

WSP worked with the precast concrete producer to define element shapes and sizes and provide input for fabrication, shipping, handling, and installation. To meet aesthetic goals, the seawall pieces feature a pigmented face and a troweled finish that was achieved through the inclusion of a special precast concrete formliner. To meet the stringent design life and durability requirements, the precast concrete producer used a high-quality marine concrete mixture and stainless steel reinforcement.

Once cast, the pieces were shipped via ocean barge from Virginia to St. Thomas and placed for storage on the seabed in the vicinity of the final installed location.

The use of full-height units counterfort wall pieces instead of quay wall blocks reduced the number of crane picks from 6600 to 251. "This approach allowed us to reduce the wall installation time frame by nine months," Berglund says. It also eliminated the need for divers to set the blocks, which was a deemed a significant safety issue. Instead, the team used underwater GPS equipment attached to an excavator to guide the precast concrete pieces to the correct height and alignment.

The first half of the wall required excavation of the existing foundation soils, which were replaced with crushed gravel prior to placing the seawall footing. "This excavation would have proved very difficult if we had used the original wall design, as the risk of the wall footing washing out prior to backfilling would have been a real concern," Berglund says. By using the precast concrete counterfort wall option, the crews were able to place the wall segments to full height with one crane pick followed immediately by backfilling.

"The precast concrete module concept was an effective and elegant solution to the seawall design and construction for Veterans Drive widening project," Berglund says. "The concept can be considered to be a viable option for shallow piers, wharves, and other shore-protection projects where durability, resiliency, and aesthetics are critical requirements."

***Photos:** WSP/American Bridge.*

"Veterans Drive Phase 1 is the largest public infrastructure project in the history of the U.S. Virgin Islands, and this wall system was instrumental in the successful completion of the project."
— Justin Berglund, American Bridge Company

PROJECT TEAM:

Owner: U.S. Virgin Islands Department of Transportation

PCI-Certified Precast Concrete Producer: Coastal Precast Systems LLC, Chesapeake, Va.

Engineer of Record: WSP USA Inc., Federal Way, Wash.

General Contractor: American Bridge Company, Tampa, Fla.

Project Cost: $42 million

Photo: Caltrans.

BRIDGE WITH A MAIN SPAN UP TO 75 FEET

21ST AVENUE UNDERCROSSING

SACRAMENTO, CALIFORNIA

PROJECT TEAM:

Owner and Engineer of Record: Caltrans, Sacramento, Calif.

PCI-Certified Precast Concrete Producer: Con-Fab California, LLC, Lathrop, Calif.

General Contractor: Bridgeway Civil Constructors, Inc., Vacaville, Calif.

Project Cost: $3.5 million

Project Length: 51 ft

KEY PROJECT ATTRIBUTES

- Route 99 was shut down for 94 hours, instead of 6 months of partial lane closures.
- Each girders was erected in less than 10 minutes.
- UHPC provides a superior joint connection to prevent longitudinal cracking.

PROJECT AND PRECAST CONCRETE SCOPE

- Replace a deteriorating bridge using accelerated bridge construction methods.
- Project included 35 precast concrete girders.
- All of the girders were placed within 4 hours.

The 21st Avenue undercrossing bridge, which carries Route 99 traffic over 21st Avenue in Sacramento Calif., is a notable example of the benefits that precast concrete and accelerated bridge construction (ABC) bring to a community.

The original bridge, built in 1958, consisted of two single-span cast-in-place reinforced concrete cored slab bridges on strutted abutments, which were later linked by a cast-in-place prestressed cored slab. The bridge deck was showing severe signs of distress in the form of heavy pitting, abrasion, cracks, and spalls, indicating it had to be replaced. However, the high volume of traffic on Route 99 meant the project design had to be completed quickly and with as little disruption as possible.

The California Department of Transportation (Caltrans) proposed replacing the existing voided slab deck with precast, prestressed concrete adjacent box girders using ultra-high-performance concrete (UHPC) connections to provide a superior joint connection and prevent longitudinal cracking. The design included 35 precast, prestressed concrete box girders, roughly 51 ft long, 4 ft wide, and 2.25 ft in height, with UHPC placed in the keyways between the girders to form the transverse connection.

The project followed an ABC method, which dramatically reduced traffic disruption.

100-HOUR PROJECT

Typically, a project of this scale would require a single lane closure for six months, as crews worked incrementally to build one side of the bridge then the other. Instead, Caltrans opted to shut down Route 99 completely for four days, to demolition the bridge and erect the replacement.

It was difficult to convince internal and external stakeholders to shut down the busy highway, but the project team persuaded them that the comparatively brief shutdown was a better alternative. It was the first high-profile ABC bridge project in California that used precast concrete elements to replace a bridge in such a short time.

With the route closed, the existing bridge superstructure was demolished, the tops of the abutments were leveled, a ½-in. thick elastomeric pad was placed on the abutment seats, and then the girders were erected. Each girder was placed in less than 10 minutes over the course of 4 hours. Then UHPC was placed in the keyway joints and cured, a 1-in. thick polyester concrete overlay was placed, and the median barrier was constructed.

The bridge reopened to traffic on Tuesday, June 15, at 11:00 p.m. — 6 hours ahead of schedule. A conventional cast-in-place construction would have taken six months to do this job. The designers believe many more bridges will be replaced using precast concrete girders and ABC methods in the future.

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