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THE CONCRETE BRIDGE MAGAZINE

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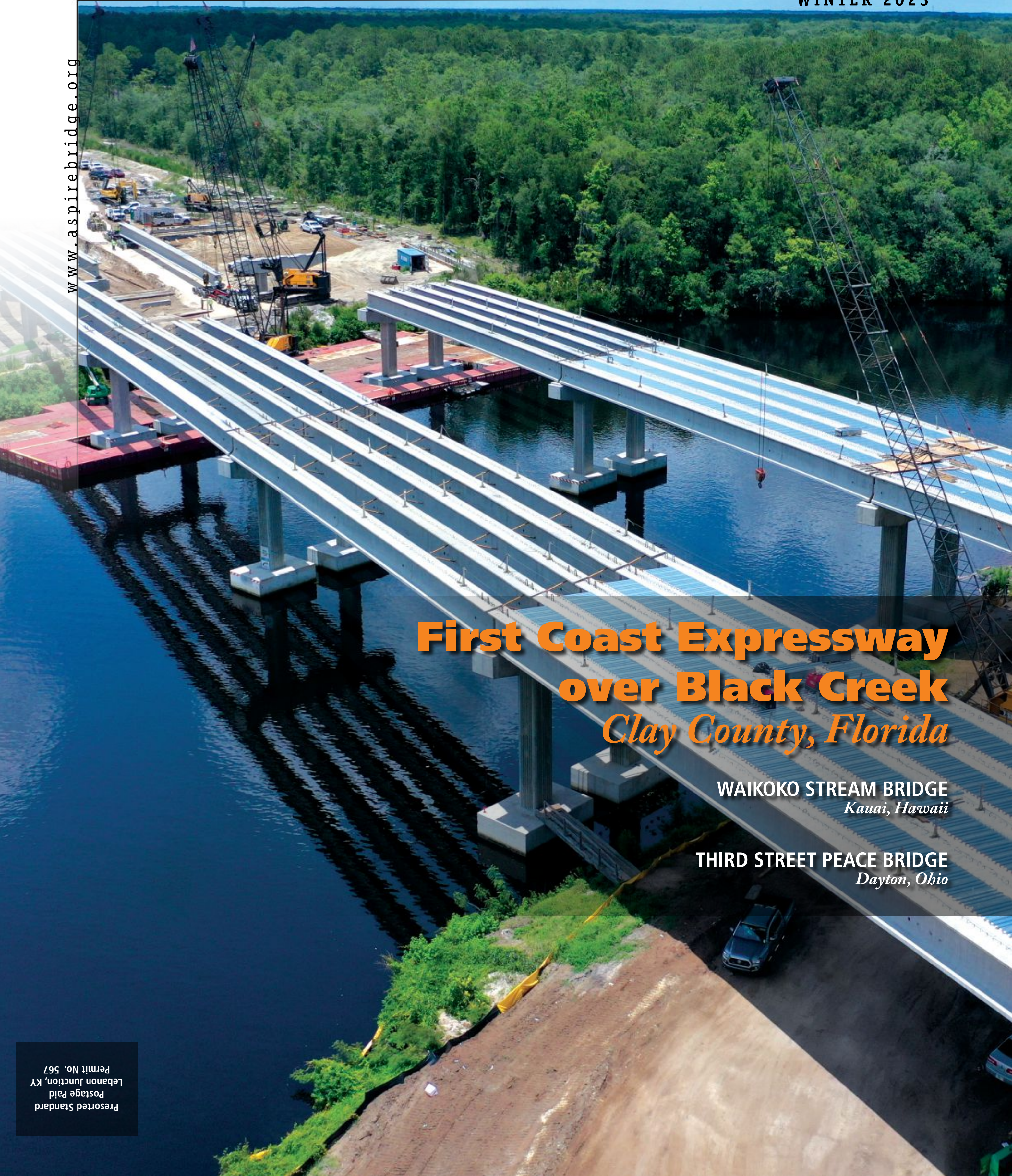

First Coast Expressway over Black Creek

Clay County, Florida

WAIKOKO STREAM BRIDGE
Kauai, Hawaii

THIRD STREET PEACE BRIDGE
Dayton, Ohio

Presorted Standard
Postage Paid
Lebanon Junction, KY
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Photo: Leware Construction Company.

Photo: Hawaiian Dredging Construction Company Inc.

Photo: Montgomery County Engineer's Office.

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Photo: Leware Construction Company.

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EDITORIAL

Photo: PCI.

How Do We Become More Agile in Delivering Transportation Assets?

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

During my travels in the last quarter of 2022, I had the opportunity to interact with a number of engineers and contractors in places such as Miami, Fla.; Austin, Tex.; Chicago, Ill.; Albany, N.Y.; and Washington, D.C. The challenges these professionals face are as varied as their locations.

The bridge engineering community as a whole could not have been more thrilled with how calendar year 2022 started. The U.S. Department of Transportation's (USDOT's) historic Bridge Formula Program (BFP) set aside $26.5 billion for bridge replacement, rehabilitation, preservation, and protection, as well as construction of new facilities where needed. The goal of addressing nearly 15,000 bridge issues across the national landscape is not only timely and crucial but also long overdue. I know I sound like a state bridge engineer fighting for the scraps during the state budget process back in the day. But when $26.5 billion gets allocated for bridge issues, that's as good as it gets. It's like the best holiday morning you can think of—it's "Somebody pinch me, is this a dream?"

But at the same time, something felt off.

The old adages "If it sounds too good to be true, it probably is" and "Be careful what you wish for" kept going through my mind—but why? When was the last time we had resources within our grasp that were specifically dedicated to meeting our needs, and at such extraordinary levels? Where's the catch? Then I came across an article authored by Deloitte subject matter experts on supply chain equilibrium,[1] in which the authors advocate a "tripolar strategy" balancing agility, resiliency, and efficiency. It led me to wonder, "Are we out of balance? And if we are, how do we incorporate agility and find equilibrium in our business model?"

If we lack agility, how do we leverage collaborative efforts to become less reactive and more proactive? State transportation agencies and most institutional organizations find strength through collaboration. Can this model with a more agile approach balance efficiency and resiliency in the current competitive, low-bid construction marketplace? For decades we have talked about minimizing user delays and integrating more prefabrication with workflow automation and tracking. Does today's operating environment bring the "tripolar" concept discussed in the Deloitte article to the forefront?

During project design, engineers strive to balance all aspects of the project, and often become reactionary to changes made post bid. Drawing from football clichés, is it time for design engineers to play more offense than defense during the construction phase of projects? Can we anticipate potential challenges and move to solutions more quickly?

The exuberance felt during the rollout of the Bipartisan Infrastructure Law and BFP was predictable. Finally, national bridge health issues were front-page news, after years of trying to get recognition, and we were eager to get moving.

The U.S. Congress and the USDOT established timelines for the expenditure of BFP funds, as is customary with traditional fiscal appropriations. These funds will expire. Is this the catch that was bothering me? The goal is to capitalize on the funding while it's available. I'd submit that, if these timelines might not be realized, conversations on expenditure, asset delivery, and modifications to the BFP ought to begin now, in earnest, to avoid the predictable "uncomfortable conversation."

The U.S. Marines motto is "*Semper Fidelis* (always faithful)." A colleague of mine prefers the waggish variation "*Semper* Gumby (always flexible)."

Timelines are finite. Our challenge is agility—to anticipate and adapt rapidly.

Reference

1. Mussomeli, A., P. Delesalle, and J. Kilpatrick. 2022. "The New Supply Chain Equilibrium." Deloitte Insights, no. 30. https://www2.deloitte.com/uk/en/insights/focus/supply-chain/supply-chain-agility-efficiency.html.

Cover
Leware Construction Company is erecting 92-ton, 160-ft-long concrete Florida I-beams for the First Coast Expressway bridge over Black Creek from a barge.

Ad Sales
Jim Oestmann • joestmann@arlpub.com
Phone: (847) 924-5497

Reprints
lisa scacco • lscacco@pci.org

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CONTRIBUTING AUTHORS

Tom Drda is a senior bridge safety engineer with the Federal Highway Administration. Since 2010, he has focused on the National Bridge and Tunnel Inspection Programs.

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

Dr. David Garber is an associate professor and interim chair in the Civil and Environmental Engineering Department at Florida International University in Miami, Fla.

Gregory Hunsicker is a research engineer at the University of Texas at Austin and deputy director of the Concrete Bridge Engineering Institute.

Samantha Lubkin is the Safety Inspection Team leader of the Federal Highway Administration Office of Bridges and Structures in Washington, D.C.

Dr. Andrea Schokker is an engineer with the American Concrete Institute and technical consultant and advisor to the board of NEU, an ACI Center of Excellence for Carbon Neutral Concrete.

Dr. Robin Tuchscherer is an associate professor in the Department of Civil Engineering, Construction Management, and Environmental Engineering at Northern Arizona University in Flagstaff.

CONCRETE CALENDAR 2023–2024

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

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 12–18, 2023
PTI Certification Week
Hyatt Regency Schaumburg
Schaumburg, Ill.

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

March 20–24, 2023
PTI Certification Week
Houston Marriott West Loop by The Galleria
Houston, Tex.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

EDITOR'S NOTE

The Federal Highway Administration has recently announced the Every Day Counts-7 Innovations for 2023-24. The topics include the use of internally cured concrete to enhance the service life of concrete bridge decks. More information is available at https://www.fhwa.dot.gov/innovation/everydaycounts/edc_7/

FOCUS

Florida Contractor with Family Ties

Leware Construction Company has more than 50 years of bridge-building experience across Florida

by Monica Schultes

Leware is installing more than 30,700 ft of Florida I-beams weighing up to 92 tons each and 36,900 ft of 24-in. prestressed concrete piling to construct two Interstate 75 ramps, each 3400 ft in length, in Manatee County, Fla. The $144 million project is a joint venture with Ajax Paving Industries. All Photos: Leware Construction Company.

Like many firms in the construction industry, Leware Construction Company bears the name of its founder, Jim Leware Sr., who started building concrete bridges in 1970. Family-owned and operated, Leware is based in Leesburg, Fla., and has focused on concrete bridges in Florida for more than 50 years. Leware's vice president, Keith Waugh, who has been around since the company's early days, says that the family business is still as steady as ever.

Much of the work that keeps Leware's crews busy is obtained through the competitive-bid process. Leware has established a solid reputation, and the Florida Department of Transportation (FDOT) respects the decades of experience that the company brings to the table.

"We focus on what we know," says Waugh. Familiarity with FDOT requirements and preferences allows Leware to take advantage of midsize and midrange bridge projects in the company's sweet spot. "For larger projects, we joint venture with partners, or we perform subcontract work," Waugh notes.

For example, Leware entered into a joint venture with Ajax Paving Industries for the Interstate 75 (I-75) and U.S. Route 301 interchange reconstruction project in Manatee County, Fla., with Leware serving as the bridge contractor and Ajax as the road and paving contractor. For this FDOT project, new 3400-ft-long bridges are being constructed for a northbound exit ramp and a southbound entrance ramp over the Manatee River. The project scope also includes the widening of two bridges over Salt Marsh that have a combined length of 2700 ft. In July 2022, Leware began installing 36,900 ft of 24-in. prestressed concrete piling for the I-75 ramps.

Solidifying the relationships that the company has in the construction industry is an important part of Leware's success. Top executives play an active role in trade associations, and they are also involved in managing projects. Their formula includes careful control of expenses, the right amount and type of technology, and managing risk.

At Leware construction sites, crane operators set the pace and orchestrate the activity. Familiarity with the

As part of the First Coast Expressway project, Leware Construction is erecting 160-ft-long Florida I-beams, each weighing 92 tons. The work is being completed from a barge floating under the toll road extension's new bridge over Black Creek.

equipment improves the flow and handling of materials, while optimizing crane use improves productivity and schedules.

Focus on Florida

The early development of tourism in Florida was driven by the state's infrastructure, and Central Florida cities along the Interstate 4 (I-4) corridor from Tampa Bay to Orlando continue to grow at an accelerated rate, with Orlando being one of the fastest-growing metropolitan areas. Whereas Florida was once famous for attracting snowbirds and retirees, people from all walks of life now move there. As the state has prospered with the influx of population over the years, so has Leware Construction.

Waugh explains that Leware stays focused on Florida because "we know the people, specs, weather, and geology, and work very closely with FDOT. We are deeply involved with industry groups like the Florida Transportation Builders Association (FTBA), and we know policies and procedures and are comfortable here."

"We know the people, specs, weather, and geology, and work very closely with FDOT."

To illustrate the company's commitment to the state's industry and communities, Jim Leware Jr. served as the chair of FTBA in 1996; the company's executive vice president, Andy Clark, served in the same role in 2001; and Keith Waugh was installed as chair in 2022. No other company has had three executives hold the position of FTBA chair.

Florida I-Beam

FDOT emphasizes consistent design and good value in the construction of its highways and bridges. Like other state transportation agencies, FDOT has collaborated with industry partners to develop more efficient bridge beams. The Florida I-beam (FIB), first produced in 2009, has a wider bottom flange and lower center of gravity than an AASHTO-type beam. As a result, FIBs can accommodate more prestressing strands and are more stable in shipping, handling, and placement.

Waugh believes that the introduction of the FIB proved to be a huge leap forward. "That was a major innovation at the time, which has streamlined and economized hundreds of bridges since then," he recalls.

Leware is in the process of setting 160-ft-long, 78-inch-deep, 92-ton FIBs as part of the First Coast Expressway project near Jacksonville, Fla. FDOT has already completed several phases of the 46-mile toll road, with two more segments currently under construction.

In Lake County, Fla., Leware replaced the Little Lake Harris Bridge along State Road 19 using FIBs and precast concrete substructure elements that were founded on 24-in.-square prestressed concrete piles with lengths up to 140 ft.

Leware Construction Company

Family-owned and operated Leware Construction Company was founded in 1970 by Jim Leware Sr., a graduate of Georgia Tech who had managed the bridge division of a major contractor in the 1960s. When Jim Sr. passed away in 1986, his elder sons, Jim Jr. and Scott, were thrust into managing the business. They continue to do so today, along with third-generation family members.

In the half century since Jim Leware Sr. bought his first crane, Florida has gone through significant changes, including an increase in population across the state and many major road and bridge projects. Leware constructed numerous bridges for the original Interstate 10 in north Florida and Interstate 75 through southwest Florida. As the state boomed, many new bridges were built for the Crosstown Expressway in Tampa, the East-West Expressway (State Route 408) in Orlando, and other major limited-access facilities throughout central and northeast Florida.

"We saw a lot of success throughout our early years along with the population boom in Florida," recalls Keith Waugh, the company's vice president. With the ever-increasing popularity of Orlando tourist attractions, there was high demand for more infrastructure in the region, and that, combined with Leware Construction's specialized knowledge of concrete bridges, sustained company growth.

Since its early days with just a few crawler cranes, Leware has grown to have a large fleet of cranes and equipment. Comfortable with maintaining the company's current size and workload, Leware focuses on preserving relationships with government officials, other contractors and subcontractors, and local communities.

"In a family business, we know how important it is that people look out for one another," says Waugh. "We all do that while protecting the sense of family that started it all. I believe Jim Sr. would be pleased that we have continued to build on the foundation he provided us."

A self-propelled modular transporter (SPMT) was used to move an eight-girder span unit with a concrete deck and railings into position at Graves Road over Interstate 4. Use of the SPMT reduced the road closure from several weeks to two nights.

The $22 million contract called for the 3250-ft-long bridge—which is often referred to as the Howey Bridge—to open in early 2020. In fact, the construction team completed the work ahead of schedule and under budget.

Success in projects such as these often depends on advance organizaton of the day's work to minimize crane idle time. Leware professionals have extensive technical knowledge, which they use to optimize day-to-day execution on the jobsite and reduce safety risks. Decades of successful projects showcase the Leware team's on-site efficiencies.

Innovative Methods

In Florida, certain construction activities—including removing existing beams, installing new beams, and placing new bridge decks—are not permitted over active traffic. To fulfill this requirement, Leware employs innovative methods to complete work while minimizing lane closures.

According to the Federal Highway Administration,[1] the first use of self-propelled modular transporters (SPMTs) over a U.S. Interstate highway occurred in Florida. The 2006 FDOT project used the relatively new method to accommodate the widening—from four to six lanes—of I-4 at Graves Avenue in Volusia County.

As a subcontractor to Ranger Construction Industries, Leware's team used the new method to transport a unit of eight 78-in.-deep Florida bulb-tee beams for each of the two spans. Weighing 1300 tons, each span unit of the new bridge included an 8-in.-thick concrete deck and traffic railings. After fabrication, the spans were then transported and erected using SPMTs. A cast-in-place reinforced concrete substructure was founded on driven prestressed concrete piles.

The SPMT system, which is more commonly used today, meant that I-4 was closed for just two nights, rather than the numerous weeks of nightly lane closures that would have been required without SPMT technology (for more details on the Graves Avenue Bridge project and concrete bridge innovations in Florida, see the State article in the Fall 2007 issue of *ASPIRE®*).

In a joint venture with the deMoya Group, Leware Construction was involved in a design-build project to widen Interstate 75 near Fort Myers, Fla. This project included six low-level bridges and twin 3850-ft-long high-level bridges over the Caloosahatchee River. That river is home to Florida's second-largest population of manatees, and FDOT's plans required extensive

On the design-build project for widening Interstate 75 across the Caloosahatchee River, two custom-built rubber-tired straddle carriers spanned 84 ft across the median gap between the east and west twin bridges to deliver materials.

coordination with numerous agencies to protect these vulnerable mammals and their habitat. All of the bridges on this project were constructed using top-down construction methods to minimize impacts to wetlands. Material deliveries for the Caloosahatchee River Bridge were handled with two custom-built rubber-tired straddle carriers with 84-ft clear spans to accelerate construction and reduce traffic interference. (For details on this project, see the Concrete Bridge Technology article in the Spring 2022 issue of *ASPIRE*.)

Sustaining Success

Concrete construction is hard, hands-on work. Building forms, tying reinforcing steel cages, and placing concrete are extremely labor-intensive activities, and maintaining an adequate workforce is challenging. However, according to Waugh, "Now is the time to consider a career in bridge construction. The vocation offers opportunities to both begin and advance in an industry that builds the basis for how we live, work, and play."

Leware Construction offers competitive wages and benefits and continues to promote the construction industry as an industry where employees can make a good living through hard work.

"Now is the time to consider a career in bridge construction. The vocation offers opportunities to both begin and advance in an industry that builds the basis for how we live, work, and play."

Leware is very much a family-oriented firm, where many of the employees are in it for the long haul. The staff wear many hats. They may be in the field one day and meeting with owners and agencies the next. According to Waugh, "The thing that sets us apart is that we are extremely mobile and flexible. We own all of our equipment and generally don't need to rent anything." Family members are actively involved in projects. "We stick to what we know, and that minimizes our risk in what is already a risky business," Waugh says.

Conclusion

Concrete—including cast-in-place, precast, and segmental concrete construction—is king in Florida. Leware has built hundreds of bridges in the past half century. The company's sense of family has pervaded their work and is reflected in their accomplishments across the region.

Reference

1. Federal Highway Administration (FHWA). 2007. *Manual on Use of Self-Propelled Modular Transporters to Move and Replace Bridges*. FHWA-HIF-07-022. Washington, DC: FHWA. https://www.fhwa.dot.gov/bridge/pubs/07022/hif07022.pdf.

PERSPECTIVE

Bridgespotting: A Guide to Bridges that Connect People, Places, and Times

A book by Bob Dover

Review by Frederick Gottemoeller

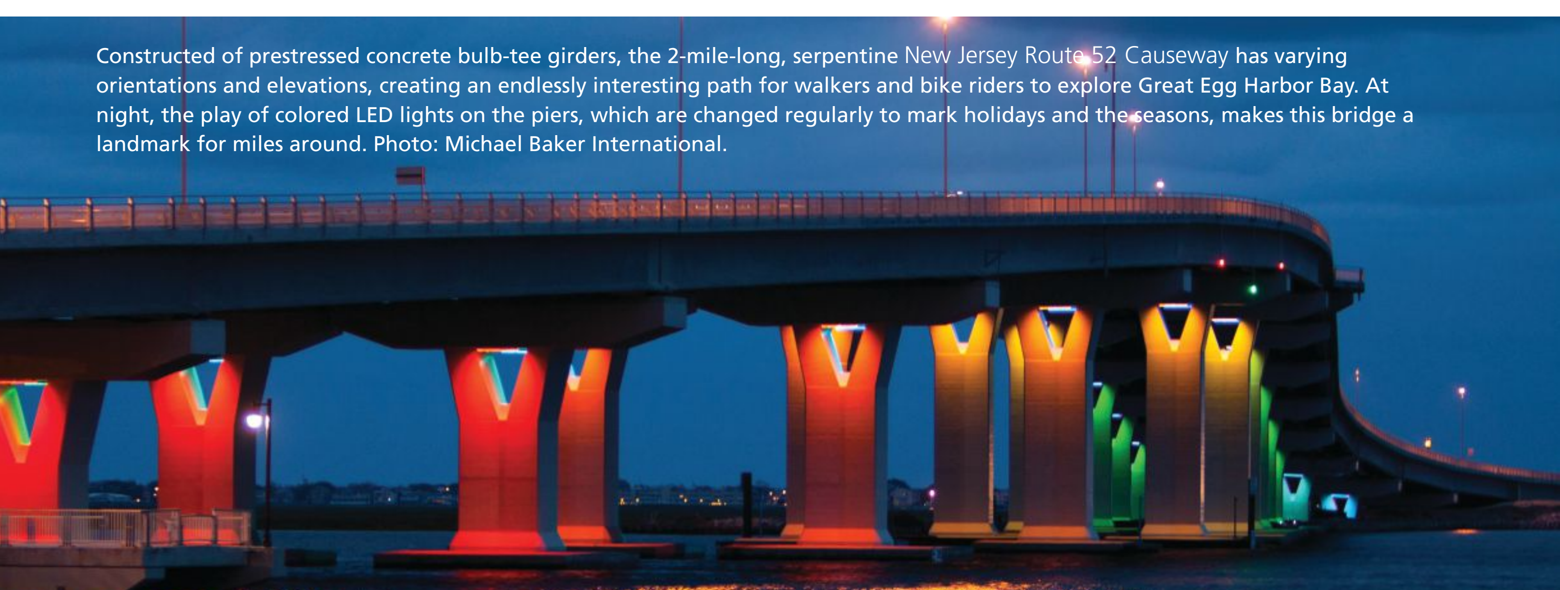
"Among everything that man builds, nothing is more valuable than bridges. They are more important than houses, more sacred than shrines. Belonging to everyone and available to everyone, useful, always built with sense, on the spot where most human needs cross, they are more durable than buildings, and serve openly and honestly, where all can see."

—Ivo Andrić, novelist and Nobel laureate

Since the advent of the railroad, which was closely followed by the development of motorized vehicles, we have primarily seen bridges as a means to get across barriers at high speeds. Many of us have forgotten about all the interesting aspects of a bridge that develop from its location, the history of that place, the culture of the people who built the bridge, the buildings or natural features that can be seen from the bridge, or any other mainly nontransportation aspects of the bridge. However, the increased popularity of walking, running, and bicycling, the growing number of bridges with sidewalks open to pedestrians and bicycles, and, most importantly, the growth of tourism as a leisure activity, are bringing these aspects back into prominence.

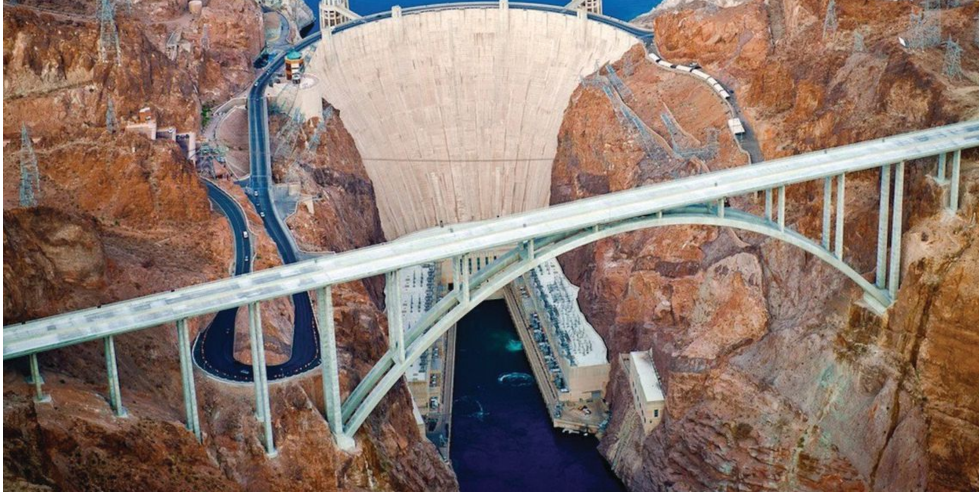
For example, take the New Jersey Route 52 Causeway, a two-mile-long, prestressed concrete bulb-tee girder bridge connecting the mainland at Somers Point with the barrier island of Ocean City, N.J. Completed in 2011 to replace a pair of aging draw spans and to raise Ocean City's main access route above the increasingly high tides, the bridge included a brand new feature: a wide walkway/bike path. Suddenly, vacationers tired of the beach had a new alternative: leisurely walks or bike trips back to the mainland. The goal of these trips could be to visit Somers Point's restaurants (and liquor store). Or maybe the aim is to take in the high-level views of the waterscapes and wetlands of Great Egg Harbor Bay, and to appreciate the bay's rich history. Or vacationers might want to visit the Ocean City Visitors Center halfway across the bridge, with its vending machines and second-level deck overlooking the surrounding bird sanctuary. Now, in addition to quick and reliable access to Ocean City, the bridge offers a variety of new recreational opportunities, along with features of environmental and historical interest.

In *Bridgespotting: A Guide to Bridges that Connect People, Places, and Times*,[1] author Bob Dover addresses this new trend. He states that his purpose in writing the book is to



Constructed of prestressed concrete bulb-tee girders, the 2-mile-long, serpentine New Jersey Route 52 Causeway has varying orientations and elevations, creating an endlessly interesting path for walkers and bike riders to explore Great Egg Harbor Bay. At night, the play of colored LED lights on the piers, which are changed regularly to mark holidays and the seasons, makes this bridge a landmark for miles around. Photo: Michael Baker International.

The Columbia–Wrightsville Bridge across the Susquehanna River in Pennsylvania is a reminder of the Art Deco artistry in concrete that was standard when the bridge was constructed in 1929. Photo: Bob Dover.



The Callahan-Tillman Bridge is the longest concrete arch in the Western Hemisphere and carries Interstate 11 and U.S. Route 93 over the Colorado River between Arizona and Nevada, just downstream of Hoover Dam. Its sidewalk offers stunning views of the Hoover Dam and the Colorado River canyon, and the bridge itself has joined the dam as a symbol of this corner of the Southwest. Photo: HDR Inc.

> *explain why people visit bridges, and how to get there to see for yourself. To encourage you to walk across at your own pace, to look at the details of the construction, to take in the scenery and understand why it was constructed here and not there. To show how the bridge influenced the location and settlement patterns of the city around it. To describe how it supports the economic and social life of the local community. To demonstrate how the presence of the bridge influenced, and even caused, important events that have changed history. To help you get up close and personal with some of the high-speed bridges that you have already seen from a distance, and to tell you about many amazing slow-speed bridges hidden in smaller towns and rural areas. To suggest some things at each bridge, whether it is historical plaques, or decorations or construction details, or bridge-focused events and festivals, that you want to make sure to see.*

Bridgespotting contains profile descriptions of the visual, cultural, and historical aspects of 140 bridges, and additional information about many others. Bridges throughout the United States and most of Europe are included. The writing is aimed at triggering your curiosity and getting you interested in visiting them. Rather than classifying bridges by size, construction type, or age, *Bridgespotting* organizes them by the features that attract visitors and tourists. The guide starts with landmark bridges like the Golden Gate, and then continues with historic bridges, community bridges (famous for the events that occur on and around them), decorated bridges, cultural bridges, and so on.

However, the themes are just the beginning. Each bridge has multiple aspects that make it unique. Maybe the bridge is historically important, such as the site of a long-remembered religious or political event; maybe it is the crossing of a particularly spectacular gorge; or maybe it has an intricate lighting scheme. The possibilities and their combinations are infinite, which makes the book great fun to read and visiting the bridges so intriguing.

For those of us who design and build bridges, *Bridgespotting* provides a useful reminder that bridges have many potential functions, and that transportation is only one of them. Reading the book, and visiting the bridges that interest you, will not just whet your appetite. It will also sharpen your ability to identify and accommodate those other functions on your bridges, even if they are not clearly articulated, or even anticipated, by the communities involved.

The Callahan-Tillman Bridge over the Colorado River is an example of a bridge with such other functions. It is adjacent to the Hoover Dam and supported by the longest concrete arch in the Western Hemisphere. Its transportation function is to carry Interstate 11 and U.S. Route 93 between Arizona and Nevada, but it also has many other functions. Most of these additional functions are made possible by the bridge's sidewalk, which connects to nearby parking. The sidewalk offers stunning views of the Hoover Dam and the Colorado River canyon, views otherwise accessible only by helicopter. The sidewalk provides an unequaled opportunity to see and understand Hoover Dam, to learn the Depression-era history in which it was created, and to see the geology of the Colorado River gorge. The bridge itself also serves a critical nontransportation function. Its image now appears along with the dam in photos describing the area. Thus, the bridge is now a partner to the dam in the mental picture that residents and visitors have of this corner of the Southwest.

The best use of *Bridgespotting* is to plan visits to bridges—both those you have always wanted to see and those you have learned about from the book. While traveling on business, you may realize that an interesting bridge is just down the street from your hotel. Perhaps you and your spouse have planned a trip to Dublin, and now you know that a dozen bridges there are worth seeing. You might even want to organize a whole trip around visiting bridges, such as a trip to Iowa to see the bridges of Madison County. In all these cases, *Bridgespotting* will provide valuable information and guidance. It can also serve as a source of inspiration to plan your own trip, say, down the Oregon coast to see the bridges of renowned designer Conde McCullough.

Reference

1. Dover, Bob. 2022. *Bridgespotting: A Guide to Bridges that Connect People, Places, and Times*. Columbia, MD: Sewell Pond Press.

ASBI Durability Survey of Concrete Segmental Bridges

by Dr. Andrea Schokker, American Concrete Institute, and Gregg Freeby, American Segmental Bridge Institute

The American Segmental Bridge Institute (ASBI) recently published the fifth edition of its *Durability Survey of Concrete Segmental Bridges*.[1] This survey includes data up to 2020 and marks 47 years of concrete segmental bridge construction in the United States. With this recent survey, ASBI has also launched an online app that provides a map and database, specific to segmental bridges.[2] The ASBI Segmental Bridge App includes information on all segmental bridges from the 2020 Durability Survey. This article summarizes the performance of bridge types found in the database. Segmental bridges continue to show excellent durability performance, with only 0.7% rated as "poor" in the National Bridge Inventory (NBI) database.[3]

Background

While some bridges are readily identifiable as segmental bridges, particularly during construction, many variations exist. For this survey, segmental bridges are confined to those defined in ASBI's *Definition of Concrete Segmental Bridges*.[4] Only bridges with segmental superstructure elements are included because that is the only segmental attribute type found in the NBI database.[3]

Concrete segmental bridge construction offers several advantages: repetitive construction procedures, minimal impacts on traffic and the environment during construction, economical construction, and a durable structure.[5] Segmental construction is particularly valuable in a variety of difficult site conditions such as when piers need to be placed on small footprints, superstructures need to span natural hazards or community landmarks, or superstructures such as curved highway access ramps need to be constructed on a small or large radius.

Segmental Bridge Inventory

The purpose of the ASBI Durability Survey is to quantify and summarize the existing condition of concrete segmental bridges in the NBI database. While owners can directly identify a bridge as a segmental box girder with the NBI codes for main span or approach span design, not all segmental bridges meeting the definition from ASBI are coded in this manner in the NBI database. Some segmental bridges are coded under one of the prestressed concrete selections or, in rare cases, are coded incorrectly. Each bridge in the data presented in the ASBI survey has been verified to meet one of the concrete segmental construction types defined in the *Definition of Concrete Segmental Bridges*.[4]

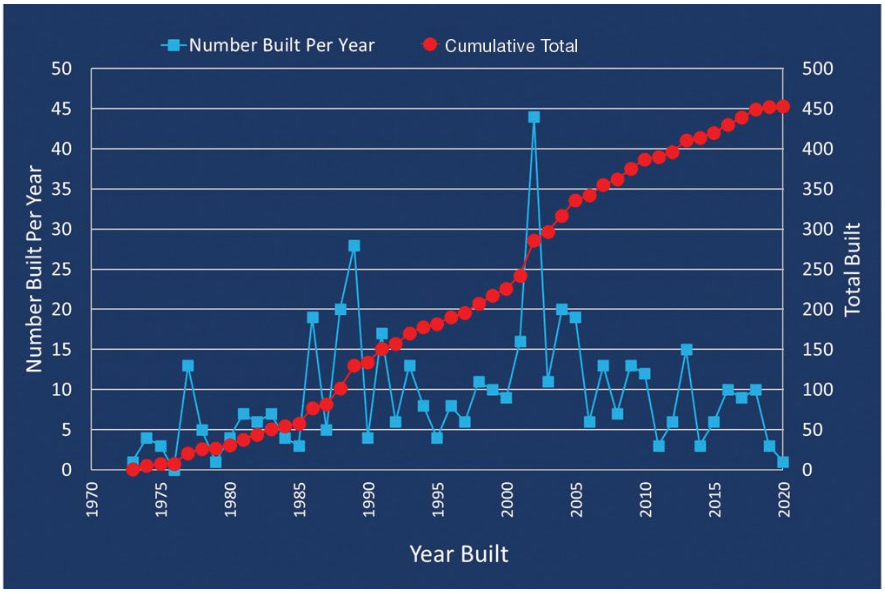
All U.S. states and territories with concrete segmental bridges in their inventories are included in the ASBI survey. In 2020, 46 states and 2 territories had at least one segmental bridge in their inventories, up from 38 in 2012. The four states without any concrete segmental bridges in their inventories are Arkansas, Kansas, South Dakota, and Wyoming. **Figure 1** shows the number of segmental bridges constructed annually along with a running cumulative total. The first recognized segmental bridge in the inventory was constructed in 1973. Each segmental bridge in the survey is assigned an ASBI number for quick reference and can be found in the ASBI online app.[2]

National Bridge Inventory Database

The NBI website includes documents describing the data, data files for direct download, and a link to the Long-Term Bridge Performance (LTBP) InfoBridge website,[6] which provides data and analytics. (See the Winter and Spring 2020 issues of *ASPIRE®* for more information about LTBP InfoBridge.)

As noted previously, the data used in the ASBI survey are NBI data through 2020. States enter data in the NBI according to directions in the Federal Highway Administration (FHWA) coding guide.[7] Since the publication of FHWA's final rule on assessing pavement and bridge condition for the National Highway Performance Program in

Figure 1. Segmental bridges inventoried by year with cumulative totals (through 2020). All Figures: Reproduced by permission from *Durability Survey of Concrete Segmental Bridges*, fifth ed. Austin, TX: American Segmental Bridge Institute, 2022.



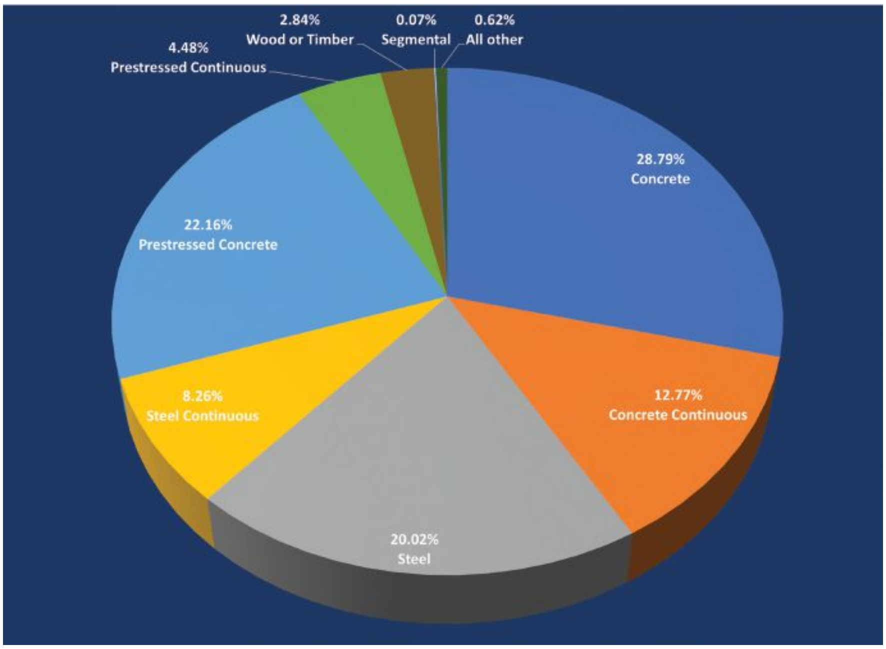


Figure 2. Types of bridges (%) in the full National Bridge Inventory database.

January 2017, overall bridge condition has been rated in the NBI as good, fair, or poor.[8]

Bridge condition ratings are based on the lowest FWHA condition rating among four items: deck, superstructure, substructure, or culvert (items 58 to 61 in the database). Because the lowest item rating controls the overall rating, a poor rating does not necessarily indicate that the segmental superstructure is in poor condition.

Data Presentation and Discussion

The 2020 NBI database includes 618,451 bridges. **Figure 2** shows the breakdown of the inventory by bridge type. Of the bridges in the NBI, 453 (0.07%) have been identified as concrete segmental bridges. Because the first segmental bridge did not appear in the database until nearly 50 years ago, a more representative comparison considers all bridges in the inventory built after 1970 (**Fig. 3**). While the overall number of segmental bridges is only 0.12% of the inventory since 1970, this is an increase of over 70% compared with the number shown in Fig. 2. Other prestressed concrete structures also increase as a percentage of the total inventory in this time frame.

For bridges built from 1970 to 2020, **Fig. 4** shows the percentages of bridges rated as "poor" by type. Considering the percentages shown for the type breakdown in the NBI database (Fig. 3), several materials are overrepresented in the "poor" category (Fig. 4): steel (combined steel, steel continuous), wood/timber, and "all other." Nonprestressed concrete (concrete, concrete continuous) and prestressed concrete (prestressed, prestressed continuous, segmental) have lower percentages of poor ratings than their percentages of the total bridge population. Specifically, segmental bridges represent 0.03% of the poor ratings of bridges constructed since 1970, compared with segmental bridges comprising 0.12% in the full data set since 1970.

Figure 3. Types of bridges constructed since 1970 (%) in the National Bridge Inventory.

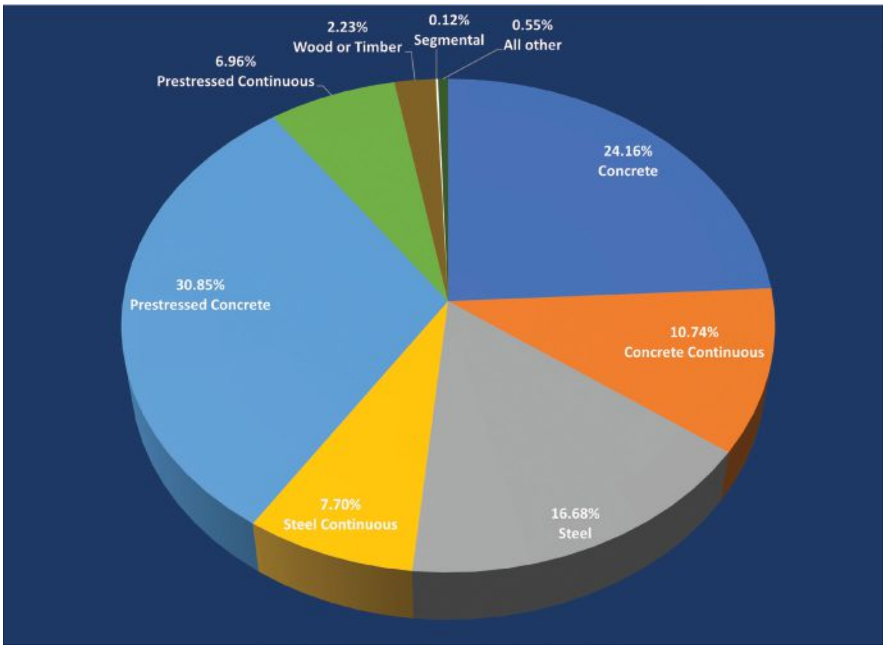


Figure 5 provides another way to visualize the condition ratings of the bridge inventory built since 1970. This figure shows the percentage of bridges in each of the three rating categories (good, fair, poor) within the total number by bridge type. The chart shows bridge types having the largest percentages of poor ratings at the top and gives the total breakdown for all bridges at the bottom. In this figure, the red bar (poor condition) percentage is the equivalent of 3 out of 453 bridges for segmental bridges, whereas concrete continuous bridges with a similar percentage of poor ratings represent 452 bridges out of 37,464 bridges.

Concrete makes up more than 70% of all bridges, and there were 4641concrete bridges in poor condition. In contrast, steel accounts for 24% of bridges built since 1970, but there were 4349 steel bridges in poor condition. These figures demonstrate the longevity and overall lack of deterioration of segmental concrete and prestressed concrete bridges in the inventory relative to other bridge types.

Performance of Older Segmental Bridges

As the first segmental bridges built in the United States are now nearly 50 years old, it is worthwhile to consider the performance of some of these first-generation structures. Significant improvements in design techniques, construction materials, and processes have occurred in the years since they were built.

The John F. Kennedy Memorial Causeway (NBI: 161780061702026; ASBI: 335) was built in 1973 on Park Road 22 over the Gulf Intracoastal Waterway in Nueces County, Texas. It was the first precast concrete balanced-cantilever segmental bridge in the United States. The 2020 NBI

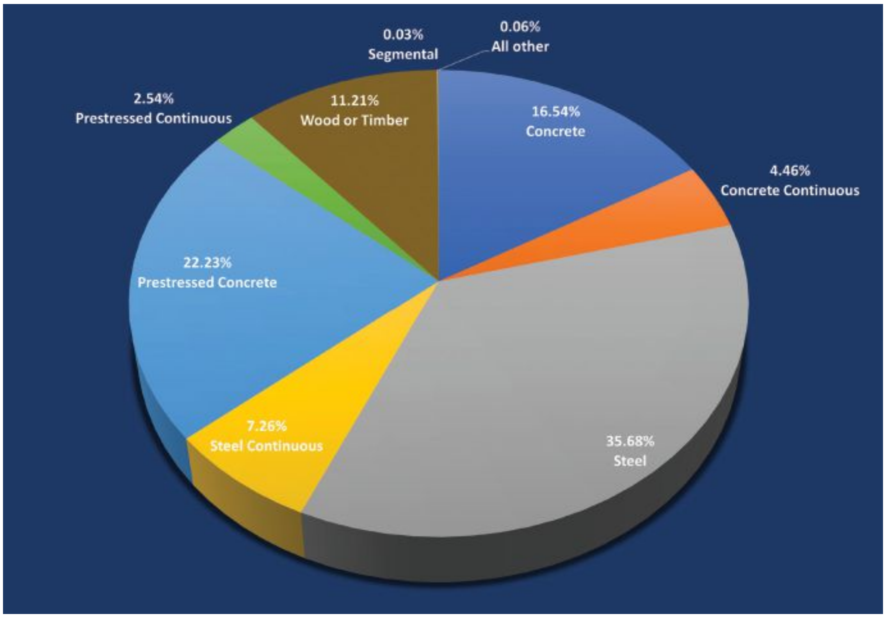


Figure 4. Types of bridges constructed since 1970 that are rated "poor" (%) in the National Bridge Inventory.

data indicate that this bridge is in "fair" condition. The deck, superstructure, and substructure were given a condition rating of 6. This is considered satisfactory. For a bridge that is approaching 50 years old in a marine environment, this is excellent performance. In addition to the routine NBI inspection, the Texas Department of Transportation commissioned an in-depth inspection and appraisal of this structure in 2019, which found very few defects. (See the Project article in the Summer 2021 issue of *ASPIRE* for more details.)

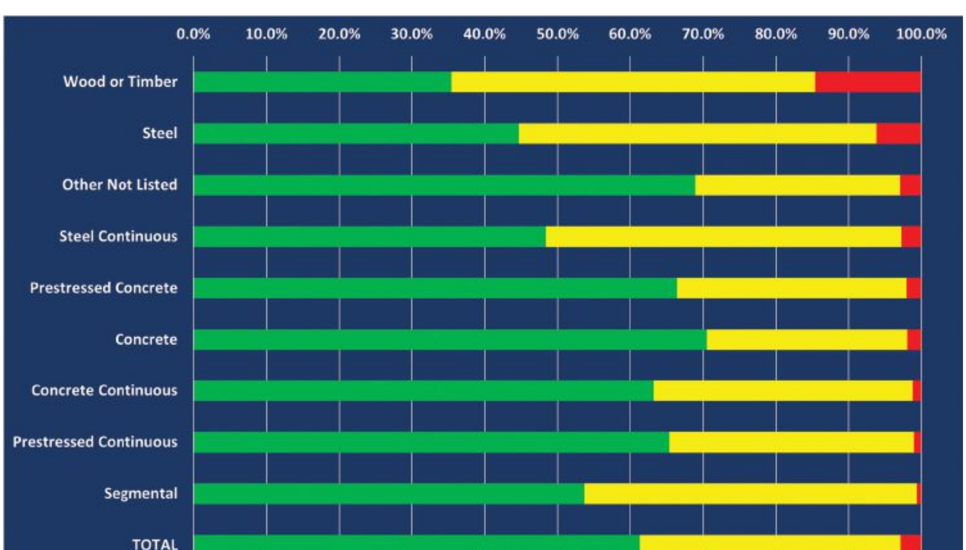
The Pine Valley Creek Bridges (respectively NBI: 57 0692L and 57 0692R; ASBI: 3 and 365) are twin structures built in 1974 in San Diego, Calif., and carry Interstate 8 over Pine Valley Creek. These were the first cast-in-place concrete, balanced-cantilever segmental bridges in the United States. The 2020 NBI data indicate that the deck, superstructure, and substructure of each bridge had a condition rating of 7. These ratings indicate overall "good" condition, which is outstanding for bridges that have been carrying interstate traffic on a daily basis for nearly 50 years.

Conclusion

The NBI data through 2020 show that concrete segmental bridges continue to perform well. Of the 453 segmental bridges in the ASBI Durability Survey, only 3 were rated as being in poor condition. Of those bridges, one is in poor condition due to the substructure (nonsegmental), and the issues with the other two have since been corrected in more recent designs by using improved design methodology, better calculation methods, and better detailing.

Bridges constructed from steel (both steel and steel continuous types) during the past 50 years have a higher percentage of structures rated as poor than concrete structures in that same period. It is reasonable to conclude that a properly maintained concrete segmental bridge can exceed a service life of 100 years, resulting in low life-cycle costs.

Figure 5. Bridges constructed since 1970 in the National Bridge Inventory categorized by type and condition.



	TOTAL	Segmental	Prestressed Continuous	Concrete Continuous	Concrete	Prestressed Concrete	Steel Continuous	Other Not Listed	Steel	Wood or Timber
% Good	61.3%	53.6%	65.4%	63.2%	70.5%	66.5%	48.4%	68.9%	44.7%	35.4%
% Fair	35.8%	45.7%	33.6%	35.6%	27.5%	31.5%	48.9%	28.2%	49.1%	49.9%
% Poor	2.9%	0.7%	1.0%	1.2%	2.0%	2.0%	2.7%	2.9%	6.2%	14.7%

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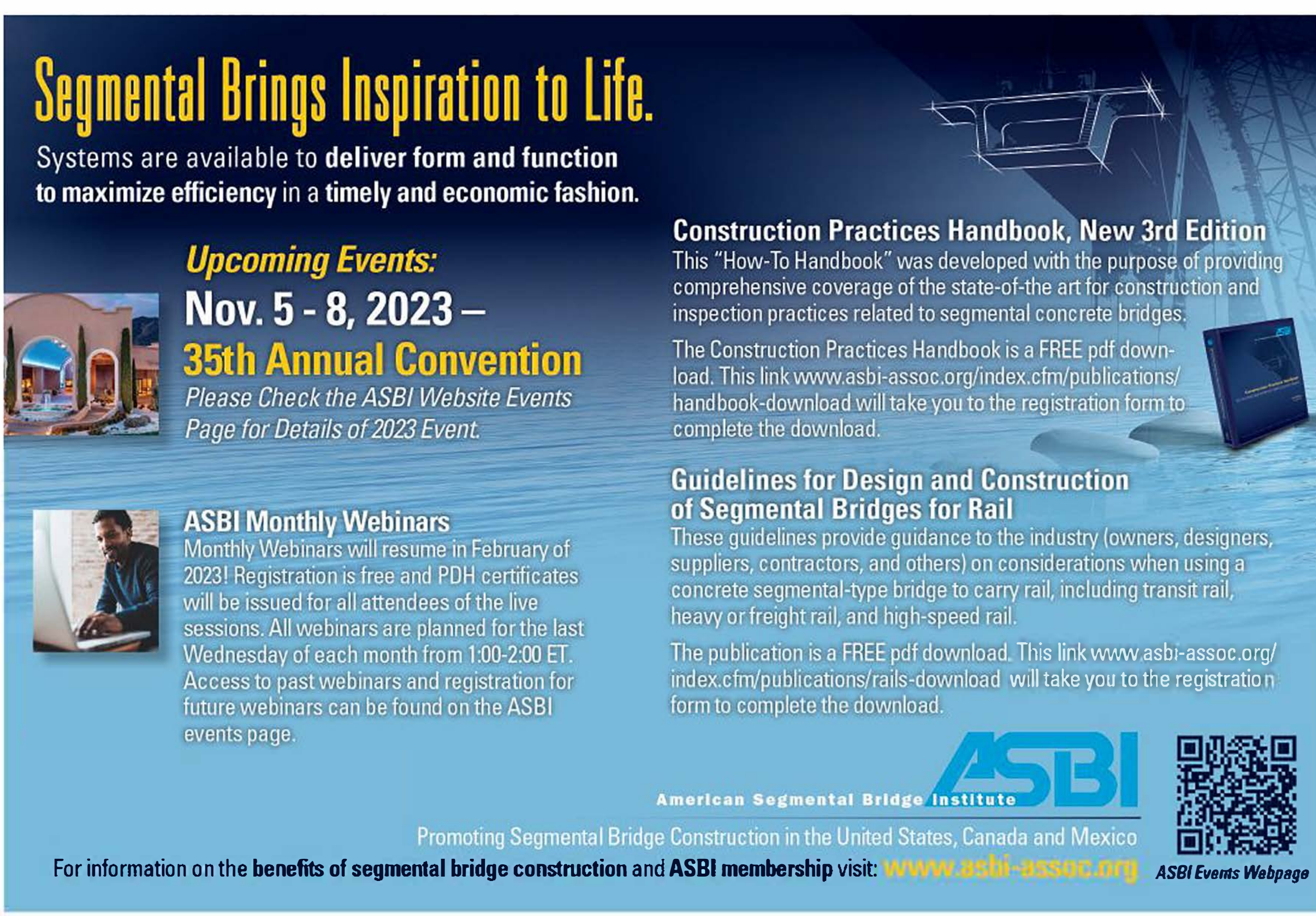
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PROJECT

Waikoko Stream Bridge Replacement

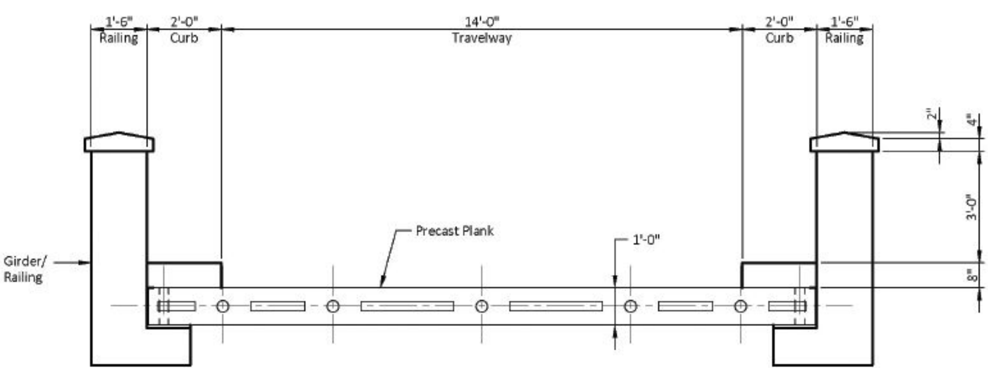
by David K. Fujiwara, Gary T. Iwamoto, and Eric Y. Matsumoto, KSF Inc.

Waikoko Stream Bridge is located on the north shore of Kauai, Hawaii. This structure is a vital component of Kuhio Highway as it provides the only access to the communities of Wainiha and Haena.

The original bridge, which was completed in 1912, had withstood earthquakes, tsunamis, and countless storm events over the years. In April 2018, thunderstorms produced a record rainfall of 49.69 in. in a 24-hour period in the Hanalei and Haena areas of Kauai. This downpour caused extreme flooding and numerous landslides. An unprecedented amount of restoration and repair work on homes, buildings, and roadways was needed. The storm also damaged Waikoko Stream Bridge, which limited vehicular traffic. To transport the necessary equipment and materials for the recovery effort at the sites beyond Waikoko, the original structure had to be replaced.

Planning

The Hawaii Department of Transportation (HDOT) tasked their bridge design consultant with the design, construction engineering, coordination, and communication efforts for the replacement of Waikoko Stream Bridge. Details for the new structure considered function, aesthetics, stream hydraulics, costs, environmental impacts, allowable roadway closures, community concerns, delivery of materials and precast concrete components, construction equipment, and site constraints. Residents of north Kauai, who are passionate about preserving the feel of this remote area, were consulted and became active participants in the bridge replacement decisions. The stakeholders, residents, and designers agreed to build a new one-lane, 72-ft-long, 21-ft-wide structure consisting of two precast concrete girders with transverse precast concrete slabs. The new bridge was designed to be similar in appearance to the original historic through-girder bridge. Notably, only one full weekend closure—a total of 57 hours—of the roadway was permitted for the bridge replacement project. This full closure allowed the structure to be constructed without a costly temporary bypass road. It also eliminated the negative impacts that a bypass road would have had on the environmentally sensitive areas adjacent to the bridge.



The typical bridge section for the one-lane, 21-ft-wide bridge consists of a 14-ft-wide travel lane, 2-ft-wide curbs, and the precast concrete L-girders that also serve as the bridge railing. Figure: KSF Inc.

The design was completed in approximately four months, and permits and required approvals were obtained under the governor's emergency proclamation. The project team then secured an off-site location to serve

profile

WAIKOKO STREAM BRIDGE / KAUAI, HAWAII

BRIDGE DESIGN ENGINEER: KSF Inc., Honolulu, Hawaii

OTHER CONSULTANT: WSP, Honolulu, Hawaii

PRIME CONTRACTOR: Hawaiian Dredging Construction Company Inc., Honolulu, Hawaii

CONCRETE SUPPLIER: O Thronas Inc., Lawai, Hawaii

PRECASTER: Hawaiian Dredging Construction Company Inc., Honolulu, Hawaii

The L-girders were transported to the site in three segments and connected with cast-in-place closure pours on site. Photo: Hawaiian Dredging Construction Company Inc.

The reinforcement at the two closure pours of the L-girder segments was detailed to facilitate placement of concrete and splicing reinforcement. Note the shear keys. Photo: KSF Inc.

as the precast concrete yard as well as parcels near the bridge site for staging and construction-related activities.

The team meticulously planned logistics for transporting the precast concrete components and necessary equipment, organizing construction efforts, and staging activities at the site. The locations of the demolition equipment, trucks, lighting, and cranes for girder and slab erection were coordinated to seamlessly operate in a relatively small area. Plans for the entire process were reviewed numerous times to ensure that the construction would be safely completed within the specified time constraints.

Precast Concrete Components

Precast concrete girders and slabs were used to construct the bridge within the allowed full weekend closure period. Two 72-ft-long, L-shaped concrete girders were designed to span the Waikoko Stream. The L-girders were cast in a controlled environment approximately 30 miles from the construction site. Load restrictions on bridges leading to the Waikoko Stream site influenced the decision to cast the girders in three segments (19 ft 4 in., 22 ft 8 in., and 19 ft 4 in. long) with a maximum weight of 17.8 tons each. The L-girder segments were transported to the site and then spliced near the end of the existing bridge.

There was limited space at the bridge site to store and splice the girder segments and to maneuver the completed girders. Therefore, the reinforcement at the closure joints was detailed to facilitate on-site placement of concrete and splicing reinforcement. The location for assembling the girders was chosen to accommodate the positions of the cranes, trucks, lighting, and other equipment needed to erect the precast concrete components.

Designing the L-girders for the construction phase was critical to safely deliver the project within the specified time constraints. When the path of the girder was mapped from storage to final placement, crane capacity, lateral torsional buckling, girder bracing, connections to the precast concrete slabs, and connections to the concrete curbs were all carefully checked, as concerns about any of these items could have jeopardized the project.

In addition to design for the construction phase, the L-girders were designed for railing test level 1 (TL-1) criteria per the American Association of State Highway

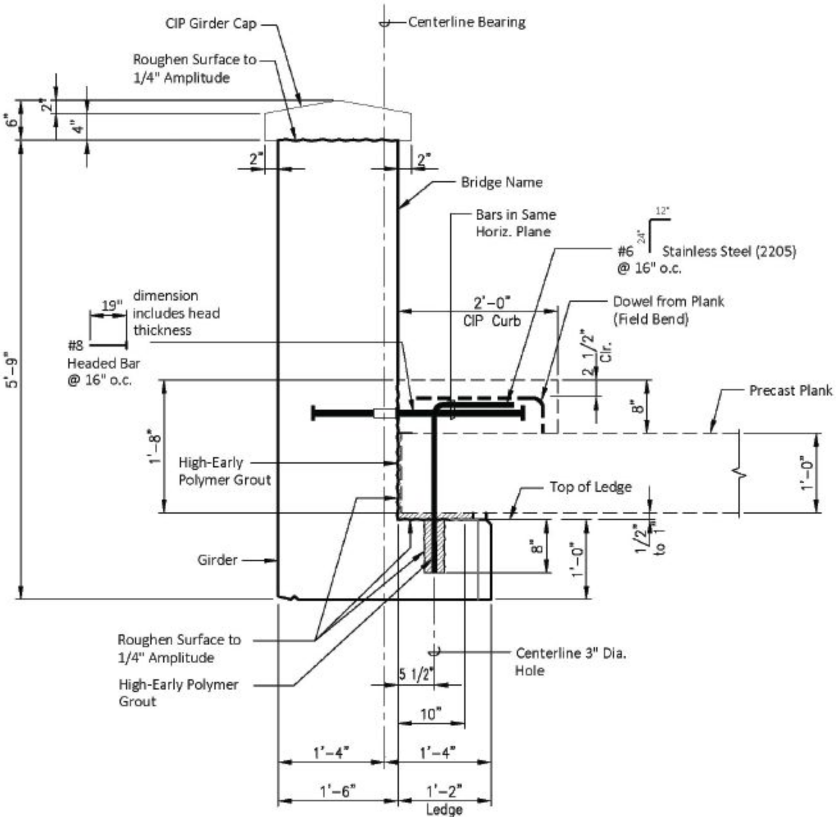
HAWAII DEPARTMENT OF TRANSPORTATION, OWNER

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

BRIDGE DESCRIPTION: 72-ft-long, 21-ft-wide, one-lane single-span through-girder bridge using precast concrete L-shaped girders and deck slabs

STRUCTURAL COMPONENTS: Two precast concrete L-shaped girders, 17 transverse precast concrete slabs with longitudinal post-tensioning, cast-in-place concrete abutments founded on micropiles

BRIDGE CONSTRUCTION COST: $4 million



Detail for the typical precast concrete girder-to-slab and girder-to-curb connections. Figure: KSF Inc.

and Transportation Officials' *Manual for Assessing Safety Hardware*[1] because they also serve as railings for the bridge in the final condition. An unmountable curb was constructed to protect the girders from potential vehicular impacts. The design of the girders and concrete caps also took into account the aesthetics desired by the community.

Precast concrete slabs measuring 17 ft 11 in. × 4 ft 0 in. × 1 ft 0 in. were designed to span between the two L-girders. The slabs were match cast in steel forms, at the same location as the girders, to ensure quality joints. Each precast concrete slab contained five 3-in.-diameter corrugated polypropylene ducts for post-tensioning. The ducts were sized to allow for the coupling of the 1⅜-in. diameter, ASTM A722[2] Grade 150 post-tensioning threaded bars. Precast concrete segmental duct couplers were used to connect the ducts in each slab. Lifting devices were placed in locations that would be covered by the concrete curb. Holes at the ends of the slabs were aligned with pockets in the ledges of the girders. For the curb connection, reinforcing bars protruding from the top of the slabs were positioned to eliminate interference with other reinforcing bars in the curb connection.

Durability

Concrete for the precast concrete components had a design 28-day compressive strength of 6000 psi. ASTM A1035[3] Type CS Grade 100 and ASTM A955[4] Type 2205 reinforcing bars were considered for the precast concrete girders and slabs. However, the lead time for delivering these materials was determined to be too lengthy because they would have to be shipped to this remote location. Therefore, the designer specified that the concrete for the precast concrete elements have a maximum water-cement ratio of 0.40 to decrease the permeability of the hardened concrete and increase the durability of the structure. In addition, the concrete included an amine carboxylate corrosion-inhibiting water-based admixture and a shrinkage-reducing admixture.

Construction Before Full Closure

Micropiles were installed near the four corners of the existing bridge to support the new structure. Equipment for the micropile installation was situated such that roadway traffic would not be disrupted. Abutment caps and grade beams were constructed with cast-in-place concrete. The precast concrete components were then delivered to the site. The L-girder segments were spliced on a sliver of land along the roadway near the bridge. Precast concrete slabs were strategically stacked to facilitate placement.

Construction During Full Closure

The weekend closure began on Friday at 7:00 p.m. Demolition equipment and trucks were immediately moved to their planned locations. The existing bridge was then demolished. After the removal of the structure was complete, two small cranes were used to set the girders in their final positions. The girders were braced at their ends. The contractor then installed 1-in.-diameter tension rods through holes at the bottoms of the L-shaped girders, and timber blocking

The substructure was installed before the full closure of the roadway. Photo: KSF Inc.

Slow-set epoxy paste adhesive was applied to the joint faces of the precast concrete slabs before erection. The slow-set epoxy was used to ensure that there was adequate time to set and post-tension the slabs. Photo: KSF Inc.

Bracing is in place between the L-shaped girders while the precast concrete slab segments are set. Photo: Hawaiian Dredging Construction Company Inc.

and compression struts were placed near the tops of the girders to resist the rotation of these components due to the eccentric loading from the slabs. Extruded polystyrene foam was placed on the girder ledges to temporarily support the slabs. The thickness of the foam was varied along the girders based on calculations that accounted for girder deflection and the final grade.

A separate crew prepared the precast concrete slabs by cleaning the ducts and edges of the components, installing seals for the ducts, and applying slow-set epoxy paste adhesive to the joint faces of the slabs. After the slabs were set, the post-tensioning bars were installed, corrosion-inhibiting amine carboxylate powder was blown into the ducts, and the bars were tensioned. As the slabs were squeezed together, excess epoxy oozed out of the joints and was subsequently removed. Upon completion of the post-tensioning, the ducts were grouted. After losses in the post-tensioning, there should be approximately 320 psi of compressive stress in the slabs. Post-tensioning was used to provide a better product with fewer long-term maintenance requirements.

For the permanent connection between the slabs and L-girders, ASTM A955[4] Type 2205 stainless steel dowels were inserted into the holes in the slabs and pockets in the girder ledges. High-early-strength polymer grout, which can achieve 2500 psi compressive strength in three hours, was placed between the slabs and girders. The temporary tension ties and compression struts were subsequently removed. In the completed structure, the dowels and grout between the sides of the slabs and the L-girders resist any loads that would cause girder rotation

Reinforcement in the curbs was placed, and the concrete curbs were cast. The no. 8 reinforcing bars that connect the L-girders to the curb are designed to transfer vehicular (TL-1) loads from the girders to the curb, and from there to the entire bridge system. Finally, the approaches were prepared for vehicular use, and after the proper curing of the curb, the bridge was opened to traffic at 4:00 a.m. on Monday at the conclusion of the 57-hour full closure.

Conclusion

The brief roadway closure window, transportation limitations, and construction area constraints were extremely challenging. However, open communication, earnest collaboration, and meticulous planning resulted in the successful completion of this project in June 2019. HDOT and the community were pleased that Waikoko Stream Bridge was replaced within the time frame permitted. Much-needed equipment and materials for the recovery efforts could then be transported to the other storm-ravaged sites.

After the slabs were set, the longitudinal post-tensioning bars were installed and tensioned. Photo: Hawaiian Dredging Construction Company Inc.

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David K. Fujiwara is the president, Gary T. Iwamoto is the director of construction services, and Eric Y. Matsumoto is a bridge designer for KSF Inc. in Honolulu, Hawaii.

PROJECT

Design and Construction of the Third Street Peace Bridge in Dayton, Ohio

by Paul Gruner and Joseph Dura, Montgomery County, Ohio, Engineer's Office

The formliner used to create the image of the 1963 Unity March (top) and the image shortly after form removal (bottom). All Photos: Montgomery County Engineer's Office.

In Dayton, Ohio, the new bridge carrying West Third Street (Dr. Martin Luther King Jr. Way) over the Great Miami River links the historic Wright-Dunbar/West Third Street community with the downtown. This bridge, which is officially known as the Peace Bridge, replaces an 80-year-old structure that was supported by 120-year-old abutments. The existing structure had reached the end of its service life, its piers were founded on spread footings making them susceptible to scour, and portions of the structure were severely deteriorated. The new prestressed concrete I-beam bridge accommodates motor vehicles, pedestrians, cyclists, public transit, and river recreational traffic with five 143-ft-long spans and a width of 86 ft. It also incorporates aesthetic treatments reflecting the community's desire for a bridge promoting peace and unity.

The Peace Bridge spans the Great Miami River, which has always been a natural divide through downtown Dayton, splitting the city into an east side and west side. The construction of Interstate 75 in the 1960s, created an additional physical barrier that further emphasized and magnified the separation between the city's two sides. The Montgomery County Engineer's Office (MCEO) specifically sought to incorporate features that would reflect the bridge's title and promote community unity.

Construction began in October 2019, and the bridge was opened to traffic in December 2021.

Concrete Solutions

A structure-type study was performed to compare steel and concrete superstructure options, determine the optimal span arrangements and number of beams per span, and estimate initial and life-cycle costs. Concrete construction was chosen as the most economical solution and because it could include the unique aesthetic treatments desired for the project. Nine 72-in.-deep, wide-flange I-beam prestressed concrete girders (WF72-49) with an 8.5-in.-thick composite cast-in-place concrete deck compose the typical bridge section for each span. The bridge accommodates a 57-ft-wide roadway section, 10-ft-wide sidewalk, and 17-ft-wide multiuse path. The cast-in-place concrete railings were chosen to reflect some of the aesthetic details from the original 1904 concrete arch structure that had been replaced in 1949.

Cast-in-place concrete wall-type abutments and piers provide durable, low-maintenance support to the superstructure. The wall-type

profile

THIRD STREET PEACE BRIDGE / DAYTON, OHIO

BRIDGE DESIGN ENGINEER: Stantec, Cincinnati, Ohio

OTHER CONSULTANTS: Aesthetic design consultant: Creative Design Resolutions, Brentwood, Md.; traffic engineering and surveying: LJB Inc., Miamisburg, Ohio

PRIME CONTRACTOR: Eagle Bridge Company, Sidney, Ohio

SUBCONTRACTORS: Roadway concrete items: Tri-State Concrete Construction Inc., Cincinnati, Ohio; reinforcing bar installation: Black Swamp Steel Inc., Holland, Ohio

CONCRETE SUPPLIER: Ernst Concrete, Dayton, Ohio

PRECASTER: Prestress Services Industries LLC, Mt. Vernon, Ohio—a PCI-certified producer

The first I-beam erected was a fascia beam that had been coated with a pigmented sealer at the precaster's facility. Only the exterior faces and bottoms of the fascia girders were sealed with a pigmented sealer. The colors were chosen through the public involvement process and harmonize with other structures in the area.

configuration also provides a blank canvas for the artwork that was incorporated into the bridge.

Historically, earth-filled concrete arch bridges were often used throughout downtown Dayton at major river crossings. As these bridges have been replaced, arch components have been incorporated into the new bridges to maintain that appearance. On the Peace Bridge, the concrete arch panels that were added at the piers are strictly architectural and nonstructural.

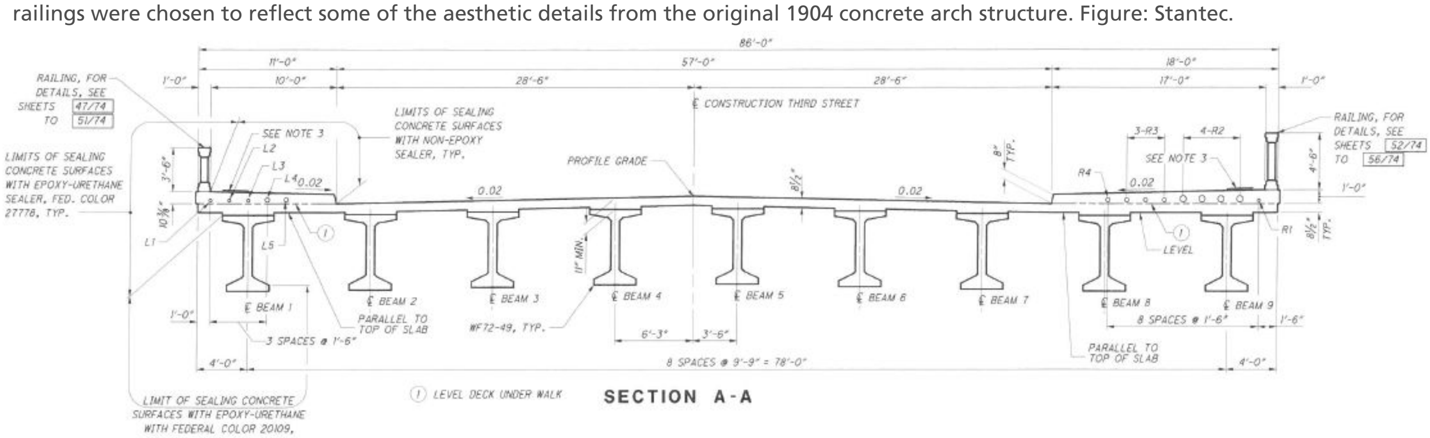
In accordance with Ohio Department of Transportation (ODOT) standards, epoxy-coated reinforcing steel was used in the cast-in-place concrete elements to enhance durability. Glass-fiber-reinforced polymer reinforcement was used in the concrete railings to control cracking and reduce corrosion potential.

Community Collaboration

The Third Street Bridge project represents extraordinary efforts of community and agency collaboration. MCEO recognized early on the importance of engaging the historic Wright-Dunbar community, a neighborhood with traditionally underserved populations. MCEO brought local and nationally recognized artist Willis "Bing" Davis and an aesthetic transportation designer onto the project to assist with aesthetic enhancements and engage the community.

MCEO held three public involvement meetings to inform the public and seek input on many project considerations, including aesthetic treatments and maintenance of traffic. Davis, as a local leader, encouraged neighborhood participation. The public was encouraged to offer ideas that would

The bridge accommodates a 57-ft-wide roadway section, 10-ft-wide sidewalk and 17-ft-wide multiuse path. The cast-in-place concrete railings were chosen to reflect some of the aesthetic details from the original 1904 concrete arch structure. Figure: Stantec.



MONTGOMERY COUNTY, OWNER

OTHER MATERIAL SUPPLIERS: Formliners: Architectural Polymers, Palmerton, Pa.; reinforcement: Baseline Supply LLC, Monroe Township, N.J.

BRIDGE DESCRIPTION: Five-span, 720-ft 6-in.-long, 86-ft wide bridge with precast, prestressed concrete girders with cast-in-place concrete substructures, deck, sidewalks, overlooks, and railings

STRUCTURAL COMPONENTS: Nine girder lines of prestressed concrete I-beams (ODOT WF72-49), 142 ft 6 in. or 143 ft 7 in. long and 72 in. deep; 8.5-in.-thick cast-in-place reinforced concrete deck; wall-type reinforced concrete abutments and piers on 16-in.-diameter cast-in-place reinforced concrete piles

BRIDGE CONSTRUCTION COST: $17.3 million total cost ($283/ft^2)

AWARD: 2021 Outstanding Short Span Roadway Bridge Award, Association of Bridge Construction and Design

Before traditional West African Adinkra symbols were sandblasted and stained into the sidewalk and multiuse path, the contractor created mock-ups (left) for the county to evaluate. The sandblasted symbols, which signify wisdom, humility, strength, advancement, unity, and other qualities, were stained (right) to make them prominent.

"tell *your* story," so those ideas could be used to develop aesthetic treatments for the structure.

MCEO specifically sought to incorporate features into the bridge that would reflect the "Peace Bridge" concept. Paul Gruner, the Montgomery County engineer, stated that "our Peace Bridge should speak to African American struggles, our city's rich history, and the legacy of this important structure." These objectives were achieved through images and tablature developed in conjunction with the Wright-Dunbar community. Concrete formliners were used to include images of the 1963 Unity March, poet Paul Laurence Dunbar, Orville and Wilbur Wright, and the Wright B Flyer, as well as quotations from Dunbar and Dr. Martin Luther King Jr. Information tablatures detailing notable Daytonians and various facets of Dayton's history are provided along the bridge.

Traditional West African Adinkra symbols have been sandblasted and stained into the sidewalk and multiuse path. Plaques define the symbols, which encompass many traits, including wisdom, humility, strength, advancement, and unity.

Creative Concrete Construction

Other concrete construction techniques that were critical in the aesthetic design included the use of computer-generated formliners for the bas-relief enhancements. Developing the details and specifications to ensure the quality of these images was challenging. Mock-ups of the reliefs allowed the county and design team to ensure that the final product met the project objectives. This method was critical because the liners were limited by 1-in. positive and 1-in. negative casting (primarily due to reinforcing steel cover). Creativity by the contractor resulted in form-tie locations that do not detract from the aesthetic images and text.

Determining the concrete mixture proportions that would be the best for the aesthetic treatments was also a challenge. The project specified self-consolidating concrete (SCC) for the piers and abutments with images and text. However, because of the calculated hydraulic pressure on the forms using SCC, the contractor submitted a request to use plasticized, 4-ksi design-strength concrete, a material that is typically used for drilled shafts, for these substructure units. The request was approved after the quality of the images and text was proven with the required mock-ups. The four large, wall-type piers were also considered a mass concrete placement per ODOT construction specifications and required a thermal control plan.

The intricate curvilinear shapes of the piers and overlook supports were made possible by using computer-generated expanded polystyrene foam forms. Also of note was the placement of the deck, two-thirds of which was done in one continuous concrete placement of 1400 yd^3 between 1:00 a.m. and 2:00 p.m. to avoid the summer afternoon heat.

Multiple Agencies Involved

The Peace Bridge is a county-owned bridge within City of Dayton corporate limits, and the county worked closely with the city government to accommodate its Livable Streets Policy, which was implemented in 2010 to promote the design of surface transportation corridors that balance the needs of users with consideration

Aerial photo of the completed Third Street Peace Bridge. The design of the new bridge not only accommodates motor vehicles but is also inviting to pedestrians, cyclists, and river recreational traffic. Its aesthetic treatments celebrate local history.

Epoxy-coated reinforcement was placed in the formwork for an overlook support pedestal at a pier. The intricate curvilinear shapes of the piers and overlook supports were made possible by using computer-generated expanded polystyrene foam forms.

The Third Street Peace Bridge design incorporates aesthetic treatments that communicate unity and peace, provide a link to Dayton's history, and help encourage the use of the bridge by pedestrians and cyclists, to the benefit of public health and regional air quality.

to community values, environmental stewardship, safety, aesthetics, and other aspects.

ODOT approved the use of additional federal funding for the project, which allowed the bridge to be widened for the inclusion of a multiuse trail. The additional federal funds were secured through Congestion Mitigation/Air Quality funding and were administered through the local metropolitan planning organization, the Miami Valley Regional Planning Commission.

Bike Miami Valley, a local bicycle advocacy group, participated throughout the public engagement process. The Greater Dayton Regional Transit Authority requested features to accommodate the bus and trolley lines that also use the Peace Bridge.

Recreation

As noted previously, the Peace Bridge extends over the Great Miami River, which is a recognized water trail. It also extends over the Great Miami Recreation Trail, which runs parallel to and along both sides of the river, and abuts two small parks. The project accommodated a new recreation trail connector to Third Street and inspired the City of Dayton to further improve bicycle connectivity to the new bridge. Multimodal design solutions were critical to the success of the project. The Peace Bridge serves as a primary connection to downtown Dayton and provides access to the Great Miami Recreation Trail and other local bike/pedestrian facilities.

A small plaza was created next to the western abutment, where pedestrians can access the Great Miami Recreational Trail. The abutment wingwall features a bas-relief enhancement celebrating the poet Paul Laurence Dunbar, a Dayton native.

To accommodate and encourage pedestrians and cyclists and improve air quality, the new bridge's cross section provides a 10-ft-wide sidewalk on the north side, consistent with City of Dayton's Livable Streets Policy, and a 17-ft-wide, design-standard multiuse trail on the south side. MCEO also worked with the Miami Conservancy District, Five Rivers MetroParks, and the City of Dayton to accommodate the many pedestrian and trail connections to Third Street within the project limits. During construction, MCEO maintained access to existing bike and sidewalk facilities, when safe to do so, and provided signed detours with advance notice when bike/pedestrian detours were required.

The project design incorporates aesthetic treatments that communicate unity and peace. Combined with the lookouts and connections to bike/pedestrian facilities, these features encourage the use of the bridge by pedestrians and cyclists, to the benefit of public health and regional air quality.

Paul Gruner is the county engineer and Joseph Dura is a project manager with the Montgomery County Engineer's Office in Dayton, Ohio.

Virginia's Strategic Approach to Bridge Management

by Adam Matteo, Virginia Department of Transportation

Virginia, like most states, is managing an aging network of bridges and roadways that must continue to provide acceptable levels of service to motorists for decades to come. The average age of a bridge in Virginia is 53 years, yet the anticipated service life of 90% of Virginia's bridges (those bridges built before 2007) is 50 years. The remaining 10% of bridges are newer bridges that are expected to have a service life of 75 years or more.

To meet the challenge of our aging infrastructure, the Virginia Department of Transportation (VDOT) is using a strategic approach that incorporates dedicated funding, asset management, new materials, and timely interventions. The aim is to maximize the life-cycle value of every dollar spent to achieve our goal of providing a sustainable inventory at an acceptable level of service for the next 50 years.

Meeting the Challenge

In 2010, when the average age of a bridge in Virginia was approximately 42 years, stakeholders acknowledged that our bridge inventory required significant improvement. There were over 1700 structurally deficient (poor) bridges, and the system was in need of recovery. This assessment led to a renewed focus on funding, asset management, technology, and materials that have put the state on a path to long-term sustainability.

That year, VDOT moved its 36 bridge crews from the Maintenance Division to the Structure and Bridge Division. These crews are highly capable, performing a wide range of activities from preventive maintenance to complete bridge replacement. Workers are replacing between 70 and 90 bridges per year, and removing these bridges from the list of poor structures has constituted one of the most significant elements of our recent improvements.

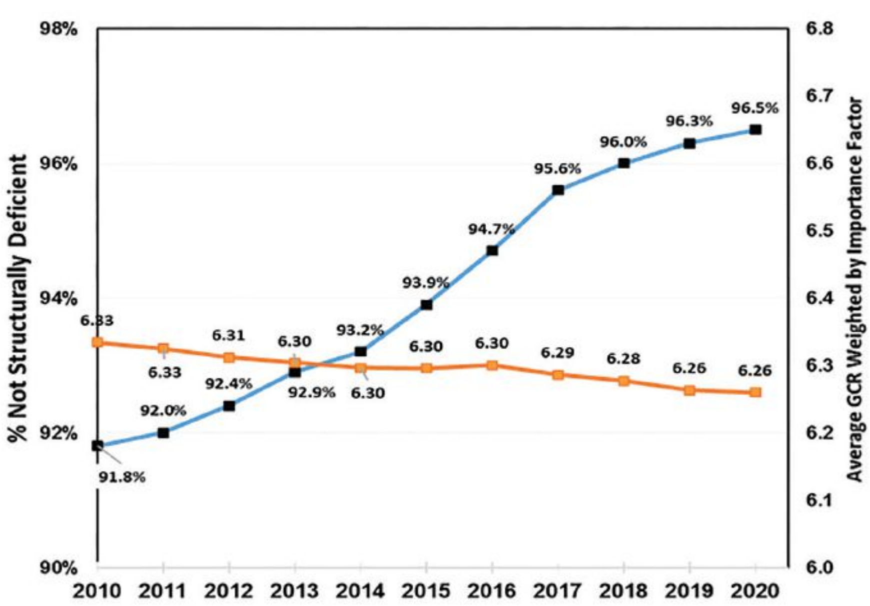


Figure 1. Percentage of bridges not structurally deficient (blue line) and average general condition rating (GCR; orange line) weighted by importance factor since 2010. All Photos and Figures: Virginia Department of Transportation.

To support this work, funding streams were established to specifically address the large number of poor bridges, with particular emphasis on the many smaller, rural bridges that were structurally deficient. Virginia's State of Good Repair[1] program, enacted in 2015, legislatively mandates that a fixed portion of highway construction funding be provided for deficient pavements and structurally deficient bridges, along with a Special Structures Fund to provide dedicated funding streams to improve the condition of bridges in the VDOT inventory.[2]

Results Since 2010

The steps taken since the program began in 2010 have led to a remarkable reduction in the number of structurally deficient bridges. **Figure 1** shows that since 2010, the percentage of bridges that are not structurally deficient has steadily improved from less than 92% to more than 96%. However, the graph also shows that this improvement has been accompanied by a slow, steady decline in the average general condition rating (GCR). The GCR is a numerical rating from 0 (failure) to 9 (excellence) that is given at every biennial bridge inspection for each of the major components of a bridge. So, while the number of poor bridges has been decreasing to a manageable level, the average condition of the overall bridge inventory has still deteriorated.

Asset Management

Virginia has employed asset management tools and deterioration modeling for over 20 years. Realizing that the inventory was reaching a potential inflection point, VDOT performed a comprehensive review in 2019.[3] This was a statewide, long-term review of its investment strategy, with particular focus on bridges and pavements. The effort sought to determine whether VDOT was investing its funds and measuring its performance in the most appropriate manner. It also sought to establish meaningful performance measures and performance targets based on acceptable levels of service.

The study found that Virginia's total funding could provide an acceptable level of service for the next 50 years if the investment strategy were changed. Currently, Virginia spends about 75% of its available bridge funding on structurally deficient bridges and 25% on preservation. However, the cost of preservation, which we defined to include rehabilitation and repair along with treatments to slow deterioration, is usually about five to six times more cost effective than replacement. The study found that allocations needed to be reversed: 75% should be used for preservation and 25% should be applied to structurally deficient bridges. If the "worst first" approach were continued, long-term projections indicated that overall bridge condition would suffer—that is, the percentage not structurally deficient would be 91% in 2070 for the "worst first" approach instead of 95% if the allocations were reversed using the "preservation" approach.

Analysis of GCR rating data led to similar conclusions. The "preservation" approach would keep the average weighted rating above the acceptable level of service of 5.6 for the entire period, whereas the average weighted rating for the "worst first" approach would fall below the acceptable level of service of 5.6 after about 10 years.

These conclusions are illustrated in **Fig. 2**, which projects bridge conditions for the next 50 years under each approach. As shown in the figure, funding was assumed to remain equal and level for both investment strategies for the period after 2020. Data presented in the figure also indicate that the average weighted GCR for the system cannot be improved without additional funding because the trend in the data is flat or still descending at the end of the study period.

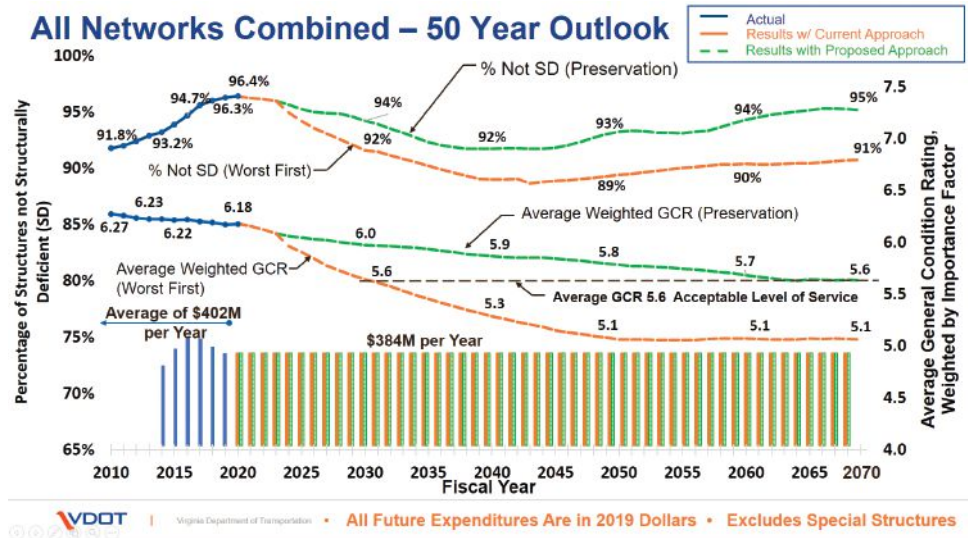


Figure 2. Fifty-year outlook for Virginia's bridges comparing two investment strategies: "worst first" (orange) and "preservation" (green). The current, "worst first" strategy allocates 75% of funds to structurally deficient bridges and 25% to bridge preservation. The proposed "preservation" strategy would reverse the allocations, dedicating 25% to structurally deficient bridges and 75% to preservation. Data are presented for the percentage not structurally deficient (upper set of lines) and average weighted general condition rating (GCR) (lower set of lines).

The investigation also determined that bridge conditions should be measured primarily through average GCR, as opposed to the percentage of structurally deficient bridges. An average GCR of 5.6 (weighted by an importance factor for each bridge) was established as an acceptable level of service. However, bridges must be preserved to significantly slow future rates of deterioration.

Preservation Methods and Durable Materials

Given that the primary cause of bridge deterioration in Virginia is corrosion, the following requirements and expectations have been widely adopted for new construction and preservation work:

- **High-performance, low-permeability concrete** is required in all bridge applications.
- **Corrosion-resistant reinforcement** is required for new and existing structures.
- **Corrosion-resistant** (stainless steel or carbon fiber) **prestressing strands** are required in critical locations.
- **Self-consolidating concrete** is required for substructure surface repair.
- **Jointless construction** is required for new bridges.
- **Installations of metal culverts are limited** because they have generally provided a significantly shorter service life than concrete.

Additionally, the following strategies are mainstays of the preservation program:

- **Concrete overlays** are placed over **hydromilled surfaces**. The use of latex-modified and silica fume concrete, in conjunction with hydromilling, is expected to extend the service life of a bridge by three to four decades.
- **Joint elimination** using link slabs and deck extensions is required for rehabilitation work.[4]
- **Beam end repair and replacement** for steel bridges is preferred, wherever practical, over superstructure replacement.
- **Concrete culvert liners** are used to restore deteriorated metal culverts.
- **Localized hydromilling** is used for substructure surface repair. This is a new strategy for substructure preservation that is more efficient than manual chipping. Hydromilling has been shown to provide an effective and rapid means for removing deteriorated concrete before replacement with patching materials.

Treatment Examples

This section presents examples of the main types of interventions that Virginia uses in its bridge preservation program. Historical data and parametric life-cycle studies have demonstrated that these treatments provide decades of additional service life at a fraction of the cost of replacement.

- **Rigid overlays (Fig. 3)**. When applied over a hydromilled surface, this intervention provides 35 to 40 years of additional service life to the bridge. (see the Concrete Bridge Preservation article on hydrodemolition in the Summer 2018 issue of *ASPIRE*®).

Figure 3. The use of latex-modified and silica fume concrete for overlays, in conjunction with hydromilling, extends the service life of a bridge by three to four decades. It is a mainstay of Virginia's bridge preservation program.

- **Joint elimination on existing bridges (Fig. 4)**. The elimination of joints with link slabs and deck extensions[4] eliminates leaking deck joints, which are the primary source of superstructure and substructure deterioration (see also the Creative Concrete Construction article on Scan 19-01 in the Fall 2022 issue of *ASPIRE*).

Figure 4. Before, during, and after photos of eliminating a joint on an existing bridge. This intervention is commonly used in the bridge preservation program in Virginia. Jointless construction is required for new bridges in Virginia.

- **Beam end repair**. This intervention can provide decades of additional service life for steel superstructures without the need for component replacement, particularly when it is performed in conjunction with joint elimination.
- **Substructure surface repair (Fig. 5)**. Substructures can be brought to a sustainable condition using self-consolidating concrete for repairs. VDOT is now beginning to employ localized hydromilling to prepare these patches.

Figure 5. Examples of substructure deterioration (top) and a substructure repaired by localized hydromilling and repair with self-consolidating concrete followed by the application of a coating (bottom).

Figure 6. A spray-on liner using fiber-reinforced concrete is installed to extend the service life of a steel culvert structure.

- **Relining steel culverts with fiber-reinforced concrete (Fig. 6)**. Steel culverts have a limited service life. However, spray-on fiber-reinforced concrete liners are extending the service life of these structures without the need for replacement.

Conclusion

By using a systematic, data-driven approach to bridge management, along with a sustainable level of funding and timely applications of preventive treatments using appropriate materials, procedures, and details, Virginia is putting its bridge inventory on a path to long-term sustainability.

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Adam Matteo is the assistant state structure and bridge engineer for bridge maintenance and bridge management for the Virginia Department of Transportation in Richmond.

Lessons Learned from Handling Long-Span Precast, Prestressed Concrete Bridge Girders

by Anthony Mizumori and Richard Brice, Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) recently completed two Interstate 5 (I-5) bridge projects near Tacoma, Wash.—the Wapato Way Bridge and the Puyallup River Bridge—with precast, prestressed lightweight concrete bridge girders having record-setting lengths of over 220 ft. Both bridge projects used the wide flange WF100G girder shape, which has a depth of 100 in. excluding camber and extended reinforcing bars.[1] This girder shape has been used with normalweight concrete to span beyond 200 ft. However, at this depth, the ability to transport WF100G girders by truck is a major design consideration due to vertical clearance restrictions, hauling weight limitations, and concerns about girder stability.

The use of lightweight aggregate concrete was an important tool to increase span capability while allowing the girders to be hauled by truck. Although the use of lightweight concrete reduced the reinforced deadweight of the girders by 15%, it is important to also note that the design elastic modulus was reduced by 35% as compared with that of normalweight concrete. Thus, the appropriate handling of slender precast concrete girders is a critical part of building longer-span precast concrete girder bridges. Whenever normal practice is pushed to new limits, there are challenges to overcome and opportunities to improve the standard of practice. The aim of this article is to share lessons learned from the erection of these extremely long and flexible girders.

Torsional Flexibility

To design girders that can be successfully lifted and transported, it is essential to follow the recommendations published in the Precast/Prestressed Concrete Institute's (PCI's) *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*.[2] One of the fundamental assumptions of the stability analysis theory detailed in that publication is that girders are very stiff in torsion and the effects of twist are small and can be neglected. Although neglecting torsion is not conservative, it greatly simplifies the stability analysis.

After the 222-ft 3-in.-long girders for the Wapato Way Bridge over I-5 in Fife, Wash.,[3] were erected in the summer of 2020, field measurements indicated that the webs were out of plumb. Additionally, the slope of the web was greater at midspan than at the ends of the beam, which suggested that there was torsional deformation in addition to lateral deflection. The greatest measured difference in web slope was 3% or about 1.7 degrees of twist. Measurements for sweep, which was within tolerance for all girders, had been taken at the fabricator's plant prior to shipment. Plumbness was measured in the field after erection.

One of the likely contributing factors of the torsional deformation is the lower shear and elastic moduli of lightweight concrete. The angle of twist is proportional to girder length; therefore, twisting effects are magnified on longer girders compared with shorter spans. Given the torsional deformation observed in the field and the uncertainty about the true factors of safety with respect to cracking and ultimate strength of long girders subjected to torsional deformations, WSDOT initiated a research project to investigate the effect of torsion on the stability of long-span, lightweight concrete bridge girders. It is hoped that this research will yield simple modifications that can be applied to PCI's recommended stability analysis to account for torsional deformations.

Bracing During Erection

For prestressed concrete girders, lifting points are typically kept close to the girder ends to minimize the required concrete strength, even though roll stability during lifting is improved when lifting points are located away from girder ends. However, for long, slender girders, stability governs many aspects of the design, and lifting points can be 20 to 30 ft away from the girder ends. With these long overhangs, the deflected shape while hanging can be significantly different from the girder shape when seated.

The Puyallup River Bridge over I-5 in Tacoma, Wash., used 223-ft-long lightweight concrete WF100G girders with a top flange modified from the standard width of 49 in. to 61 in. to improve stability and lower stresses during handling, hauling, and erection (see the Creative Concrete Construction article in the Fall 2019 issue of *ASPIRE*® for more information). The curves in **Fig. 1** show the combined prestress and self-weight deflection calculated between the girder ends and the midpoint for hanging and seated Puyallup River Bridge girders. While hanging, the girder is supported 26 ft from its ends. Once erected, the girder is supported on an elastomeric bearing pad at one end and an oak block at the other end. The bearing

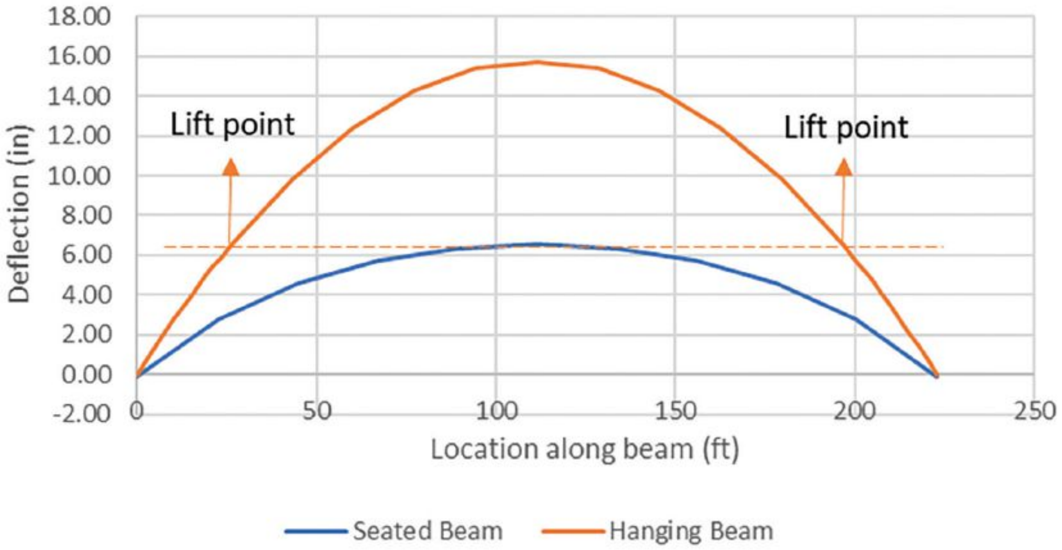

Figure 1. Comparison of seated and hanging beam total deflection calculated relative to the ends of the beam using the properties of girders from the Puyallup River Bridge in Tacoma, Wash. All Photos and Figures: Washington State Department of Transportation.

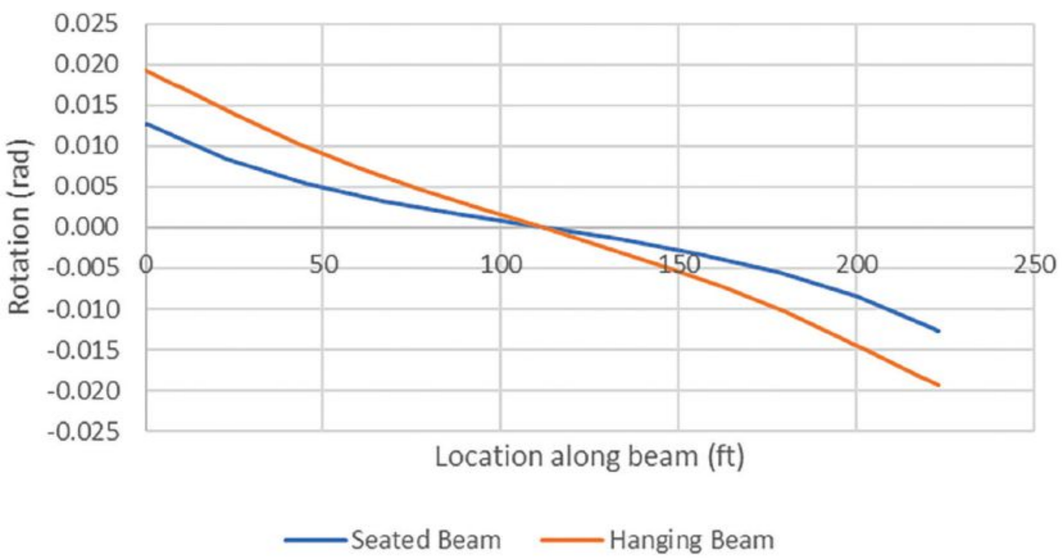

Figure 2. Comparison of end rotations of seated and hanging beams for the Puyallup River Bridge girders.

supports are 8 in. from the ends of the girder. **Figure 2** plots the slope of the elastic curve (rotation) along the length of the deformed beam while hanging and seated; the data for the curves were computed using standard beam formulas. These comparisons illustrate how significantly the deflected shape of the girder changes during erection.

For safety and stability, WSDOT requires that girders be braced at least at midspan and each end during and after erection. Typically, when the second and subsequent girders are erected in a span, cross bracing is installed between the hanging girder and the previously erected girder. As the hanging girder is lowered into contact with its bearings, there can be a large differential camber between the adjacent girders (**Fig. 3**). If in-span bracing is installed before significant load is transferred from the lifting lines to the bearings, force is induced in the diagonal bracing with a horizontal reaction component that tends to roll the girders as the hanging girder deflects downward into its fully seated position.

While this effect can exist for any concrete girder, the magnitude becomes significant for longer girders. To avoid locked-in bracing forces and undesired girder deformation, the erector should develop a precise sequence of load transfer and bracing installation for inclusion with the erection plan. Adjustable-length bracing components, while certainly not required, could also be used to reduce any locked-in bracing forces.

Bearing Design Considerations

Transferring the weight of the girder to the bearings presents its own unique challenges. As girder weight transfers from the lifting lines to the bearings, the camber decreases, causing a change in rotation at the girder ends (**Fig. 4**). The rotation manifests as a longitudinal force at the girder-bearing interface. Firm bearings,

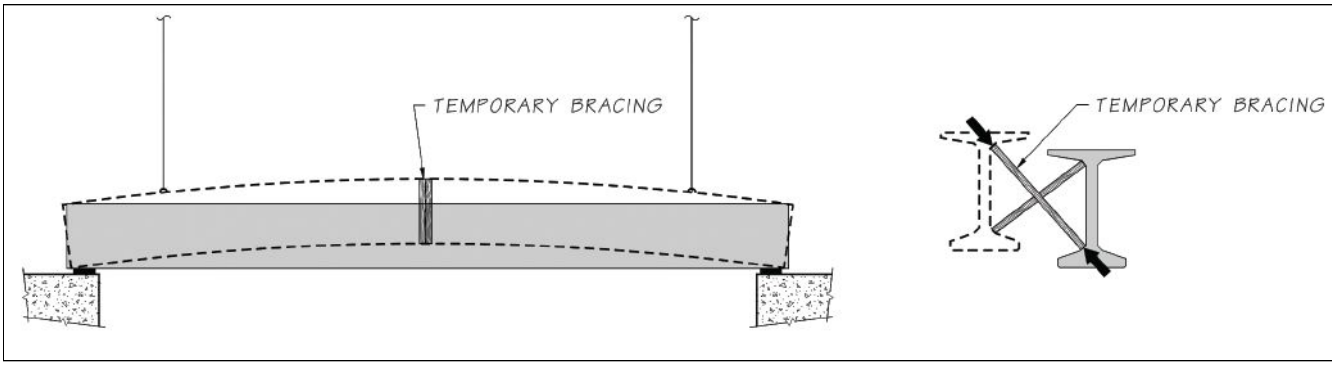

Figure 3. Elevation view of girders showing differential camber at erection and section of adjacent girders showing bracing geometry and forces.

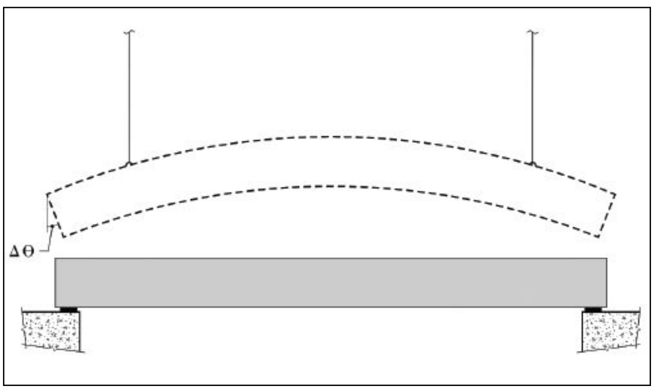

Figure 4. End rotations of a girder in the hanging and seated support conditions.

such as wood blocks, induce a shear force through friction and deform very little in any direction. Elastomeric bearings undergo a shear deformation. For spans with a firm bearing at one end and an elastomeric bearing at the other, the total change in rotation from both ends of the girder is taken up by the elastomeric bearing. **Figure 5** shows bearing scenarios and shear deformations.

The following calculations illustrate the magnitude of bearing shear deformation that can occur. **Table 1** lists the girder properties used in the calculations.

End rotations due to prestress:

$M_o = Pe = (3385)(33.6) = 113{,}736$ kip-in.

$$\theta = \frac{M_o \ell}{2EI} = \frac{(113{,}736)(223)(12)}{(2)(4009)(1{,}612{,}834)} = 0.0235 \text{ rad}$$

where
M_o = moment due to prestress
θ = end rotation

End rotations due to self-weight for the seated girder:

$$\theta = -\frac{w\ell^3}{24EI} = -\frac{(1.07)(223)^3(144)}{(24)(4009)(1{,}612{,}834)} = -0.011 \text{ rad}$$

End rotations due to self-weight for the hanging girder:

$$\ell_h \ \ell = 223 - \left[2(26)\right] = 171 \text{ ft}$$

$$\begin{aligned}\theta &= \frac{w}{24EI}\left(6a^2\ell_h - \ell_h^3 + 4a^3\right)\\ &= \frac{(1.07)}{(24)(4009)(1{,}612{,}834)}\left[(6)(26)^2(171) - (171)^3 + 4(26)^3\right](144)\\ &= -0.004 \text{ rad}\end{aligned}$$

where
ℓ_h = length between lifting points
a = length from lifting point to girder end

Change in rotation $\Delta\theta$ as the girder weight is transferred from the lifting lines to the bearing:

$$\begin{aligned}\Delta\theta &= (0.0235 - 0.004) - (0.0235 - 0.011)\\ &= 0.0195 - 0.0125 = 0.007 \text{ rad}\end{aligned}$$

Table 1. Girder properties

Girder length ℓ	223 ft
Area	1118.8 in.^{2}
Moment of inertia I	1,612,834 in.^{4}
Bottom of girder to centroid y_b	49.89 in.
Unit weight of girder, including allowance for reinforcement	0.138 kip/ft^3
Girder self-weight w	1.07 kip/ft
Modulus of elasticity E	4009 ksi
Lifting points from girder ends a	26 ft
Support points from girder ends	8 in.
Total prestressing force (permanent and temporary strands) P	3385 kip
Prestressing force eccentricity e	33.6 in.

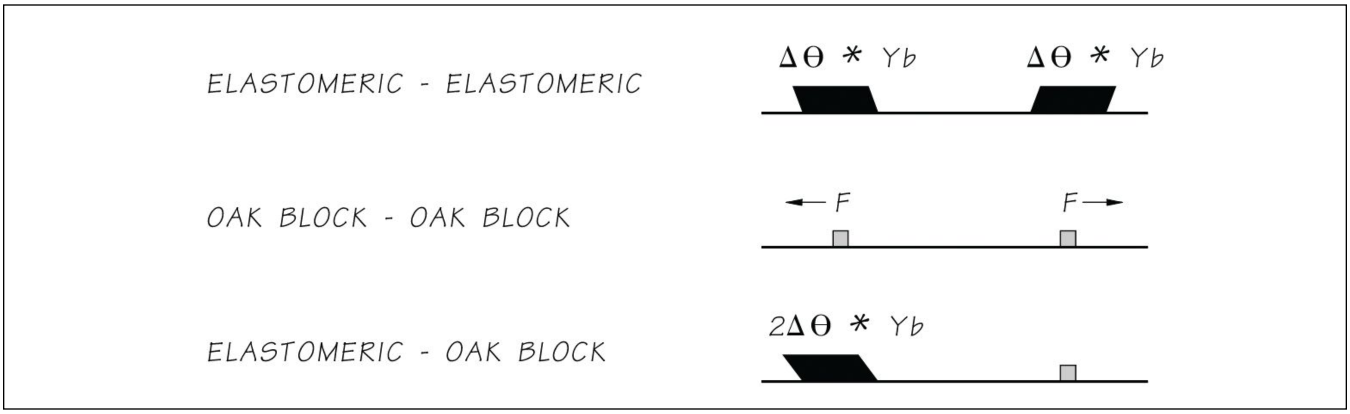

Figure 5. Shear forces and deformations for various bearing support scenarios.

Estimated shear deformation in the elastomeric bearing pad:

$$2\Delta\theta\ y_b = 2(0.007)(49.89) = 0.70 \text{ in.} \approx \frac{11}{16} \text{ in.}$$

Figure 6 shows the bearing shear deformation observed in the field. The measured deformation was approximately ⅝ in. and could not be explained by thermal effects.

Again, while this effect can exist for any concrete girder, the magnitude becomes significant for longer girders supported away from their ends during lifting. This effect could be addressed by applying horizontal load during erection, lifting girder ends after erection to reseat them, or designing end-rotation effects into the bearings themselves.

Design for Lifting

Typically, lifting girders from the casting bed is the critical lifting case because the prestress is at its highest value and the concrete is at its lowest strength and its lowest modulus of elasticity. The locations of the lifting points are determined for this critical case. As the girder ages, the prestress is reduced due to time-dependent losses and the concrete gains strength. For these reasons, the field erection case typically does not govern the stability of the girder. However, when designing long-span girders for constructability, designers should investigate all lifting and handling load cases in an assumed construction process. The challenges of bracing a girder with large differential camber caused by hanging and the accompanying bearing shear deformations can be mitigated by providing additional lifting embedments for erection that are closer to the girder ends. Lifting closer to the girder ends reduces this differential camber and changes in girder end rotation at seating. The reduced prestress and increased strength and stiffness of the concrete at the time of erection as compared to lifting from the form, allow the lifting points to be moved closer to the ends without compromising stability.

Figure 6. A ⅝ in. bearing pad shear deformation was observed after erection of a 223-ft-long WF100G girder on the Puyallup River Bridge.

Conclusion

Handling and erecting very long and flexible girders presents unique challenges. Using secondary lifting embedments for on-site erection is an effective technique to reduce differential camber and shear deformation caused by girder end rotation. The challenge of addressing the destabilizing effect of torsional deformation and its interaction with lateral stability requires additional study. For future projects, WSDOT has limited the lateral slenderness ratio of beams to 310.[4] This limit is an empirical judgment based on recent experience and can be satisfied by widening the girder top flange as needed.

Long-span precast, prestressed concrete girders can be an economical bridge superstructure type for projects that have access to precast concrete fabricators with the appropriate facilities, experienced heavy-load haulers, and a viable delivery route from plant to site. Designers, contractors, and erectors should be aware of the challenges of handling, hauling, erecting, and bracing long-span bridge girders. Constant attention to safety is essential for success.

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Anthony Mizumori is a senior bridge design engineer and the concrete structures specialist and Richard Brice is the bridge design technology unit manager and bridge software engineer at the Washington State Department of Transportation in Olympia, Wash.

Controlling Bridge Deck Cracking in Virginia

by H. Celik Ozyildirim and Harikrishnan Nair, Virginia Transportation Research Council, Virginia Department of Transportation

Bridge deck cracking can cause serious durability concerns, leading to costly repairs and inconvenience to the traveling public. Cracks can occur in early stages due to plastic shrinkage, and in later stages due to drying shrinkage, or they can be caused by either loading or chemical reactions, or both. Cracks and high-permeability concretes facilitate the intrusion of water and salt solutions, which can result in reinforcing steel corrosion, the main cause of deterioration in concrete bridge decks. The products of corrosion, such as rust and expansion, can cause more cracking and spalling, which can then adversely affect ride quality. Other possible distress mechanisms related to water and solutions are damage from cycles of freezing and thawing, alkali-aggregate reactivity (alkali-silica and alkali-carbonate reactions), and sulfate attacks. To control cracking in decks, project stakeholders should pay close attention to the design of the structure, material selection and proportioning, construction practices, and specifications. Such attention can lead to bridge decks with proper crack control (**Fig. 1**).

Strategies for Crack Control

The following details and design strategies can help limit deck cracking and increase longevity of the structure:

- In geometric design, adequate drainage should be provided to eliminate ponding on the deck because the intrusion of water and salt solutions can initiate and/or accelerate the corrosion of reinforcing steel.
- Span length and beam rigidity should be carefully evaluated in the design stage. Decks that have shorter spans or are supported by rigid beams will have limited deflection and will typically exhibit less cracking. Beam rigidity depends on the material and the geometry of the section.
- Sufficient concrete cover on reinforcing is necessary, as it provides resistance to the penetration of solutions.
- Skewed decks are subject to torsional stresses that can lead to diagonal cracking at the joints. Minimizing the skew angle can reduce such cracking.

Appropriate choice of materials can also help control bridge deck cracking. Bridge decks typically contain both concrete and reinforcement. Corrosion-resistant reinforcement is commonly used in new structures in Virginia.

Synthetic or steel fibers can also be added to deck concrete to control cracking. The type and the amount of fiber are selected to address the expected distress from environmental factors and loads. In general, small quantities of synthetic fibers are added to control early-age cracking, such as that caused by plastic

Figure 1. Bridge decks using low-shrinkage concretes with no cracks after one year of exposure. The bridge deck on the left was constructed with normalweight concrete, and the bridge deck on the right used lightweight concrete. All Figures: Virginia Department of Transportation.

shrinkage. Larger amounts of steel fibers are effective in controlling later-age cracking, such as that caused by drying shrinkage and loads. Fibers can minimize the loss of water from concrete that can cause plastic shrinkage cracking, improve tensile strength, and provide ductility that can reduce the occurrence and width of cracks in hardened concrete.

In the selection of concrete materials, supplementary cementitious materials (SCMs) are very effective in reducing the permeability of concrete and resisting chemical attack such as alkali-silica reactivity. In addition, SCMs can reduce the heat of hydration and limit thermal stresses.

Lightweight concrete is expected to diminish cracking because of a reduced modulus of elasticity, internal curing, and a lower thermal coefficient of expansion. In addition, reduced permeability is expected with lightweight concrete because the contact zone (interface) between the lightweight aggregate and the paste is improved.

Solutions for Specific Types of Cracking

1) Cracking from Drying Shrinkage
Drying shrinkage is a common cause of deck cracking. Using concrete with relatively low proportions of water, cementitious material, and paste, as well as appropriate admixtures, can minimize such cracks. Use of well-graded aggregates and increasing the proportion of large aggregates in the concrete mixture design will result in reduced paste content. Water-reducing admixtures can also be used to lower the water content, and shrinkage-reducing admixtures (SRAs) can be used to reduce drying shrinkage.

Figure 2. Wet burlap is placed immediately after screeding.

2) Thermal Cracking
A high cement content leads to high temperatures and temperature differentials within the deck, which can cause thermal cracks. The temperature difference between the deck and the beam can also lead to deck cracking. In hot weather, the temperature of the concrete mixture should be reduced using chilled water or shaved ice. In cold weather, heat may be needed to ensure a proper temperature for the hydration process. In mixture proportioning, a proper water–cementitious material ratio (*w/cm*) can achieve satisfactory strength and low permeability. However, a low *w/cm* may lead to autogenous shrinkage and high cement and water contents, making the concrete prone to cracking.

3) Cracking from Freezing and Thawing
When concrete with a poor air-void system becomes critically saturated, it is prone to damage from cycles of freezing and thawing. Therefore, attention should be paid to proper air entrainment, use of sound aggregates, and achieving a minimum compressive strength of 4000 psi before the concrete is exposed to a harsh, cold environment.

Table 1. The Virginia Department of Transportation's *Road and Bridge Specification*[1] gives the minimum percent (by mass of cementitious material) of mineral admixture as a portion of the total cementitious materials based on the alkali content of the cement

Mineral admixture	Total akali content of cement ≤0.75%	Total alkali content of cement > 0.75% and ≤1.0%
Class F fly ash	20%	25%
Ground granulated blast-furnace slag	40%	50%
Silica fume	7%	10%
Metakaolin	7%	10%

Placement and Finishing

Proper placement, consolidation, and curing of the deck concrete are critical to achieve satisfactory strength and permeability. In continuous multispan bridges, sequential deck placement reduces the risk of cracking when compared with continuous placement. In hot weather, night placement should be considered. In continuous placement, a delay in the process, particularly on hot days, can lead to cold joints that can leak and cause finishing difficulties.

Concrete is commonly placed by pumping, which requires proper workability. If a steady flow is not maintained during pumping or a large free drop occurs, loss of slump and air content can occur. Suitable mixture proportioning and materials selection, including admixtures, should be used to achieve a workable mixture; the addition of "extra" water above the specified amount is not appropriate.

Proper concrete consolidation eliminates large, entrapped air voids, which can reduce the strength and permeability of concrete. Internal vibrators are used at a uniform spacing that overlaps the previous radius of action. Roller screeds with the specified vibration frequency are used for surface consolidation and finishing.

For finishing, a burlap drag provides a good microtexture with minimal working of the surface. Additional hand-finishing should be discouraged, except along the edges where the screed cannot reach.

During screeding, water should not be sprayed on the concrete to facilitate the finishing operation. Fog misting can be applied, but only after screeding, to prevent loss of moisture from the surface.

Plastic shrinkage commonly occurs in decks where the rate of surface evaporation exceeds the rate of bleeding (the rate at which bleed water can rise to replace evaporated water). Fog misting and immediately covering the surface with wet burlap (**Fig. 2**) and white polyethylene sheeting are effective curing measures that mitigate plastic shrinkage. Proper wet curing should continue until the specified strength and age and the curing duration are reached.

In addition to external curing, internal curing is recommended. Properly prewetted lightweight aggregates, especially fine aggregates, can provide moisture to the interior of the concrete as it cures. This internal moisture promotes the hydration process and minimizes autogenous and drying shrinkage. (For details on the internal curing of concrete for decks see the Safety & Serviceability article in the Summer 2019 issue of *ASPIRE*®.)

Specifications to Control Bridge Deck Cracking

The Virginia Department of Transportation (VDOT) continually updates the agency specifications[1] to control bridge deck cracking. VDOT emphasizes the need to improve both concrete and reinforcement materials and reinforcement details to ensure deck longevity.

Corrosion-resistant reinforcement is used based on location and exposure conditions and is categorized into classes, with certain types of stainless steel being the highest class. A minimum concrete cover of 2.5 in. to the center of the top bar has been typical for VDOT.

Concrete specifications include strength, shrinkage, and permeability requirements, depending on the application. For low-shrinkage bridge deck concrete, instead of a minimum total cementitious material content, a maximum of 600 lb/yd^3 is specified. To achieve low shrinkage, SRAs are used in concrete with normalweight aggregates. For lightweight concrete, the maximum total cementitious material content is 650 lb/yd^3 and SRAs are not used because lightweight concrete is less prone to cracking.

To mitigate alkali-silica reactivity, VDOT uses a prescriptive method that specifies the types and amounts of SCMs based on the alkali content of cement (**Table 1**). Currently, the maximum permitted alkali content is 1%. A new study will investigate whether alkali loading in concrete should be considered rather than the alkali content of the cement. New test procedures for performance specifications may be an outcome of this research.

Internal curing is permitted in VDOT structures and can be achieved by using the lightweight aggregates. External curing for bridge decks requires a minimum seven-day moist curing followed by the use of a curing compound. The grooves for surface texture are cut after the curing period such that proper curing is maintained and the desired groove geometry achieved. VDOT also has an extensive program in fiber-reinforced concrete, which is used in shear keys, link slabs, and connections, and can be used in decks or parts of decks.

Reference

1. Virginia Department of Transportation (VDOT). 2020. *Road and Bridge Specifications*. Richmond, VA: VDOT. https://www.virginiadot.org/business/resources/const/VDOT_2020_RB_Specs.pdf.

H. Celik Ozyildirim is a principal research scientist and Harikrishnan Nair is an associate principal research scientist with the Virginia Transportation Research Council, a division of the Virginia Department of Transportation, in Charlottesville, Va.

Concrete Materials for Bridges Program at the Concrete Bridge Engineering Institute

by Dr. Kevin Folliard, Dr. Thano Drimalas, Gregory Hunsicker, and Dr. Oguzhan Bayrak, Concrete Bridge Engineering Institute

As part of a series of articles on the Concrete Bridge Engineering Institute (CBEI), an article in the Fall 2022 issue of *ASPIRE*® explored the key components of CBEI and presented the institute's Transportation Pooled Fund (TPF) study. This article presents information about the Concrete Materials for Bridges training program and highlights CBEI's collaboration with the National Concrete Bridge Council (NCBC).

Concrete Materials for Bridges

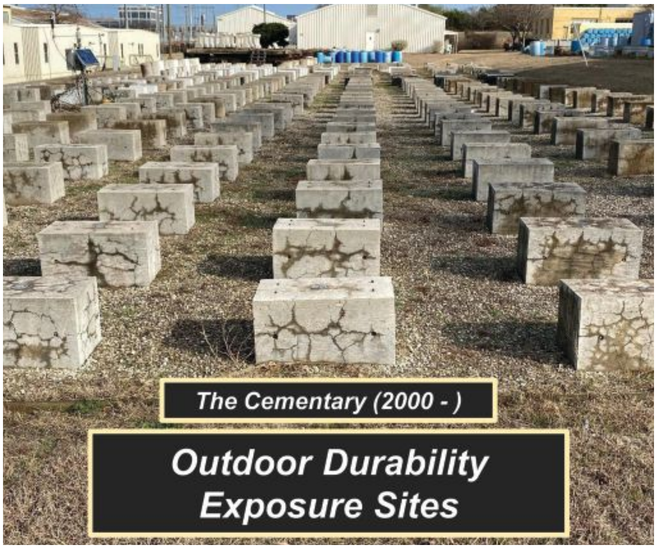
Previous articles in this series discussed the three "pillars of learning"—concrete materials, bridge deck construction inspection, and post-tensioning—of CBEI's initial training and certification programs. The first course, which is scheduled to be offered later this year, is the Concrete Materials for Bridges training program.

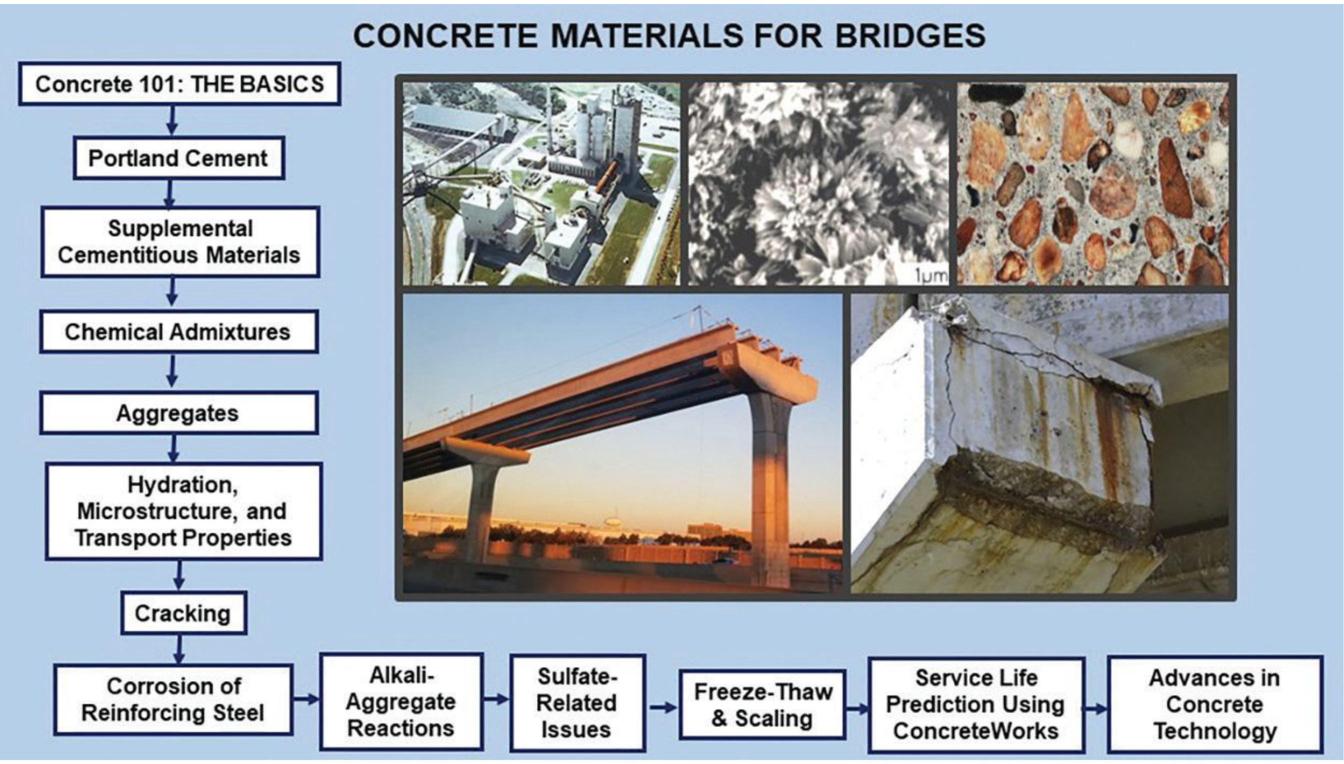
Recognizing the critical role that concrete materials play in long-term bridge performance, CBEI has developed a three-day training course. It is anticipated that this course will be offered four times per year, with a target of 25 students per course offering. The course is intended for laboratory technicians, engineers, inspectors, and contractors and will provide important background information about concrete materials and user-friendly tools for concrete design, analysis, and performance prediction. Its goal is to guide students to improve concrete mixture designs for their projects.

The course will include formal lectures and group projects as well as tours of laboratory facilities, outdoor durability exposure sites, and the concrete bridge component collection. It is anticipated that two instructors will teach each of the three-day courses. The instructors will include Dr. Kevin Folliard and Dr. Thano Drimalas of the University of Texas at Austin, Dr. Anton Schindler of Auburn University, and Dr. Michael Thomas of the University of New Brunswick.

This comprehensive course will cover the constituent materials used in concrete bridge elements and focus on the key durability issues that can affect various bridge components. It is recommended that course participants have a basic knowledge of concrete materials; however, the course starts off with a basic "Concrete 101" module to provide an introduction to concrete materials.

The Concrete Materials for Bridges course will include tours of outdoor durability exposure sites, known as the Cementary (left) and the Concrete Bridge Engineering Institute's concrete bridge component collection (right). All Figures and Photos: Concrete Bridge Engineering Institute.





Outline for the Concrete Materials for Bridges course, a three-day course focusing on the critical role of concrete materials in bridges.

The course then goes into more detail on how to select the appropriate mixture proportions for concrete in a given environment and addresses many of the variables in both materials and the environment. In addition to describing the underlying causes of potential deterioration, this course will provide guidance on how to minimize or avoid durability-related issues during the intended service life of a bridge.

The course will also cover current industry trends, including how evolving changes to improve sustainability may affect other relevant concrete properties, and how these issues can be addressed. Advances in materials and different types of cements, including portland-limestone cement, will be discussed.

An additional topic within the curriculum will be the availability of fly ash. Fly ash is sometimes used in mixtures to improve concrete workability and durability; however, with changes in fly ash quality and quantity spurred by new emissions standards and changes in fuel sources, there is a concern that fly ash may not be as readily available or effective in the future. The course will provide the latest information on the availability of concrete materials and the necessary considerations for using different materials.

The course will include a group project where teams will design the concrete mixture for a bridge designed for a 100-year service life in an aggressive marine environment. Bridge elements such as

During a tour of the Concrete Bridge Engineering Institute, students presented ongoing research projects at the Ferguson Structural Engineering Laboratory to attendees of the 34th Annual American Segmental Bridge Institute Convention in Austin, Tex.

As part of a tour of the Concrete Bridge Engineering Institute, Dr. Kevin Folliard and Dr. Thano Drimalas showed the outdoor durability exposure sites to attendees of the 34th Annual American Segmental Bridge Institute Convention in Austin, Tex.

bridge decks, mass concrete elements, and precast concrete components are among those that will be evaluated using real-world scenarios. This exercise will be done in class using laboratory software that considers concrete designs, analysis, and performance prediction. Features of the software include mixture proportioning, cracking probability, chloride concentration prediction, and predicting the heat generated during early ages of concrete.

The course will also present information on coatings/sealers for concrete bridges for both new and existing bridges and how they can potentially extend the life of the structure.

The ultimate goals of the Concrete Materials for Bridges course are to help students improve their understanding of concrete as an integral material for bridges and to help facilitate the long-term durability and sustainability of concrete bridge design and construction. Upon completion the course, participants should be able to do the following:

- Describe portland cement hydration and reaction products.
- List the most common supplementary cementitious materials and explain how they can improve concrete performance.
- Describe the various types of chemical admixtures.
- Describe the most important durability problems that affect concrete bridges.
- Describe how to identify different types of materials-related distress.
- Understand the importance of designing and constructing bridges with a focus on sustainability and long-term durability.
- Discuss recent innovations in concrete technology that can be applied to concrete bridges, such as ultra-high-performance concrete.

Collaboration with the National Concrete Bridge Council

In addition to the invaluable vision, support, and collaboration of the partner agencies of the TPF, including the participating state departments of transportation and the Federal Highway Administration, CBEI has received tremendous support and contributions from NCBC and NCBC members. A Perspective article in the Fall 2022 issue of *ASPIRE* featured the NCBC and presented its mission, activities, and partnerships.

The members of NCBC have been actively engaged in helping to develop the programs in support of the CBEI mission. For example, in December 2021, leadership from the American Segmental Bridge Institute (ASBI), Precast/Prestressed Concrete Institute, and Post-Tensioning Institute—all of which are NCBC members—kicked off discussions in a two-day workshop together with CBEI staff. These meetings were helpful in identifying needs and goals from an overall industry perspective.

CBEI has hosted representatives of several of the NCBC member organizations over the past year, and CBEI representatives have presented at NCBC meetings and conferences, including the July 2022 NCBC summer meeting, which was held at the CBEI facility in Austin, Texas. During the 34th Annual ASBI Convention in Austin, Dr. Bayrak presented information about CBEI, and an on-site tour of the CBEI facility was offered to attendees. During the tour, the CBEI component collection was highlighted, and students gave presentations about ongoing research projects at the Ferguson Structural Engineering Laboratory and the concrete materials/outdoor durability exposure sites.

The collaboration and support of NCBC and its members are crucial and instrumental in creating valuable and effective programs. The CBEI programs are designed to complement and work in conjunction with existing training and certification programs offered by NCBC member organizations.

Conclusion

This is the third in a series of articles about CBEI and its impact on the construction industry. Articles in upcoming issues of *ASPIRE* will explore other CBEI technical programs in greater detail and provide a status update.

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

Dr. Kevin Folliard is the Walter S. Bellows Centennial professor in the Department of Civil Engineering at the University of Texas at Austin.

Dr. Thano Drimalas is a research associate at the University of Texas at Austin.

Gregory Hunsicker is a research engineer at the University of Texas at Austin and deputy director of the Concrete Bridge Engineering Institute.

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

CONCRETE CONNECTIONS

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

IN THIS ISSUE

https://www.fhwa.dot.gov/bridge/prefab/gravesave.cfm
In 2006, Leware Construction Company (profiled in the Focus article on page 6) worked with the Florida Department of Transportation to use self-propelled modular transporters in the Graves Avenue Bridge over Interstate 4 replacement project. The new bridge superstructure was moved into place during only two night closures. This is the link for the Federal Highway Administration webpage about the project, which includes links to photos and videos of the move.

https://abc-utc.fiu.edu/mc-events/hawaii-dots-waikoko-bridge-replacement-project
The Waikoko Stream Bridge replacement in Kauai, Hawaii, is the subject of the Project article on page 16. This bridge replacement was accomplished using just one 57-hour full-road closure. Innovative precast concrete solutions allowed the design team to manage the challenging site conditions and remote location. This is a link to a recorded webinar about the project.

https://engineer.mcohio.org/projects/third-street-bridge
The Third Street Bridge in Dayton, Ohio, also known as the Peace Bridge, is the subject of the Project article on page 20. This is a link to a webpage that discusses additional details about the bridge's aesthetic design and community involvement in the project.

https://www.pci-foundation.org/studio-history
The Professor's Perspective by Dr. David Garber of Florida International University on page 42 discusses the many roles that professors fill and how industry involvement can help professors develop their careers. This link provides information about the PCI Foundation Studios, which are mentioned in the article.

https://www.youtube.com/channel/UCIL0NyWPPAqrikLb6hJMA8Q/featured
With support from the PCI Foundation, Dr. David Garber of Florida International University developed 46 videos and over 23 hours of content for his prestressed concrete design course. This is the link to his YouTube channel, where the videos are available to view. Dr. Garber reflects on establishing his career in academia in the Professor's Perspective on page 42.

https://par.nsf.gov/servlets/purl/10072455
In the Professor's Perspective article on page 44, Dr. Robin Tuchscherer of Northern Arizona University discusses the balance needed in engineering education between theory and practical applications. The article mentions an ongoing study that is testing instructional interventions designed to help engineering students succeed in their studies and their future careers. This is the link to the report from one of Dr. Tuchscherer's previous studies on a similar topic.

https://www.virginiadot.org/vtrc/main/online_reports/pdf/16-r14.pdf
The Virginia Transportation Research Council (VTRC) has conducted multiple studies on strategies to reduce cracking in cast-in-place concrete decks. This is a link to a VTRC report on the use of lightweight concrete to reduce cracks in bridge decks. The Safety and Serviceability article on page 32 discusses some effective crack-control strategies based on experience and research in Virginia.

https://www.fhwa.dot.gov/bridge/nbis2022.cfm
The updated National Bridge Inspection Standards (NBIS) are designed to strengthen the main safety program for highway bridges, as discussed in the FHWA article on page 51. This link takes you to the Federal Highway Administration's webpage devoted to information on NBIS 2022, including links to an overview presentation about the NBIS updates and the *Specifications for the National Bridge Inventory*.

https://doi.org/10.15554/CB-02-16
The Concrete Bridge Technology article on page 28 focuses on lessons learned when handling long-span prestressed concrete girders, such as the 223-ft-long girders on the Puyallup River Bridge in Washington state. In the article, PCI's *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders* is referenced. This is a link to download the free publication.

OTHER INFORMATION

https://structuraltechnologies.com/preserving-extending-the-service-life-of-concrete-bridges
The National Concrete Bridge Council has made the six-part Summer Enrichment Series on Preserving and Extending the Life of Concrete Bridges available for viewing for a limited time. Follow this link to access information about the six modules and register for access to the webinars.

https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/22065/22065.pdf
The Federal Highway Administration's *Design and Construction of UHPC-Based Bridge Preservation and Repair Solutions* is available via this link. This publication presents common and emerging solutions for using ultra-high-performance concrete for preservation and repair. It includes design and construction recommendations for bridge deck overlays, link slabs, and steel beam end repairs.

https://www.gotostage.com/channel/b14f2c1519a3434dbede1a217a9033d7/recording/4848d47d76f542ad8beac2f2644f3cd8/watch
In the Fall 2022 issue of *ASPIRE*®, a Perspective article discussed the recent changes to the "Buy America" requirements for highway bridge projects. This is a link to a Florida Department of Transportation webinar about the Infrastructure Investment Jobs Act, which includes the Build America, Buy America Act.

Perspective of an Early(ish)–Career Professor

by Dr. David Garber, Florida International University

Dr. Garber (second from left) and three of his PhD students from Florida International University attended the 2019 PCI Convention in Louisville, Ky. All Photos: David Garber.

The life of a professor is a balancing act, with work responsibilities typically grouped into three categories: research, teaching, and service. Time commitments depend on one's annual assignments, interests, and levels of competency. Through the lens of a graduate student entering academia, academic life is all about research: submitting proposals, conducting research, advising students. The general public (including most family and friends) view academia as all about teaching: *What courses are you teaching? What are you doing with your summers off? If you are only teaching one (or two) courses this semester, what do you do with all of your free time?* From the perspective of a professor's spouse (or close friends and family), a key question is, "How do you have the time and mental capacity to complete everything?"

I was honored to receive one of the two PCI 2021 Educator of the Year Awards. I was asked to reflect on how my involvement with PCI and the precast concrete industry has been valuable for me professionally and how it has helped me to balance the many responsibilities of a professor with family life.

Nobody can really fully prepare a graduate student for entering academia or industry. Advisors give students an opportunity to "lead" research projects (with differing levels of oversight), present the work at conferences and at peer-reviewed venues, and possibly participate in grant writing. However, research expectations are magnified in tenure-track faculty positions. Students take courses during their graduate studies, but they typically do not receive much instruction on the aspect of teaching. A student may also have the opportunity to participate in and possibly lead student organizations or other activities, but that is far different from navigating university service and departmental politics.

I came out of high school thinking that I wanted to be an engineer—after

Florida International University students participating in a plant tour sponsored by the Florida Prestressed Concrete Association.

all, my father was an engineer and I was good at math and physics. In my youth, I enjoyed buildings, bridges, and construction, and I spent a summer on a road crew for the Pennsylvania Department of Transportation, which led me to pursue civil engineering. After graduating with my bachelor of science degree in civil engineering from Johns Hopkins University, I decided to continue my studies at the University of Texas at Austin. I was blessed to be able to work on several different research projects and help my laboratory colleagues with their projects.

I was given my first introduction to PCI when a convention was held in Fort Worth, Tex. My advisor, Dr. Oguzhan Bayrak, arranged for me to present my work on prestress losses to the Committee on Bridges (COBs), which was one of my first presentation experiences and my first committee meeting. My first PCI COBs meeting was positive, exciting, and intimidating. The committee had many questions, but I appreciated that the members were generally supportive even if they had different opinions.

I joined Florida International University (FIU) in August 2014 as an assistant professor. During my first few years, I continued to participate in PCI by joining several committees and regularly attending Committee Days and the annual PCI convention. During the first few years, I was able to obtain travel support as a new faculty member, so I also regularly attended events and meetings of other concrete-related organizations. After this funding source ended, I needed to evaluate in which organizations I wanted to continue to actively participate. I appreciated the balance between academia and industry as well as the collegial environment at PCI, so I decided to continue with this organization.

Participation in PCI committees and regularly attending Committee Days and conventions has helped me to better understand the many facets of precast and prestressed concrete, including fabrication, erection, and design. I have learned more about the subject and research needs through a few hours in committee meetings and informal discussions with industry professionals

A group of students from Florida International University casting their beam at Coreslab Structures (Miami) Inc. for the 2020–2021 PCI Big Beam Competition.

than in all my time reading textbooks and journal articles. I have also learned about the numerous resources available (many of them free) related to precast and prestressed concrete. Being able to participate in discussions with subject matter experts in the field is an invaluable experience.

I have also appreciated the support that PCI, its regional affiliates, and the PCI Foundation provide to professors. PCI offers numerous resources at no cost that have helped me develop content for my courses, including Prestressed in a Box (which I am currently revising), the *PCI Bridge Design Manual,* eLearning Modules, and many other assets that are available to professors and students. The Florida Prestressed Concrete Association, a regional chapter of PCI, has been incredibly supportive by facilitating plant tours, industry events, and invitations to regional chapter meetings, and providing resources for me and my students. The connections I have made through PCI have also provided unique opportunities for my students, as many industry professionals have presented in my classes either in person or virtually. In addition, the PCI Foundation has been supportive through its annual Professors Seminar and studio programs.

The Foundation has sponsored studios at more than 40 different universities, with more than 6000 students having participated to date. These studios help universities develop or improve their curricula related to precast and prestressed concrete design. The studio program emphasizes connecting students and faculty to industry. I was awarded a PCI Foundation Studio, "Advanced Building and Bridge Construction with Precast Concrete," in January 2020. There were two primary goals for the studio: to develop a new course, "Precast Concrete Design," and to transform an existing course, "Prestressed Concrete Design," into a hybrid course with both synchronous and asynchronous components. Thanks to the support of the studio, I was able to develop the new course, including 633 pages of notes and 962 slides of content, to lead undergraduate and graduate students through the basic design and construction of precast concrete buildings and bridges. I also created 46 videos and more than 23 hours of content (publicly available on YouTube) based on 543 pages of notes and 734 slides for "Prestressed Concrete Design," and I provided students with the opportunity to interact with more than 30 different industry experts through guest speakers, plant tours, participation in PCI's Engineering Student Design (Big Beam) Competition, and end-of-semester design competitions with a panel of industry judges.

More recently, I have had a few additional balls to juggle: having three children ages three and under and being appointed interim department chair. Participation in PCI has continued to help me balance my time through this busy period.

While I have shared my experience with PCI, there are many other organizations that offer similar support. My recommendation to young engineers is to get involved and actively participate in organizations that best align with your interests and career goals.

A PROFESSOR'S PERSPECTIVE

The Balancing Act of Engineering Education

by Dr. Robin Tuchscherer, Northern Arizona University

A challenge I often experience as an instructor is balancing theoretical content with its applications. Too much of one or the other can result in negative learning outcomes. For example, consider derivations in a statics or mechanics of materials textbook. The theoretical model may show a differential area inside a nebulous blob (such as a "pancake" or "potato"), and it is explained in generalized terms. While these types of models are important, I will quickly lose students' attention if I spend too much time deriving, for example, the center of gravity of a potato in terms of numerous variables. It is incredibly difficult for most students to grasp highly abstract conceptual models. On the other hand, simply giving students an equation does not encourage a fundamental understanding of the basis or assumptions of the concepts built into the derivation. Students' engineering successes are not predicated on their ability to remember and repeat information, but rather on their ability to find and use it. We expect engineering students to be able to apply fundamental principles in varying conditions, but if they do not know the basis of these principles because they were simply "given the equation," they will struggle when applying the principles in a new or even slightly altered context. Theory is best learned through and in harmony with applications, yet finding the appropriate balance is a constant challenge that depends on course learning objectives, the topic, and the needs of students.

The purpose of continuously examining this balance between theory and application is ultimately to foster the ability of students to seamlessly and productively transition into their future professions, which will require them to be able to transfer knowledge from the classroom to the office or jobsite. Knowledge transfer is the ability to apply knowledge, skills, and practices across time and contexts.[1] According to Bransford et al.,[2] a person's ability to transfer what they have learned depends on several factors:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information, or they may learn concepts and information for a test but revert to their preconceptions afterward.
- How instructors assess students' comprehension matters. Many approaches to instruction look equivalent when the measure is based on rote memorization. Instructional differences become more apparent when they are evaluated from the perspective of how well the learning transfers to a new setting.
- Spending a lot of time studying a topic is not sufficient in and of itself to ensure effective learning. Time spent learning for understanding has different consequences for transfer than time spent simply memorizing facts or procedures. For learners to gain insight into their comprehension, frequent feedback is critical.
- The context in which one learns is also important. Students are motivated to spend the time needed to learn complex subjects and to solve problems that they find interesting, particularly opportunities to create products or provide services that benefit others.
- Knowledge that is taught in only a single context is less likely to support flexible transfer (transfer to an unfamiliar context) than knowledge that is taught using multiple scenarios. Students are more likely to grasp the underlying principles with varying contexts. Helping learners choose and adapt tools for solving problems is one way to promote transfer and encourage flexibility.
- A metacognitive approach to teaching is recommended (for example, defining learning goals and allowing students to reflect on their achievement of these goals). One characteristic of experts is their ability to monitor and regulate their understanding in ways that allow them to continually adapt the application of their expertise. Thus, it is important for instructors to model their own inquiries, questioning, and testing of principles, as part of their instruction.

At Northern Arizona University, I am part of a team of structural engineering faculty who are testing instructional interventions intended to create more practice-ready bridge engineers by improving students' ability to transfer knowledge. Our approach is aligned with the previously mentioned factors and the constructivist position that transfer can be facilitated by involvement in authentic tasks anchored in meaningful contexts. Using an approach that is sometimes referred to as "anchored instruction," we repeatedly anchor engineering concepts across the curriculum to actual bridges in the surrounding area. For example, we may have students use the method of joints to analyze internal forces in a truss bridge in their statics class, then determine the factor of safety of each component for the same bridge in their mechanics of materials class, and then use the method of virtual work to calculate structure deflections for the same bridge in their structural analysis class. By repeatedly revisiting the same structure in varying contexts and across the curriculum, we can increase the relevance of the underlying theories and reduce the cognitive load needed to relate an actual structure to its conceptual model. **Figure 1** illustrates the concept of the anchored approach to learning.

We have completed the first year of our four-year project to test instructional interventions. Key considerations and findings that continue to guide our work include the following:

- Instructional materials must be

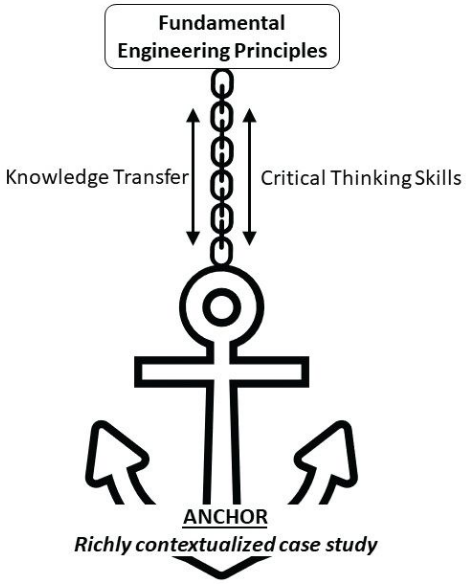


Figure 1. Conceptual model for "anchored instruction." At Northern Arizona University, instructors "anchor" engineering concepts to actual bridges in the surrounding area. All Figures and Photo: Dr. Robin Tuchscherer.

formatted and disseminated in a manner that allows instructors to easily incorporate them into their classes. The civil engineering program is packed full of content, and there is little room for drastic alterations. To improve ease of adoption of our interventions, the materials must be user friendly and intuitive, and have low "overhead," such that there are few additional costs in terms of time or money.

- Grounding the anchor is crucial. In other words, student engagement is higher when the bridge's context is fully described with its location, construction means, fabrication details, and cultural and historical significance (**Fig. 2**).
- An anchor by itself is not effective—providing a concept in only one context does not encourage students to apply the concept in other contexts. To encourage transfer and abstraction of principles (such as flexible transfer), the instructor should integrate each concept along with several contextual variations.
- The level of student engagement in learning depends on the proximity of the anchor. For example, we have discovered that although a bridge students walk under every day on their way to campus is fairly ordinary, it has a lasting impact on students' interest and motivation to learn the associated concepts.
- Students' attitudes toward the bridge engineering profession seem to be positively and significantly influenced by their exposure to bridges through the anchored instruction approach in the classroom.

When thoughtfully executed, anchored learning can be an effective means of harmonizing the balance between theory and practice. The success of any intervention requires instructors to continuously hone their craft for the benefit of learners. Teaching and learning are complicated. Instructors, like other professionals, attain expertise through years of practice, experience, and, most importantly, their motivation to improve. Focusing on how people learn will help instructors move beyond the "either/or" dichotomies that have plagued the field of education, such as whether one should emphasize "the basics" or teach problem-solving skills. Both are necessary. Students' abilities to acquire skills are enhanced when they are connected to meaningful problem-solving activities and when they are helped to understand why, when, and how those facts and skills are relevant. Attempts to teach thinking skills without a strong base of fundamental knowledge does not promote problem-solving ability or support knowledge transfer to new situations.[2]

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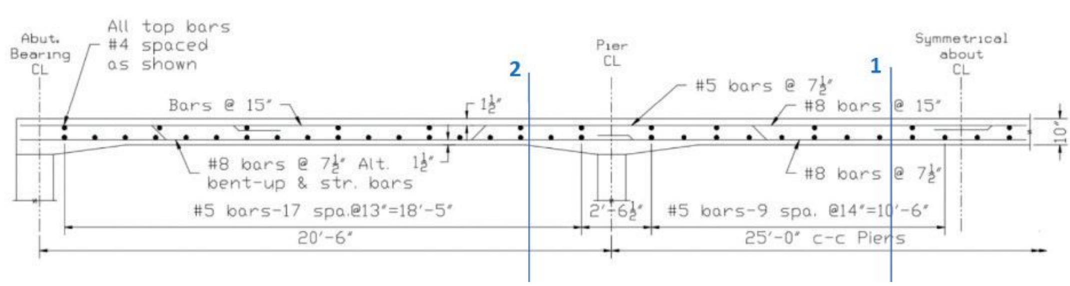
Figure 2. At Northern Arizona University, a team of structural engineering faculty is testing strategies to create more practice-ready bridge engineers. One approach is to enhance students' abilities by revisiting the same structure in varying contexts and across the curriculum. In this assignment, the students are tasked with determining the flexural capacity of the two-span Earp Wash Bridge. In a previous class, the students may have determined the live-load moments.



Determine the positive and negative flexural capacity for the bridge at Sec 1 and 2, respectively. f'_c = 4 ksi fy = 40

Approved Changes to the Ninth Edition *AASHTO LRFD Bridge Design Specifications*: Reinforcing Bar Anchorage

by Dr. Oguzhan Bayrak, University of Texas at Austin

Current structural design codes in the United States treat the development of straight reinforcing bars, standard hooks, and deformed headed bars with separate equations and procedures. In contrast, the *fib Model Code for Concrete Structures 2010* (MC2010)[1] uses a unified approach. In their June 2022 meeting, the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures approved an approach similar to the one used in MC2010 for inclusion in the forthcoming 10th edition of the *AASHTO LRFD Bridge Design Specifications*.

Unified Approach

According to the newly adopted reinforcement anchorage provisions, the modified tension development length ℓ_d (Eq. [1]) is to be taken as follows:

$$\ell_d = \ell_{db} \times (\lambda_{rl} \times \lambda_{cf} \times \lambda_{rc}) \qquad (1)$$

where

ℓ_{db} = basic development length, in.
$\lambda_{r\ell}$ = reinforcement location factor
λ_{cf} = coating factor
λ_{rc} = reinforcement confinement factor

These factors are described in Articles 5.10.8.2.1b and 5.10.8.2.1c of the AASHTO LRFD specifications[2] and in the following section.

$$\ell_{db} = 0.17 d_b \left(\frac{\lambda_{er} f_y - \dfrac{F_h}{A_b}}{1.97 \lambda f_c'^{0.25}} \right)^2 \qquad (2)$$

where

d_b = nominal diameter of reinforcing bar or wire, in.
λ_{er} = excess reinforcement factor
f_y = specified minimum yield strength of reinforcement, ksi
F_h = force developed by hooks or heads, kip
A_b = nominal area of reinforcing bar or wire, in.^{2}
λ = concrete density modification factor as specified in Article 5.4.2.8 of the AASHTO LRFD specifications[2]
f_c' = compressive strength of concrete for use in design, ksi

The modified tension development length ℓ_d (Eq. [1]) is to be not less than the basic tension development length ℓ_{db} (Eq. [2]). The tension development length for nonheaded straight reinforcing bars and wires is to be not less than 12.0 in., except for development of shear reinforcement.

For nonheaded straight reinforcing bars and lap splices in tension, F_h is to be taken as zero. The basic development length in Eq. (2) is to be used for the straight portion of reinforcing bars developed in tension. It is primarily based on the partly cracked elastic model for bond behavior proposed by Tepfers.[3] The inclusion of the term F_h, which accounts for forces developed by hooks or heads, enables a unified approach to tension development length for straight bars, lap splices, hooked bars, and headed deformed bars. In the formula for ℓ_{db} (Eq. [2]), the denominator represents the effective splitting strength of concrete in bond, based on a fourth-root dependency on concrete strength.[4] The fourth-root dependency on the compressive strength of concrete for use in design has been shown to be more accurate for bond than the typical square-root dependency used in many tension strength approximations.[5,6]

Modification Factors

Modification factors are to be applied to the basic development length to account for the various effects specified in the AASHTO LRFD specifications. These factors are to be taken to be equal to 1.0, unless they are specified to either increase ℓ_d in Article 5.10.8.2.1b or decrease ℓ_d in Article 5.10.8.2.1c of the AASHTO LRFD specifications. The following parameters are to be used in calculating the development length of straight reinforcing bars.

- For horizontal reinforcement, placed such that more than 12.0 in. of fresh concrete is cast below the reinforcement, $\lambda_{r\ell} = 1.3$.
- For epoxy-coated or zinc and epoxy dual-coated bars with either cover less than $3d_b$ or clear spacing between bars less than $6d_b$, $\lambda_{cf} = 1.5$.
- For epoxy-coated or zinc and epoxy dual-coated bars not covered by the previous parameter, epoxy-coated or zinc and epoxy dual-coated hooked bars designed according to Article 5.10.8.2.4 of the AASHTO LRFD specifications, and epoxy-coated or zinc and epoxy dual-coated headed bars designed according to Article 5.10.8.2.7, $\lambda_{cf} = 1.2$.
- For uncoated or zinc-coated (galvanized) bars, $\lambda_{cf} = 1.0$.

For horizontal reinforcement, placed such that not more than 12.0 in. of concrete is cast below the reinforcement, no modification factor is necessary, in other words, $\lambda_{r\ell}$ is equal to 1.0. In the ninth edition of the AASHTO LRFD specifications, $\lambda_{r\ell}$ is not required for the development of hooked bars. The accumulation of bleed water underneath top-cast bars has been documented to reduce bond strength in nonheaded straight bars.[7] Equations (1) and (2), which are to be used to calculate the length of the straight portion of a hooked bar, are based on the behavior of a straight length of reinforcement subjected to uniform, average bond stresses. As a result, the influence of bar casting position is now required for hooked and headed bars. The proportion of anchorage resisted by the hook F_b is not affected by the reinforcement location factor.

The coating factor λ_{cf} is limited to no more than 1.2 for hooked and headed bars. The original coating factor for hooked bars was 1.2, based on tests by Hamad et al.[8] that did not satisfy the $3d_b$ clear cover and $6d_b$ clear spacing requirements. Therefore, it is unnecessary to use the larger value of 1.5. This limit also applies to headed bars based on recommendations in *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*.[9]

The basic development length ℓ_{db} is to be modified by the previously discussed factors, as appropriate, and may be multiplied by the factors λ_{rc} and λ_{cr} as described in the following paragraphs.

For reinforcement being developed in the length under consideration, λ_{rc} shall satisfy the following:

$$0.3 \le \lambda_{rc} \le 1.0$$

and

$$\lambda_{rc} = \frac{d_b c_b}{\left[c_b\left(1-\beta_t\right)+1.67 n_s k_{tr}\right]^2} \quad (3)$$

where

c_b = the smaller of the distance from the center of bar or wire being developed to the nearest concrete surface and one-half of the center-to-center spacing of the bars or wires being developed, in.

β_t = ratio of unfactored compressive stress due to permanent loads (taken as a negative value) transverse to the plane of splitting to the modulus of rupture as determined by Article 5.4.2.6 of the AASHTO LRFD specifications ($-1 \le \beta_t \le 0$)

n_s = modular ratio = E_s/E_c

k_{tr} = transverse reinforcement index = $A_{tr}/(sn)$

E_s = modulus of elasticity of reinforcing steel

E_c = modulus of elasticity of concrete

A_{tr} = total cross-sectional area of all transverse reinforcement that is within the spacing s and crosses the potential plane of splitting through the reinforcement being developed, in.[2]

s = maximum center-to-center spacing of transverse reinforcement within ℓ_d, in.

n = number of bars or wires developed along plane of splitting

In tests to determine development lengths, splitting cracks have been observed to occur along the bars being developed. When the center-to-center spacing of the bars is greater than about twice the distance from the center of the bar to the concrete surface, splitting cracks occur between the bars and the concrete surface (case 1 in **Fig. 1**). When the center-to-center spacing of the bars is less than about twice the distance from the center of the bar to the concrete surface, splitting cracks occur between the bars along the plane of the bars being developed (case 2 in Fig. 1). The presence of bars crossing the splitting plane, as denoted by A_{tr}, controls these splitting cracks and results in shorter development lengths. In any component, A_{tr} may be taken conservatively as zero.

The ratio of unfactored compressive stress due to permanent loads transverse to the plane of splitting to the effective concrete tension strength β_t accounts for the beneficial effects of clamping stresses that may exist perpendicular to the plane of splitting. Transverse compressive stresses act as confinement that delays the onset of splitting failures.[1] For example, concentrated stresses above or below a load/support can be assumed to enhance the bond strength over the length of reinforcement that passes through the load/support plate length.[1] For a new design, β_t can be conservatively taken as zero. While the concrete modulus of rupture determined according to Article 5.4.2.6. of the AASHTO LRFD specifications overestimates the concrete splitting strength, it is conservative for use in the calculation of β_t because overestimating the splitting strength reduces the calculated β_t.

Where anchorage or development for the full yield strength of reinforcement is not required, or where reinforcement in flexural components is in excess of that required by analysis:

$$\lambda_{cr} = \frac{\text{Required } A_s}{\text{Provided } A_s} \quad (4)$$

The excess reinforcement factor modifies the yield stress instead of the development length, based on the following relationship:

$f_s \times (\text{Provided } A_s) = f_y \times (\text{Required } A_s)$

Hooked Bars

New provisions for hooked bars were also included in this update. For hooks in reinforcing bars having a specified minimum yield strength greater than 75.0 ksi, ties satisfying the requirements of Article 5.10.8.2.4c shall be provided.

In the ninth edition of the AASHTO LRFD specifications, Article 5.10.8.2.4 was verified for concrete compressive strengths up to 15.0 ksi used in design based on the National Cooperative Highway Research Program (NCHRP) Report 603,[10] except for lightweight concrete. The previous limit of 10.0 ksi was retained for lightweight concrete. The updated procedure described herein has been validated over a similar range of concrete strengths and recommends

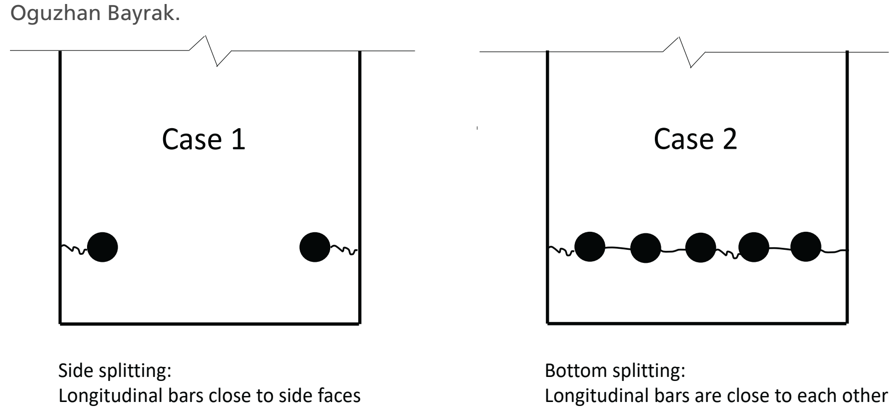


Figure 1. Cross section of beam subjected to tension showing the reinforcing bars being developed in tension with potential splitting-crack locations illustrated. Figure: Dr. Oguzhan Bayrak.

the same limits as Zaborac and Bayrak.[4] To improve the bond strength of no. 11 and larger reinforcing bars in tension terminating in a standard hook, NCHRP Report 603 recommends a minimum amount of transverse reinforcement consisting of no. 3 U-bars at $3d_b$ spacing in the anchorage length. Similar to the provisions of ACI 318-19, NCHRP Report 603 does not consider hooks to be effective in developing bars in compression.

The modified development length ℓ_{dh} in inches for deformed bars in tension terminating in a standard hook specified in Article 5.10.2.1 shall be taken according to Eq. (5), but shall not be less than the greater of 8.0 bar diameters and 6.0 in.

$$\ell_{dh} = \ell_d + R + \frac{d_b}{2} \quad (5)$$

where

R = radius of the hook measured from the center of the bend to the centroid of the bar, in.

To calculate the modified development length of a standard hook in tension, the force developed by a standard hook F_h is to be calculated according to Eq. (6).

$$F_h = d_b R \nu f_c' \quad (6)$$

where

ν = concrete efficiency factor for a compression-tension-tension (CTT) node specified in Table 5.8.2.5.3a-1 of the AASHTO LRFD specifications

Confinement of hooked bars by stirrups perpendicular and parallel to the bar being developed is illustrated in Fig. C5.10.8.2.4b-1 of the AASHTO LRFD specifications. The influence of parallel tie reinforcement is conservatively neglected in deriving the development length expressions for hooked bars; however, research has shown that parallel tie reinforcement is an effective method for improving hooked bar performance.[11] This provision does not apply for hooked bars at discontinuous ends of slabs where confinement is provided by the slab on both sides, perpendicular to the plane of the hook.

The concrete efficiency factor for a CTT node specified in Table 5.8.2.5.3a-1 is appropriate, regardless of the percentage of reinforcement confining the bar, due to low strain values associated with tensile failure of concrete around the bar being anchored and based on the experimental validation reported by Zaborac and Bayrak.[4]

There are no publicly available test results for no. 14 and no. 18 bars. As a result, the hooked bar development length calculations are limited to no. 11 bars and smaller based on experimental validation.[4] However, ACI 318-19 doubles the calculated hooked-bar development length for no. 14 and no. 18 bars, regardless of the provided confinement reinforcement and clear cover. Based on this ACI 318-19 guidance, the new commentary for the AASHTO LRFD specifications will recognize that it may be possible to develop a conservative estimate of the hooked-bar development length for no. 14 and no. 18 bars by doubling the value of ℓ_{dh}. Based on guidance from the Concrete Reinforcing Steel Institute, to address worker safety concerns, bars larger than no. 14 with Grade 75 or higher should not be bent.[12]

It is permissible to conservatively take k_{tr} as zero and reduce the calculated ℓ_{dh} by 20%, provided any of the detailing requirements in **Fig. 2** are met. However, for bars being developed by a standard hook at discontinuous ends of components with both side cover and top or bottom cover less than 2.5 in., the hooked bar shall be enclosed within ties or stirrups spaced not greater than $3d_b$ along the full development length ℓ_{dh} (Fig. 2). The transverse reinforcement index k_{tr} is to be taken as zero in this case, and ℓ_{dh} is not to be reduced.

For normalweight concrete with design concrete compressive strengths between 10.0 and 15.0 ksi, the development length of the hooked bars shall be enclosed with no. 3 bars or larger ties or stirrups along the full development ℓ_{dh} at a spacing not greater than $3d_b$. A minimum of three ties or stirrups shall be provided.

Headed Bars

The new provisions for headed bars are to be used for headed no. 11 bars or smaller with a net bearing area of head equal to or larger than four times the bar area, and in normalweight concrete with a design concrete compressive strength of up to 15.0 ksi or lightweight concrete up to 10.0 ksi. Headed bars designed with these provisions shall conform to ASTM A970/A970M[13] and satisfy requirements for Class HA head dimensions (Annex 1 of ASTM A970/A970M).

Headed deformed bars designed according to the new AASHTO LRFD specifications must have a clear cover to the heads not less than two times the bar diameter and a center-to-center spacing not less than three times the bar diameter. The head must be considered when satisfying minimum cover requirements for main reinforcing steel, as listed in Table 5.10.1-1 of the AASHTO LRFD specifications, and the minimum clear spacing requirements of Article 5.10.3.1.

The modified development length in inches for headed deformed bars in tension ℓ_{dt} shall be taken as $\ell_{dt} = \ell_d$ but shall not be less than the greater of 8.0 bar diameters and 6.0 in.

To calculate ℓ_{dt} of a headed deformed bar in tension, the force developed by a head F_h is to be calculated as:

$$F_h = 0.5 A_{ht} \nu f_c' \quad (7)$$

where

A_{ht} = net area of the head that bears on concrete

ν = concrete efficiency factor for a CTT node specified in Table 5.8.2.5.3a-1

For headed no. 11 bars or smaller within beam-column joints, it is

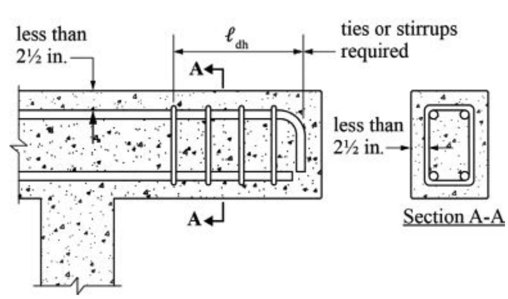


Figure 2. For bars being developed by a standard hook at discontinuous end of components with both side cover and top or bottom cover less than 2.5 in., the hooked bar shall be enclosed within ties of stirrups spaced along the development length ℓ_{dh}. The ties shall have a spacing not greater than $3d_b$. Source: Adapted from Fig. 5.10.8.2.4c-1 of the *AASHTO LRFD Bridge Design Specifications*, 9th ed.

permissible to reduce the development length by 20% if a total area of parallel tie reinforcement equal to 30% of the total area of headed bars is provided between the headed bar and the center of the beam-column joint within $8d_b$ of the centerline of the headed bar.

The development length equations presented in this article have been validated by Zaborac and Bayrak[4] for headed deformed bar sizes up to no. 11 with net bearing area of head equal to or larger than four times the bar area in normalweight concrete with a design concrete compressive strength of up to 15.0 ksi. The MC2010[1] contains a similar general formulation, and it does not restrict the use of lightweight concrete in combination with headed bar anchorage. Equation 5.10.8.2.1a-2 of the AASHTO LRFD specifications accounts for the influence of lightweight concrete by reducing the effective concrete tension strength in bond with the concrete density modification factor λ. Therefore, the use of lightweight concrete is allowed by these provisions, and it is subject to the same concrete strength limits as nonheaded straight bars, lap splices in tension, and hooked bars.

The minimum spacing, cover, and development length requirements are based on the requirements of ACI 318-19. The influence of parallel tie reinforcement is conservatively neglected in the derivation of the headed-bar equations; however, research has shown that parallel tie reinforcement is an effective method for improving the performance of headed deformed bars.[14] The reduction of ℓ_{dt} permitted for the presence of parallel tie reinforcement within beam-column joints is a conservative interpretation of the ACI 318-19 provisions, and it is analogous to the previously described reduction for hooked bars. The influence of confinement reinforcement can be investigated with the strut-and-tie modeling procedure in Article 5.8 of the AASHTO LRFD specifications for most typical cases. If a headed bar does not comply with Article 5.10.8.2.7, then Article 5.10.8.3 or Article 5.13 should be considered.

The concrete efficiency factor for a CTT node specified in Table 5.8.2.5.3a-1 is appropriate for headed bars, regardless of the percentage of reinforcement confining the bar. This is due to low strain values associated with tensile failure of concrete around the bar being anchored and based on the experimental validation reported by Zaborac and Bayrak.[4]

Conclusion

The design expressions presented in this article and approved by the AASHTO Committee on Bridges and Structures were validated by Zaborac and Bayrak by using 1006 tests from the relevant, published technical literature.[4] The statistical performance of the expressions was deemed to be consistent with the calibration intent of the AASHTO LRFD specifications. The revised specifications will reduce the number of unconservatively estimated hooked bar development lengths, particularly for larger bar sizes.

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

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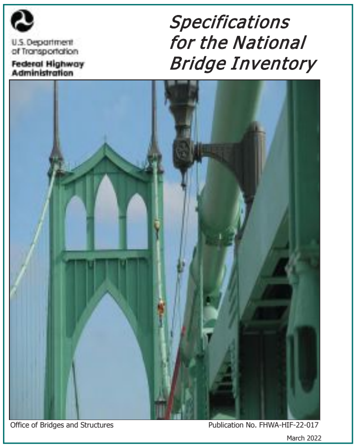

National Bridge Inspection Standards—Part 2, Recent Updates

by Samantha Lubkin and Tom Drda, Federal Highway Administration

Since 1971, the National Bridge Inspection Standards (NBIS) have been at the core of bridge safety in the United States. Part 1 of this article series (see the Fall 2022 issue of *ASPIRE*®) presented a brief history of the NBIS and discussed bridge inspection practices and technologies.

The Federal Highway Administration (FHWA) recently updated the NBIS to address statutory requirements, provide flexibility, and address ambiguities identified since the previous update to the regulation in 2009 (**Table 1**). These changes, many of which were required by the Moving Ahead for Progress in the 21st Century Act (MAP-21),[1] will strengthen the main safety program for highway bridges and bring the NBIS into closer alignment with the National Tunnel Inspection Standards. In addition, the changes will result in improved choices for bridge projects, programs, and policies, and will help focus the Federal-Aid Highway Program to achieve improved bridge performance outcomes. The updates complement the focus of the bipartisan Infrastructure Investment and Jobs Act on bridge improvement and safety, including dedicated funding of more than $27 billion under the Bridge Formula Program and $12.5 billion under the Bridge Investment Program.

Where possible, FHWA has already implemented some of the requirements of MAP-21 through policy or practice. These changes aim primarily to ensure national uniformity for inspections and evaluations as well as clarify responsibilities. Specific changes to the NBIS are described in this article.

Section 650.303 – Applicability

MAP-21 requires that applicability of the NBIS be extended to public highway bridges owned by tribal governments. Applicability has also been extended to temporary bridges, bridges under construction with portions open to traffic, and privately owned bridges that carry public roadways. This update closes a previous loophole.

Section 650.305 – Definitions

The updated regulation includes new terms such as "in-depth inspection," "load path redundancy," and several scour-related terms to provide consistency and clarity in the implementation of the regulations. This revision also renames some existing terms in a more descriptive way; for example, "fracture critical member" is now "nonredundant steel tension member (NSTM)." Several added terms, such as "risk assessment panel (RAP)," are associated with the new risk-based processes for inspection intervals that are required by MAP-21.

Section 650.307 – Bridge Inspection Organization Responsibilities

In some instances, inspection and data submittal responsibilities for bridges that cross a border between states have not be clearly delineated. These situations have led to undue delays in required inspections, inaccuracies in data submittals, and issues with the overall management of border bridges. Consequently, written agreements that document each state's roles and responsibilities are now required. Similarly, any delegated roles or functions (for example, from a state department of transportation to a local agency) must be documented. Any such delegation does not relieve the delegating organization of its responsibilities, as it is accountable for all aspects of the program.

The NBIS now also require all states, federal agencies, and tribal governments to maintain a registry of nationally certified bridge inspectors. It is important for each entity to maintain its own specific registry of certified bridge inspectors, as many agencies have additional requirements beyond those specified by the NBIS.

Section 650.309 – Qualifications of Personnel

The updated NBIS more clearly define the comprehensive bridge inspection training required for program managers and team leaders,

Table 1. *National Bridge Inspection Standards* (NBIS) timeline for implementation

Date	Action
May 6, 2022	Regulation published in *Federal Register*
May 2022	Internal and external webinars on the NBIS and the *Specifications for the National Bridge Inventory*
June 6, 2022	Regulation effective 30 days after publication in *Federal Register* unless noted otherwise in regulation
June 6, 2024	Sections that allow up to 24 months to implement: • 650.309(a), (b)(5), and (c)(3) – qualification requirements for program managers, team leaders, and nonredundant steel tension member (NSTM) team leaders who were in the position prior to the May 2022 regulation update; • 650.309(h)(3) – approval of alternate training that was approved prior to the May 2022 regulation update; and • 650.311(g) – the requirements of 650.311(a)(1)(ii), 650.311(b)(1)(ii), and 650.311(c)(1)(ii) must be satisfied within 24 months (reduced inspection intervals for routine, underwater, and NSTM inspections).

Source: Federal Highway Administration.

Table 2. *Specifications for the National Bridge Inventory* (SNBI) timeline for implementation

Target Date	Action
May 2022	Internal and external webinars on the National Bridge Inspection Standards and the SNBI
July 2022	Data crosswalk available (logic/mapping to transition from legacy National Bridge Inventory [NBI] data to SNBI data)
October 2022	Data submittal schema and data submittal validation logic available
Early 2023	Free training on the SNBI, developed by the Federal Highway Administration, available to inspection staff
April 2023	Transition tool available online
October 2024	NBI NextGen available online for data validation only
March 2025	Last submittal in 1995 Coding Guide[5] format
March 2026	First submittal of SNBI data; 1995 Coding Guide[5] data no longer accepted
June 2026	Transition tool sunsets
March 2028	100% populated and verified SNBI data submittal

Source: Federal Highway Adminstration.

and training participants are now required to score 70% or higher on end-of-course assessments. Additionally, the regulation requires a specific amount of refresher training for program managers and team leaders, and describes the training required to become a team leader for an NSTM inspection or a diver for an underwater inspection.

Professional engineers are now required to have six months of bridge inspection experience to be a qualified team leader, assuming other requirements are met. This requirement was added to ensure that all team leaders have some experience and familiarity with the collection and recording of bridge inspection information, as well as the processes and procedures associated with bridge inspection activities.

Section 650.311 – Inspection Interval

One of the more significant changes to the regulation moves the program to a risk-based approach for determining inspection intervals.[2] This change requires reduced inspection intervals for bridges determined to be at risk based on specific bridge condition criteria. However, it also provides simplified options for establishing extended inspection intervals of up to four years for bridges that are considered low risk.

Alternatively, an agency may choose to employ more rigorous risk-based methods to determine intervals for each inspection type (routine, NSTM, or underwater). Using these methods, a routine or underwater inspection interval could be extended to 72 months for some bridges, but an NSTM inspection interval cannot exceed 48 months. Additionally, agencies will have some flexibility for completing inspections when delays occur, as tolerance windows of up to three months are allowed.

This new approach provides bridge owners the flexibility needed to optimize limited resources to maintain their inventories more efficiently. It may also create cost savings that can potentially be used for maintenance, repair, and reconstruction.

Section 650.313 – Inspection Procedures

To maintain the safety of the traveling public, the NBIS require that agencies establish documented procedures for timely completion of load ratings, load postings, and bridge closures within defined maximum allowances. The regulation also establishes maximum timelines for the initial inspection of a bridge after construction or rehabilitation.

The updated NBIS require hands-on inspection for primary steel components in tension without load path redundancy. However, the "hands-on" requirement may be waived where system redundancy, internal redundancy, or low risk of fracture can be demonstrated through an FHWA-approved procedure.[3]

Previously considered a best practice, quality assurance must now be performed by individuals other than those who completed the initial work. The importance of documenting quality assurance activities is emphasized through the new language in this section. A prevalent theme in this updated regulation is the importance of documentation to ensure consistency and uniformity of inspections, timely follow-up actions, and identification and implementation of improvement opportunities.

The new NBIS update the procedures for reporting critical findings and provide minimum criteria to determine critical findings, for national consistency. A critical finding is a structural or safety-related deficiency that requires immediate follow-up action to ensure public safety.

Section 650.315 – Inventory

Finally, the new *Specifications for the National Bridge Inventory*[4] (SNBI) are incorporated by reference in the new NBIS, superseding the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*[5] (Coding Guide). The FHWA has established a transition timeline (**Table 2**) and will provide specific training on the new specifications. In addition, all bridge-related courses at the National Highway Institute are being updated to incorporate the changes to the NBIS and the adoption of the SNBI.

Information on the NBIS can be found at www.fhwa.dot.gov/bridge/inspection. Questions can be emailed to NBIS_SNBI_Questions@dot.gov.

References

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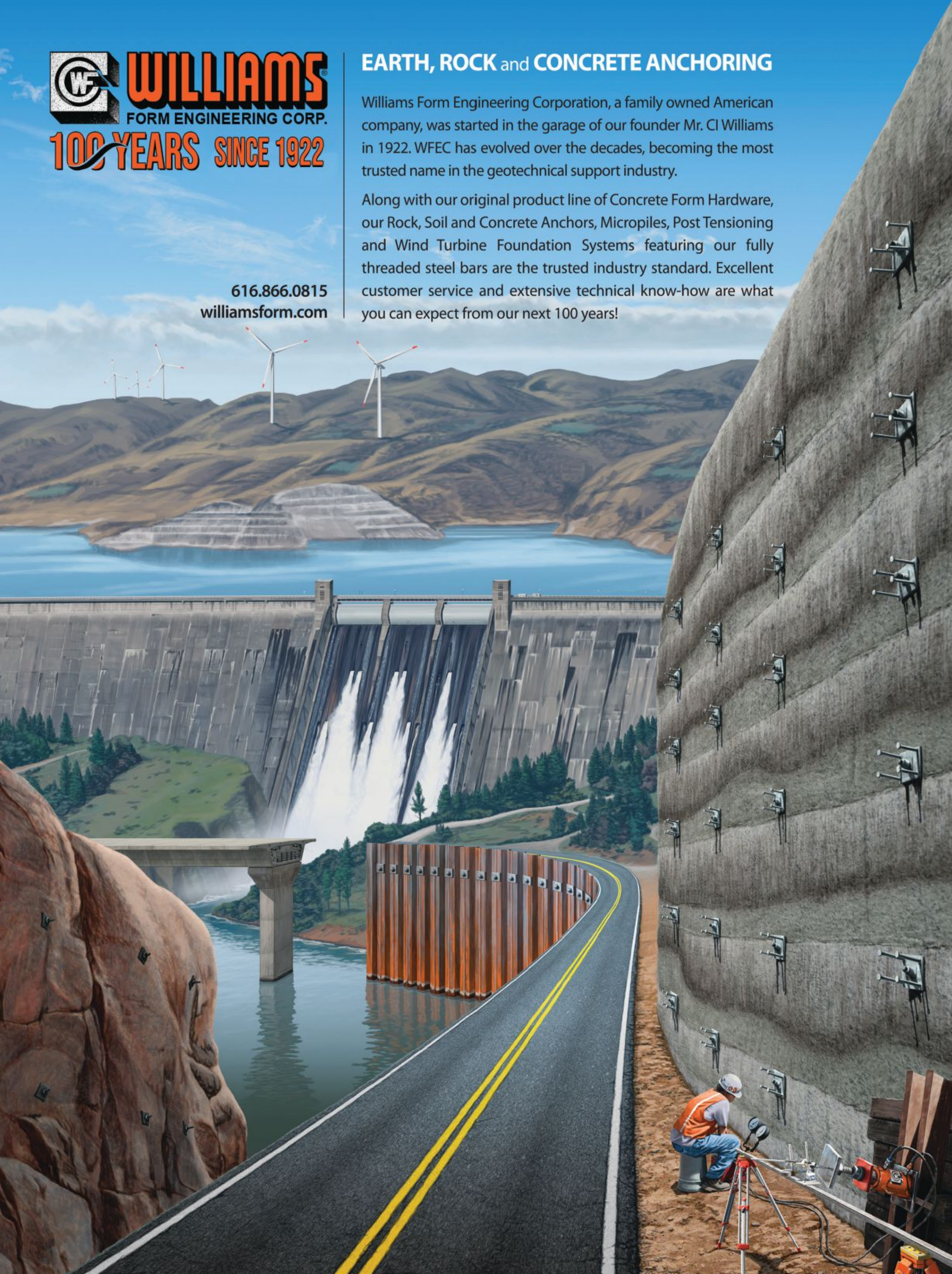
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