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THE CONCRETE BRIDGE MAGAZINE
FALL 2025
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Fuchs Consulting Inc.

Using infrared technology for a closer look at concrete bridges

CHRISTIAN TO CRESCENT BRIDGE
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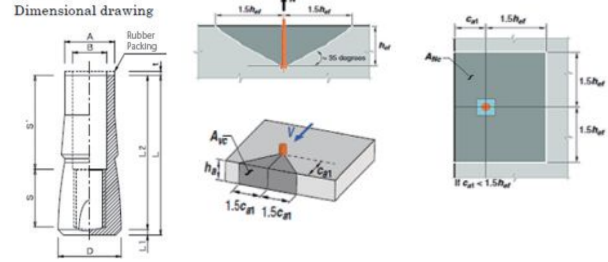
CAPACITY TABLE

Capacity in Concrete fc' = 4,000psi (27.61MPa)

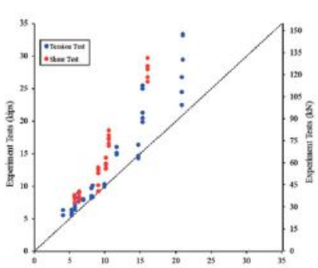
Bolt Diameter	L (hef)	L1	L2	D	A	B	S	S'	Min. Edge Distance	Tension Ca1 >1.5 hef	Tension Ca1 = hef	Shear (ha<1.5Cal)	Shear (ha>1.5Cal)
1/2" 12mm	2.34" 59.5mm	0.079" 2mm	2.26" 57.5mm	0.94" 24mm	0.748" 19mm	0.512" 13mm	0.846" 21.5mm	1.38" 35mm	3.51" 89.25mm	5.1kips 22.71kN	4.8kips 21.38kN	6.7kips 29.84kN	6.3kips 28.06kN
1/2" 12mm	3.11" 79mm	0.079" 2mm	3.03" 77mm	0.94" 24mm	0.748" 19mm	0.512" 13mm	0.846" 21.5mm	2.15" 54.5mm	4.67" 118.5mm	7.0kips 31.18kN	6.7kips 29.84kN	6.5kips 28.95kN	7.2kips 32.07kN
5/8" 16mm	2.97" 75.5mm	0.079" 2mm	2.89" 73.41mm	1.30" 33mm	0.984" 25mm	0.669" 17mm	0.945" 24mm	1.91" 48.5mm	4.46" 113.25mm	6.1kips 27.17kN	5.9kips 26.28kN	11.9kips 53.00kN	6.9kips 30.73kN
5/8" 16mm	3.37" 85.5mm	0.079" 2mm	3.29" 83.5mm	1.30" 33mm	0.984" 25mm	0.669" 17mm	0.945" 24mm	2.30" 58.5mm	5.06" 128.25mm	9.3kips 41.42kN	7.8kips 34.74kN	12.1kips 53.89kN	6.1kips 27.17kN
1" 24mm	4.72" 120mm	0.157" 4mm	4.57" 116m	1.97" 50mm	1.30" 33mm	0.984" 25mm	1.57" 40mm	2.95" 75mm	7.08" 180mm	19.3kips 85.96kN	12.5kips 55.67kN	21.8kips 97.09kN	15.0kips 66.81kN
1" 24mm	5.51" 140mm	0.157" 4mm	5.35" 136mm	1.97" 50mm	1.30" 33mm	0.984" 25mm	1.57" 40mm	3.74" 95mm	8.27" 210mm	18.4kips 81.95kN	11.2kips 49.88kN	23.96kips 106.71kN	15.0kips 66.81kN

*Nominal capacity based on 5% fractile. Φ factors are in accordance with governing code ACI 318-19, 0.9 for tension and 0.75 for shear. For sustained load use Φ=0.33.
*Table is based on 4000psi and 145 pcf concrete.
*For strengths greater/less than 4.000 psi multiply the value by $\sqrt{\frac{f_c'}{4,000}}$.
*Maintain the minimum spacing between inserts of at least 2 x the edge distance.
*ha: concrete block thickness; Ca1: edge distance.

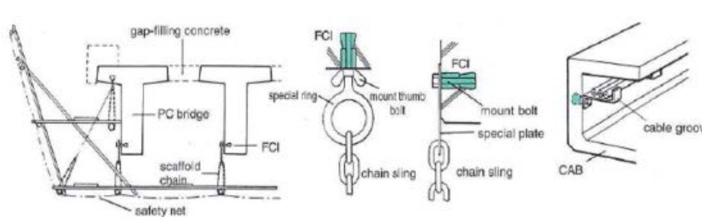
■FCI
Dimensional drawing



The overall testing results for both tension and shear tests for FCI 1 in. [25.4 mm], FCI 5/8 in. [16.0 mm], and FCI 1/2 in. [12.7 mm] inserts.



Bridge Applications



Japan Life Co., Ltd.
1-5-7, Kameido, Koto-ku, Tokyo 137-0071 Japan
tel: +81-3-6260-6346 Fax: +81-3-6260-6328
E-mail: info@japanlife.co.jp URL: www.japanlife.co.jp

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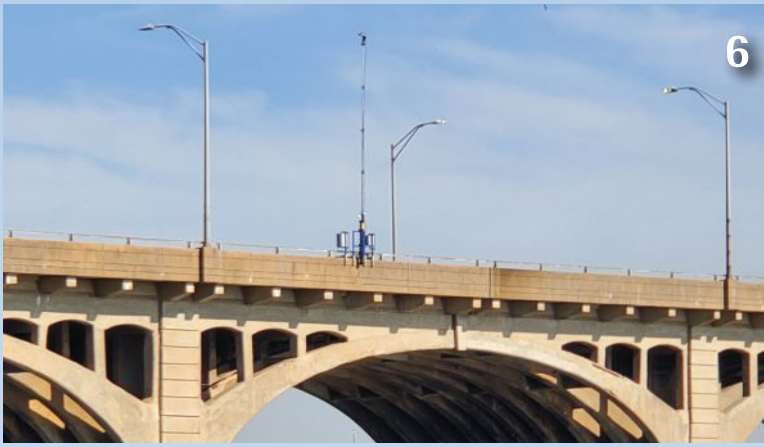

Photo: Fuchs Consulting Inc.

Photo: Michael Worthington, Jr.; Worthington Images.

Photo: Gregg Freeby, American Segmental Bridge Institute.

Features

Departments

Photo: Fuchs Consulting Inc.

Advertisers' Index

EDITORIAL

Photo: PCI.

Ya Don't Know What Ya Don't Know

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

There is a high likelihood that you are aware I have a bit of a concrete bias. I know what you're thinking: that's an understatement! It is not that I believe that concrete is the only material solution that can meet every construction requirement related to durability and sustainability, but I do believe, as Mary Poppins would say, that concrete is "practically perfect in every way."

So imagine my surprise when I was discussing the topic of structural (bridge) design with a fairly new engineer and he told me that we can't mix structural material types on a bridge superstructure. I wasn't sure I heard that correctly, so I asked him to clarify what he meant. He replied, "Well, if you build a bridge out of steel and it needs widening or a retrofit, you need to stick with steel. It just makes sense to stay with the materials previously used." Does it?

The relationship between the component and the connection within the total bridge system is paramount.

Our discussion shifted to connections, how they relate to the structural member or components, and then we returned to the subject of basic overall bridge geometry and load demand. At this point, I decided to start from the beginning and raise some fundamental questions. What's the problem we're trying to solve? What are our environmental (load and deterioration) limitations and restrictions? How do the principles of any general structural design apply to the members and through the connections?

Refocusing the conversation on the load path and basic structural analysis helped the young engineer (and me) better understand possible solutions for superstructure design. We were both reminded that each step in the design process requires the engineer to understand and communicate an overall (holistic) solution that meets strength and stability criteria as well as the performance requirements for current and future needs.

Whenever we have a new project or are planning for the widening of an existing structure, a thorough understanding of all things related to connections, compatible deflections, and load path is the key to addressing misconceptions regarding the feasibility of mixing materials. In my conversation with my young colleague, I explained how ultra-high-performance concrete (UHPC) materials are being used to achieve innovative solutions for connection challenges. By the time we finished our conversation, the young engineer was considering a design in which lightweight precast, prestressed concrete components would be connected to that other material (structural steel) with cast-in-place normalweight concrete diaphragms, and UHPC would be used for the connections and deck closure pours.

In this conversation, exploring some "what if" scenarios was productive and enlightening for us both. My colleague's initial confusion about mixing materials being impractical was resolved by really understanding how to design the connection and defining expectations for the critical sections adjacent to the connection. The relationship between the component and the connection within the total bridge system is paramount. A solid grasp of these concepts should be the starting point for design and can open the aperture as it relates to "mixing materials." Changes in materials could involve several classes of concrete or connecting to structural elements made from carbon-fiber-reinforced polymers, carbon steel rolled shapes, or a lightweight concrete member.

So, the next time you find yourself in a conversation that seems limited by what you perceive or your unfamiliarity with your full range of options, go back to basics and make a connection. I bet that you'll choose a concrete one because concrete offers such a wide range of viable and cost-effective solutions!

Editor-in-Chief
William N. Nickas • wnickas@pci.org

Managing Technical Editor
Dr. Richard Miller

Technical Editors
Monica Schultes, Angela Tremblay, Dr. Krista M. Brown

Program Manager
Trina Brown • tbrown@pci.org

Associate Editor
Thomas L. Klemens • tklemens@pci.org

Copy Editor
Elizabeth Nishiura

Layout Design
Walter Furie

Cover
The Christian to Crescent Bridge winds gracefully along the banks of the Schuylkill River with the Philadelphia, Pa., skyline in the background.

Ad Sales
Scott Cunningham • scunningham7@aol.com
(678) 576-1487 (mobile)
(770) 913-0115 (office)

Reprints
lisa scacco • lscacco@pci.org

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Bob Risser, President

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CONTRIBUTING AUTHORS

Ahmad Abu-Hawash is the infrastructure team leader at the National Cooperative Highway Research Program. He joined the National Academies of Sciences, Engineering, and Medicine in 2021 after a 38-year career at the Iowa Department of Transportation, where he was the chief structural engineer.

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.

Timothy Cullen, PE, is the director of technical activities for Precast/Prestressed Concrete Institute.

R. Kent Montgomery, PE, SE, was a senior technical manager for complex bridges at GM2 Associates in Denver, Colo. He retired in June 2025 but continues to serve as the chair of the Design Subcommittee of the American Segmental Bridge Institute's Technology and Innovation Committee.

Dr. Pinar Okumus is an associate professor in the Department of Civil, Structural and Environmental Engineering at University at Buffalo, the State University of New York. Her research focuses on infrastructure resiliency and longevity. She obtained her PhD from University of Wisconsin, Madison, in 2012 and her BS degree from Middle East Technical University, Turkey, in 2006.

Anthony Ragosta, PE, previously served as the regional director and chief operating officer of ceEntek North America in Albany, N.Y.

CONCRETE CALENDAR 2025–2026

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

October 1–15, 2025
PTI Certification Week
Building Industry Association Hawaii
Waipahu, Hawaii

October 2–5, 2025
Carbon Conscious Concrete (C3) Symposium
Westin Chicago River North
Chicago, Ill.

October 20–22, 2025
Midwest Bridge Preservation Partnership Meeting
Hyatt Regency Columbus
Columbus, Ohio

October 20–25, 2025
PTI Certification Week
Atlanta Marriott Northeast/Emory
Atlanta, Ga.

October 23, 2025
PCI Recommended Practice for Strand Bond Webinar
2 p.m. – 3 p.m. CT

October 26–29, 2025
ASBI Annual Convention and Committee Meetings
Hyatt Regency
Bellevue, Wash.

October 26–29, 2025
ACI Concrete Convention
Hilton Baltimore and Marriott Baltimore Inner Harbor
Baltimore, Md.

November 2–5, 2025
CRSI Fall Business and Technical Meeting
The Drake Hotel
Chicago, Ill.

November 17–22, 2025
PTI Certification Week
Hilton Austin Airport
Austin, Tex.

January 11–15, 2026
Transportation Research Board Annual Meeting
Walter E. Washington Convention Center
Washington, D.C.

January 19–22, 2026
World of Concrete
Las Vegas Convention Center
Las Vegas, Nev.

February 2–6, 2026
PCI Convention at The Precast Show
Kansas City, Mo.

February 27–March 2, 2026
NRMCA Annual Convention
Las Vegas, Nev.

March 29–April 1, 2026
ACI Concrete Convention
Hyatt Regency O'Hare
Rosemont, Ill.

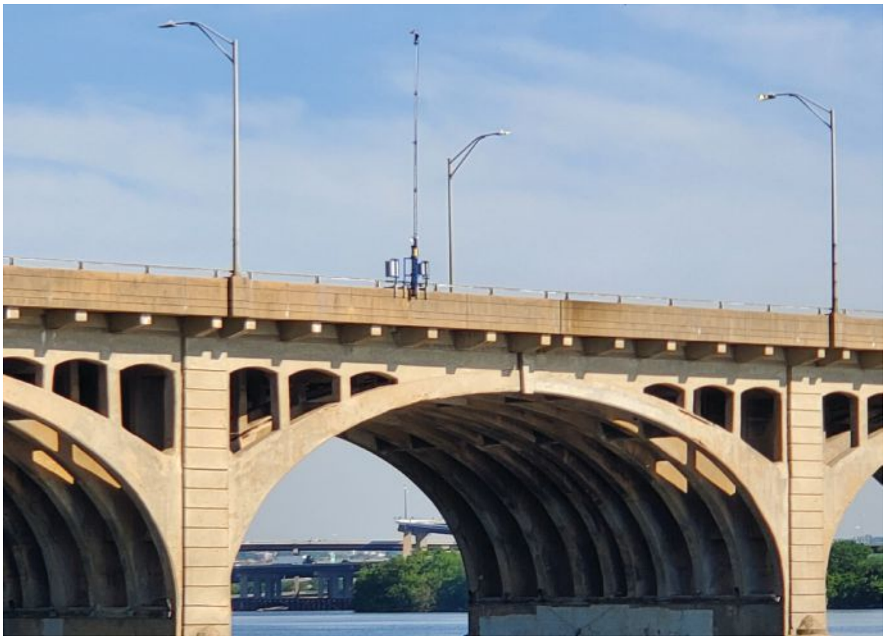
April 13–16, 2026
CRSI Spring Business and Technical Meeting
Silverado Resort
Napa, Calif.

FOCUS

Fuchs Consulting Inc.

With a novel approach to using infrared technology, Fuchs Consulting takes a closer look at concrete bridges

by Monica Schultes



On the Hanover Street Bridge (Vietnam Veterans Memorial Bridge) in Baltimore, Md., infrared ultra–time domain measurements were taken to assess subsurface defects in the concrete deck. All Photos: Fuchs Consulting Inc.

Fuchs Consulting Inc. (FCI) was established in 1998 by Dr. Paul Fuchs. With a background in the field of electrical engineering, Fuchs has brought a fresh perspective to the field of nondestructive evaluation (NDE) and condition inspections of concrete bridges. The firm Fuchs started from his home remains small, with just two employees. FCI specializes in developing NDE systems and instrumentation used to assess highway bridge structures and for military applications.

Improving Bridge Inspection Techniques

Fuchs became interested in NDE when his doctorate research in electrical and electronics engineering brought him to the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center. "My PhD project was sponsored by FHWA, and I developed an ultrasonic strain gauge system to rapidly take strain measurements on bridge structures. My work with FHWA was an introduction to the bridge community," says Fuchs, who is president and CEO of FCI.

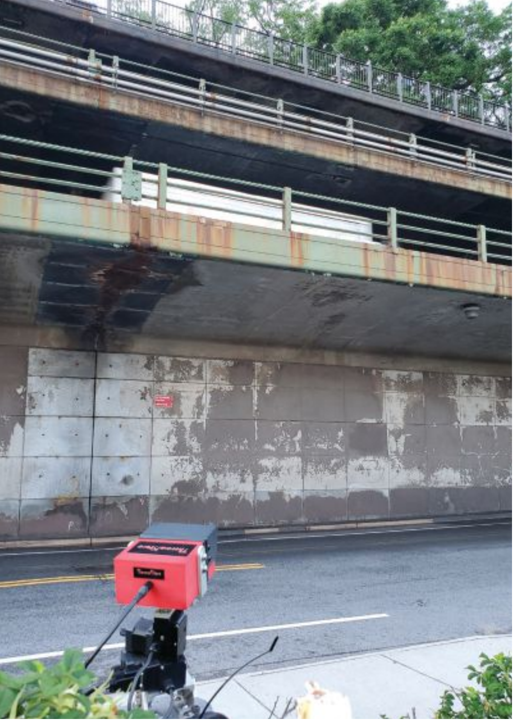
The work that Fuchs performed at the FHWA Turner-Fairbank Highway Research Center helped launch FCI, with the firm taking on consulting and research projects related to the bridge industry. During that time, Fuchs developed a partnership with Dr. Glenn Washer, and the two made significant headway in using infrared technology to acquire data for assessing concrete bridge decks.

Initially, FCI researched concepts to improve the inspection and assessment of all types of infrastructure, such as concrete bridges. In 2009, about a decade after Fuchs founded his consulting business, the U.S. Department of Transportation awarded a Small Business Innovation Research (SBIR) grant to FCI for a project to develop a method to inspect bridge paints. FCI's approach used an infrared-based system to assess and quantify subsurface defects. That initial concept ultimately led to FCI's patented ThermalStare technology for the concrete bridge industry. (For more information on this technology, see the Concrete Bridge Technology article in this issue of *ASPIRE*®.)

Infrared Thermography

Thermal imaging can be an effective tool for the condition assessment of concrete, and specifically for the detection of subsurface delamination. While FCI was developing its infrared technology for the SBIR-funded project, Fuchs recalls thinking, "If this localized system measures a small area of paint on a steel structure, can we expand that and examine larger areas and different substrates?" During those pilot stages, the investigators examined all types of materials, and both concrete and steel bridges. FCI also performed concrete deck assessments and studied the current methods of NDE and bridge-condition evaluations. The firm developed the concept of placing an infrared camera above a bridge deck and leaving it in place to operate for an extended period. "No one had ever used that approach to find internal subsurface defects before," says Fuchs.

In 2014, Fuchs and Washer founded the company ThermalStare to focus on developing and applying their innovative infrared-based NDE technologies. Since then, Fuchs and Washer have created a suite of products for the bridge industry inspired by the original time-lapse thermography concept. Their technology can show subsurface damage in concrete, and



Infrared ultra–time domain measurements were taken on the triple cantilever design section for the Brooklyn-Queens Expressway for the New York City Department of Transportation. Measurements of the soffit or underside of the deck were taken with the equipment at ground level.

The Indiana Department of Transportation was an early adopter of the ThermalStare system, using it to measure defects in Indiana's concrete bridges. The camera attached to the bridge parapet uses time-lapse infrared thermography to detect damage.

it can also detect defects in coatings used in military applications. Today, FCI and ThermalStare offer a diverse range of options to their customers, from building the thermal imaging equipment to performing inspection services to analyzing the data. While most of their work focuses on bridges, their applications extend to cooling towers at power plants, tunnels, dams, and military installations.

A New Inspection Paradigm

FCI and ThermalStare are based in Leesburg, Va., but their small team is often on the road, deploying ThermalStare equipment on bridges and demonstrating the benefits of this technology to departments of transportation and others. While much of their work is on the East Coast, the consultants have also crisscrossed the United States, completing work from Washington, D.C., to Salt Lake City, Utah, and Portland, Ore.

Agencies and owners can make use of FCI services and ThermalStare technologies in a variety of ways. For example, FCI and ThermalStare may serve as consultants to a prime contractor or as an engineering consultant for an owner seeking to evaluate a bridge deck as part of a larger rehabilitation study.

The Indiana Department of Transportation (INDOT) was an early adopter of ThermalStare technology. INDOT operates the systems with their own personnel and then sends the accumulated data to FCI to analyze. In other states, including Maryland, South Carolina, North Carolina, Missouri, Oregon, New Jersey, New York, Virginia, Utah, Pennsylvania, Ohio, and Washington D.C., agencies have used FCI as an independent consultant to examine bridge decks or substructures.

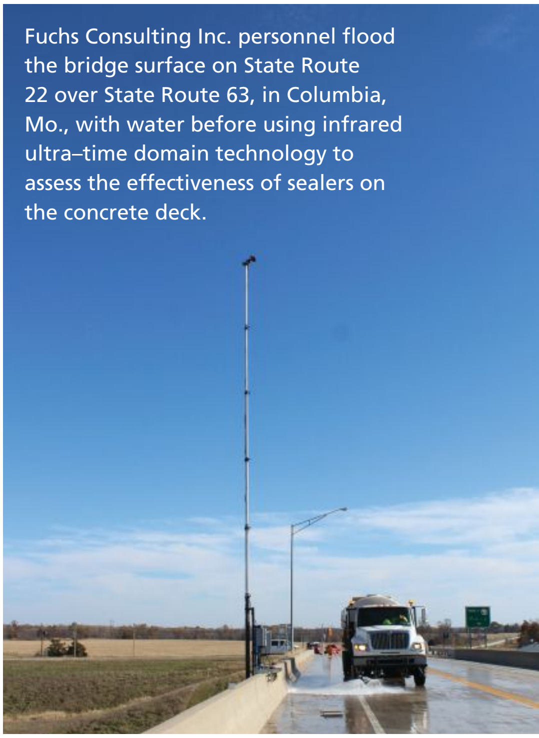
"We have proposed and developed a new paradigm for the way inspections are done on structures," says Fuchs. "We are introducing our capabilities to the industry, so that is why we offer a combination of services, depending on the owners' needs."

"We have proposed and developed a new paradigm for the way inspections are done on structures."

Reliability and Safety Advantages

Because deterioration in bridges from subsurface damage cannot be seen through visual inspections, owners need alternative inspection methods for early detection of such damage. The infrared technologies developed by FCI address this need for early detection and provide accurate measurements that were not previously achievable.

The concept of finding defects in concrete with infrared technology has a storied past. While the industry has used infrared imaging for decades, concerns about unreliable data have



Fuchs Consulting Inc. personnel flood the bridge surface on State Route 22 over State Route 63, in Columbia, Mo., with water before using infrared ultra–time domain technology to assess the effectiveness of sealers on the concrete deck.

been raised. When measurements are taken at one point in time, there will be uncertainty as to the best time to perform the inspection and there is a high likelihood that the imaging will miss some defects.

Compared with traditional infrared imaging technology, the equipment and methodologies developed by FCI are highly innovative. The time-lapse approach to take measurements is uniquely their own, and so is the camera equipment packaged into the system for bridge inspection. FCI has also developed software to capture and analyze the data, and the firm's offerings can be customized to the client's specifications or applications.

FCI's infrared ultra–time domain (IR-UTD) methodology vastly increases measurement reliability because the data are collected over time, providing more information than can be gathered at a single point in time. As a result, owners can identify and analyze defects more effectively than was previously possible. Data collected with ThermalStare technology provide a deeper look into concrete than is possible with conventional infrared cameras. "In a side-by-side comparison, owners are shocked at how much more information is available," Fuchs says.

Using infrared ultra–time domain equipment, Fuchs Consulting Inc. was part of an investigative team that performed a condition assessment of the 11-span Interstate 66 ramp bridge to the Whitehurst Freeway in Washington, D.C. The ramp bridge is a concrete box-girder structure with a concrete overlay.

The reach of IR-UTD technology is a matter of optics and positioning. The equipment is typically installed approximately 36 ft above the deck. From that vantage point, inspectors can view 12,000 to 15,000 ft^2 of bridge deck at one time. The camera is usually mounted for two days, which will generally provide sufficient data. The equipment is robust and built for all conditions, so variations in weather and traffic do not affect the data gathered. As Fuchs explains, "the measurements are ideal for structures with heavy traffic that cannot be easily disrupted to assess the deck."

"The measurements are ideal for structures with heavy traffic that cannot be easily disrupted to assess the deck."

Another advantage of the technology is improved safety. Because ThermalStare cameras are attached to a pole or similar perch and left in place, their use avoids safety concerns related to lane closures and inspectors performing bridge soundings and other NDE on sites adjacent to traffic.

Fuchs predicts that small IR-UTD assemblies similar to traffic cameras could eventually be used in ways that have not yet been identified. States have thousands of bridges of all different ages and conditions, and reliable data that can be collected economically will lead to more informed decisions. "Our goal is to make the technology economical enough to put these assemblies on all major structures," he says.

Ramp to Whitehurst Freeway, Washington, D.C.

In 2021, when the District (of Columbia) Department of Transportation (DDOT) retained RK&K to create a condition assessment report of the Interstate 66 ramp bridge to the Whitehurst Freeway in Washington, D.C., FCI doing business as ThermalStare was part of the investigative team. This bridge had a total deck thickness of 9 in. (a 6½-in.-thick top flange of the multiple cell box girders with a 2½-in.-thick concrete overlay). ThermalStare used stationary, time-lapse infrared imaging systems mounted to the bridge parapet at five locations to perform infrared imaging of all 11 spans of the bridge over a two-day period.

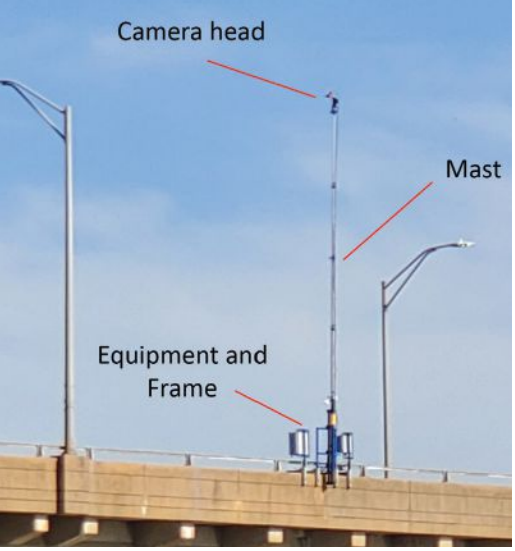
In addition to the infrared imagery, the condition assessment involved a visual inspection, concrete coring, compressive-strength testing, chloride-content analysis, petrographic analysis, half-cell potential testing, and ground-penetrating radar. The infrared imagery data were used to plan the coring and half-cell potential measurement locations. Using these data,

History of Fuchs Consulting

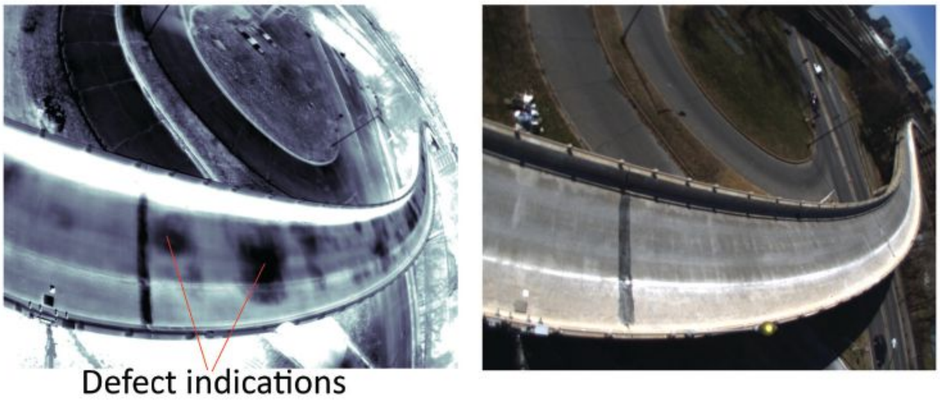
Dr. Paul Fuchs, founder of Fuchs Consulting Inc. (FCI), established his firm in 1998. A major milestone in the FCI's history was its award of the highly competitive Small Business Innovation Research (SBIR) grant from the U.S. Department of Transportation in 2009. The SBIR program helps small businesses like FCI develop solutions for transportation challenges, and FCI used the funding to develop an infrared-based system to assess and quantify subsurface defects.[1] That system offers alternatives to bridge owners in condition assessments of their concrete structures. The success of the SBIR-funded project enabled FCI to acquire a new facility for research and development as well as manufacturing and expand their patented technology.

FCI has continued to have success turning research into commercial products. Fuchs and Dr. Glenn Washer formed ThermalStare in 2014 as a new company for commercial applications.

Today, the FCI/ThermalStare team remains committed to developing promising ideas, refining their methods, and creating innovative applications.



The assembly for taking measurements with infrared ultra–time domain equipment, shown here on the Hanover Street Bridge in Baltimore, Md., is similar to the light poles that are supported by the bridge parapet.



Infrared ultra–time domain equipment can capture data over a large bridge deck area with a single setup, allowing inspectors to view 12,000 to 15,000 ft^2 of bridge deck at one time to find deteriorating or delaminated concrete.

ThermalStare correctly predicted 95% (21 of 22) of the concrete cores to be either defective or intact. The average depth to a defect was 3.25 in. (2.25 in. minimum to 4.50 in. maximum). The assessment helped DDOT determine the necessary repairs to extend the service life of the structure, evaluate alternatives, and estimate the repair cost.

Hanover Street Bridge, Baltimore, Md.

Working as a consultant to RK&K, FCI/ThermalStare recently completed bridge condition measurements for the five-lane Hanover Street Bridge (Vietnam Veterans Memorial Bridge) over the middle branch of the Patapsco River in downtown Baltimore, Md. The historic, 2200-ft-long concrete arch bridge, built in 1916, is in poor condition, and stakeholders are grappling with the decision to rehabilitate or replace the structure. The bridge experiences high traffic volumes, and FCI technology facilitated data collection while minimizing inconvenience for the traveling public.

Studying Surface Sealants

While surface sealants are frequently used on bridges across the United States, there are currently no standardized methods to assess the need for resealing a concrete deck or the quality of the sealant installation. When the FHWA's Innovations Deserving Exploratory Analysis (IDEA) Program funded research into the effectiveness of sealants applied to concrete bridge decks, FCI began to study sealants as an extension of their success with IR-UTD technology.

"Instead of looking at the defects deep in the concrete, we used the same idea to assess if the sealant applied to the top of the concrete is working effectively or not," says Fuchs. In 2021, FCI developed Thermal SealCheck, which uses time-lapse thermography to measure water evaporation.

To evaluate sealant effectiveness, FCI floods a concrete deck with water, measures the evaporation of the water with time-lapse thermal imaging, and analyzes the data to determine whether the sealant is working to prevent water from penetrating the concrete. This technology can differentiate sealed from unsealed concrete, and the measurement test is completed in 1 hour in the field. This method also evaluates whether the initial sealant was applied effectively. With enough accumulated data, transportation departments could develop prescriptive protocols related to sealants, rather than relying exclusively on periodic applications every few years.

Future Innovations

Going forward, FCI intends to expand the use of IR-UTD technology for applications beyond the deck. For example, the technology can be used to inspect concrete abutments, column caps, piers, and the undersides of bridges. The collected data could help agencies better understand what types of elements perform better, where typical defects occur, and when the optimal time is to make repairs. Furthermore, if the technology is stationed on structures for lengthy periods of operation, a constant flow of information could improve decision-making processes related to maintenance, repair, and rehabilitation. "Usually, nondestructive testing of a bridge deck is a one-time measurement, which gives you limited information. In the future, we envision cameras mounted on critical structures constantly collecting data," says Fuchs.

"In the future, we envision cameras mounted on critical structures constantly collecting data."

Bridge engineers design structures for a long service life, but do not always have the tools to visualize how their decisions impact the maintenance phase. FCI explores how infrared technology, something that has been used for NDE for decades, can be used as a practical data-driven tool to support maintenance and serviceability goals. Data from their IR-UTD products can add value to future maintenance efforts and help owners make informed decisions regarding rehabilitation schedules.

Reference

1. U.S. Department of Transportation Volpe Center. 2018; updated 2022. "Detecting Damage in Structural Components with New Infrared Technologies." https://www.volpe.dot.gov/news/detecting-damage-structural-components-with-new-infrared-technologies.

PERSPECTIVE

The National Cooperative Highway Research Program Works to Move Concrete Bridges Forward

by Ahmad Abu-Hawash, National Academies of Sciences, Engineering, and Medicine

In my role with the National Cooperative Highway Research Program (NCHRP), I am often asked about what we do and how the NCHRP fits into the broader research ecosystem. From refining technical specifications to enabling the adoption of cutting-edge materials and methods, NCHRP helps shape the future of concrete bridge engineering. The program's collaborative and expert-driven approach ensures that research translates into practice, facilitating the building of a safer, longer-lasting, and more innovative infrastructure nationwide.

NCHRP's Contributions to Concrete Bridges

NCHRP has a long history of supporting innovations in concrete bridge research. This research has provided the technical foundation for several sections in many editions of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] As illustrated by the publications and projects listed in **Tables 1** and **2**, NCHRP research covers a wide range of concrete innovations such as ultra-high-performance concrete (UHPC), accelerated bridge construction (ABC), precast and prestressed concrete bridge elements, and tensioning elements (0.7-in.-diameter strand, stainless steel strand, fiber-reinforced polymer strand).

The National Academies

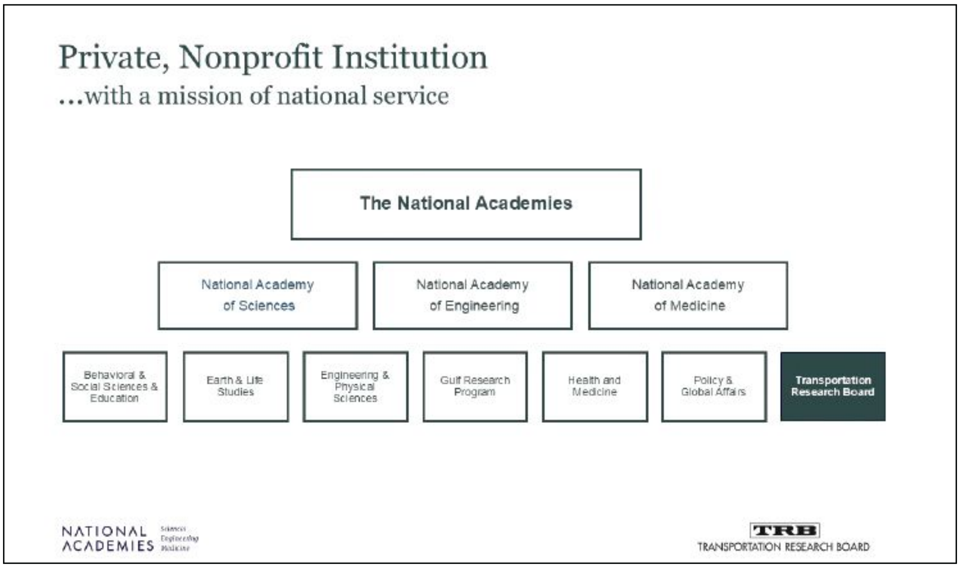
The National Academies of Sciences, Engineering, and Medicine began in 1863, when the National Academy of Sciences was established by an act of Congress signed by President Abraham Lincoln. The National Academies are private, nonprofit organizations, whose primary function is to advise the United States on issues related to science and technology to help solve complex problems and inform public policy decisions. Under the umbrella of the National Academies, the Transportation Research Board (TRB) is the unit that is responsible for transportation research.

Table 1. Selected National Cooperative Highway Research Program (NCHRP) publications

Publication	Project
NCHRP Research Report 906: *LRFD Minimum Flexural Reinforcement Requirements* (https://doi.org/10.17226/25527)	**12-94**
NCHRP Research Report 1026: *Guidelines for Adjacent Precast Concrete Box Beam Bridge Systems* (https://doi.org/10.17226/27029)	**12-95A**
NCHRP Research Report 895: *Simplified Full-Depth Precast Concrete Deck Panel Systems* (https://doi.org/10.17226/25562)	**12-96**
NCHRP Research Report 907: *Design of Concrete Bridge Beams Prestressed with CFRP Systems* (https://doi.org/10.17226/25582)	**12-97**
NCHRP Research Report 935: *Proposed AASHTO Seismic Specifications for ABC Column Connections* (https://doi.org/10.17226/25803)	**12-105**
NCHRP Research Report 994: *Use of 0.7-in. Diameter Strands in Precast Pretensioned Girders* (https://doi.org/10.17226/26677)	**12-109**
NCHRP Research Report 1139: *Considerations for the Design and Construction of Bonded and Unbonded Post-Tensioned Concrete Bridge Elements* (https://doi.org/10.17226/29033) NCHRP Web-Only Document 417: *Background and Resources for the Design and Construction of Bonded and Unbonded Post-Tensioned Concrete Bridge Elements* (https://doi.org/10.17226/29032)	**12-118**
NCHRP Research Report 1161: *Stainless Steel Strands for Prestressed Concrete Bridge Elements* (forthcoming)	**12-120**
NCHRP Research Report 1128: *Load Rating of Segmental Bridges* (https://doi.org/10.17226/28597)	**12-123**
NCHRP Research Report 999: *Design and Construction of Deck Bulb Tee Girder Bridges with UHPC Connections* (https://doi.org/10.17226/26644)	**18-18**

Table 2. Selected in-progress and anticipated National Cooperative Highway Research Program projects

Project	Title	Status
12-121	Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement	In progress
12-129	Evaluating Concrete Girders with Noncompliant Shear Details	Contract pending
12-130	Holistic Re-evaluation of Service III Limit State for Prestressed Concrete Bridge Members	Anticipated
20-123(20)	Roadmap to Update Bridge Deck Design Requirements	In progress
22-56	Development of Non-proprietary Prefabricated Solutions for Concrete Barrier Systems for Accelerated Bridge Construction	In progress



Organization of the National Academies of Sciences, Engineering, and Medicine. All Figures: National Cooperative Highway Research Program.

TRB has three divisions:

- Technical Activities, which is responsible for the TRB standing committees, annual meetings, papers, workshops, webinars, and other technical activities
- Consensus and Advisory Studies, which is responsible for research on complex and controversial transportation issues at the request of the U.S. Congress, executive branch agencies, states, and other sponsors
- Cooperative Research Programs (CRP), which is focused on research to address the toughest transportation challenges in the United States

To cover most modes of transportation, CRP has four programs. NCHRP is responsible for highway research while the other three focus on traffic safety, airports, and transit. In partnership with AASHTO, NCHRP is focused on applied research that is important to state transportation agencies with national and shared interests. Each year, state departments of transportation (DOTs) voluntarily contribute 5.5% of the State Planning and Research portion of their Federal-Aid Highway funds to support NCHRP research. The transfer of funds is administered by the Federal Highway Administration (FHWA).

The NCHRP Process

Problem statements for NCHRP projects are conceived through collaboration among state DOTs, AASHTO committees and councils, industry stakeholders, and academic institutions to address specific needs such as helping AASHTO develop new design and construction methods or enhance existing methods. While many practitioners from industry and academia participate in developing problem statements, only state DOTs, AASHTO committees and councils, and FHWA may formally submit them. NCHRP, AASHTO, and FHWA staff review the submissions and provide comments and questions to the submitters. Submitters have an opportunity to respond to those questions, but problem statements may not be revised and resubmitted. In other words, the comments and the submitters' responses will be noted with the problem statement to help reviewers in the evaluation process, but the original submission cannot be changed. Problem statements are always due on November 1.

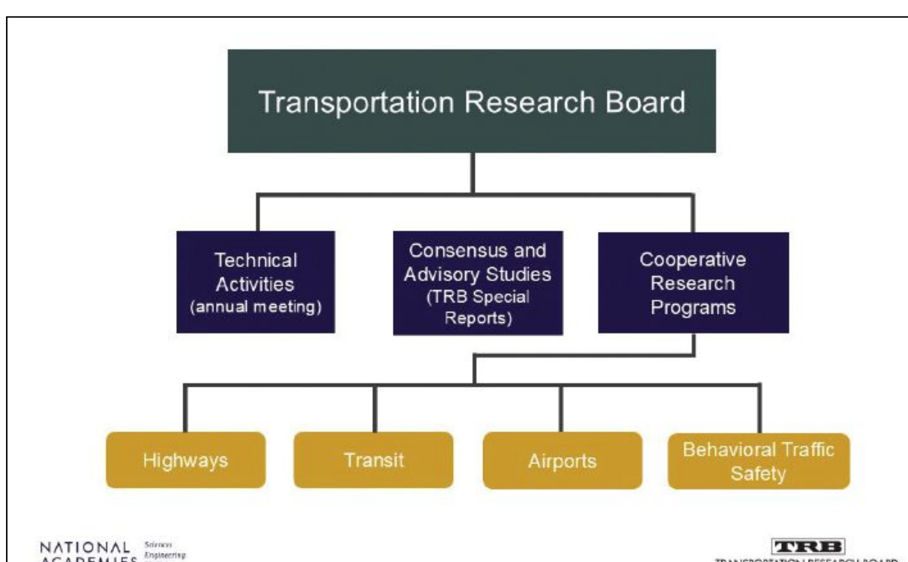
Every April, the AASHTO Special Committee on Research and Innovation (R&I) selects problem statements for funding and forwards them to the AASHTO Board of Directors for approval. Each problem statement is evaluated based on specific criteria, including the following:

- Does the statement represent a current and relevant problem?
- Is the problem shared among many DOTs?
- Is the problem appropriate for NCHRP, or should it be addressed by another program or entity?

For fiscal year 2026, of the 123 problem statements submitted, 60 were selected for funding, including 10 related to bridges and structures.

The journey does not end once problem statements are selected for funding. Assembling project panels, developing clear and actionable requests for proposals, and selecting a team to carry out each project are subsequent parts of the process.

The Transportation Research Board (TRB) is the unit of the National Academies that is responsible for transportation research.



Each project panel includes six to eight expert volunteers representing all AASHTO regions and includes representatives from industry and academia. These panels are managed by an NCHRP senior program officer and include a liaison from FHWA and AASHTO.

A Culture of Service

As a former state DOT engineer, I relied on the research NCHRP produces and I served as a panelist on many NCHRP projects. That experience allowed me to see firsthand the impact NCHRP has on the state of practice. It also gave me a deeper understanding of AASHTO specifications, many of which are based on NCHRP research, and the collaborative process that shaped them.

Serving on a project panel is a unique opportunity to both contribute and learn. Panel members are selected for their technical expertise—but we look for more than just technical expertise. At NCHRP, we strive to form well-balanced and objective panels. We also aim for broad representation in terms of geography and organization types (for example, public and private agencies, universities, associations, local and state governments). I can say from experience, being a panel member is one of the most impactful ways to stay engaged with the profession and help shape the future of transportation.

If you are interested in joining a panel, visit the TRB website for information about the nomination process: https://www.trb.org/NCHRP/CRPInfoPanelMembers.aspx.

Final Thoughts

Bringing together professionals from across the United States and across sectors helps ensure that NCHRP research is widely respected and broadly applicable. The research reflects the real-world challenges and insights of those working in transportation every day.

Having participated in the NCHRP program, first as a state DOT engineer and now as part of the team that spearheads it, I remain proud to be part of work that truly moves our profession forward.

Reference

1. American Association of State Highway and Transportation Officials (AASHTO). 2024. *AASHTO LRFD Bridge Design Specifications*. 10th ed. Washington, DC: AASHTO.

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Japan Life www.japanlife.co.jp	**Japan Life's FCI (Fine Ceramic Insert)** was tested and FEM analyzed at University of Houston, and was confirmed it meets and exceeds all ACI predictions. **FCI** is inherently corrosion free, and its weight is 1/2 of metals while its hardness is next to diamond. **FCI** is ideal for bridges and other structures under corrosive environment hanging scaffolding for maintenance and brackets for cabling. Japan Life is a one-stop supplier for the global precast/prestressed industry including the inserts and lifting devices as well as all the customized materials and equipment, and is now ready to serve US Precast and Prestressed Concrete industry focusing first on **FCI**.	Kinshicho Prime Tower Koto City, Tokyo 136-0071 Japan iwashita@japanlife.co.jp
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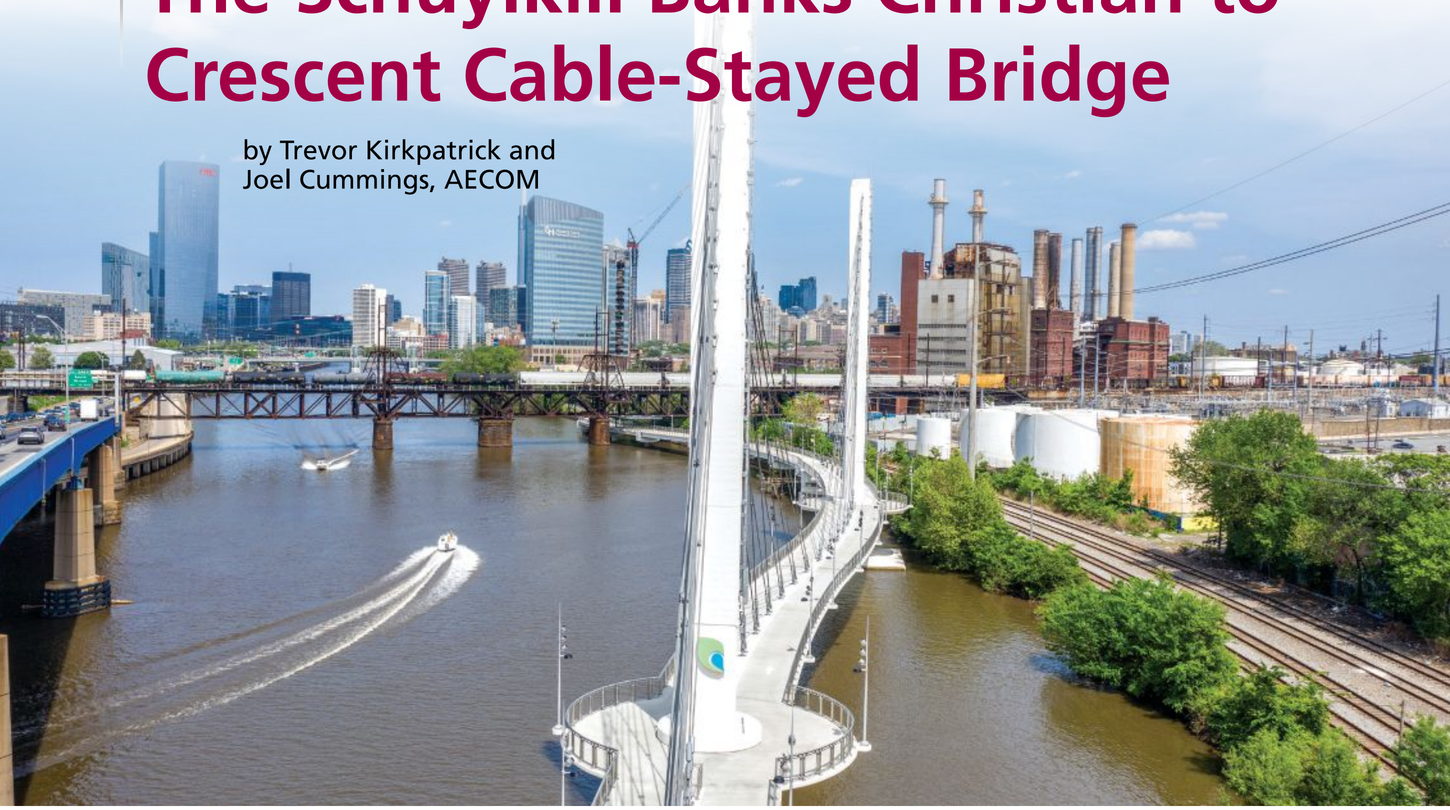
PROJECT

Bridging Innovation and Practicality: The Schuylkill Banks Christian to Crescent Cable-Stayed Bridge

by Trevor Kirkpatrick and
Joel Cummings, AECOM



A view of the graceful S-curve alignment of the Christian to Cresent Bridge, with the Philadelphia, Pa., skyline in the background. Photo: Michael Worthington, Jr.; Worthington Images.

The Schuylkill Banks Christian to Crescent Bridge in Philadelphia, Pa., is a striking example of the integration of precast concrete U-beams into a complex pedestrian bridge structure. In this project, precast concrete U-beams were selected for four key reasons: U-beams can span long distances with limited permanent and temporary supports; construction would be fast and efficient; the structure would have long-term durability with minimal maintenance; and the U-beams would give stakeholders the needed flexibility to meet structural and aesthetic design goals. Each of these aspects played a role in the success of this bridge.

About the Bridge

The new, 650-ft-long Christian to Crescent Bridge is a cable-stayed structure that links Philadelphia's Center City section of the Schuylkill River Trail with the Grays Ferry Crescent segment of the trail. The elegant and practical bridge design features precast concrete U-beams made integral with two cast-in-place towers that rise 139 ft above the deck. Each of the towers anchors 28 wire-rope cables supporting the superstructure. The cables are 2¾-in.-diameter ASTM A586 galvanized structural strand with Class A coating

profile

CHRISTIAN TO CRESCENT BRIDGE / PHILADELPHIA, PENNSYLVANIA

BRIDGE DESIGN ENGINEER: AECOM, Tampa, Fla.

BRIDGE ARCHITECT: Bradley Touchstone, AECOM, Tampa, Fla.

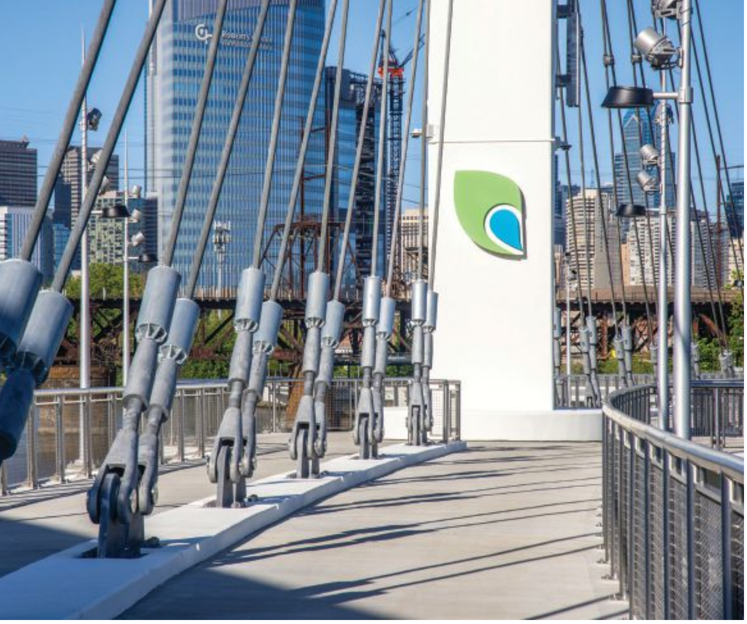
OTHER CONSULTANTS: Construction management and inspection: Pennsylvania Department of Transportation; Urban Engineers, Philadelphia, Pa.; TRC, Philadelphia, Pa.; City of Philadelphia; construction engineer: Janssen & Spaans Engineering, Indianapolis, Ind.

PRIME CONTRACTOR: PKF-Mark III, Newtown, Pa.

CONCRETE SUPPLIER: Silvi Materials, Philadelphia, Pa.

PRECASTER: The Fort Miller Co. Inc., Greenwich, N.Y.—a PCI-certified producer

POST-TENSIONING SUPPLIER: DYWIDAG-Systems International, Bolingbrook, Ill.



The center-cable arrangement with streamlined pin-and-clevis cable anchors supports the superstructure. Photo: Michael Worthington, Jr.; Worthington Images.

The bridge features a streamlined, curved precast concrete spliced U-beam superstructure with cables in a basketweave pattern. Photo: Michael Worthington, Jr.; Worthington Images.

inner wires and Class C coating outer wires. The curved, spliced, precast and post-tensioned concrete U-beams are integrated with a cast-in-place 25-ft-wide bridge deck with circular overlooks at each tower. The deck thickness varies from 9 in. at the fascias to 11¼ in. at the bridge centerline. Above the deck, the towers taper in two directions, adding dimension and interest. The cables are arranged in a distinctive basketweave pattern and are anchored with elegant pin and clevis anchors for a streamlined look. The towers are founded on nine 6-ft-diameter steel-encased caissons that extend 60 ft below the bottom of the footing, including 20 ft of rock socket.

The Schuylkill River Trail is a planned 130-mile-long, off-road recreational trail and greenway that extends along the river from Schuylkill County, Pa., to the confluence of the Schuylkill and Delaware Rivers. The new pedestrian bridge, which is part of the trail, was completed in May 2025, closing the last remaining gap in the 4 miles of trail on the east side of the river and transforming how people move throughout the city.

Integrating Architectural and Structural Form with Community Needs

More than just crossings, bridges are community landmarks that reflect shared values and aspirations. By using precast concrete U-beams, the project team for the Christian to Crescent Bridge integrated thoughtful structural innovations to create a highly functional and visually distinctive bridge that enhances the Schuylkill River Trail experience for pedestrians and cyclists.

Reinforcement and the draped post-tensioning ducts for one of the U-beam segments are set up at the precast concrete manufacturing facility. Photo: Fort Miller Precast.

CITY OF PHILADELPHIA/SCHUYLKILL RIVER DEVELOPMENT CORPORATION, OWNER

OTHER MATERIAL SUPPLIERS: Precast concrete transport: Carver Companies, Albany, N.Y.; concrete formwork: Doka (custom tower form and deck overhang); EFCO (deck overlook support and end diaphragms); reinforcement fabricators: Re-Steel Supply, Eddystone, Pa.; Men of Steel, Bensalem, Pa. (prefabricated drilled shaft cages); bearings: RJ Watson, Alden, N.Y.

BRIDGE DESCRIPTION: 1800-ft-long pedestrian bridge structure, including a 650-ft-long cable-stayed bridge with a basketweave cable pattern on an S-curve alignment with a curved, precast concrete, post-tensioned U-beam superstructure

STRUCTURAL COMPONENTS: 84-in.-deep, curved, spliced, and post-tensioned precast concrete U-beams with a variable thickness (9 to 11¼ in.) cast-in-place concrete deck; 72-in.-diameter drilled shafts; cast-in-place concrete footings and towers

BRIDGE CONSTRUCTION COST: $48 million total project cost; $22 million for the cable-stayed bridge (approximately $1300/ft^2)

AWARDS: PCI Bridge Award; 2025 PTI Award of Merit Bridges Category

A precast concrete U-beam segment is transported to the dock facility in Albany, N.Y., before being shipped by barge to the project site. Photo: Fort Miller Precast.

The project team developed the concept through careful planning and in close collaboration with the City of Philadelphia and the Schuylkill River Development Corporation. The initial effort began with a 2016 feasibility study that explored four bridge types and recommended a straight alignment. Ultimately, the alignment was adjusted to incorporate a graceful 950-ft-radius reverse curve to avoid obstructions along the river. This practical and aesthetic decision led to the selection of a cable-stayed bridge with precast concrete U-beams.

After the bridge type was established, precast concrete U-beams became a central element in achieving the objective of providing a landmark structure to connect the communities. Unlike cast-in-place alternatives, precast concrete U-beams could be fabricated in long sections off site. In addition, erection required fewer temporary piers than would be used for a cast-in-place structure, thereby reducing the impact of construction on the community. Equally important, the use of precast concrete U-beams provided a clean, streamlined appearance, free of bolted splices or segment joints that might distract from the bridge's elegant silhouette. The U-beams also paired well with steel cable anchors cast into concrete diaphragms.

The center-cable arrangement required a torsionally rigid superstructure to support loading demands. To address this challenge, the design combined curved, spliced, post-tensioned precast concrete U-beams with a cast-in-place composite concrete deck. Together, these elements create a closed cross section that efficiently resists torsional forces generated by the curved geometry while maintaining durability, safety, and constructability within a highly constrained urban environment. The result is a smooth, modern structure that fits comfortably into the urban landscape and serves as a civic destination.

Advancing Curved U-Beam Technology

The curved precast concrete U-beams used in the Christian to Crescent Bridge exemplify the advances in technology developed over the years. Curved precast concrete U-beams were initially developed by the Colorado prestressed concrete industry during the 1990s, and their use has since expanded across the United States. A collaboration of designers, contractors, and owners developed PCI's *Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges*.[1]

The U-beam section on the Christian to Crescent Bridge followed the web and top flange proportions recommended in PCI's guide document, but the bottom flange was widened to suit the project's unique needs, and embedded couplers

AESTHETICS COMMENTARY

by Frederick Gottemoeller

When it is completed, the Schuylkill River Trail will extend from Tuscarora Springs in Schuylkill County some 120 miles until it joins the Delaware River in Philadelphia's Center City, providing recreational opportunities and pedestrian and bicycle routes in the communities through which the river passes. For most of its length, the trail winds its way through the woods along the riverbanks. But the design challenges are very different in the urbanized sections of the valley, and most different of all in downtown Philadelphia.

In Center City, the riverbanks are already occupied by highways, railroads, and power lines. Therefore, most of the trail's Christian to Crescent section must be over water. (Unlike most river bridges, this one runs parallel to the riverbanks.) Notably, the highways, railroads, and power lines have ramps, bridges, and pylons that not only occupy the riverbank space but also conceal the river itself from the surrounding city. In this setting, the design challenge was twofold: to provide a physical passage along the river and to create a visual symbol that says "Hey, I am here."

To provide physical passage, it made economic sense to minimize the number of foundations in the water, a decision that suggested the use of long spans. Long spans inspired the vision of a cable-stayed structural system that would give the bridge tall vertical elements capable of visually competing with the confining ramps, bridges, and pylons. These aspects of the design were all just applied common sense.

The art of the design is evident in the unique basketweave pattern of the stays. The pattern's peaked profile stands out among its visual competition and inserts a memorable shape into the scene. (The redundant stay pattern also reduces the load per stay, allowing the use of less-expensive, standard wire rope cables and fittings.) The art is also found in the vertically tapered, dramatically truncated towers and in the gradual reversed curves of the bridge's alignment, which, as pedestrians move along the bridge, slowly sweeps their gaze across their surroundings.

Another innovative aspect of the design is the application of a spliced, precast concrete U-beam. To river users, the bridge presents as an enclosed, light-colored element, with no visible hollows or recesses to accumulate dirt, debris, or pigeons.

The result is a memorable urban landmark that fits its environment, is a pleasure to use, and attracts people and activity to the riverfront.

A barge-mounted marine salvage crane with a crawler assist crane is used to lift the U-beam segments onto temporary falsework. Photo: Pennsylvania Department of Transportation.

U-beam segments sit on temporary falsework after the deck is placed but before cables are tensioned. Photo: AECOM.

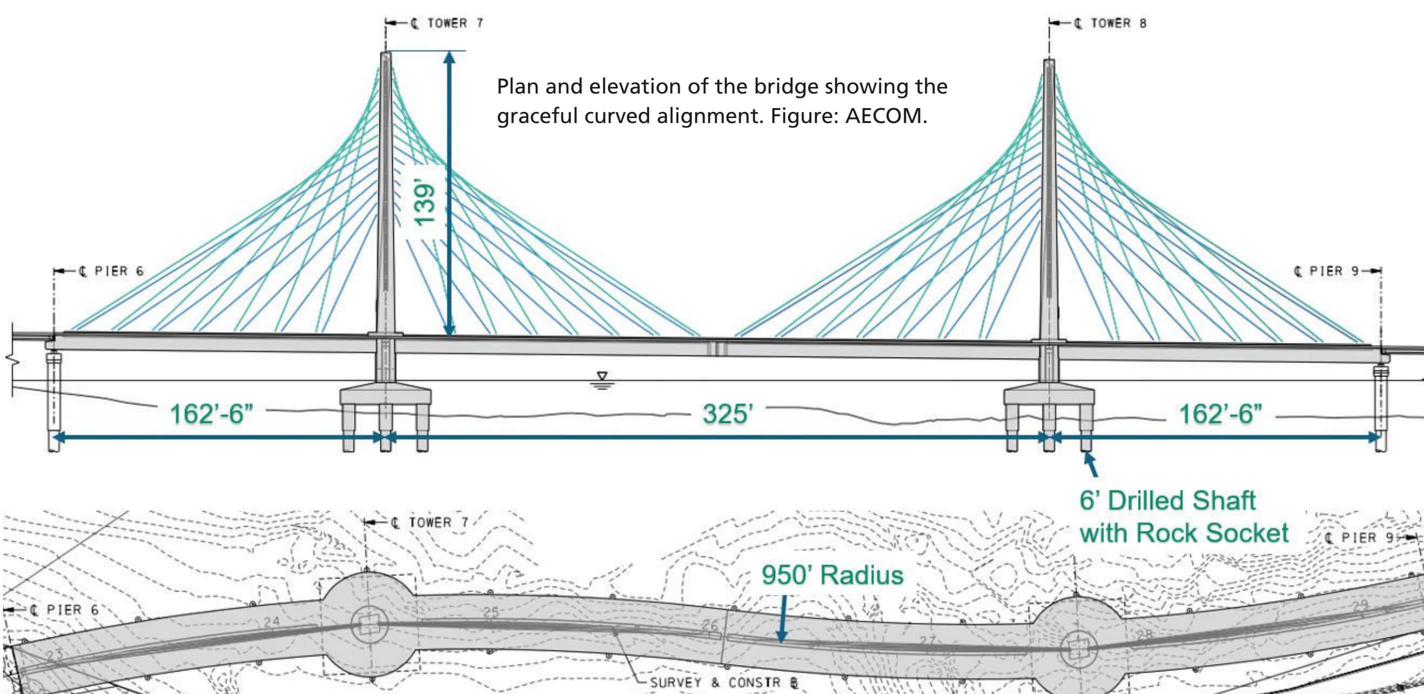
View of the basketweave pattern of the center stay cables shortly after the cables were tensioned. Photo: Pennsylvania Department of Transportation.

and shear keys were incorporated to accommodate cast-in-place diaphragms. The bridge has a cast-in-place lid slab—a small portion of the deck that spans between the precast concrete webs—which increased torsional stiffness 50 times compared with the open precast concrete section and allowed the girders to function as a composite closed section before post-tensioning and concrete deck placement.

The U-beam design used 7-strand tendons that were installed in the casting yard and tensioned before the U-beams were shipped. The rest of the 12- and 15-strand continuity tendons were installed and tensioned after diaphragms, closure joints, and the lid slab were placed, but before the remainder of the cast-in-place concrete deck was placed. The design concrete strength for the precast concrete U-beams at transfer was 6.8 ksi, and the 28-day design concrete strength was 8 ksi.

Reducing Costs and Maintenance

Costs and long-term maintenance are always top of mind when planning major bridge projects. The Christian to Crescent Bridge is a great example of



Plan and elevation of the bridge showing the graceful curved alignment. Figure: AECOM.

how careful design decisions can help reduce future costs.

From the outset, the project team set out to minimize future maintenance needs, which guided the selection of the bridge's structural system. While steel tub girders offer some of the same constructability advantages as precast concrete U-beams, they require regular repainting to prevent corrosion, which would be an especially challenging and expensive task given the bridge's location over the Schuylkill River. In addition, steel structures often require detailed, "arms-length" inspections at welds and connections.

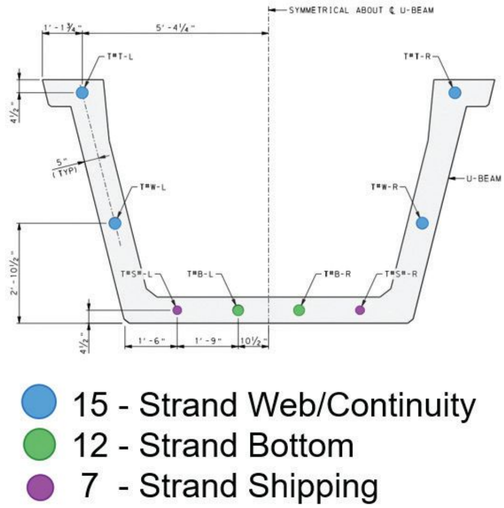
Another option was segmental cast-in-place concrete, which offered some advantages in reducing temporary supports in the river. However, this system came with higher costs and required specialized contractors, which could limit competition during bidding.

Ultimately, precast concrete U-beams stood out as the best fit for the project. They combined durability with cost-efficiency, and would have lower long-term maintenance needs than the other alternatives. Precast concrete offers resistance to weathering and corrosion when protected from the elements. To further protect critical components, the design included stainless steel reinforcement in the deck, reducing the likelihood that the deck would need to be replaced in the years ahead. All exposed steel elements, such as cable connections, plates, and anchors, were galvanized or stainless steel to help guard against corrosion.

Accessibility for inspections was also a priority. The bridge incorporates deck-level access openings and built-in ladder and rope access systems, making it easier for maintenance teams to carry out routine inspections safely and efficiently without using heavy equipment.

Maximizing Conventional Construction in Complex Structures

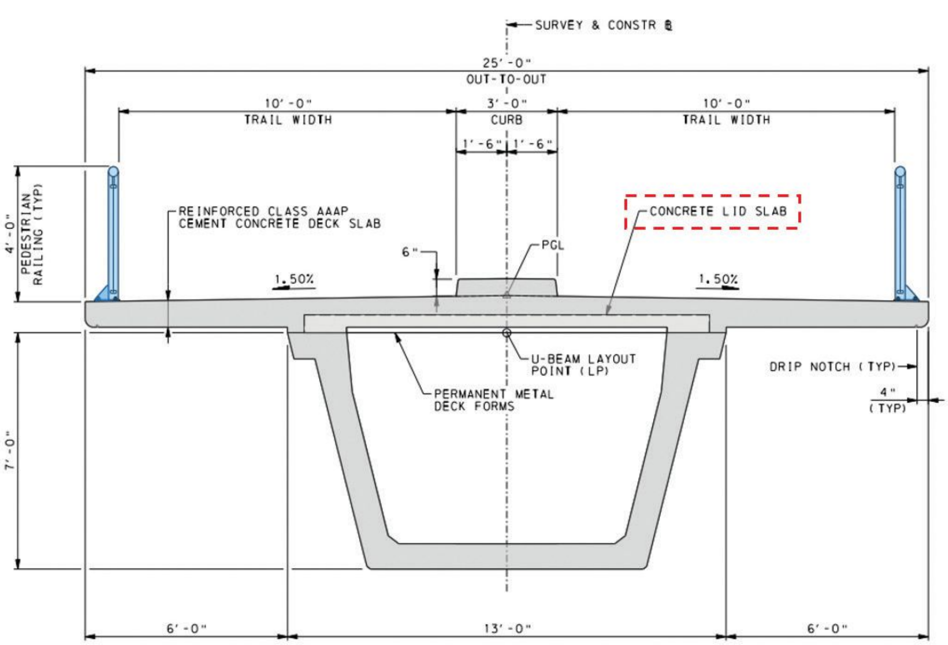
The Christian to Crescent Bridge is a clear example of how thoughtful design can deliver a distinctive structure while relying on conventional construction methods. The team prioritized—and maximized—the opportunity to develop an ambitious bridge design that could be built using conventional construction techniques, equipment, and workflows to maintain efficiency on a challenging site. The site was constrained due to an industrial docking facility, high-voltage electric lines, the narrow footprint against railroads along the shoreline, and vertical limitations because the structure passes underneath a rail bridge and the Schuylkill Expressway.



Cross section of the U-beams showing layout of shipping and continuity post-tensioning. Figure: AECOM.

The cast-in-place concrete towers are 9 ft × 8 ft at the base and taper to 5 ft × 8 ft at the top. Intersecting triangular planes give the illusion of a rotating section. The towers were constructed using custom adjustable formwork in eight total lifts above the deck. Eight 1¾ in. vertical post-tensioning bars, offset from the center of gravity of the column, counteract the eccentric loading caused by the curved alignment. In other words, the cables pull the tower toward the center of the curve and the vertical post-tensioning pulls the tower back to near vertical.

Superstructure cross section showing the 13-ft-wide U-beam and lid slab. Figure: AECOM.



Precast concrete curved U-beams were chosen as the main structural elements because they could handle the bridge's pronounced horizontal curve and because cranes and conventional lifting techniques could be used to erect them. These beams were fabricated offsite in upstate New York, transported by truck overland to a dock, and then delivered by barge to the project site. There was very little land access at the site due to the adjacent active rail lines, industrial facilities, and overhead power transmission lines. Delivery by rail was an alternative discussed during the design phase, but barges were ultimately chosen to simplify erection. This approach ensured that the precast concrete elements arrived ready to install without requiring complex formwork or specialized erection equipment.

Construction proceeded largely from barges on the river, minimizing disruption

Barge-mounted crawler assist crane lifts the U-beams from the transport barge. Photo: PKF-Mark III.

to adjacent properties and enabling work to proceed within the tight site constraints. To place the U-beams, the team sourced a unique marine salvage crane not commonly used for bridge construction and supplemented it with a crawler assist crane. This equipment, while specialized in capacity, still fit within the realm of conventional lifting operations rather than requiring custom gantries or launching trusses.

After the beams were set, the diaphragms and closure joints were placed, and then the lid slab was placed. After lid slab placement, 12- and 15-strand continuity tendons were placed and tensioned in one stage. This was followed by the concrete deck placement.

Contractors with expertise in cable-stayed bridges were engaged early in the design phase and returned during construction to oversee the installation of the bridge's distinctive cables. These cables, which contribute to the bridge's visually striking profile, were installed sequentially in pairs at each tower, progressing from the lowest to the highest positions. After all the cables were in place, each cable was carefully tensioned to a specified force to control stresses and maintain the intended geometry of the towers and the superstructure. As the cables were tensioned, the beams lifted off the falsework and into their final position.

By focusing on conventional construction methods, the Christian to Crescent Bridge proved that ambitious design does not have to come at the expense of practicality or efficiency.

Conclusion

The Christian to Crescent Bridge highlights how precast concrete U-beams can redefine what is possible in bridge construction. The curved, spliced U-beam superstructure achieved a graceful alignment while delivering the torsional stiffness needed for a central plane of support cables. Off-site fabrication in a controlled environment ensured consistent quality and efficient installation with conventional equipment.

This project demonstrates how these innovative components can unlock complex geometries and durable structures without requiring specialized methods or crews. From highways to pedestrian crossings, precast concrete U-beams are proving their value in creating bridges that are practical to build and inspiring to experience. Christian to Crescent Bridge stands as a testament to this approach—and serves as a model for what is next in modern infrastructure.

Reference

1. Precast/Prestressed Concrete Institute (PCI). 2020. *Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges*. Chicago, IL: PCI. https://doi.org/10.15554/CB-03-20.

Trevor Kirkpatrick is a senior structural engineer for AECOM in Tampa, Fla.
Joel Cummings is a project manager for AECOM, in Philadelphia, Pa.

Stainless steel reinforcement in the cast-in-place concrete deck. Photo: Pennsylvania Department of Transportation.

Demonstration Workshop for Unducted External Post-Tensioning Using Epoxy-Coated Strand

by Gregg Freeby, American Segmental Bridge Institute, and Tim Christle, Post-Tensioning Institute

On March 27, 2025, the National Concrete Bridge Council (NCBC), in conjunction with the Concrete Bridge Engineering Institute, and the Federal Highway Administration (FHWA), hosted a workshop in Boone, N.C., titled Construction of Unducted External Post-Tensioning with Epoxy-Coated Strand in the Laurel Fork Bridge. This one-day workshop was an opportunity for attendees to learn about the state-of-the-art use of epoxy-coated steel strands and a demonstration of how the technology is applied at the Laurel Fork Bridge, which is located on the Blue Ridge Parkway in Laurel Springs, N.C.

Epoxy-coated strand (ECS) technology is part of the evolution of industry solutions focused on the durability of prestressing steel strand used in post-tensioning (PT) tendons in bridges and other structures. Progressive strategies developed by the industry have included continuous improvement in the quality of PT systems, grout materials, and installation for ducted, bonded PT tendons; the use of alternative wax "flexible fillers" for ducted, unbonded PT tendons; the implementation of electrically isolated tendon technology for long-term condition monitoring; and advancements in techniques to allow for the replacement of tendons over time. Today's version of ECS in an unducted tendon offers excellent protection of the steel strand, while also facilitating in-service inspection as well as the future replacement of the tendon, if needed.

View of Laurel Fork Bridge under construction. The workshop was held after the post-tensioning was installed. Photo: Gregg Freeby, American Segmental Bridge Institute.

Need for Post-Tensioning Innovation

At an international PT technology exchange hosted by the American Segmental Bridge Institute in November 2022, a group of 58 worldwide industry experts convened in Austin, Tex., to discuss the current state of PT practice and identify areas for potential improvement. One of the six technology goals identified by the group was to "expand the use of un-ducted epoxy-coated (flow-filled) external PT tendons."[1] In support of that goal, FHWA organized the recent workshop to foster the use of the latest ECS tehcnology.

Modern Epoxy-Coated Strand Technology

ECS was developed in the United States more than 40 years ago, and the

LAUREL FORK BRIDGE, BLUE RIDGE PARKWAY / ASHE COUNTY, NORTH CAROLINA

BRIDGE DESIGN ENGINEER: U.S. Department of Transportation, Eastern Federal Lands Highway Division, Washington, D.C.

ENGINEER OF RECORD AND CONSTRUCTION ENGINEER: COWI North America Inc., Tallahassee, Fla.

PRIME CONTRACTOR: A Joint venture of Vannoy Construction, Jefferson, N.C., and Structural Technologies LLC, Fort Worth, Tex.

PRECASTER: Coastal Precast Systems, Wilmington, N.C.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Structural Technologies, Fort Worth, Tex.

Classroom instruction by Jon Cornelius, Sumiden Wire Products Corporation. The workshop consisted of a morning classroom session followed by a site visit in the afternoon. Photo: Gregg Freeby, American Segmental Bridge Institute.

technology has significantly advanced since its inception. Today's ECS is much more than just seven-wire steel strand coated with a surface layer of epoxy. The modern manufacturing process completely encapsulates each individual wire in epoxy, as well as the spaces between them. This advanced epoxy-coating technology achieves exceptionally strong adhesion between the steel wire surfaces and the epoxy, resulting in a material that is highly resistant to both corrosion and fatigue. The enhanced fatigue resistance is due to the reduction of fretting movements among the individual wires. Typically, the external epoxy layer has a thickness ranging from 0.5 to 0.7 mm on the crowns of the outer wires. For bonded applications, aluminum oxide grit is impregnated into the epoxy coating to enhance bonding capacity, matching or surpassing that of traditional bare strands. The modern unducted ECS introduces four key improvements over current PT practices: increased durability, simplified installation, easier condition assessment of the coating, and the possibility of tendon repair or replacement, if necessary. The use of ECS has been somewhat limited in the United States over the past four decades. However, for more than 30 years, ECS has been used in Japan for hundreds of bridge projects, all without issues.

U.S. PARK SERVICE, OWNER

OTHER MATERIAL SUPPLIERS: Epoxy-coated strand: Sumiden Wire Products Corporation, Dickson, Tenn.; post-tensioning system: Structural Technologies, Fort Worth, Tex.

BRIDGE DESCRIPTION: A 565-ft-long, three-span (155-235-155 ft) precast concrete, balanced-cantilever segmental bridge. Each of the 56 segments are 30 ft $3\frac{5}{8}$ in. wide, and the roadway width is 29 ft 6 in. The segments vary in depth from 8 ft at midspan to 13 ft at the piers. Segments are 10 ft 1 in. in length. The bridge is in a constant vertical grade and constant horizontal curve. The structural design made use of internal and external post-tensioning tendons with diabolos used in place of bent steel pipe for deviating external post-tensioning tendons. The substructure consists of cast-in-place concrete H-shaped piers with heights of 70 and 53 ft.

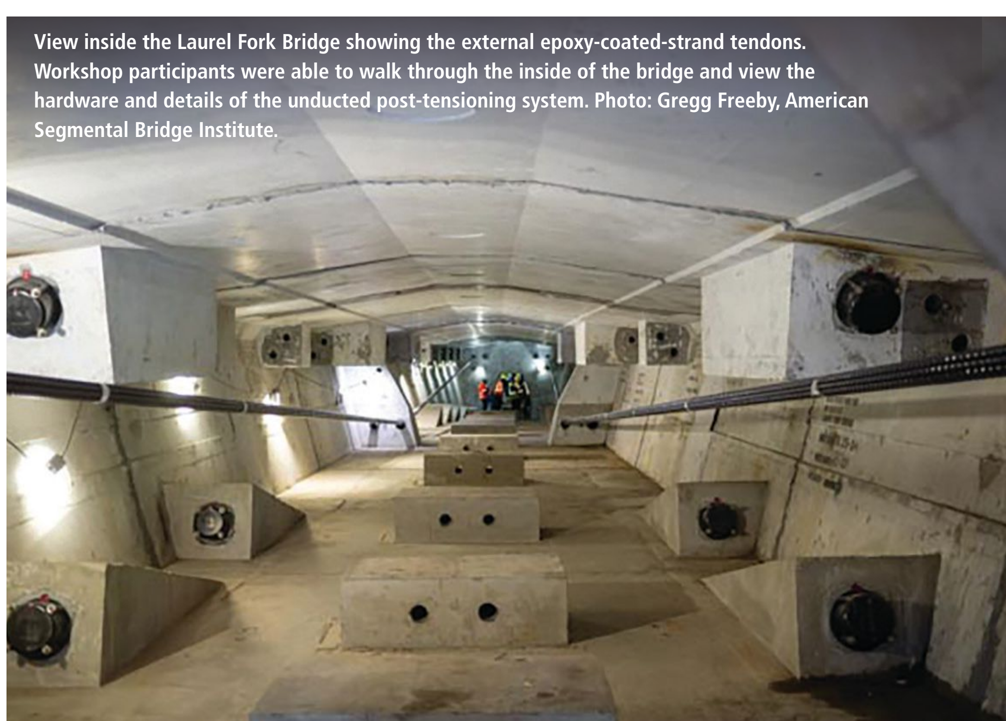
STRUCTURAL COMPONENTS: 56 precast concrete box-girder segments

Epoxy-Coated Strand Manufacturing and Testing

In the United States, ECS is manufactured and tested in accordance with ASTM A882, *Standard Specification for Filled Epoxy-Coated Seven-Wire Steel Prestressing Strand.*[2] After the bare strand is manufactured, the strand is splayed open and an electrostatically charged epoxy powder is sprayed within a containment chamber such that each wire is individually coated and all internal voids are filled with epoxy. After coating, the strand is inspected using a 3000-volt dry spark pinhole detector, and any holidays or defects are then repaired. This manufacturing of a "filled" strand is one of the improvements distinguishing modern-day ECS from the earlier-generation, nonfilled versions of this product. In addition, new bite-through PT wedges are used in tendon anchorages, eliminating the need to strip off the epoxy coating to grip and tension strands. ECS, especially when used in unbonded external tendon systems with bite-through wedges, provides a high-performance, durable, and inspectable alternative to traditional grouted tendon systems. (For more information on ECS, see the Spring 2020 issue of *ASPIRE*®.)

Tendon Design and Detailing for Replaceability

A major benefit of unducted ECS for external PT tendons is that it facilitates designs and detailing allowing for the installation, removal, and replacement of the external PT tendons in bridges, thereby improving the durability, service life, and ease of maintenance of these structures. The use of diabolos is a key component of the removable tendon system. Diabolos are trumpet-shaped



View inside the Laurel Fork Bridge showing the external epoxy-coated-strand tendons. Workshop participants were able to walk through the inside of the bridge and view the hardware and details of the unducted post-tensioning system. Photo: Gregg Freeby, American Segmental Bridge Institute.

Site-visit group photo. Photo: Gregg Freeby, American Segmental Bridge Institute.

formed voids in deviators or diaphragms used to guide the tendon. They also improve alignment, stress distribution, and replaceability. (For further information about diabolos, see the Fall 2015 issue of *ASPIRE*.)

To learn more about replaceable PT tendons, refer to the Summer 2020 issue of *ASPIRE*. Another resource is the FHWA report *Replaceable Grouted Post-Tensioned Tendons*.[3] While that report focuses on grouted PT tendons, much of the guidance on detailing also applies to unbonded systems such as ECS.

Unducted Post-Tensioning

Traditionally, external tendons in a concrete segmental box girder are carried inside a polyethene duct, which is also grouted. For the Laurel Fork Bridge, the strands for the external tendons were epoxy coated and unducted. The advantages of this system are that no duct or grout is needed, and the corrosion protection, in the form of the epoxy coating, is applied before installation. For the Laurel Fork Bridge, the decision to use unducted ECS tendons was made well into the construction phase; however, because the project was already making use of diabolos, the change was fairly easy to incorporate. The unducted, external tendons with ECSs that were ultimately installed on this project are fully inspectable and replaceable.

Laurel Fork Bridge Design and Construction

The Laurel Fork Bridge is a three-span (155-235-155 ft) precast concrete, balanced-cantilever segmental bridge. It includes six unducted tendons with twelve 0.6-in.-diameter ECSs per tendon. (See the Perspective article in the Spring 2025 issue of *ASPIRE* for more about the precast concrete segments for the Laurel Fork Bridge.)

Custom hardware and wedges were used to specially adapt the PT anchorages for ECS. Custom anchor heads were also developed and tested specifically for ECS. This testing included two fatigue tests—one consisting of 500,000 cycles at 60%–66% guaranteed ultimate tensile strength (GUTS) and a second, more extreme test with 50 cycles at 40%–80% GUTS—as well as static tensile tests at 97.8% of actual ultimate tensile strength (AUTS; that is 101.7% GUTS).

Tendon installation was adapted to site constraints. For example, strands were delivered on wooden reels and uncoiled with care. Also, given their short lengths, the unducted tendons were hand-pushed into place, one strand at a time. (Note: On larger ECS external tendon installation projects, the use of preassembled tendons is recommended, instead of the strand-by-strand method used on this smaller demonstration project.) Bundling, taping, and alignment were critical for protecting the epoxy coating. For strand tensioning, existing equipment was adapted with new wedge grippers and seating chucks. The wedge-recess plate depth and wedge seating required special consideration.

Workshop Summary

The workshop on March 27 provided 67 participants from across the United States with the opportunity to learn more about the use of ECS for unducted external PT through a classroom session in the morning and an afternoon site visit to the bridge. The morning session included 55 people in person and 12 participating virtually. Fifteen state departments of transportation were represented. Due to the limited size of available classroom facilities and limited access to the bridge site, attendance was limited to representatives of select departments of transportation and private sector organizations.

The workshop kicked off at the campus of Appalachian State University with presentations by industry experts on ECS technology. Vendors and producers of these materials and components provided tabletop displays to further enhance the attendees' experience.

After the morning classroom educational session, the participants traveled by bus to visit the Laurel Fork Bridge under construction. This two-hour visit was an opportunity for participants to tour

Workshop attendees view the unducted epoxy-coated strand inside the Laurel Fork Bridge. Photo: Jon Cornelius, Sumiden Wire Products Corporation.

the overall construction site and gain access inside the concrete segmental box to observe the unducted ECS in place. The abutment backwall had not yet been placed, so participants could easily walk through the opening in the abutment end diaphragm and then roam inside the bridge to observe the hardware and details necessary for unducted ECS, including the previously installed and tensioned tendons. Near the bridge, a learning station was set up for participants to observe the equipment and process for performing repairs should damage to the coating occur during construction. Opportunities to view the structure from above and below were also afforded. Many participants indicated that the site visit was the highlight of the workshop and enhanced the classroom learning experience.

Resources from the workshop are available to allow interested individuals to learn more about the application of this PT technology in future projects. Links to video recordings of the morning sessions, copies of the presentation documents, and additional resources can be found on the NCBC website (www.nationalconcretebridge.org).

Acknowledgments

The National Concrete Bridge Council would like to acknowledge the following organizations for their contributions of time and resources to the successful workshop: the American Segmental Bridge Institute, Appalachian State University, the Concrete Bridge Engineering Institute, COWI North America, DYWIDAG-Systems International, the Federal Highway Administration Office of Bridges and Structures, the Precast/Prestressed Concrete Institute, the Post-Tensioning Institute, Sumiden Wire Products Corporation, Structural Technologies, and Vannoy Construction.

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Gregg Freeby is the executive director of the American Segmental Bridge Institute and past chair of the National Concrete Bridge Council. Tim Christle is the executive vice president of the Post-Tensioning Institute and the current chair of the National Concrete Bridge Council.

Concrete Segmental Bridges—Preliminary Determination of Post-Tensioning Layouts

by R. Kent Montgomery, formerly with GM2 Associates

This article, which is the fourth in a series discussing preliminary design approximations for concrete segmental bridges, covers the determination of preliminary post-tensioning layouts. With a good preliminary layout, the changes in final design are usually minimal, leading to an efficient final design process.

The moments for dead loads of structural components, nonstructural attachments, the wearing surface, and utilities (DC and DW) and for live loads can be obtained by a simple finite element model with a limited number of nodes and elements, and no consideration of time-dependent effects. Approximations for moments from creep redistribution and temperature gradients can be determined as described in a previous article (see the Summer 2025 issue of *ASPIRE*®).

Longitudinal Post-Tensioning Layouts

For span-by-span bridges, the limiting compression stresses rarely govern the design, and the preliminary amount of post-tensioning can be based on the limiting tension stresses for positive moments at the critical sections near midspan (or the 0.4 times the span length L point for end spans). For balanced-cantilever bridges, compression stresses in the bottom slab near the piers must be limited. Setting the bottom-slab thicknesses to control the compression stresses, as well as determining the amount of cantilever post-tensioning, was discussed in the Winter 2025 issue of *ASPIRE*. This article focuses on the method for determining the amount of post-tensioning for span-by-span bridges and the amount of continuity post-tensioning for balanced-cantilever bridges. The process for determining the amount of preliminary continuity post-tensioning for balanced-cantilever bridges is similar to that for span-by-span bridges in that it can be based on the limiting tendon stresses for positive moments at the critical sections near midspan (or the $0.4L$ point for end spans).

The limiting tensile stresses for the longitudinal design of post-tensioned bridges are based on the Service III limit state in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] For concrete segmental bridges and most other post-tensioned bridges, the load factor for live load for the Service III limit state is 0.80. Article 3.4.1 describes load combinations for segmental bridges. Moments are combined to determine the governing design moment as follows:

$$M_{Design} = M_{DC} + M_{DW} + M_{CR} + M_{SH} + 0.80M_{LL} + 0.50M_{TG}$$

(typically governs at critical sections)

or

$$M_{Design} = M_{DC} + M_{DW} + M_{CR} + M_{SH} + M_{TG}$$

where

M_{Design} = design moment for flexural tension

M_{DC} = moment from structural components and attachments

M_{DW} = moment from wearing surface and utilities

M_{CR} = moment from creep (redistribution)

M_{SH} = moment from shrinkage (typically small, except for near the piers for monolithic substructure connections)

M_{LL} = moment from live loads

M_{TG} = moment from temperature gradients (for preliminary design, an equivalent linear gradient can be used, as discussed in the Summer 2025 issue of *ASPIRE*.)

Using the design moments, the governing tension stresses for design σ_{Design} can be calculated using classical beam theory.

As discussed in the Summer 2025 issue of *ASPIRE*, the concept of tendon efficiency can be used to estimate the amount of post-tensioning required. For example, for a tendon where the amount of secondary moment is 25% of the primary moment, the tendon is 75% efficient and the total stresses due to post-tensioning can be calculated from the full axial force and 75% of the primary moment. A preliminary estimate for the amount of post-tensioning can be determined as follows.

First, calculate the compression stresses for one strand for each tendon type being used:

$$\sigma_{PT} = \frac{P_{PT}}{A} + \frac{\alpha\left(P_{PT}ec\right)}{I}$$

where

σ_{PT} = compressive stress from post-tensioning at governing location

P_{PT} = post-tensioning axial force at governing section

A = cross-sectional area at governing section

α = tendon efficiency as described previously

e = tendon eccentricity from neutral axis of the cross section

c = distance from neutral axis to extreme fiber at governing section

I = cross-sectional moment of inertia

Second, select the number of strands n of each tendon type to keep the tension within the stress limits specified by the AASHTO LRFD specifications:

$$\sigma_{Design} + \sigma_{PTi} \times n_i + \sigma_{PTj} \times n_j \leq \sigma_{LIMIT} \quad (1)$$

(Note that compression is negative and tension is positive.)

where

$\sigma_{PTi}, \sigma_{PTj}$ = compressive stress from tendon types *i* and *j*

n_i, n_j = number of strands for from tendon types *i* and *j*

σ_{LIMIT} = tensile stress limit from Article 5.9.2.3.2 of the AASHTO LRFD specifications

Note that Eq. (1) shows consideration of two tendon types but may be expanded to consider additional tendon types.

Span-by-Span Layout

For typical span-by-span bridges with only draped tendons anchoring in the pier and end diaphragms, there is typically only one tendon type (draped external) and estimating the number of strands reduces to Eq. (2).

$$n = \frac{-\left(\sigma_{Design} - \sigma_{LIMIT}\right)}{\sigma_{PT}} \quad (2)$$

The next step is to determine the size and number of tendons to supply the number of strands required. This step involves making sure that the pier and end diaphragms can accommodate the selected number of tendons. **Figure 1** shows a post-tensioning layout for span-by-span construction. Note that temporary external post-tensioning bars located inside the box are needed to facilitate the erection of the precast concrete segments. During the erection sequence, an epoxy adhesive is applied to the joint as each segment is erected and then a clamping force is applied to the joint (epoxy-squeeze technique). The temporary bars are removed after the permanent post-tensioning in each span has been tensioned.

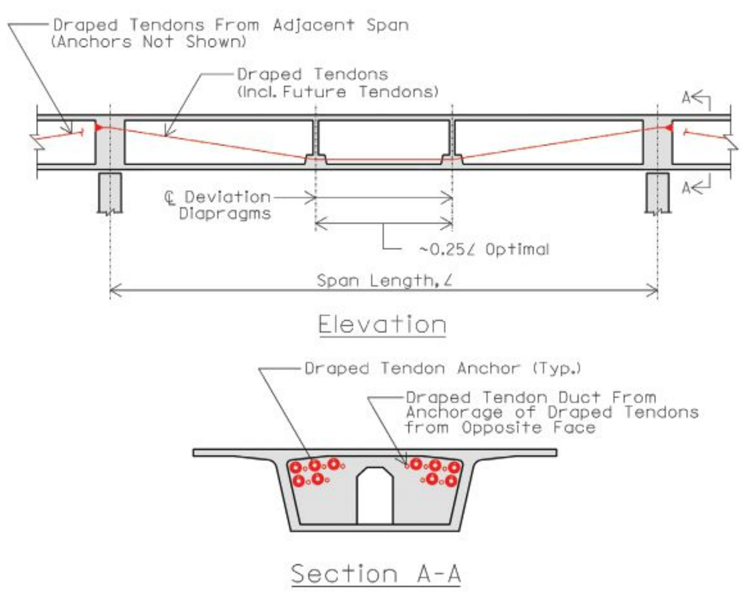

Figure 1. Typical post-tensioning layout for span-by-span construction. All Figures: R. Kent Montgomery.

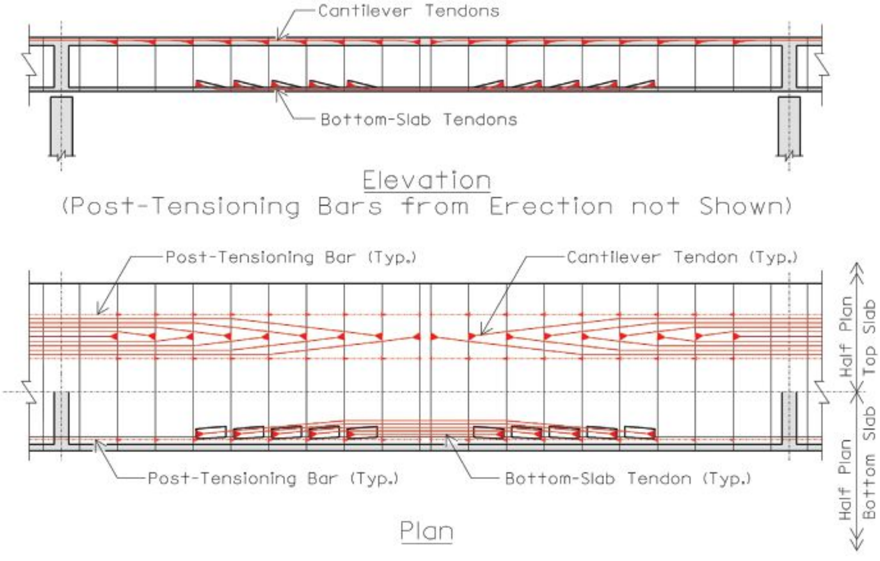

Figure 2. Typical post-tensioning layout for a constant-depth, balanced-cantilever bridge.

Balanced-Cantilever Layout

For balanced-cantilever bridges, in addition to the cantilever tendons, the design can use a single tendon type (for example, bottom slab internal), or there can be two tendon types (bottom slab and draped external), each supplying a different amount of compression per strand. For those bridges using a single tendon type, the number of strands can be estimated using the same equation used for span-by-span bridges (Eq. [2]). For bridges using two tendon types, the number of strands selected for each tendon type needs to satisfy the general equation (Eq. [1]).

For constant-depth bridges, draped- and bottom-slab tendons have approximately the same efficiency. Draped tendons can be used, and they have the benefit of reducing web shear. Using draped tendons also reduces the number of bottom-slab tendons required, and their maximum extents are typically 40% to 50% of the span length and centered on midspan for internal spans. However, many constant-depth, balanced-cantilever bridges exclusively use bottom-slab tendons. When only bottom-slab tendons are used, more tendons are required. The maximum extent for these bottom-slab tendons is typically 65% to 75% of the span length, and the tendons are centered on midspan for internal spans. For end spans, at least some bottom-slab tendons anchor in the end diaphragm and the maximum extent of the tendons is approximately 60% to 65% of the span length from the end of the unit. It is important to ensure that the precise placement of the continuity tendons adequately controls stresses and provides the required strength for the design moment diagrams, including creep redistribution, live load, and the kinematic moment from temperature gradients.

Figures 2 and **3** present a post-tensioning layout for a constant-depth, balanced-cantilever bridge. This layout is for

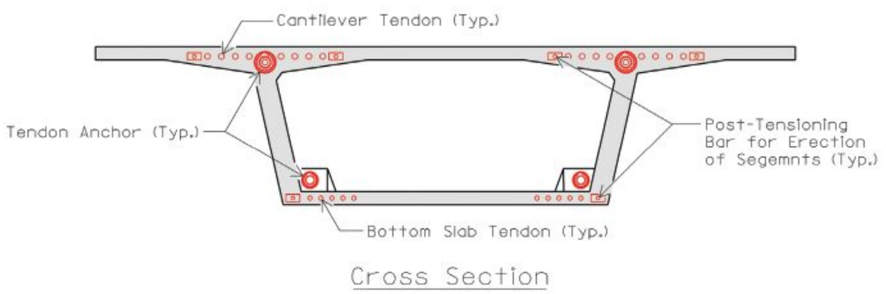

Figure 3. Typical cross section of post-tensioning layout for a constant-depth, balanced-cantilever bridge.

precast concrete segments and bottom-slab continuity tendons only; no draped tendons are used. The following items about this layout are noteworthy:

- There are post-tensioning bars that anchor at every typical segment joint for the epoxy-squeeze technique applied after each segment is erected. Subsequent lengths of the bars are coupled near the segment joints. This layout shows internal bars that become permanent parts of the bridge. It is also possible to use temporary bars that are removed after erection of the cantilever.
- Cantilever tendons anchor at each typical segment joint and are tensioned after the erection of a pair of segments (one on each end of the cantilevers). This arrangement provides the total number of required tendons over the pier. The number of tendons decreases gradually away from the pier, roughly matching the negative moment diagram.
- Bottom-slab tendons anchor in typical segments to provide the number of required tendons at midspan. The number of tendons decreases gradually away from midspan, roughly matching the positive moment diagram.

For variable-depth bridges, draped tendons are typically more efficient than bottom-slab tendons. Therefore, it makes sense to use the maximum number of draped strands that can reasonably be anchored in the pier and end diaphragms. Note that the radius of the intrados curve results in radial forces acting downward on the bottom slab. These forces result in bottom-slab bending and tendon pullout effects. These forces and their effects become larger as the radius of the curve decreases away from midspan. Therefore, it makes sense to limit the extent of bottom-slab tendons to approximately 50% of the span length centered on midspan for internal spans, assuming draped tendons are also present. (Also, as discussed in the Summer 2025 issue of *ASPIRE*, bottom-slab tendons become less efficient as they get longer.) If draped tendons are not being used, the extent of bottom-slab tendons should be increased to 60% to 65% of the span length; however, designing for the tendon radial forces becomes more challenging. **Figures 4** and **5** show a variable-depth, balanced-cantilever post-tensioning layout. This layout is for cast-in-place (CIP) segments with bottom-slab and draped continuity tendons. The following are items to note about this layout:

- For CIP balanced-cantilever construction, segments are typically cast in an alternating fashion, one segment at a time. Cantilever tendons are tensioned after the casting of each segment. To accommodate this sequence, a staggered layout is used, with two anchors at each web per segment. The layout provides for the total number of required tendons over the pier. The number of tendons decreases gradually away from the pier, roughly matching the negative moment diagram. An epoxy adhesive is not applied at the joints for CIP construction; therefore, post-tensioning bars are typically not used.
- The bottom-slab tendon layout is similar to that for a precast concrete bridge. Given the length of typical CIP segments, two tendons per web typically anchor in each segment. When developing this type of layout, consideration must be given to allow access for tensioning jacks between the anchor blocks and the deviation diaphragm.
- The draped tendon layout for balanced-cantilever construction is similar to that for span-by-span bridges.

Experience has shown that it is better to anchor a minimum number of bottom-slab tendons at any longitudinal location to avoid excessive general-zone effects. Therefore, it is common to locate a single anchor block next to each web (two blocks per cell) at any longitudinal location. Longitudinally, the blocks are typically spaced every 8 to 10 ft (depending on segment lengths), resulting in many longitudinal anchor locations spread along the span, as can be seen in Fig. 2 and 4.

Transverse Post-Tensioning

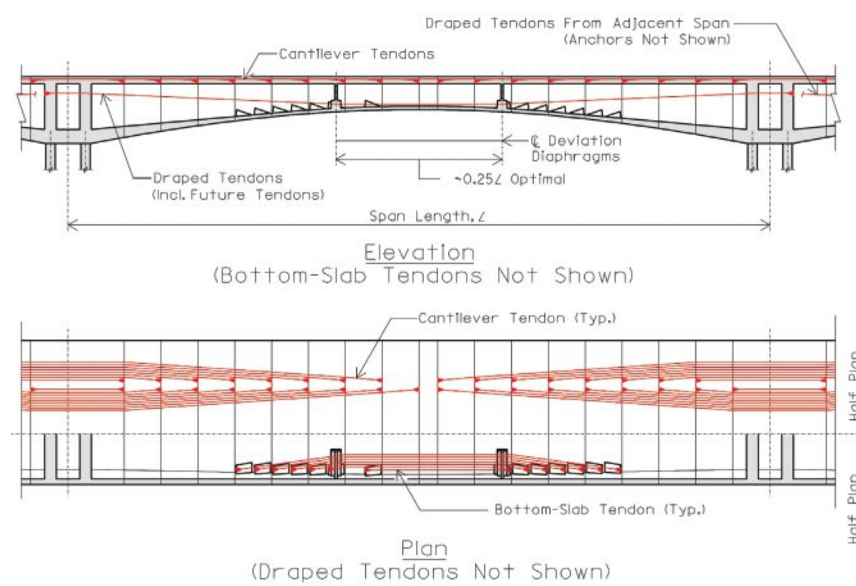

Figure 4. Typical post-tensioning layout for a variable-depth, balanced-cantilever bridge.

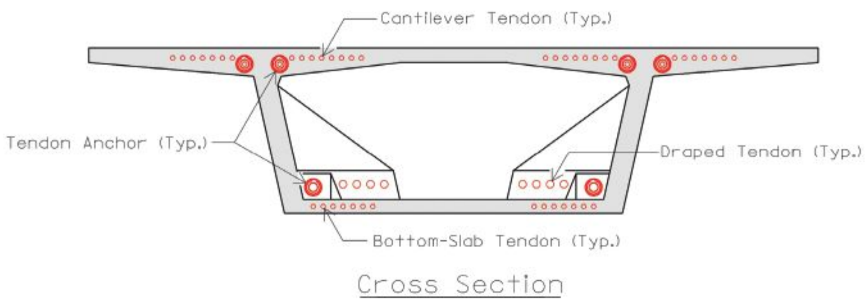

Figure 5. Typical cross section of post-tensioning layout for a variable-depth, balanced-cantilever bridge.

Layouts

To determine the preliminary amount of transverse post-tensioning, simple cantilever wing calculations can be used. Because the cantilever wing is statically determinate, the moment demand at the root of the cantilever wing can be calculated with simple hand calculations and the use of Homberg charts for live loads.[2] As noted in the Spring 2025 issue of *ASPIRE*, a cantilever wing length of approximately 42% of the interior transverse span is optimal for balancing transverse demands. Therefore, for wing lengths equal to or greater than 42% of the interior span, using the cantilever wing for preliminary calculations will produce a good estimate. For cross sections with cantilever wing lengths less than 42% of the interior span, a theoretical cantilever wing that is 42% of the internal span can be constructed using similar thicknesses as the actual wing. Simple cantilever calculations using the notional wing typically produce a good estimate for the amount of required transverse post-tensioning.

Controlling tensile stresses at the service limit state usually governs the transverse design. For transverse design, the AASHTO LRFD specifications specify the Service I limit state, which has a load factor of 1.0 for live load, for checking both tension and compression stresses. Typically, temperature gradients are not considered for transverse design of concrete box girders. (However, some owners specify a small linear gradient.) Therefore, the design moment for transverse design is as follows:

$$M_{Design} = M_{DC} + M_{DW} + M_{CR} + M_{SH} + M_{LL}$$

Note that M_{CR} and M_{SH} are zero for the cantilever wing.

Using the design moments, the governing tension stresses for design σ_{Design} can be calculated by applying classical beam theory. The moments are usually tabulated for a unit strip, and the stresses are calculated based on section properties for a unit strip. Because there are no secondary moments in the statically determinate cantilever wing, the stresses from post-tensioning can be calculated using the full axial force, the primary moment, and the section properties for a unit strip. This is usually done for a single strand, and the amount of post-tensioning can be calculated as

$$n = \frac{-\left(\sigma_{Design} - \sigma_{LIMIT}\right)}{\sigma_{PT}}$$

This equation provides the required amount of post-tensioning in terms of the number of strands per foot longitudinally. The result can easily be converted to the number of tendons required per foot.

Four-strand tendons in flat ducts are typically used for transverse tendons. The flat ducts allow for the maximum eccentricity for all strands in the tendon. The profile for a transverse tendon typically runs as high as possible over the webs, and the clear cover and the reinforcing steel mat above the tendon need to be considered. Usually, the longitudinal reinforcing bars are the top bar in the mat, and the transverse bars are the bottom bar in the mat. This arrangement allows the transverse tendon duct to fit between the transverse bars and be higher than if the opposite reinforcing bar arrangement were used. The profile also runs low across the interior transverse spans, although it is often not as low as possible. At the haunch points, the positive and negative live-load moments are both significant, although smaller than over the webs and at midspan. Therefore, the transverse tendons typically do not run high or low; rather, they run near the center of the top slab. **Figure 6** presents a profile for a transverse tendon.

For concrete segmental bridges, an integral number of tendons must be placed in each segment. This requirement can result in more post-tensioning than required being supplied. A small additional amount above that required usually is not an important issue. For some designs where the additional amount is larger, four-strand and three-strand tendons can be alternated.

Summary

This article presents a methodology for a quick and simple means of developing post-tensioning layouts. The layouts can be advanced into final design for a complete check of stresses at all joints (or span tenth points if the structure is not a segmental bridge), as well as strength verification. Experience with this methodology has shown that it produces good quality, preliminary post-tensioning layouts that need only minimal changes for the final design.

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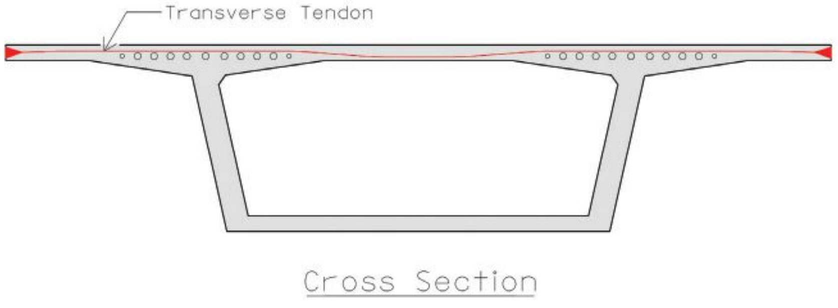

Figure 6. Typical cross section showing the transverse tendon profile.

PCI Updates the Recommended Practice on Strand Bond

by Dr. Clay Naito, Lehigh University, and Dr. Richard Miller

The Precast/Prestressed Concrete Institute (PCI) Technical Activities Council has published a second edition of the "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand."[1] This second edition—which was published in the January/February 2025 issue of *PCI Journal* with errata published in the September/October 2025 issue[2]—supersedes the first edition that was approved in July 2020.[3]

The new edition of the recommended practice retains the information from the original version that set thresholds for strand bond assessed by ASTM A1081, *Standard Test Method for Evaluating Bond of Seven-Wire Steel Prestressing Strand*,[4] and provided equations for bond and development lengths that include concrete strength as a parameter. The second edition also provides demonstrated bond strength equivalents for prestressing strand diameters other than the two given in the standard test method (0.5 in. and 0.6 in.).

The most important change in the recommended practice is the addition of methodologies to assess the bond characteristics of tensioned strand in a precast concrete producers' product.

ASTM A1081 provides a valuable approach for consistently evaluating strand independent of strand production methods. The ASTM method uses consistent materials and methods to evaluate the untensioned strand in a surrogate grout material, thereby providing the strand user confidence in the bond quality of the produced strand. The methods added to and described in the PCI recommended practice allow for assessment of the concrete-to-strand bond properties in plant-produced precast concrete components. To do this, the tests incorporate standard precast concrete plant production procedures, including tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing conditions, and curing duration. The methods for assessing the bond of tensioned strands in a precast concrete producer's product allow for resolution testing (which is also covered in the new version of the recommended practice) if there are concerns about the quality of bond.

The recommended practice details two testing methods: the pretensioned strand block pullout test and the strand draw-in test, which were both approved by the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures in June 2025 as agenda item 39, to be published in 2027 as Article 5.9.4.3.1 in the 11th edition of the *AASHTO LRFD Bridge Design Specifications*.[5]

The recommended practice also contains an extensive list of frequently asked questions (FAQs) to assist with interpretations of provisions, and two examples illustrating applications to specification requirements.

A Brief History of the Recommended Practice

In a *PCI Journal* article that accompanies the first edition of the PCI recommended practice, Dr. Jared Brewe[6] provides an in-depth history of strand bond and the development of the recommended practice. A brief summary is provided here. (For details, see also Dr. Brewe's article in the Spring 2021 issue of *ASPIRE*®.)

In the late 1980s, a concern developed regarding the quality of the bond between seven-wire prestressing strand and concrete. In 1988, the Federal Highway Administration (FHWA) issued a memorandum[7] that provided a multiplier of 1.6 to the development length equation for fully bonded strands in the *AASHTO Standard Specifications for Highway Bridges*.[8] This multiplier continues to be specified in Article 5.9.4.3.2 of the *AASHTO LRFD Bridge Design Specifications*[9] for members with a depth greater than 24 in. The use of 0.6-in.-diameter strand was also banned for a time. In 1995, PCI issued an alert to producers about possible premature bond failure of untensioned strand used in lifting loops, and the institute published a second alert in 1996 that reiterated the previous concerns and recommended that producers conduct pull-out testing on the strand.

The concerns about strand bond quality led to research by the FHWA, PCI, various state departments of transportation, and North American Strand Producers (NASP). One result of the NASP research was the development of ASTM A1081. Subsequent testing under National Cooperative Highway Research Program (NCHRP) Project 607 and additional testing sponsored by PCI resulted in various recommendations for the threshold value of the pull-out strength assessed by the ASTM A1081 test.

The first edition of the "PCI Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" set the minimum ASTM A1081 threshold value for prestressing strand to be a demonstrated bond strength equivalent to ½-in.-diameter, 270-ksi strand exhibiting a six-quarter running average value of 14,000 lb with no quarterly test average less than 12,000 lb. Strand manufacturers use this test for quality control, and precast concrete producers use this test and the minimum value when procuring strand for use in pretensioned concrete. In addition, the original PCI recommended practice defined a "high-bond" strand with threshold values of a demonstrated bond strength equivalent to ½-in.-diameter, 270-ksi strand exhibiting a six-quarter running average value of 18,000 lb with no quarterly test average less than 16,000 lb. However, as will be discussed later, the high-bond strand was intended to be used only in certain prestressed concrete components where bond is particularly critical.

The first edition of the PCI recommended practice also recognized that bond strength is dependent on concrete strength and recommended alternate equations for transfer and development lengths that contained a term for concrete compressive strength f'_c. To date, these equations remain recommendations and have not been adopted in any of the design specifications.

Additions to the Recommended Practice

The second edition of the recommended practice retains the information from the first edition. The threshold values for prequalifying pretensioning strand are based on 0.5-in.-diameter strand; however, a change was made to clarify and amplify the requirements for testing strands of different diameters with a table that provides equivalent threshold values.

The recommended practice adds two methods for assessing the bond of tensioned strand in concrete. The ASTM A1081 test uses untensioned strand in surrogate material. The surrogate material consists of a mortar composed of only fine aggregate meeting requirements of ASTM C33, *Standard Specification for Concrete Aggregates*;[10] Type III cement; and water. The test is conducted when the mortar has a cube strength between 4500 and 5000 psi. However, in pretensioned concrete applications, the strand is tensioned and embedded in concrete, which results in additional, mechanical contributions to the bond strength that are not evaluated in the ASTM A1081 test. The two methods in the recommended practice for evaluating tensioned strand are the strand block pullout test and the evaluation of strand draw-in.

It is interesting to note that the pull-out test evaluates development length, whereas the draw-in test evaluates transfer length. While not usually necessary, both tests could be used simultaneously to provide an estimate of each quantity.

Strand Block Pullout Test

The pretensioned strand block pullout test consists of pulling a tensioned strand out of a concrete prism with cross-section dimensions of 12 in. × 6.5 in. (**Fig. 1**). The length of the specimen is equal to a bonded length L_b plus a 2-in. debonded length. The bonded length L_b is taken as the transfer length of the strand (60 strand diameters in the AASHTO LRFD specifications).

The pullout force and end slip are measured to quantify the bond capacity. The recommended practice states that "the test specimens are fabricated using standard procedures of the precast concrete producer. These standard procedures include the tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing condition, and curing duration." In the ideal case, the test specimen is made at the end of a bed while the precast concrete producer is manufacturing other products; however, the specimen can be made by itself, using the precast concrete producer's standard procedures.

After the specimen is made and cured, the strand is pulled out of the block using the apparatus setup shown in **Fig. 2.** The strand at the dead end of the specimen is saw cut flush with the face of the specimen and a gauge is used to measure the end slip. The test is performed as follows:

1. The specimen is loaded until the end slip measures 0.10 in., with load and end slip being recorded such that at least 10 data points of load and end slip are collected before the end slip reaches 0.10 in. (A reading of an increased load and no end slip is acceptable as a data point.)
2. The specimen is then loaded until:
   a. a 25% decrease in load is measured, or
   b. the strand fractures, or
   c. a displacement of 0.5 in. is measured at the dead end.
4. The estimated minimum length to fracture the strand L_{ult} (in.) is found from:

$$L_{ult} = \frac{f_{ps} A_{ps}}{F_u} L_b$$

(Recommended Practice Eq. 5.2.1.14)

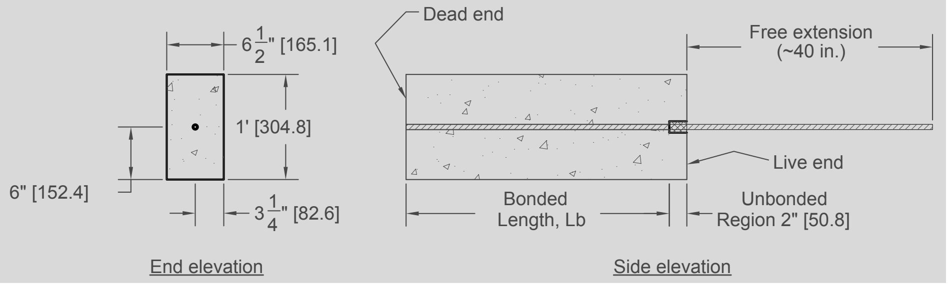

Figure 1. Strand block pullout test specimen.[1] All Figures and Photos: PCI.

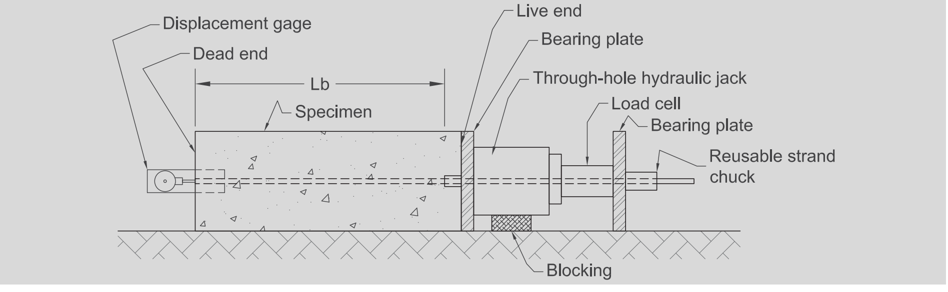

Figure 2. Strand block pullout test setup.[1]

where
f_{ps} = minimum tensile strength of the strand, ksi
A_{ps} = area of the strand, in.^{2}
F_u = average force to achieve an end slip of 0.10 in. at the dead end for three specimens, kip
L_b = bonded length of the strand, in.

According to the commentary for the recommended practice, L_{ult} provides a best estimate of the in-place development length of that combination of strand and concrete. For fitness-for-service design evaluations, these estimates of development length should be taken as more representative values than those obtained from design equations for development length.

If the value of L_{ult} is less than the development length provided by a code-based equation, the pretensioned fabrication conditions exceed specification estimates. This test is not intended to justify the use of a development length that is shorter than specification estimates, and shorter lengths are not allowed in the forthcoming Article 5.9.4.3.1 of the AASHTO LRFD specifications.[5] If the value of L_{ult} is greater than the development length provided by a specification-based equation, the required development length may not be achievable and the value of L_{ult} obtained from Recommended Practice Eq. (5.2.1.14) should be communicated to the designer and used as the development length.

Although the pretensioned strand block pullout test provides an assessment of the bond quality needed to provide an adequate development length, it can be assumed that strand with an acceptable value of L_{ult} will also have adequate transfer length.

Strand Draw-in Test

The second method for evaluating the bond of tensioned strand is the strand draw-in test. This method uses the strand slip from the cut face of a concrete member or prism to assess bond. Some prestressed concrete producers have used this method informally for many years to assess the bond in hollow-core precast concrete elements.

Figure 3 shows a typical case of strand slip and a gauge for measurement. Movement of the outer six wires with respect to the cut concrete face is measured. The slip of the center wire is not measured because that wire is not directly bonded to the concrete.

Figure 3. An example of a strand draw-in measuring device.[1]

This test can be performed two ways: on a concrete member that is detensioned by saw cutting, such as a hollow-core precast concrete component, or by creating a prism. As with the pull-out test, the prism can be cast at the end of the bed during the production of another product or cast separately. In either case, the precast concrete producer's standard procedures of tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing conditions, and curing duration must be used.

A prism for the strand draw-in test has the same cross section and strand placement as a specimen for the pull-out test (Fig. 1), but the specimen length is a minimum of 240 times the strand diameter d_b. The prism is saw cut at midspan. Measurements should be taken within 24 hours of saw cutting.

The draw-in of the strand (outer six wires) is measured from two cut faces to at least the nearest 1⁄64 (0.016) in. The average draw-in of the outer wires on each face is determined, and the average of the two face measurements is the average draw-in value Δ_s. The maximum allowable value of Δ_s in inches is found from:

$$\Delta_{s,max} = \frac{L_{ti} f_{pi}}{2E_{ps}}$$

(Recommended Practice Eq. 5.2.2.9)

where
L_{ti} = transfer length of the strand, in.
f_{pi} = initial stress in the strand, ksi
E_{ps} = modulus of elasticity of the strand, ksi

Specimens or components with an average draw-in value less than the maximum value obtained by Recommended Practice Eq. (5.2.2.9) can be assumed to have adequate transfer and development lengths. Specimens or components with an average draw-in value greater than the maximum value obtained by Recommended Practice Eq. (5.2.2.9) require additional investigation.

It is important to note that the draw-in approach is sensitive to the accuracy of the measurement. As an example, if we have a typical pretensioned concrete component with 0.5-in.-diameter strands with initial prestress of 65% of the strand's 270-ksi guaranteed ultimate tensile strength, elastic modulus of 28,500 ksi, and a transfer length of $60d_b$, the allowable $\Delta_{s,max}$ is 0.0924 in. For that magnitude, a 1⁄64 in. measurement results in an accuracy of 17% of the allowable value. If the measurement drops to the nearest $1/32$ in., this accuracy decreases to an unacceptable 34% of the allowable value. If additional accuracy is desired, micrometers that can measure to the nearest 0.001 in. are inexpensive and readily available, and they provide accuracy within 1% on the allowable draw-in value.

Resolution Testing

The recommended practice notes that the pull-out test or the draw-in test can be used for resolution testing if a strand does not meet the requirements of ASTM A1081. The precast concrete producer should cast six specimens for either the pull-out test or the draw-in test to evaluate the quality of the strand bond. The recommended practice explains that development or transfer lengths determined by either the pull-out test or the draw-in test are more representative of the in-service quality of the strand bond than the ASTM A1081 test because the pull-out test or the draw-in test uses tensioned strand in the precast concrete producer's concrete mixture. The recommended practice also notes that, in some cases, development length and/or transfer length may not be controlling for design, and that the results of either the pull-out test or the draw-in test may yield results that are still acceptable to the owner.

Proper Use of High-Bond Strand

The first edition of the recommended practice defined two classes of strand bond quality: standard bond and high bond. Unfortunately, this classification caused some confusion about when to specify high bond in the industry. New language in the second edition will help clear up this confusion.

The class of high-bond strand was created for use only in those products where the strand bond is particularly critical. One example is lightly prestressed hollow-core slabs. The fabrication method for hollow-core slabs generally does not allow for transverse (shear) reinforcement to be used; thus, the shear strength of the member is controlled by the shear strength of the concrete and the strength provided by the longitudinal reinforcing steel (tension tie). The absence of transverse reinforcement means that the strand bond quality is critical to ensure the integrity of the tension tie. Other cases where high-bond strand is appropriate are those where there is limited internal redundancy or where there are fewer than three strands in a section, web, or stem.

For most designs, standard-bond strand is adequate. When the high-bond class was introduced, some designers assumed that "high bond" must be superior to "standard bond" and began to specify it. However, this assumption is not necessarily true. Consider the end of a precast, prestressed concrete beam. The designer will use the assumed transfer length of 60 strand diameters ($60d_b$) to determine the number of harped strands and/or the number and length of debonded strands. If the transfer length is significantly shorter than assumed, the stresses at the end of the girder will not be calculated correctly, and there is an increased possibility of cracking.

When standard-bond strand is properly manufactured and meets the requirements of ASTM A1081, it will provide acceptable transfer and development lengths for the majority of precast, prestressed concrete component designs. Specifying high-bond strand when it is not necessary adds cost and may create unnecessary compliance problems.

Conclusion

The intent of the updated "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" is to inform structural designers, strand manufacturers, precast concrete producers, and owners on the methods of assessing strand bond performance. In this way, strand bond–related processes from design to production of a product, with due consideration given to quality control and quality assurance, can be performed consistently. The recommended practice describes processes and testing methods that can be used for fitness-for-service analysis, which accounts not only for the bonding characteristics of the strand but also for a precast concrete producer's plant processes.

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***Dr. Clay Naito is a professor of civil engineering at Lehigh University. He has an extensive record of concrete bridge-related research, and he was the primary developer of the pull-out test shown in the recommended practice. Dr. Richard Miller is professor emeritus and former head of the Department of Civil and Architectural Engineering and Construction Management at the University of Cincinnati. He is the chair of the PCI Technical Activities Council and managing technical editor of* ASPIRE.**

Ultra-High-Performance Concrete: The Keystone for Adjacent Prestressed Concrete Box-Beam Bridges

by Anthony Ragosta, formerly with ceEntek North America

The keystone is an engineering marvel whose origin dates back thousands of years. When this innovation was developed, its use in combination with traditional materials and construction methods revolutionized the performance and value of the arch. Ultra-high-performance concrete (UHPC) may be considered a comparable "keystone" development for recent bridge design. When this revolutionary construction material is combined with appropriate application and construction methods, UHPC can significantly improve the strength, performance, durability, and resiliency of structures such as those constructed from prestressed concrete box beams.

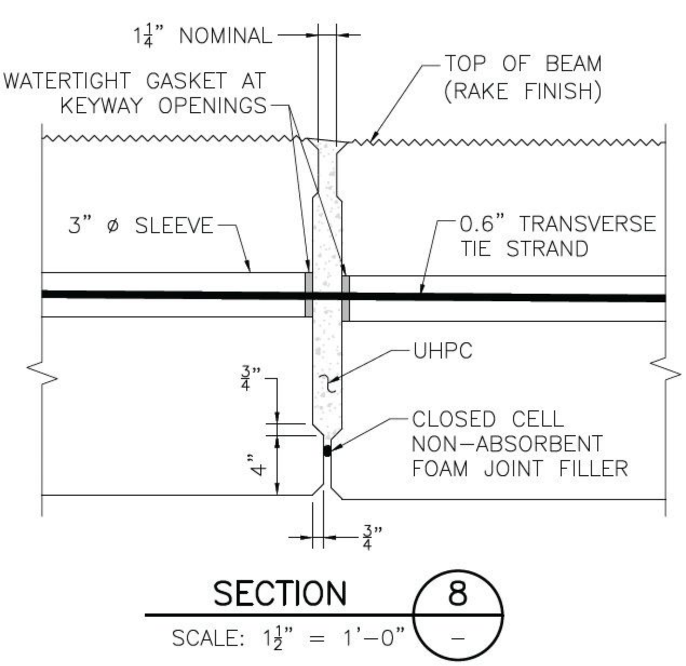
As shown in the preliminary design charts in Chapter 6 of the *PCI Bridge Design Manual*,[1] adjacent prestressed concrete box beams can be a very economical and efficient shape for short- to medium-span bridges. These adjacent box beams were quite popular for some time before owners began reporting challenges such as leaking joints, reflective cracking in asphalt or overlay surfaces, loss of continuity between beams, and other negative behaviors that were generally associated with the lack of performance of the grouted keyways between the box beams. The unreinforced grout frequently cracks due to a combination of forces and water-ingress-related deterioration such as damage from freezing and thawing cycles.

In recent years, some owners and engineers have begun leveraging the advanced mechanical properties of field-cast UHPC to revitalize these bridges. For this application, UHPC-class materials are strain-hardening materials reinforced with steel fibers at common volume fractions of 2% in joints or 3% in overlays. UHPC materials can be applied in the following three specific ways to improve the structural performance and durability of adjacent prestressed concrete box-beam structures:

- A simple keyway, which is filled with UHPC with no reinforcing bars present (**Fig. 1**)
- A UHPC field-cast joint between two beams with reinforcement in the joint at the top of the box beam only (**Fig. 2**)
- A UHPC overlay (typically 1.5 to 2 in. thick) on top of the box beams (**Fig. 3**)

Each of these construction details has a distinctive effect on the behavior of the superstructure, but all three leverage the same unique material properties of UHPC to impart structural benefits that can extend service life. To date, these details have mostly been used to structurally rehabilitate prematurely failing bridges in service. However, information gathered through these necessary repairs can also be applied to improve new construction, and some new bridges have been constructed with UHPC joints. By improving the weakest link of the system, a portion of the existing infrastructure can be revitalized, and prestressed concrete box beams can once again be a durable and cost-effective option for designers in the short- to medium-span bridge market. In new bridge design, the use of UHPC for improvements to this type of bridge system could increase initial costs. However, the cost analysis should extend beyond just initial cost and consider the service life of the bridge and the reduction in maintenance costs, which would be captured in a life-cycle cost analysis. A similar cost analysis process should be followed for rehabilitation efforts.

Figure 1. Detail for ultra-high-performance concrete in an unreinforced keyway. Figure: Massachusetts Department of Transportation.



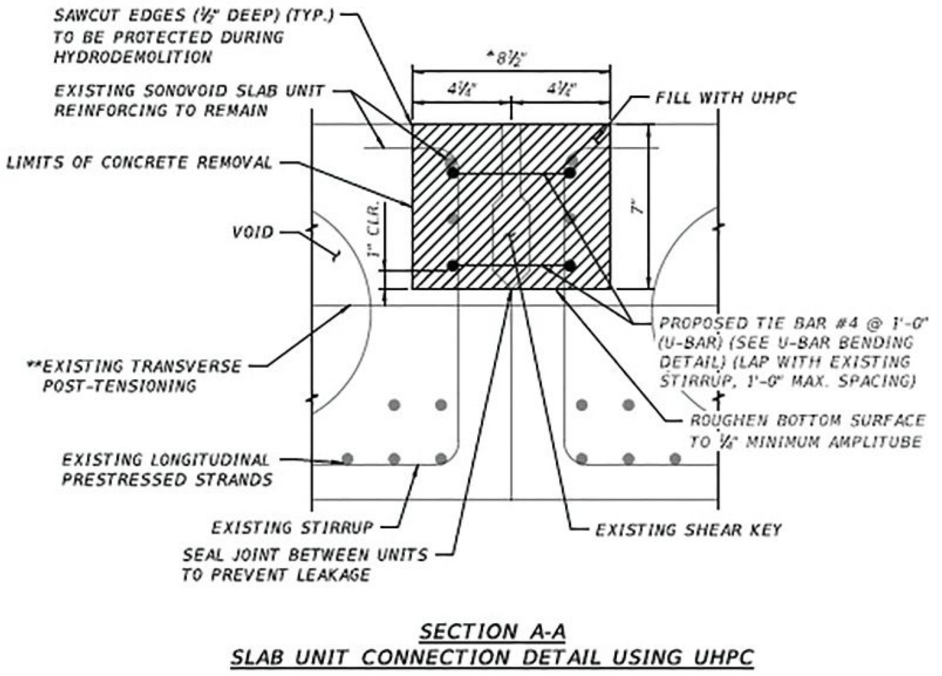


Figure 2. Detail for ultra-high-performance concrete in a reinforced joint between beams. Figure: Florida Department of Transportation.

The UHPC applications detailed in this article use the strain-hardening behavior to continue load transfer and maintain watertightness after cracking occurs in the joints. The stiffening response after cracking allows the keyway, joint, or overlay to continue to provide efficient load transfer between beam units. This load transfer can reduce the forces on an individual beam by enhancing load distribution, leading to potential benefits such as improved load ratings, reduced deflection through improved stiffness, improved fatigue performance through reduced stress ratios, enhanced resiliency, increased redundancy in the event of deterioration or sudden loss of capacity in a beam, and preservation of wearing surfaces through reduction of independent girder movements. The use of UHPC in critical locations in box-beam bridges is analogous to the behavior of a keystone; the relative volume of UHPC in the structure is low, but the effect on the performance of the overall system is substantial because selective application of UHPC optimizes the benefits of UHPC's mechanical properties.

These applications also benefit from other enhanced properties inherent to UHPC-class materials such as the enhanced capability of UHPC materials to bond with the concrete substrate and reinforcement. This capability allows the UHPC to transfer loads, achieve composite behavior, develop reinforcement, and maintain watertightness at the vertical interface.[2] The bond can be accomplished in existing or new structures, aiding in the development of strength properties and prevention of substructure damage caused by leaking joints. The combination of increased compressive strength and tensile and flexural toughness allows the material to absorb more energy, enhancing strength and resiliency relative to traditional materials. The durability characteristics of UHPC-class materials are typically an order of magnitude higher than those of high-performance concrete and another order of magnitude greater than those of conventional concrete (**Table 1**).[3] These properties extend the useful life of the system, further enhancing the value for the owner.

On an interstate highway in New York that is subject to significant truck traffic, a prestressed concrete box-beam bridge was rehabilitated using a UHPC overlay (Fig. 3). The UHPC overlay reestablished a safe and smooth riding surface and improved the structural response of the

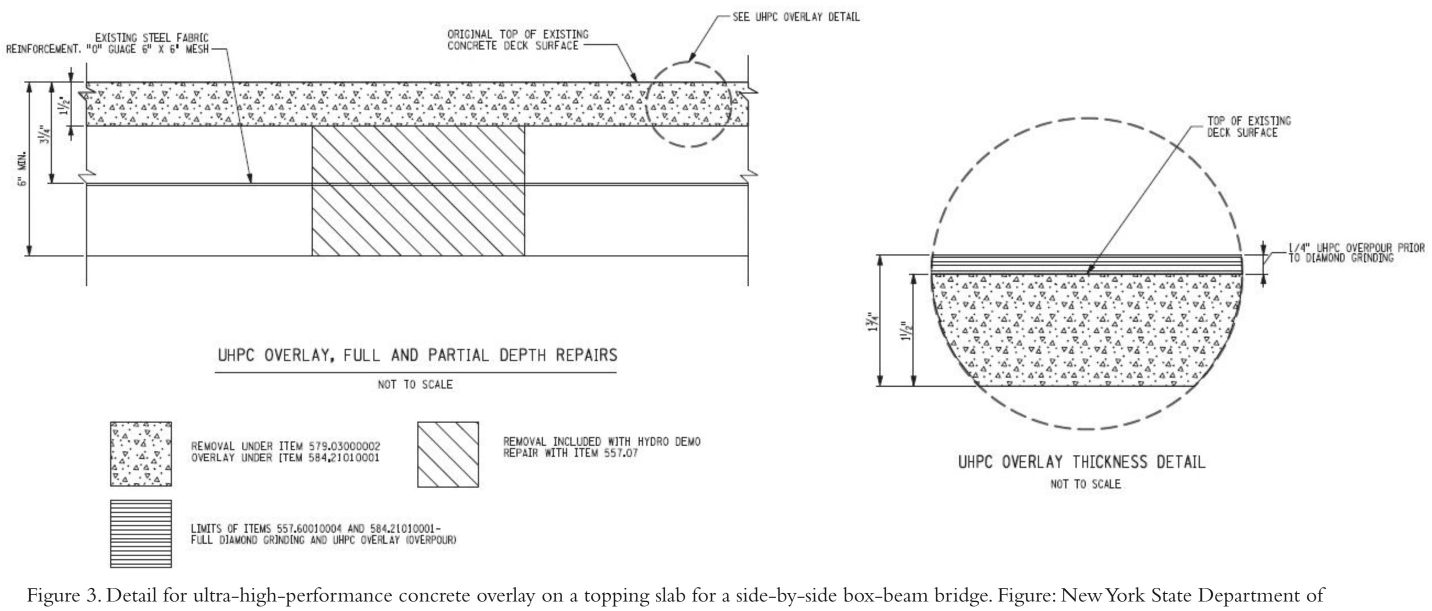


Figure 3. Detail for ultra-high-performance concrete overlay on a topping slab for a side-by-side box-beam bridge. Figure: New York State Department of Transportation.

Table 1. Comparison of the durability properties of ultra-high-performance concrete (UHPC), high-performance concrete, and conventional concrete materials

Parameter	UHPC	High-performance concrete		Normal concrete	
		Value	Ratio to UHPC	Value	Ratio to UHPC
Salt scaling mass lost (28 cycles)	0.010 lb/ft^2	0.031 lb/ft^2	3.0	0.31 lb/ft^2	30
Chloride ion diffusion coefficient	2.2 × 10^{-13} ft^2/s	6.5 × 10^{-12} ft^2/s	30	1.2 × 10^{-11} ft^2/s	55
Chloride ion penetration depth	0.04 in.	0.32 in.	8	0.91 in.	23
Chloride ion permeability total charge passed	10 – 25 coulombs	200 – 1000 coulombs	34	1800 – 6000 coulombs	220
Carbonation depth (3 years)	0.059 in.	0.16 in.	2.7	0.28 in.	4.7
Reinforcement corrosion rate	4 × 10^{-7} in./yr	9.8 × 10^{-6} in./yr	25	4.7 × 10^{-5} in./yr	120
Abrasion resistance relative volume loss index	1.1 – 1.7	2.8	2.0	4.0	2.9
Resistivity	53.9 kΩ-in.	37.8 kΩ-in.	0.70	6.3 kΩ-in.	0.12

bridge. After hydrodemolition and before placement of the overlay, significant cracking was observed in the joints between the box-beam units, indicating loss of load transfer between units. The UHPC overlay was placed continuously over the skewed abutment to the end of the approach slabs, which were more than 25 ft long. Upon observation after one year in service, the UHPC overlay exhibited no signs of distress and no cracking between units. There was one hairline crack directly over the skewed abutment at both ends of the bridge; it was due to the negative moment created in the overlay by extending beyond the expansion joint between the bridge and approach slabs. The strain-hardening behavior of the UHPC overlay keeps the crack tight, and the material protects the expansion joint, preventing moisture ingress to the bearings or beam ends.

Similar to the keystone, the use of UHPC materials increases the strength and durability of the overall system. The benefits of UHPC extend beyond the isolated joint placements to improve the overall structural system performance. The details used on a given bridge should reflect the challenges that must be addressed, and they should also be uniquely tailored to the bridge design to maximize the enhanced properties of UHPC materials. The significant systematic improvements that can be accomplished with relatively small amounts of UHPC can help owners improve bridges in their existing inventory, salvage bridges that might otherwise be demolished, or facilitate further use of the economically efficient adjacent prestressed concrete box-beam bridge type.

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Transient Thermography for Detecting Corrosion Damage in Concrete

by Dr. Glenn A. Washer, University of Missouri

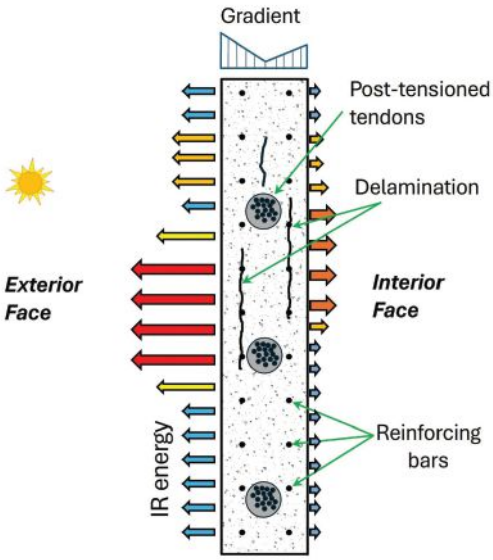


Figure 1. Illustration of conventional infrared thermography showing infrared radiation from the interior and exterior surfaces of a post-tensioned box girder. All Figures: ThermalStare LLC.

Effective condition assessment of concrete structures is critical to maintaining structures and ensuring safety. Corrosion damage in concrete is a problem, often manifesting in spalling that decreases the strength of the concrete component and exposes the embedded reinforcing steel to the environment. Methods to detect areas of subsurface delamination that precede spalling can provide early indications of corrosion damage, identify areas requiring repair, and assist engineers in ensuring the safety and serviceability of conventionally reinforced, pretensioned, and post-tensioned concrete structures. Infrared ultra–time domain (IR-UTD) imaging is a new, nondestructive tool based on transient infrared thermography (IRT) to detect subsurface corrosion damage in concrete. It captures thermal data over time to provide more reliable detection of corrosion damage in its early stages and identifies emerging corrosion issues in large concrete structures.

Corrosion Damage

Corrosion damage initiates below the surface of the concrete where embedded reinforcing bars corrode due to exposure to moisture and corrosive agents. Hidden from view in its earliest stages, the corrosion causes the steel bars to expand, introducing tensile stress in the concrete. Cracking relieves the tensile stresses and can produce areas of subsurface delamination. As the corrosion process progresses, the subsurface damage emerges toward the surface and can produce spalling of the concrete that weakens the concrete structure and exposes internal reinforcement to additional corrosive elements.

To prevent spalling, it is critical to identify areas of the subsurface where moisture and corrosion agents are penetrating the concrete, exposing reinforcement and embedded post-tensioned tendons to a corrosive environment. Detection of evolving corrosion damage in its early stages can identify areas in need of repair or the need for further exploration such as intrusive inspections to assess the integrity of the protective layers of embedded post-tensioning tendons or pretensioned strands.

Conventional Infrared Thermography

Conventional IRT has been used to detect subsurface damage based on the thermal anomalies appearing in images of the surface of the concrete. The technology depends on significant daily temperature variations to produce a thermal gradient in the concrete. **Figure 1** illustrates the increased thermal energy emitted from areas of subsurface damage that heat more rapidly than intact areas of concrete due to the reduced thermal mass. The thermal contrast, which is the difference in temperature between an intact area and a defect area measured at the surface of the component, appears as different colors in an IRT image. **Figure 2** presents quantitative data from thermal images to illustrate the detection process. The graph shows the ambient temperature variations over a 24-hour interval in which temperatures are cool at night, increase during the morning hours, and decrease again during the afternoon. The thermal contrast from a simulated subsurface defect is referenced to the secondary vertical axis on the right. This thermal contrast varies over the course of the day, and at times, there is no thermal contrast ΔT produced by the subsurface defect, resulting in no color difference in an IRT image.

Therefore, the reliability of IRT for detecting subsurface damage varies depending on the surrounding environmental conditions and varies throughout the course of a day. IRT results can be difficult to confirm through repeat testing because exact ambient conditions are rarely reproduced. The magnitude of the thermal contrast depends on ambient temperature changes, exposure to solar heating, and the depth from the surface to the damage. The magnitude of the thermal contrast is reduced significantly as the depth to the damage increases, when ambient temperature changes are small, or when solar loading is not present. Conventional IRT is typically most effective when the damage is 2 in. or less from the concrete surface and ambient temperature changes are large (greater than 15°F to 20°F) or direct solar loading is present. Additionally, for thermal contrasts from damage to be detectable, the damage-related thermal anomalies must exceed thermal anomalies produced by other surface features such as paints, stains, or areas where surface roughness varies.

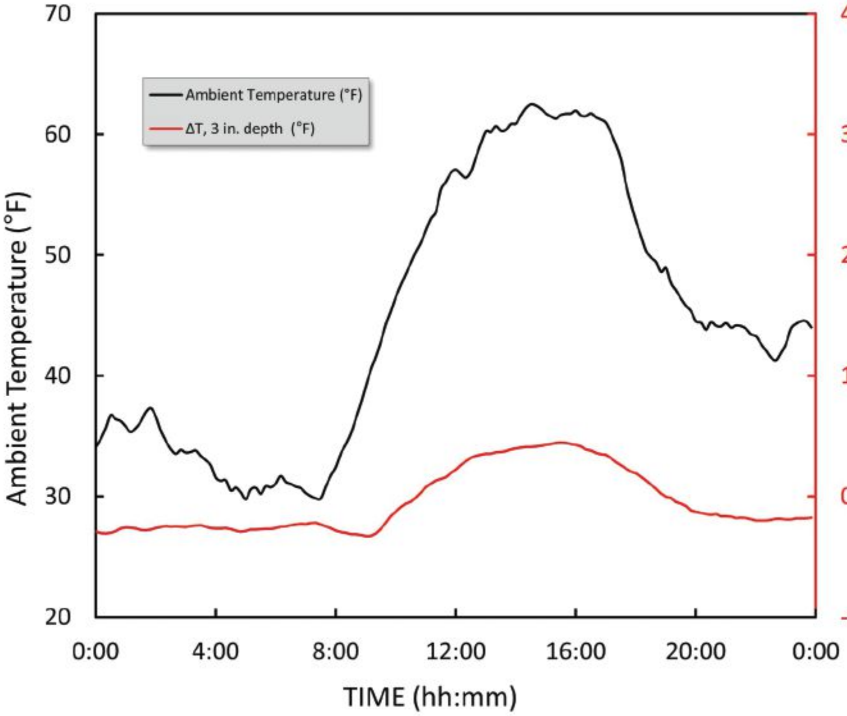


Figure 2. Quantitative data from thermal images show the ambient temperature variations over a 24-hour interval on the left axis and the thermal contrast from a simulated subsurface defect at a depth of 3 in. on the right axis. The thermal contrast is the difference in temperature between an intact area and a defect area measured at the surface of the component.

Infrared Ultra–Time Domain Technology

IR-UTD imaging overcomes the environmental limitations of conventional IRT by using advanced signal processing algorithms that use time-lapsed data to analyze heat flow through the concrete. The heat flow is affected when there is subsurface damage in the concrete. **Figure 3** shows how thermal images are captured periodically throughout the heating and cooling of the concrete structure, and these data are analyzed to produce images showing the subsurface features in the concrete.

IR-UTD technology differs significantly from conventional IRT because the new technology captures thermal images throughout the heating and cooling of the day and night. The thermal data are postprocessed to detect the thermal wave (heat flow) propagating through the concrete rather than simply identifying surface temperature anomalies at any single point in time. Compared with conventional IRT imaging, heat-flow analysis can better distinguish between real damage and surface features that produce thermal anomalies because those features behave differently than damage when analyzed over time. Also, IR-UTD technology can identify the inertial effects of subsurface features, so it facilitates detection of damage and other features at much greater penetration depths than can be achieved with convention IRT imaging. For example, IR-UTD technology can be used to image internal diaphragms or supporting members through a concrete deck (Fig. 3).

IR-UTD technology creates easy-to-interpret images showing subsurface damage and structural features of buildings, bridges, dams, tunnels, and other structures. Quantitative, reliable, and reproducible images can be obtained without the use of traffic control or lane closures for highway bridges, or without access to the large surface areas of other concrete structures such as buildings, tunnels, or dams.

Thermal cameras embedded in the IR-UTD technology system use wide-angle lenses and scanning technology to collect data on bridge decks over an area of 15,000 ft^2 from a single setup location with a spatial resolution of less than 1 in.^{2}. For highway bridge decks, cameras are typically mounted 35 to 40 ft above the deck. For large structures such as cooling towers, dams, or buildings, telephoto lenses are used to produce images of similar resolution from large distances. The IR-UTD images are accompanied by images that document the corresponding visual condition of the surface.

Whereas hammer-sounding and nondestructive technologies such as impact echo or ground-penetrating radar require access to the surface of

Figure 3. Transient infrared thermography concept presenting time-lapse imaging and the resulting infrared ultra–time domain images showing corrosion damage in a bridge deck.

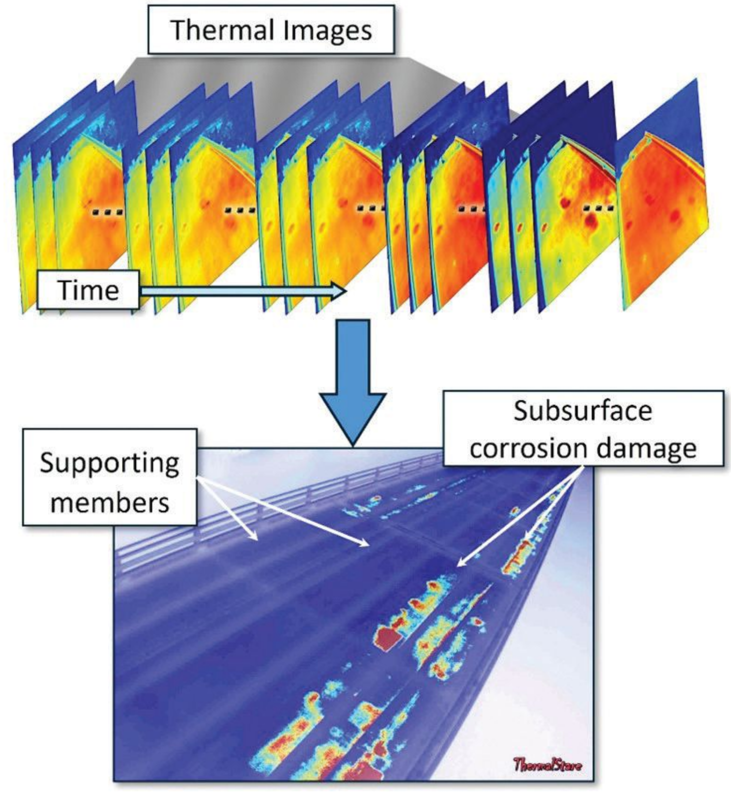


Figure 4. Using a camera installed at ground level, infrared ultra–time domain (IR-UTD) images are taken of a concrete cooling tower (left). Thermal and visual images depict the IR-UTD vertical scan-ning area from the base to the top of the 500-ft-tall tower (center). At an elevation of 470 ft, areas of defective concrete are shown in infrared data superimposed over a graphic image of the tower (right).

a structure, IR-UTD can be used to evaluate large structures without such access. For example, **Fig. 4** shows the application of IR-UTD technology to a 500-ft-tall cooling tower. The IR-UTD technology was mounted on a tripod at ground level and scanned the entire height of the tower (Fig. 4, left). Figure 4 (center) shows visual images captured during vertical scanning from the base to the top of the 500-ft tower. Both thermal and visual images are captured during the vertical scan. Figure 4 (right) shows a single thermal image superimposed on the visual image of the top of the tower and then a zoomed-in view with the subsurface damaged areas circled. The defect areas can be quantified in the IR-UTD image, such that the total area of damage can be determined by summing the individual defect areas.

IR-UTD technology rapidly collects images during heating and cooling of the concrete surface and analyzes the heat flow through the concrete to detect damage at greater depths than previously possible with conventional IRT. The ability of IR-UTD to detect subsurface damage when asphalt, concrete, or polymer coatings are present is unique among nondestructive evaluation technologies currently available for condition assessment.

State departments of transportation can use this new technology for quantitative assessment of repair needs because the technology produces accurate and repeatable measurements of corrosion damage. IR-UTD technology is often employed during rehabilitation planning to identify critical areas for coring to assess structural capacity, material properties, and the extent of deterioration in a structure. For post-tensioned structures, IR-UTD technology can quantify damage and indicate areas where subsurface corrosion damage is evolving, which helps investigators locate critical areas for intrusive inspection to assess the corrosion protection system of internal tendons. Current and future applications for IR-UTD technology include inspection of concrete bridge decks and deck soffits, buildings, tunnels, dams, and other large civil structures where detection and characterization of corrosion damage is critical for ensuring safety and serviceability.

Dr. Glenn A. Washer is a professor of civil and environmental engineering at the University of Missouri. He previously served as the director of the Federal Highway Administration's Nondestructive Evaluation Program at the Turner-Fairbank Research Center.

A Crack Is Not a Crack: Torsional Cracking

by Dr. Oguzhan Bayrak, University of Texas at Austin

This article, which is the sixth article in this series on cracking, focuses on torsional effects and how additive stresses imposed by torsional effects can influence structural behavior. Torsional effects are typically observed in combination with the effects of other loads, and the interpretation of the observed cracking in bridges can sometimes be a challenging task. By providing a sufficiently in-depth discussion on combined load effects in the presence of torsional effects, this article aims to help engineers perform structural evaluation on bridges that show signs of torsional distress. To the extent necessary, we will consult the structural design provisions for combined effects of bending, shear, torsion, and axial loads published in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] In doing so, we will revisit my LRFD article published in the Spring 2025 issue of *ASPIRE*®.

Combined Loading Effects and Cracking

To facilitate our discussion on torsion, I will use a series of loading scenarios rooted in field issues I have encountered over the past 25 years. To that end, let us focus our attention on the straddle bent shown in **Fig. 1**. As can be observed in this figure, the north ledge supports more load than the south ledge. This loading configuration results in the cap beam being subjected to torsion, in addition to other loading effects (shear and bending).

Next, let us consider five loading scenarios that could go along with this unbalanced load configuration. **Figure 2** illustrates cracking based on the first loading scenario (scenario A), in which we do not see any diagonal cracking on the south face but we do see a diagonal crack on the north face of the cap beam. This type of cracking may result from the additive nature of shear stresses on the north face of the cap, which is illustrated in **Fig. 3**. Conversely, the shear stresses created by the torsional effects and shear effects oppose each other on the south face. In this specific case, it is possible to conclude that the net diagonal tensile stress resulting from the superposition of loading effects is not large enough to result in cracking on the south face.

This condition may be one where the torsional effects are not considered significant. According to Article 5.7.2.1-3 and associated commentary of the AASHTO LRFD specifications, if the factored torsional moment is less than 25% of the factored pure torsional cracking moment, torsional effects can be deemed negligible. More specifically, AASHTO LRFD specifications include the following requirements:

Torsional effects shall be investigated where:

$$T_u > 0.25\phi T_{cr} \qquad (5.7.2.1\text{-}3)$$

- *For solid shapes:*

$$T_{cr} = 0.126K\lambda\sqrt{f'_c}\,\frac{A_{cp}^{2}}{p_c} \qquad (5.7.2.1\text{-}4)$$

- *For hollow shapes:*

$$T_{cr} = 0.126K\lambda\sqrt{f'_c}\,2A_o b_e \qquad (5.7.2.1\text{-}5)$$

in which:

$$K = \sqrt{1 + \frac{f_{pc}}{0.126\lambda\sqrt{f'_c}}} \le 2.0 \qquad (5.7.2.1\text{-}6)$$

Figure 1. Straddle bent configuration used for the five loading scenarios presented in subsequent figures. Figure: Dr. Oguzhan Bayrak.

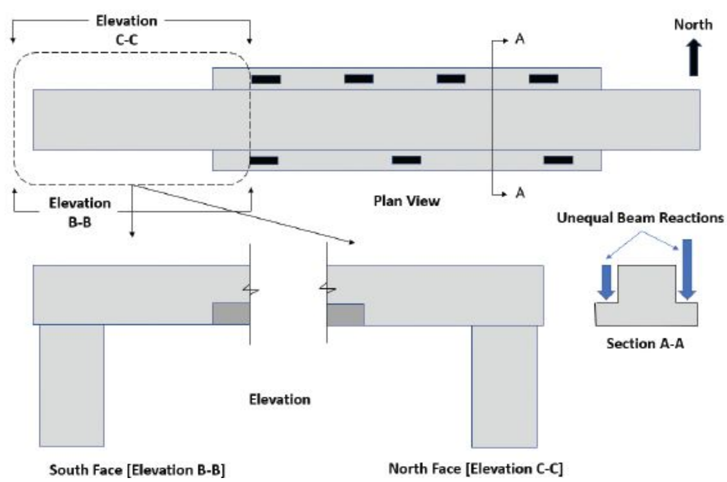
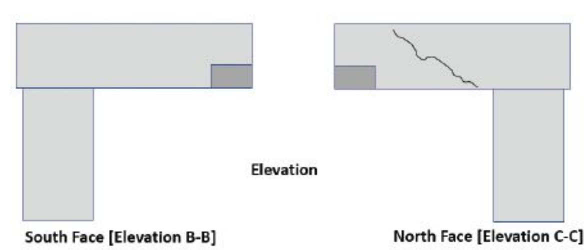


Figure 2. Cracking resulting from loading scenario A. Figure: Dr. Oguzhan Bayrak.



where:

T_u = *applied factored torsional moment (kip-in.)*

ϕ = *resistance factor [for torsion], specified in Article 5.5.4.2*

T_{cr} = *torsional cracking moment (kip-in.)*

λ = *concrete density modification factor, as specified in Article 5.4.2.8*

f'_c = *compressive strength of concrete for use in design (ksi)*

A_{cp} = *area enclosed by outside perimeter of concrete cross-section (in.^{2})*

p_c = *length of outside perimeter of the concrete section (in.)*

A_o = *area enclosed by the shear flow path, including any area of holes therein (in.^{2})*

b_e = *effective width of the shear flow path taken as the minimum thickness of the exterior webs or flanges comprising the closed box section (in.). b_e shall be adjusted to account for the presence of ducts.*

f_{pc} = *unfactored compressive stress in concrete after prestress losses have occurred either at the centroid of the cross-section resisting transient loads or at the junction of the web and flange where the centroid lies in the flange (ksi)*

The value of b_e, defined above, shall not exceed A_{cp}/p_c unless a more refined analysis is utilized to determine a larger value.

The effects of any openings or ducts in members shall be considered. K shall not be taken greater than 1.0 for any section where the stress in the extreme tension fiber, calculated on the basis of gross section properties, due to factored load and effective prestress force exceed $0.19\lambda\sqrt{f'_c}$ in tension.

When calculating K for a section subject to factored axial force, N_u, f_{pc} shall be replaced with $f_{pc} - N_u/A_g$. N_u shall be taken as a positive value when the axial force is tensile and as a negative value when it is compressive.

However, Article 5.7.2.1-3 references a design scenario, as opposed to a structural evaluation scenario, which is what is being discussed here. For structural evaluation, torsional effects shall be investigated. As shown in Fig. 3, seemingly negligible torsional effects may be sufficient to result in diagonal cracking on one face of the cap due to the additive nature of torsional and shear stresses on that face.

Figure 3. Stresses from shear and torsion are additive. On the north face of the cap the stresses are in the same direction, increasing the overall magnitude. On the south face, the shear stresses created by the torsional effects and shear effects oppose each other, thereby reducing the total magnitude. Figure: Dr. Oguzhan Bayrak.

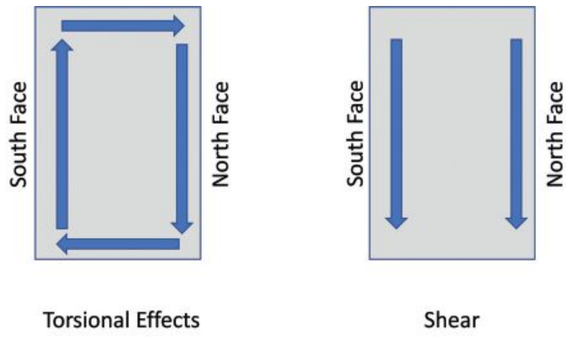


Figure 4 shows the cracking that results from our second loading scenario (scenario B). In Fig. 4, there is diagonal cracking on both faces of the cap. More specifically, on the north face of the cap, we see a diagonal crack in the typical shear cracking orientation. On the south face of the cap, we also see a diagonal crack; however, the inclination of this crack is in the reverse direction (that is, in the opposite direction to typical shear cracks). This type of cracking implies that torsional effects are significant, and their effects on the cap overshadow the effects from shear stresses. That is to say, in reference to Fig. 3, the torsional effects are large enough to overcome the shear effects on the south face and increase the diagonal tension to a stress level sufficient to cause cracking in the "reverse shear" direction on that face. Therefore, the cracks seen on north and south faces may complete a helical pattern of cracking that wraps around the entire cap. Such cracks would approximately follow the helical diagonal strut formation pattern (**Fig. 5**).

Figure 5 is constructed for a pure torsion case, and as such, the cracking angles in our example would differ due to combined loading present on the cap. With that stated, the stress flow shown in Fig. 5 helps us gain a complete understanding of how diagonal cracks that helically wrap around the element can occur. The strut-and-tie modeling (STM) approach offers a powerful tool in visualizing the stress fields and flow of forces through structural members from their point of application to the foundations. The torsional model shown in Fig. 5 is a good example for this truss analogy. However, to examine even earlier examples of the STM construct, we must go back to the pioneering work conducted by Ritter and Mörsch in the late 19th and early 20th centuries.[2,3]

Figure 4. Cracking resulting from loading scenario B. Figure: Dr. Oguzhan Bayrak.

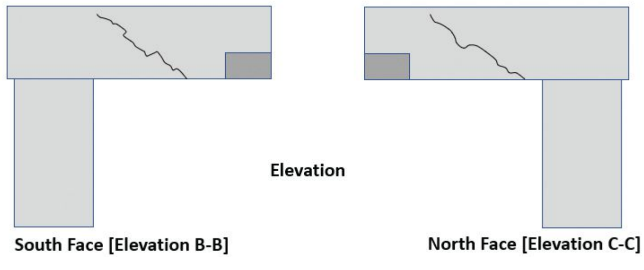
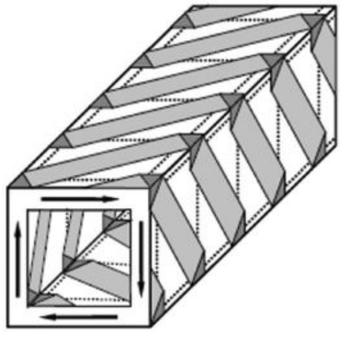


Figure 5. Formation of diagonal struts under torsional loads. Figure: Adapted from reference 4.



I would be remiss if I did not mention that the seemingly similar-looking cracking patterns shown in **Fig. 6** signal yet a different loading scenario (scenario C). The diagonal cracking seen in Fig. 6, which is the same on both faces, is attributable to the splitting of the diagonal strut that forms between the inside corner of a knee joint and the outside corner that redirects the tension field on the top side of a cap to the back face of a column. While such cracking can also be important in column-to-cap connections designed to accommodate bending-moment transfer, such diagonal cracks are not to be confused with the other diagonal cracking patterns discussed in this article. After all, not all diagonal cracks are created equal—a crack is not a crack.

The Additive Effects of Torsion on Cracking

Let us now focus our attention on a new cracking pattern resulting from a new loading scenario (scenario D) (**Fig. 7**). In this case, we see the formation of diagonal cracks on the north face, and these cracks have consistent direction with shear cracking. We also see the "reverse shear cracking" direction on the south face. At first glance, this cracking appears consistent with the second loading case we discussed previously. It is true that due to the reverse direction of diagonal cracks, significant torsional effects are at play. We also see that the cracks appear steeper (that is, the inclination from the horizontal axis is greater than 45 degrees), which may be a telltale sign of axial tension that has developed in the cap beam due to restraint provided by the two columns in the straddle cap. In the situation where the cap beam experiences drying shrinkage, the restraint provided by the columns may result in significant tensile forces in the cap. In this combined loading and structural restraint scenario, we expect the inclinations of the cracks to be steeper than those shown in Fig. 4, as shown in Fig. 7. Overall, the axial tension will impose additional demand on the longitudinal reinforcement, increase the widths of the diagonal cracks, and serve to reduce the ability of the cracked concrete to transmit shear stresses across the diagonal cracks.

Figure 6. Cracking in cap-to-column connection due to strut splitting (loading scenario C). Figure: Dr. Oguzhan Bayrak.

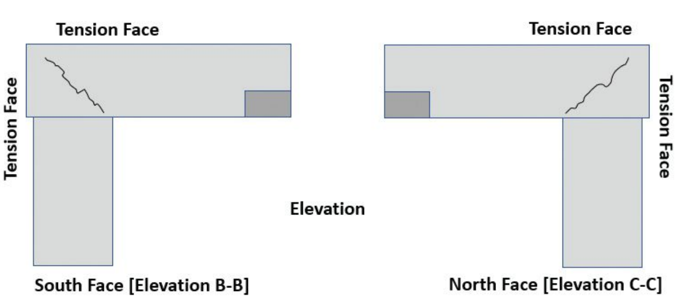
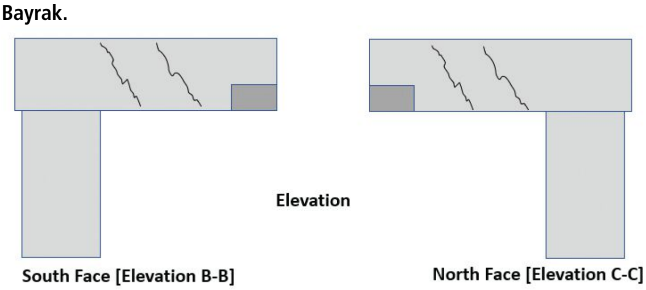


Figure 7. Cracking resulting from loading scenario D. Figure: Dr. Oguzhan Bayrak.



As I discussed in my LRFD article in the Spring 2025 issue of *ASPIRE*, torsion increases the demand on shear reinforcement. Torsion also increases the demand on longitudinal reinforcement. For a quick overview, let us direct our attention to Eq. 5.7.3.6.3-1 of the AASHTO LRFD specifications, which addresses the longitudinal reinforcement required in solid sections:

$$A_{ps}f_{ps} + A_s f_y \geq \left| \frac{|M_u|}{\phi d_v} + \frac{0.5N_u}{\phi} + \cos\theta \sqrt{\left(\left| \frac{V_u}{\phi} - V_p \right| - 0.5V_s \right)^2 + \left(\frac{0.45 p_h T_u}{2A_o \phi} \right)^2} \right|$$

This equation shows that bending moment, axial force, shear force, and torsion all impose additive demands on the longitudinal reinforcement. If we greatly increased the axial tensile force until it overshadows all other effects, the observed cracking would be nearly vertical. The cracking shown in Fig. 7 reflects a case in which all contributing factors (load effects as well as the structural restraint) are contributing to the observed cracking in a more "balanced" manner. That is to say, restrained shrinkage effects and the tensile stresses that result from those effects influence the orientation of the torsional cracks. The formation of multiple cracks in Fig. 7 indicates that the cap is being challenged to a great extent with respect to its structural capacity.

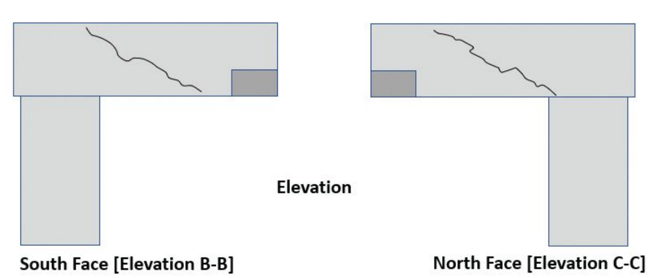
Figure 8 illustrates the cracking pattern that results from our fifth and final loading scenario (scenario E). This cracking pattern somewhat resembles those shown in Fig. 4 and 7. The one notable difference we see in this case relates to the "flatter" inclination of the diagonal cracks. That is to say, the orientation of the cracks with respect to the horizontal seems to be less than 45 degrees. This flatter cracking is in contrast to that shown in Fig. 7, where axial tension was present due to restraint effects. The flatter diagonal crack patterns in the cap beam seen in Fig. 8 suggest that axial compression is a factor. For example, the presence of post-tensioning force, in addition to shear, bending moment, and torsion, can lead to the flatter, diagonal cracking inclinations shown in Fig. 8.

Concluding Remarks

Considering the crack patterns and probable loading scenarios presented in this article, it is appropriate to review a few points we can take away from this discussion:

- Combined loading conditions may create complex stress states that require us to give consideration to boundary conditions that may or may not generate forces in the structural elements that are being investigated. The straddle bent considered in this article includes structural connections between the column and

Figure 8. Cracking resulting from loading scenario E. Figure: Dr. Oguzhan Bayrak.



cap. In the 25 years I have spent researching and investigating concrete bridges, I have also encountered cases in which inverted tee beams are supported on bearing pads placed on columns. Such support conditions will allow rotations at support points, and the stresses, cracks, and deformations will be quite different than the examples in this article. In short, the support/boundary conditions matter. They influence the forces that may develop in structural components. Finally, and importantly, in such circumstances, the rotations need to be considered in the bearing design process.

- The interaction among various loads and the resulting principal tensile stress influences the cracking of a reinforced or prestressed concrete component. That is to say, consideration of torsional effects in isolation can be misleading unless those effects dominate the overall structural response. Holistic consideration of all loads and their effects is necessary to reach correct conclusions.
- Diagonal cracking observed in a bent cap may not be indicative of reduced capacity of that structural component. The examples considered in this article focus on cracking that may occur in service conditions. The AASHTO LRFD specifications for strength limit state are based on the ability of cracked concrete to transmit shear stresses. In older bridge designs that were based on approaches developed in the 1940s, 1950s, and 1960s, the formation of initial diagonal cracking was interpreted as a clear indication of the "strength" or "structural capacity" of a member. This interpretation led to conservative design approaches that worked well within the bridge design and construction community. Over the years, particularly since the adoption of the modified compression field theory, more-refined designs and interpretations of structural behavior have become possible. With that serving as a backdrop, we should be careful about setting aside initial formation of diagonal cracks from the exploitation of the full structural capacity by the loads.

In summary, a holistic view of structural behavior will give due consideration to loading effects, boundary conditions, and, most importantly, the first principles of structural engineering. The examples we considered in this article are not intended to be comprehensive or exhaustive. They were selected to facilitate the discussion that is rooted in the first principles that include safety, stability, and serviceability.

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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.

Design of Attachments to Concrete with Shear Lugs—A Primer

by Timothy Cullen, Precast/Prestressed Concrete Institute

Shear lugs are steel elements used to transfer shear forces from a steel base plate into concrete. They consist of rectangular plates or steel shapes composed of plate-like elements that are welded to a steel base plate and either cast directly into concrete or post-installed into a grout-filled blockout (**Fig. 1**).

The American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*[1] introduced provisions for shear-lug design in Section 17.11. These provisions are now referenced in Article 5.13.1 of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*, 10th edition,[2] which permits the use of attachments to concrete with shear lugs. ACI 318-19 Section 17.11 requires two concrete failure modes to be evaluated in shear-lug design:

- **Bearing strength in shear.** This refers to the bearing strength before concrete fracture in front of the shear lug (that is, on a vertical plane). The ACI 318 provisions are based on a uniform bearing stress of $1.7f'_c$ acting over the effective area of the shear lug. Resistance provided by the embedded plate and welded anchors is conservatively neglected in this evaluation.
- **Concrete breakout strength.** This is calculated similarly to how the concrete breakout strength of anchors is determined in ACI 318 Section 17.7.2. The difference is in the determination of the projected area of the failure surface on the side face of the concrete A_{vc}. For shear lugs, A_{vc} is approximated as the rectangular shape that results from projecting 1.5 times the edge distance c_{a1}, both horizontally from the shear lug and vertically from its effective depth (**Fig. 2**).

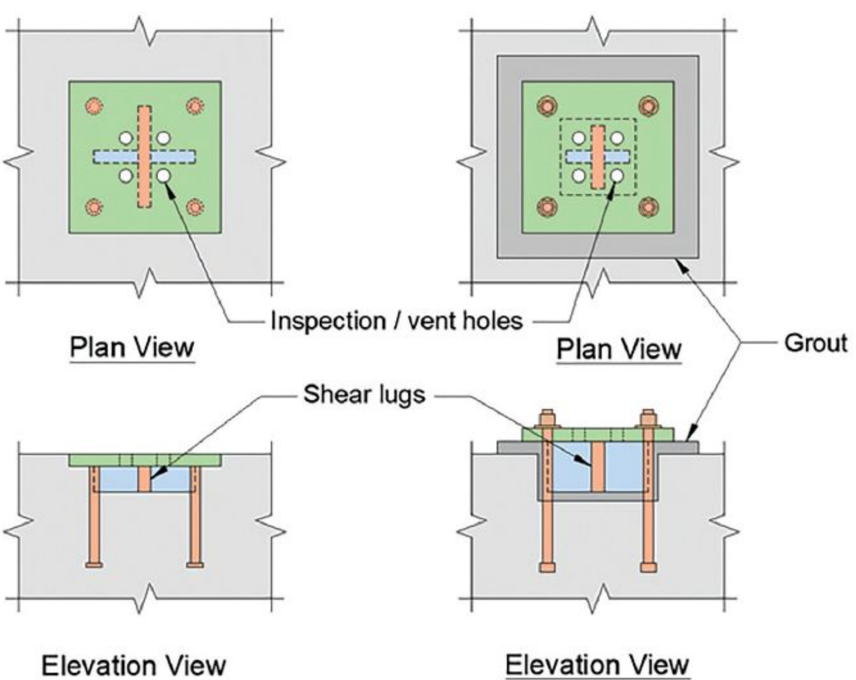

Figure 1. Examples of attachments with shear lugs. The example on the left illustrates a cast-in-place detail, and the example on the right shows a post-installed option. Figure: Adapted from ACI 318-19, Figure 17.11.1.1a.[1]

While these two failure modes are specifically addressed in ACI 318, the steel and weld design of the attachment base plate and shear lugs must also be checked. Additionally, practitioners should note that the ACI 318 provisions use pound units, whereas the AASHTO LRFD specifications use kip units (1 kip = 1000 lb).

In accordance with ACI 318 Section 17.11.1.1.2, a minimum of four anchors that satisfy the anchorage to concrete requirements of Chapter 17 must be welded to the attachment base plate. The anchors provide moment resistance, which prevents pry-out action on the shear lugs.

ACI 318 Section 17.11.1.2 presents an important detailing requirement: Steel base plates must include a minimum 1-in.-diameter hole along each of the long sides of the shear lug. This detail complies with the installation requirements of ACI 318 Section 26.7.2, which require proper consolidation of concrete or grout around the shear lugs to be verified using base plate inspection holes. For a cruciform-shaped shear lug, the commentary to ACI 318 Section 17.11.1.2 recommends four inspection holes, one per quadrant (Fig. 1).

A more in-depth discussion of the shear lug provisions of ACI 318 can be found in the September 2021

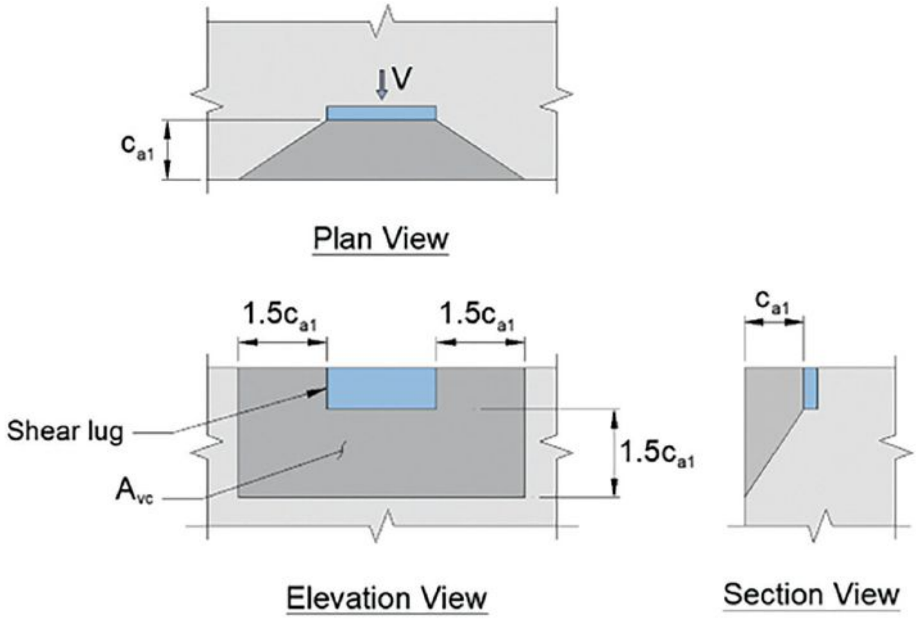

Figure 2. The projected area of the failure surface on the side face of the concrete for a shear lug near an edge. Figure: Adapted from ACI 318-19, Figure R17.11.3.1.[1]

STRUCTURE Magazine article titled "Integrating Shear Lug Design Anchoring-to-Concrete Provisions."[3] For practical guidance, designers can also refer to Anchorage Example 21 in Chapter 15 of the *ACI Reinforced Concrete Design Handbook* (ACI MNL-17).[4] That example illustrates the design of a column base plate subjected to both shear and tension, with shear lug calculations beginning at Step 17d.

The inclusion of shear lug provisions in ACI 318 and their adoption by reference in the AASHTO LRFD specifications represents a significant advancement in codified concrete anchorage design, providing engineers with a valuable tool for addressing shear demands. In bridge construction, shear lugs can be especially effective in enhancing the lateral resistance of bearing assemblies in long-span bridges, particularly in seismic design applications.

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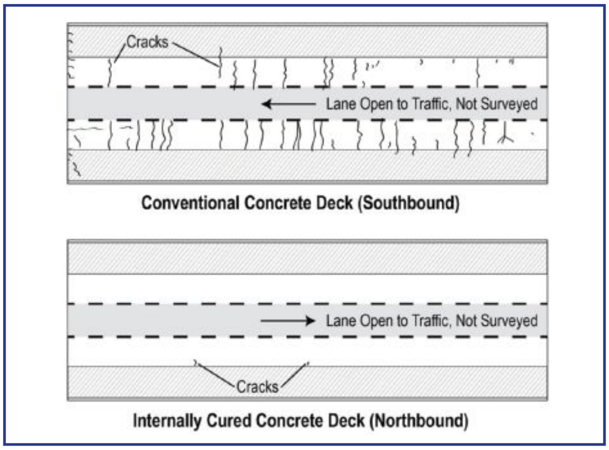
Improving Service Life of Concrete Bridge Decks using Prewetted Lightweight Aggregate

An article in the Summer 2024 issue of ASPIRE by Dr. Barrett, who works for the Federal Highway Administration (FHWA), describes the "Enhancing Performance with Internally Cured Concrete (EPIC2)" initiative in FHWA's current Every Day Counts (EDC) program. This initiative highlights the relatively simple approach of replacing a portion of the conventional fine aggregate with prewetted lightweight fine aggregate to provide internal curing. The higher absorption of manufactured structural lightweight aggregate is used to carry curing water into concrete so the entire body of concrete can more fully hydrate and have the improved characteristics of well-cured concrete. The absorbed water does not contribute to the mixing water (that is, it does not affect the *w/cm*) because it remains within the lightweight aggregate until after the concrete has set and pore sizes in the partially cured cement paste become smaller than the pores within the lightweight aggregate particles. As mentioned in Dr. Barrett's article, projects in Ohio and New York have demonstrated that internal curing can significantly reduce cracking in bridge decks.

The concept of internal curing from absorbed water in lightweight aggregate is not new. It has been known to some concrete technologists since at least 1957 when the beneficial curing effects were reported for lightweight concrete in papers by Klieger and by Jones and Stephenson that were presented during the World Conference on Prestressed Concrete held in San Francisco, CA.



"Enhancing Performance with Internally Cured Concrete (EPIC[2])"
by Timothy J. Barrett, *ASPIRE*, Summer 2024

Replacing a portion of the conventional fine aggregate with prewetted lightweight fine aggregate to provide internal curing is a more recent approach that provides internal curing but without significantly reducing the concrete density.

More information is available on the EPIC[2] webpage (see ref. 3 in FHWA article), as well as on the ESCSI webpage: www.escsi.org/internal-curing/

Information on other uses of lightweight aggregate can be found at www.escsi.org

Reinforcing the Future: Advancing Concrete Bridge Knowledge at the University at Buffalo

by Dr. Pinar Okumus, University at Buffalo, the State University of New York

There is no doubt that designers of modern bridges stand on the shoulders of the giants of engineering who preceded them. But a modern bridge is far from our grandparents' bridge. Today's bridges must meet more criteria than ever before. They need to be functional, safe, resilient, durable, redundant, adaptable, sustainable, aesthetically pleasing, and, of course, structurally efficient and economical. So how do we check so many boxes? We invest in research and education that empower us to create new structural materials, systems, and construction methods. We study how in-service bridges respond to complex loads and environmental conditions. And we make sure that our field is welcoming and accessible to all bright minds. The Institute of Bridge Engineering at the University at Buffalo (UB) was established more than a decade ago to address some of these needs. I started my academic career at UB with these ambitions in mind in 2013.

Testing of a precast concrete rocking column with ultra-high-performance concrete at the base column segment. Photo: Dr. Cancan Yang.

For many people, the word "professor" is synonymous with teaching, but at research-centered universities like mine, the professor is also a researcher who generates new information to share with the next generation. My research has revolved around structures that are rapidly built, can be repaired or replaced for resiliency after extreme loading, and that are serviceable after environmental deterioration. What better tool do we have than precast concrete for rapid construction, replacement, and durability? In this article, I provide examples of bridge-focused research at UB, which has been made possible by the hard work of many talented undergraduate and graduate students, as well as

At the University at Buffalo, additively manufactured strain-hardening fiber-reinforced concrete shells are being investigated for bridge applications to leverage the concrete's exceptional crack-width control and durability. Photo: Pranay Singh.

collaborators both within and beyond the field of civil engineering.

Research for Resilient and Serviceable Bridges

One way to create repairable bridges is to use advanced materials where they are needed and in a cost-efficient manner. My colleagues and I showed through testing of self-centering segmental bridge columns that even without mild steel reinforcement in the column base segment or between segments, there is virtually no damage due to large lateral drifts when ultra-high-performance concrete (UHPC) is used for the base column segment.[1] And our research on fiber-reinforced concrete extends beyond UHPC. We are investigating whether strain-hardening fiber-reinforced concrete shells can reduce crack sizes and mitigate the durability-reducing effects of detensioning cracks in pretensioned concrete girders.[2] To create shells in the shape of common pretensioned concrete girders and to one day be able to create free-form beams, we explored additive manufacturing—also known as three-dimensional (3-D) printing. Our initial flexure test findings show that bond failure at the interface between the additively manufactured shell and core concrete is not an issue.

Artificial intelligence (AI) has already penetrated our daily lives, and students are chasing opportunities to develop AI skills and applications in bridge engineering. In one study, our research team used machine learning to look for correlations between shear cracks in concrete beams and structural health indicators like stiffness and loading corresponding to crack widths. We then created a data-driven, web-based evaluation tool for bridge owners to prioritize repair. This work was partially funded by the precast concrete–focused University Transportation Center (TRANS-IPIC), of which UB is a member.[3]

My final research examples involve modeling as a powerful tool for understanding prestressed concrete structures. When it comes to a composite, nonlinear material such as concrete, aligning simulation predictions with test measurements can, in and of itself, be a learning experience that offers insights into numerous factors that affect structural response. For a National Cooperative Highway Research Program study (NCHRP Project 12-118), our research team has expanded the work of our collaborators at Purdue University with simulations that help us understand flexure and shear strength of prestressed concrete beams with bonded and unbonded strands.[4] In another study, we used similar simulations to verify strain measurements of optical fiber sensors embedded within the epoxy coating of prestressing strand as a step toward monitoring prestress for in-service bridges.[5,6] (For a description of this technology, see the article in the Fall 2024 issue of *ASPIRE*®.) That work was

Bridge inspection field work for a research project with former graduate students Lissette Iturburu Al-tamirano and Mauricio Diaz Arancibia, and Larry Mathews of the Association for Bridge Construction and Design of Western New York. Photo: Dr. Pinar Okumus.

Undergraduate students visiting the Sidley Precast plant in Thompson, Ohio, pose with star-shaped reinforcing bars, one of which was later decorated for the holidays. Photo: Dr. Pinar Okumus.

also conducted with Purdue University with funding from the Federal Highway Administration.

Educating the Next Generation of Bridge Engineers

Research can be a winding road that does not always provide immediate rewards. Some research questions need to be answered using tomorrow's technology; funding can shift with changing priorities; and implementation can take years, especially for fundamental research. In contrast, teaching can offer instant gratification, particularly when students reach their full potential, producing work around the world that makes us feel delighted and, if we are lucky, envious.

UB offers a master of science degree and a certificate concentrating on bridge engineering with remote course options. Responding to the needs of the industry, we cover subjects such as prestressed concrete design, advanced concrete materials and design, hazard (earthquake, wind, and fire) engineering, risk and reliability, bridge management, public policy, and emerging technologies, among others. A course on prestressed concrete bridge design has been in high demand and is taken by students and practicing engineers worldwide. In 2025, participants from the New York State Department of Transportation made up about one-third of the class. The course covers fundamentals of prestressed concrete and bridge engineering, neither of which are typical undergraduate curriculum.

I want to end this reflection on an aspect of teaching that is often overlooked. A bright PhD student destined for a stellar academic career recently told me that he may no longer be considering academia because professors seem to do nothing but work. This comment was a wake-up call for me: However much we love our spirited debates about shear reinforcement over coffee, work does not have to be our only hobby. We need to show students that it is possible to have friends, family, a healthy life, and time off. For me, the friendships I have built at PCI are one example that work and life can coexist.

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CBEI Full-Scale Bridge Completed for Deck Construction Training

Dr. Oguzhan Bayrak, Doug Beer, and Gregory Hunsicker, Concrete Bridge Engineering Institute

The mission of the Concrete Bridge Engineering Institute (CBEI) at the University of Texas is to serve the concrete bridge community and profession with regard to the most pressing issues encountered in concrete bridges across the United States. One of the focal points of CBEI is the design and construction of concrete bridge decks.

Bridge Deck Construction Inspection Training Course

Between March and June 2025, CBEI staff, working with the Texas Department of Transportation (TxDOT) and SEMA Construction, successfully constructed a full-scale, three-span bridge in Austin, Tex. The bridge is 34 ft wide and 134 ft long, with each span representing a different stage of construction. Span 1 demonstrates forming and bracing only; span 2 has formwork and reinforcing steel; and span 3 has a completed cast-in-place concrete deck. This structure, which is designed for hands-on instruction, will serve as the centerpiece of the new Bridge Deck Construction Inspection Training Facility. A "dry run" training session was held in May 2025, while construction was still underway, and the inaugural training session was held July 15–17, 2025.

This purpose-built training environment represents a significant leap forward in bridge construction education. Unlike conventional classroom-based instruction, this facility offers engineers and inspectors the rare opportunity to engage with a full-scale bridge deck, physically staged at multiple points in its construction life cycle. Throughout the three-day course, participants work through eight training modules, each focused on a critical stage of concrete bridge deck construction:

- Minimum bracing and forming
- Setting forms, screeds, and grading
- Reinforcement
- Prepour
- Concrete placement and screed
- Finish and cure
- Final inspection
- Special cases and troubleshooting

The curriculum blends classroom instruction with extensive field-based

Span 1 of the full-scale bridge deck showcases three different forming methods: stay-in-place corrugated metal deck (left); wood forms (center); and partial-depth precast concrete deck panels (right). Photo: Concrete Bridge Engineering Institute.

The deck of span 3 was placed using a telescopic concrete pump. Concrete Bridge Engineering Institute staff collaborated with the Texas Department of Transportation and SEMA Construction to construct the full-scale training structure. Photo: Concrete Bridge Engineering Institute.

Specimen for the Bridge Deck Construction Inspection Training Facility. Photo: Concrete Bridge Engineering Institute.

learning, with primary emphasis on the latter. By removing variables such as live traffic, active contractor crews, and strict production schedules, the training provides a safe, controlled environment to explore inspection scenarios in detail without the constraints of an active jobsite.

Testimonies

To prepare for the official launch, CBEI hosted a successful "dry run" session in May 2025 with members of the Transportation Pooled Fund Program. While the bridge was still under construction at that time, event participants provided valuable feedback and collaborated to refine the course structure and logistics. The input received has been instrumental in finalizing the training modules and ensuring that the facility will meet the expectations of both experienced and early-career professionals.

The following quotes are testimonies from participants who built the demonstration structure that will be used for hands-on training for the CBEI Bridge Deck Construction Inspection Programs.

> *My role here at TxDOT has given me the opportunity to go out to a lot of projects to see bridges in different construction stages. Being able to go out into the field helps tremendously in understanding how a specific stage is performed and what it takes to successfully complete it. The CBEI project has allowed me and my group to get our hands dirty and perform some of this work ourselves. This allows us to understand the specific process and all the minute details and techniques that go into its completion. I've realized how many tasks must be completed during construction that involve items that won't be a part of the structure after completion—for example, all of the formwork, brackets, cables, etc., that are used to keep the screed secure on the structure and the beams from rotating when placing the deck. This is something that isn't always obvious to an observer because there may be something more interesting catching the eye, like a pump truck distributing concrete onto a bridge deck. I've had minimal experience working with concrete in this way, so being able to be involved in the placement gave me a lot of insight into how fast it happens and what needs to be done in the short amount of time you have to pour, vibrate, and trowel before possible complications can happen. I got to do this specifically for the concrete pedestals which the beams would sit on, and all the labor we did before we could place the concrete was surprising. This work included cutting the protruding reinforcing bar extending from the top of the cap and shaping it in such a way that we could get a wood form built around it with our 2 in. clearance in mind. Then chamfering on the insides of the forms was necessary so that the top surface of the pedestal would be level, and reinforcing bar needed to be tied to keep the reinforcement from moving. It's been a while since I've been able to weld, so any chance I got I jumped at the opportunity, and that was my favorite part.*
>
> —Michael Ballinger, TxDOT Bridge Division

> *The time we have spent constructing this bridge has proven invaluable. For an engineer, the ability to create something from plans and drawings with your own hands is perspective altering. In my experience, there has always been a great divide of knowledge separating the engineer from the contractor. This is our attempt to bridge that divide. We are fortunate to provide a living classroom for future engineers and inspectors to use, and we hope that anyone coming to see it at CBEI will gain a lot from the experience. Thank you for the opportunity.*
>
> —Jeffrey Douglass, TxDOT Bridge Division

The value of this initiative has already been recognized by TxDOT leadership. With Austin as the host location, the facility is easily accessible to TxDOT districts, construction engineering and inspection (CEI) partners, contractors, members of the pooled fund transportation agencies, and the broader concrete bridge engineering and construction community.

> *Having a real, full-size bridge deck to train inspection staff will be a massive benefit to our training curriculum. For something like construction inspection, classroom training alone is just the tip of the iceberg. The only way to truly understand the issues you might encounter in the field is to see them—in the field. To have this in our own backyard in Austin means it is readily accessible to all TxDOT employees and our CEI and contractor partners. I think this is truly a game changer for the professional development of inspection staff!*
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> —Seth Cole, construction and maintenance branch manager, TxDOT Bridge Division

Future Offerings

Following the July kickoff course, the dates for additional training courses have been confirmed:

- October 14–16, 2025
- November 11–13, 2025
- January 13–15, 2026
- February 17–19, 2026
- March 10–12, 2026

More dates will be announced soon.

Participation is open to all inspectors and engineers from Transportation Pooled Fund Group agencies, consultants, and contractors. Given the anticipated demand for spaces, we strongly encourage early registration.

As the CBEI Bridge Deck Construction Inspection Program launches, it joins our growing suite of technical training offerings, including the well-received Concrete Materials for Bridges course. Together, these programs reflect TxDOT and the Transportation Pooled Fund members' commitment to workforce development and investment in the next generation of highly competent, field-ready engineers and inspectors.

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

Inaugural Bridge Deck Construction Inspection class, July 2025. Photo: Texas Department of Transportation.

STATE

Idaho

Idaho leverages pooled fund initiatives and develops seismically resilient precast concrete pier connection details

by Elsa Johnson, Idaho Transportation Department

The Idaho Transportation Department (ITD) makes effective use of limited funding by collaborating with neighboring states to tackle a variety of transportation challenges. For many years, one of the ways that the agency has achieved its strategic goals is through the Transportation Pooled Fund (TPF) program, which is a collaborative effort among multiple state and/or federal agencies and other entities that is administered by the Federal Highway Administration (FHWA). The TPF program enables agencies to pool their funds and conduct research to solve shared transportation problems.

Transportation Pooled Fund Initiatives

Overheight Truck Impacts

One TPF initiative addresses accidental bridge strikes and methods to repair prestressed concrete girders. Across the United States, overheight vehicle impacts are a frequent cause of bridge damage. Through the TPF program with the Missouri Department of Transportation as the lead organization, ITD and other state agencies are evaluating the load-carrying capacity of damaged concrete bridge girders and prioritizing girders in need of repair through their involvement with TPF-5(462), Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts (OHTI). The project is testing fourteen 50-ft-long, full-scale, prestressed concrete bridge girders subjected to overheight vehicle impact. Four of the girders will be experimentally tested to determine their residual load-carrying capacities under static load, and ten girders will be repaired using different repair options, which will then be compared. The final report for the project is expected to be published in fall 2025.

In the last few years, ITD has seen an increase in the number of overheight vehicle bridge strikes across the state. In November 2024, the bridge carrying Brunner Road over U.S. Route 95 (U.S. 95) was struck by an oversized trailer load. That same week, Bunco Road over U.S. 95 was struck by a truck hauling an improperly secured load. Having improved tools to assist in the evaluation of the damaged girders will be extremely beneficial.

Alkali-Silica Reactivity Evaluation Methods

Another TPF initiative is TPF-5(521), New Performance Approach to Evaluate ASR in Concrete. Participating states are evaluating new methods to determine the likelihood of alkali-silica reactivity (ASR) gel formation in concrete. The American Association of State Highway and Transportation Officials' (AASHTO's) test methods for aggregates, TP144-23, *Standard Method of Test for Determining the Potential Alkali–Silica Reactivity of Aggregates (TFHRC-TFAST)*,[1] and T416-24, *Standard Method of Test for Determination of Alkali Threshold for Alkali–Silica Reactivity in Aggregates Used in Concrete (ATT)*,[2] are being appraised in conjunction with local concrete mixture design data, cement mill reports, and supplementary cementitious material properties. States are looking to the more accurate TFAST method because it predicts ASR expansion using chemical measurements, and the ATT method because it measures the likelihood of ASR formation in concrete, not just the aggregate reactivity. Understanding the likelihood of ASR formation will alleviate ITD's concerns regarding the long-term durability of the concrete if reactive aggregate sources are used.

ITD Research Projects

Type IL Cement

In addition to participation in TPF projects, ITD has been working on several of its own research projects. One project underway is the investigation of the use of Type IL cement (also known as portland-limestone cement). Type IL cement improves sustainability by decreasing carbon dioxide emissions, but its impact on bridge construction is not fully documented. Currently, ITD specifications for Type IL cement limit limestone content to a maximum of 12.5% (10% ± 2.5%). On average, Type IL cement specifications across the United States allow up to 15% limestone content, but ITD is gathering additional data before fully embracing that threshold. The effects of Type IL cement on prestress losses, shrinkage, creep, camber, cure time, and strength raise questions about the long-term performance of Type IL cement in Idaho bridges. (See the Winter 2022 issue of *ASPIRE*® for more information on Type IL cement.)

To measure the consequences of an increase in limestone content in Type IL cement, ITD is actively collecting data and monitoring strength gains from recent construction projects. Concrete mixtures that use Type IL cement do not follow the typical 28-day strength development curve but reach maturity closer to 56 days. ITD will be modifying Idaho specifications to accept the 56-day strength test

Across the United States, overheight vehicle impacts are a frequent cause of bridge damage. The Idaho Transportation Department is participating in a Transportation Pooled Fund initiative to research ways to assess and repair prestressed concrete girders impacted by bridge strikes. All Photos: Idaho Transportation Department.

Precast concrete columns and pier caps receive the same rustic quarry stone pattern used throughout the Fort Hall interchange project near Blackfoot, Idaho.

results for all cement types to better capture the appropriate testing for Type IL cements. Because the properties and water demands of Type IL concrete mixtures can sometimes lead to increased shrinkage, ITD is collecting data on bridge deck cracking. The objective is to better understand the concrete performance and refine the concrete mixture designs before the state accepts the average industry standard of 15% maximum limestone content for Type IL cement.

Camber Predictions

ITD is also conducting research to develop more reliable camber predictions for prestressed concrete girders. ITD currently uses formulas based on research that does not represent modern prestressed concrete girder shapes or the higher concrete strengths commonly used in construction today. Accurate camber predictions are especially critical for deck bulb-tee girders, where the top flange is the riding surface and mitigation methods for camber variations are limited and difficult to perform in the field. In contrast, camber variations in standard bulb tees or AASHTO girders with a cast-in-place (CIP) concrete deck can be accommodated by varying the haunch thickness. The current camber formulas are underpredicting girder cambers, and this excess camber has sometimes exceeded the haunch depth, causing the girders to encroach into the CIP deck. This issue has been addressed by either grinding down beam seats or raising the grade over the bridge. Both methods are costly and time-consuming. More accurate camber-prediction formulas will minimize the impact of camber during construction.

Strand Debonding

Idaho has historically not permitted debonding of strands in prestressed concrete girders, but ITD is currently investigating the best ways to optimize girder designs. To control stresses and subsequent cracks in the end regions of pretensioned concrete girders, transportation agencies specify the use of strands that are either harped (deflected) or debonded. ITD design policies discourage debonding, preferring to harp strands. While harping comes with potential safety hazards associated with tensioned strands, both methods have been successfully used in pretensioned concrete beams. ITD is researching the use of debonded strands, particularly in prestressed concrete voided slabs where harping is not possible. The current practice is to provide top strands to help reduce the girder stresses; however, the addition of top strands becomes less effective as span length and stresses increase. This research will help designers develop more-efficient girder designs for prestressed concrete voided-slab bridges.

Ultra-High-Performance Concrete

Ultra-high-performance concrete (UHPC) has been used in Idaho for longitudinal closure pours between deck bulb-tee girders and between side-by-side voided slabs. While these keyway applications have been the primary focus in Idaho, ITD is also considering UHPC for girder repairs and looking for a project that is a good fit for a UHPC overlay.

The recent project to replace the Division Street and Elizabeth Park overpasses on Interstate 90 (I-90) near Kellogg, Idaho, used UHPC. Work began in 2022 on the I-90 bridges over the two local streets, but the project was suspended during winter months. Designed to improve safety, the I-90 bridge over Division Street is supported by a spread footing and steel H-pile foundation with concrete columns. The three-span structures use side-by-side precast, prestressed concrete voided slabs which are connected using shear keys filled with UHPC. After curing, the tops of the shear keys were ground smooth, and a polyester polymer concrete overlay was applied to provide the final riding surface.

ITD is using AASHTO's *Guide Specifications for Structural Design with Ultra-High*

The Interstate 90 over Division Street project near Kellogg, Idaho, features multispan precast, prestressed concrete voided slabs. Construction crews place ultra-high-performance concrete in the shear keys to make the connections.

Precast concrete arch sections create a safe passage for herds of deer, elk, and other wildlife over State Highway 21 near Boise, Idaho.

The overcrossing at State Highway 21 near Cervidae Peak complements the topography of the natural landscape while reducing the risk of wildlife-vehicle collisions.

Performance Concrete,[3] which addresses the design of UHPC structural components. This specification was a collaborative effort among AASHTO, FHWA, and other industry leaders to understand how the design of bridges using UHPC compares to design using conventional concrete. A companion material specification is under consideration by the AASHTO Committee on Bridges and Structures, and ITD plans to adopt it once it is available.

The use of nonproprietary UHPC mixtures for the construction and rehabilitation of Idaho bridges is a goal of the agency. An optimum nonproprietary UHPC mixture that incorporates locally sourced materials will lower costs and decrease construction lead times. ITD intends to adopt a nonproprietary performance specification by the end of 2025 to allow customized UHPC mixtures that meet specific project requirements.

Precast Concrete Pier Connections

ITD is working in conjunction with Idaho State University (ISU) to develop seismically resilient precast concrete pier-element connection details. The research was initiated to develop a connection that is simple, easy to use, and faster to construct, and that eliminates potential concerns regarding the seismic performance of traditional pier connections at the top and bottom of pier columns. This endeavor has involved two separate research projects: one to study the precast concrete element connections for response during an earthquake and another to investigate the retrofitting of damaged precast and CIP concrete bridges following an earthquake.

With the help of an AASHTO High Value Research grant, a unique precast concrete pier system was developed and implemented on Interstate 15 (I-15) at Exit 80 in Fort Hall, Idaho. The new Fort Hall interchange features a precast concrete pier supporting the 222-ft-long, 88-ft-wide bridge spanning I-15. The pier system incorporates a combination of structural elements where the connections between the elements are crucial for seismic resiliency. The developed system uses structural steel tubes filled with concrete strategically placed in the plastic hinge zones, which are critical locations that dissipate the energy associated with a seismic event and reduce the enormous stresses put on the piers during an earthquake. This new method replaces a method that uses proprietary couplers to connect a precast concrete column with the pier caps and foundation.

The response from contractors involved in the Fort Hall interchange project was overwhelmingly positive and indicated that the new method of constructing precast concrete piers is much easier and faster to install than previous methods. Idaho plans to adopt this system on future projects where accelerated bridge construction methods are warranted.

Wildlife Crossings

In addition to research, ITD has several areas of focus behind project development. The safety of the traveling public is of paramount importance to ITD, and strategies that protect the environment at the same time are win-win solutions. Idaho is committed to reducing wildlife-vehicle collisions by introducing concrete culverts, voided-slab bridges, or concrete arches for wildlife crossings. ITD was recently awarded a $21 million grant to construct three wildlife underpasses flanked by 8-ft-tall fencing. The project spans 6 miles along U.S. Route 30 in rural Bear Lake County and will reduce collisions along the mule deer migration route.

A successful example in support of habitat linkage is the concrete arch constructed over State Highway 21 (SH 21) at Cervidae Peak northeast of Boise, Idaho. The overpass along this mountainous roadway is ideally located to improve safety along a heavy migration route for mule deer. The project involved constructing a 150-ft-long wildlife overpass with an 18-ft vertical clearance over SH 21. The structure incorporates a precast concrete arch connected to CIP concrete footings with a grouted keyway. The span width of 54 ft is sufficient for two lanes of traffic with 4-ft-wide shoulders. The arch structure is composed of 25 precast concrete segments that have a nominal length of 6 ft and a 13-in.-thick wall. Each segment consists of two precast concrete halves joined at the crown with a CIP concrete closure pour. The segments are also bolted together to complete the connection. Since the crossing was completed, the U.S. Forest Service has been monitoring its use and has identified multiple wildlife species using the crossing, resulting in fewer wildlife-vehicle collisions.

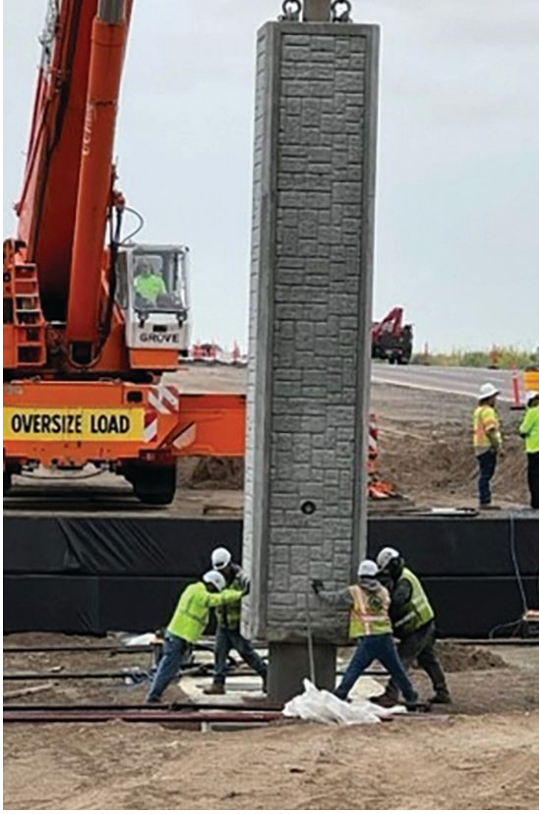
Aesthetics

While the budget for aesthetics is small, ITD makes every effort to use formliners or other components to blend work along a corridor with the aesthetics of the surrounding community. For gateway projects that lead into cities, ITD works with local communities, business owners, and other stakeholders to determine affordable aesthetic treatments. On occasion, the local groups can fund some of those efforts, so there is an opportunity to include artwork, decorative fencing, textured concrete, drought-resistant landscaping, formliners, specific color schemes, and anti-graffiti applications. For example, as a part of the reconstruction of the interchange at I-90 and State Highway 41 in Post Falls, Idaho, improvements were made to the underpass at Greensferry Road, which now features patterned concrete and sheet-metal fish attached to the parapet wall.

Addressing Workforce and Inspection Challenges

In the field, it is a challenge to keep up with the demand to perform inspections and load ratings on the 1848 highway bridges and 2375 local bridges across the state. ITD outsources some inspection work to consultants, who also provide supplemental training for young engineers in the

The interchange of Interstate 90 and State Highway 41 in Post Falls, Idaho, includes improvements to Greensferry Road. The underpass features formliner and russet-colored concrete adorned with sheet-metal fish.



As part of improvements along the Interstate 15 corridor, crews install precast concrete columns over driven steel H-piles for the Fort Hall interchange near Blackfoot, Idaho.

field. ITD's in-house inspection team is seeking inspectors who are also engineers-in-training or professional engineers. This background will assist them if they encounter issues in the field. For example, inspector engineers may update the load rating, create initial repair plans, or suggest fixes and repairs, which would then be corroborated by a consultant or maintenance team. In the past, an inspection report was submitted to an engineer, but in the future, the inspection-intervention process will be a more streamlined and collaborative effort.

Conclusion

Known for its natural beauty and diverse terrain, Idaho relies on its bridges to promote safety, mobility, and economic opportunity, while enhancing tourism and supporting connectivity with neighboring states. ITD is making the most of its budget by pooling funds with other states and working with universities and federal agencies to develop innovative solutions to manage Idaho's assets.

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3. AASHTO. 2024. *Guide Specifications for Structural Design with Ultra-High Performance Concrete*. Washington, DC: AASHTO.

Elsa Johnson is a senior bridge engineer with the Idaho Transportation Department.

CONCRETE CONNECTIONS

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

IN THIS ISSUE

https://www.buffalo.edu/ibe.html
https://trans-ipic.illinois.edu/July-2025-Webinar
The Professor's Perspective on page 44 covers the topic of educating the next generation of bridge engineers through both research and innovative educational programs. The first link connects to the webpage for the Institute of Bridge Engineering at University at Buffalo, the State University of New York, which offers specialized courses in bridge engineering. A webinar recording about some of the research discussed in the article is available at the second link.

https://www.volpe.dot.gov/news/detecting-damage-structural-components-with-new-infrared-technologies
The article at this link describes the development of infrared technology by Fuchs Consulting Inc. (FCI), which was funded by the U.S. Department of Transportation's Small Business Innovation Research program. FCI is the subject of the Focus article on page 6, and infrared ultra–time domain thermography (IR-UTD) is discussed in the Concrete Bridge Technology article on page 35. IR-UTD is a nondestructive evaluation method that can detect early signs of defects in concrete components.

https://www.youtube.com/watch?v=C6OqgIEZwfI
This is a link to a time-lapse video of the construction of the Schuylkill Banks Christian to Crescent Bridge in Philadelphia, Pa., which is the subject of the Project article on page 14. The pedestrian bridge features precast concrete U-beams made integral with two cast-in-place towers that anchor the wire-rope cables supporting the superstructure. Innovative solutions were required due to the considerable site constraints, which included an industrial docking facility, high-voltage electric lines, a narrow footprint against railroad along the shoreline, and vertical limitations where the structure passes underneath a rail bridge and the Schuylkill Expressway.

https://nationalconcretebridge.org/ncbc-epoxy-coated-strand-workshop
The Concrete Bridge Technology article on page 20 discusses the one-day Construction of Unducted External Post-Tensioning with Epoxy-Coated Strand in the Laurel Fork Bridge workshop presented by the National Concrete Bridge Council, in conjunction with the Concrete Bridge Engineering Institute and the Federal Highway Administration. This is a link to presentations from the workshop, additional resources, and site-visit photos.

https://nationalconcretebridge.org/2025-ncbc-webinar-series
The second edition of the "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" was published in the January/February 2025 issue of *PCI Journal,* with errata published in the September/October 2025 issue. The recommended practice is the topic of the Concrete Bridge Technology article on page 28. On August 20, 2025, the National Concrete Bridge Council presented a webinar about the updated recommended practice. Recordings for that webinar and the rest of the completed 2025 NCBC webinar series are available at this link.

https://www.ndt.net/article/ndtce2015/papers/167_washer_glenn.pdf
The Concrete Bridge Technology article on page 35 presents the development and uses of infrared ultra–time domain thermography (IR-UTD) for the detection of delamination in concrete components. This is a link to a paper presented at the 2015 International Symposium Non-Destructive Testing in Civil Engineering, which includes background information about the technology and bridge deck images that illustrate the evaluation results.

https://www.fhwa.dot.gov/resourcecenter/teams/structures-geotechnical-hydraulics/Structural_Design_UHPC_Workshop_Manual.pdf
The Concrete Bridge Technology article on page 32 focuses on the selective uses of ultra-high-performance concrete (UHPC) to enhance durability and extend the service lives of concrete bridges. The August 2024 Federal Highway Administration's *Structural Design with UHPC Workshop Manual* is available at this link.

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/research-notes/task4396-rns-05-25-a11y.pdf
This is a link to a summary of New Performance Approach to Evaluate ASR in Concrete, a Transportation Pooled Fund (TPF) project that is mentioned in the State article on Idaho on page 50. The Idaho Transportation Department is an active participant in several TPF projects that research ways to solve transportation challenges and improve the state's infrastructure.

https://cbei.engr.utexas.edu
Regular readers of *ASPIRE*® will know that the training facility and coursework development at the Concrete Bridge Engineering Institute (CBEI) at the University of Texas at Austin has been ongoing. CBEI reached another milestone this summer with the completion of a full-scale bridge for the Bridge Deck Construction Inspection Training Facility, which is discussed in the CBEI article on page 47. The recently improved CBEI website, which can be accessed at this link, includes dates and registration links for upcoming courses.

OTHER INFORMATION

https://www.post-tensioning.org/FAQTECHNICALNOTES
In June 2024, the Post-Tensioning Institute published two technical notes (Tech Note 23 and Tech Note 24) focused on developing industry awareness about variations in the relaxation properties of alternative materials for high-strength steel bars used in prestressing and post-tensioning applications. The alternatives discussed are "Non-ASTM A722" and "ASTM A722 Like" bars. Both technical notes can be downloaded at this link.

Upcoming Changes to the *AASHTO LRFD Bridge Design Specifications*

by Dr. Oguzhan Bayrak, University of Texas at Austin

The 2025 meeting of the American Association of State Highway and Transportation Officials' (AASHTO) Committee on Bridges and Structures (COBS) took place in June 2025, in Dallas, Tex. The AASHTO Concrete Committee presented seven agenda items for approval by COBS, and all seven items were approved. In addition, the Safety and Evaluation (SE) technical committee presented an agenda item that relates to the load rating of segmental concrete bridges, which was approved as well. This article provides an overview of these eight agenda items, which will be discussed in greater detail in upcoming issues of *ASPIRE*®.

The eight agenda items approved at the 2025 COBS meeting are as follows:

1. Agenda item 34 (working agenda item [WAI] 235): Strain Compatibility. Strain compatibility analyses typically require the use of commercial, open source, or academic software. Strain compatibility analyses can also be performed by using spreadsheet applications, which have been developed by many designers. Performing such analyses was once burdensome, and many designers preferred to use simplified hand calculation tools. However, with the advent of computers and appropriate software, strain compatibility analyses have become more feasible for designers to consider. Consistent with this trend, this agenda item informs the design engineer of cases when the closed-form equations of the *AASHTO LRFD Bridge Design Specifications*[1] Article 5.6.3 that use a rectangular stress distribution method can be overly conservative. In addition, the item provides guidance to design engineers for performing strain compatibility analysis. The closed-form equations of Article 5.6.3 can significantly underpredict the flexural resistance of flanged precast, prestressed concrete girders. In contrast, strain compatibility analyses provide more accurate estimates of flexural capacity.
2. Agenda item 35 (WAI 233): AASHTO/National Concrete Bridge Council (NCBC) Guide to Post-Tensioned Transportation Structures: Volume I – General. One of the major advancements in bridge construction in the United States in the second half of the 20th century was the development and use of prestressed concrete—here, prestressed concrete refers to both pretensioned and post-tensioned concrete bridges. With their proven field performance, prestressed concrete bridges offer a broad range of engineering solutions and a variety of aesthetic opportunities. Additionally, prestressing in concrete bridges offers potential benefits in costs and durability. The objective of this agenda item and guide is to provide guidance to individuals involved in the design, installation, grouting, and inspection of post-tensioning tendons for prestressed concrete bridges, primarily during construction. While providing new information, this document also includes, revises, and updates the body of knowledge previously presented in the FHWA *Post-Tensioning Tendon Installation and Grouting Manual*.[2]
3. Agenda item 36 (WAI 225): Minimum Reinforcement. It has been shown that the flexural cracking stress of concrete members significantly decreases as member depth increases. Past research has suggested that flexural cracking strength may be proportional to member height. For example, a 36.0-in.-deep girder achieves a flexural cracking stress that is 31% to 57% percent lower than that of a 6.0-in.-deep modulus-of-rupture test specimen. Since modulus-of-rupture units are either 4.0 or 6.0 in. deep and typically moist cured up to the time of testing, the modulus of rupture should be significantly greater than the flexural cracking stress of an average-size, typical bridge member composed of the same concrete. Based on this technical fact, this agenda item serves to revise the *AASHTO LRFD Bridge Design Specifications*[1] in the manner outlined in National Cooperative Highway Research Program (NCHRP) Research Report 906, *LRFD Minimum Flexural Reinforcement Requirements*.[3] The approved changes in Agenda item 36 offer significant advantages in meeting the minimum reinforcement design requirements of the AASHTO LRFD specifications in a rational way.
4. Agenda item 37 (WAI 238): Reinforcement Properties. This agenda item consolidates information about reinforcing bar properties found in multiple locations in Section 5 of the AASHTO LRFD specifications into one table. With this agenda item, specified minimum yield strength, minimum tensile strength, and minimum tensile strain properties of ASTM A615,[4] A706,[5] A955,[6] A1035,[7] and A1064[8] reinforcement are consistently presented in a new table.
5. Agenda item 38 (WAI 234): ASTM A615 Updates. This agenda item intends to correct the ratios of minimum yield strength to ultimate tensile strength for AASHTO M 31[9] (ASTM A615) Grade 60 and Grade 80 reinforcing bars. This correction will increase the cracking moment M_{cr}, which would increase the minimum amount of flexural reinforcement required in cases where M_{cr} is less than 1.33 times the ultimate moment M_u. Agenda item 38 also adds the ratios for AASHTO M 31 (ASTM A615) Grade 100 reinforcing bar, ASTM A706 Grade 100 reinforcing bar, and ASTM A955 Grades 60, 75, and 80 reinforcing bars. Additionally, it provides correct values for minimum tensile strength of reinforcing bar to use when determining spacing of noncontact lap splices of longitudinal reinforcement that extends from columns and anchors in oversized drilled shafts. This agenda item refers users to the new table discussed in agenda item 37.
6. Agenda item 39 (WAI 146): Strand Bond. Earlier this year, PCI updated the "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand."[10] The PCI recommended practice establishes ASTM A1081[11] minimum values for standard bond and high bond strand. The standard bond strand is considered as the strand typically

used in pretensioned applications. This agenda item incorporates information from the updated PCI recommended practice, which includes resolution testing. The implementation of this agenda item is covered in a Concrete Bridge Technology article in this issue of *ASPIRE*. In addition, the August 20, 2025, webinar hosted by NCBC focused on this item. The recording of the webinar can be accessed through the NCBC website (https://nationalconcretebridge.org/webinars).

7. Agenda item 40 (WAI 230): Concrete Piles. The AASHTO LRFD specifications do not explicitly address the structural design of prestressed concrete piles; rather, they rely on general provisions developed for the design of reinforced concrete compression members, and more specifically, for columns in buildings. There are important differences between a simple compression member and a compression member that is laterally supported, at least partially, due to the presence of soil around a drilled shaft or pile. Agenda item 40 considers boundary conditions that are more representative of drilled shaft or pile foundations and incorporates best practices in designing and detailing such deep foundations. As a result, this agenda item unifies the prestressed concrete pile provisions of the AASHTO LRFD specifications with the current research findings and best practice-based design provisions for piles presented in *Specification for Precast, Prestressed Concrete Piles* (ANSI/PCI 142-24).[12] With the approval of this agenda item, performance-based design techniques in ANSI/PCI 142 have been adopted by the AASHTO LRFD specifications.

8. SE agenda item 2: The changes proposed in this agenda item from the SE technical committee are aimed at improving AASHTO's *The Manual for Bridge Evaluation*.[13] The changes are based on recent findings from the NCHRP 12-123 research project,[14] which involved the calibration of load factors, multiple presence factors, and system factors; revision of provisions related to the application of striped versus design lanes; and introduction of stress limits in concrete for inventory and operating ratings at the service limit state, which are specific to segmental concrete bridges. This agenda item benefits from the work product of Corven Engineering published by the Florida Department of Transportation titled *New Direction for Florida Post-Tensioned Bridges—Volume 10A: Load Rating PostTensioned Concrete Segmental Bridges*.[15]

As I mentioned in my Fall 2024 AASHTO LRFD article, the AASHTO Concrete Committee, with the support and collaboration offered by various concrete technical institutes, has been quite active in developing these agenda items. In addition, the committee has been working on a comparable number of agenda items slated to be finished for the next cycle. The approved Concrete Committee agenda items noted in this article will be incorporated in the forthcoming 11th edition of the AASHTO LRFD specifications[16] and the approved SE agenda item will be included in the forthcoming 4th edition of *The Manual for Bridge Evaluation*.[17]

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Richard Miller, PhD, PE, FPCI, is Professor Emeritus and former head of the Department of Civil and Architectural Engineering and Construction Management at the University of Cincinnati, where he taught for 36 years. Dr. Miller's research focuses on concrete materials and prestressed concrete bridges. He has been principal or co-principal investigator on seven projects for the National Cooperative Highway Research Program. Work performed by Dr. Miller and his colleagues has resulted in numerous changes to the *AASHTO LRFD Bridge Design Specifications*, including incorporation of high-strength reinforcing bar and provisions on debonded strands and continuous for live-load bridges. Dr. Miller has also completed numerous projects for the Ohio Department of Transportation and the Federal Highway Administration related to concrete bridges. He has served on and chaired several PCI councils and committees and currently serves on the PCI Board of Directors as the chair of the Technical Activities Council. He is a Fellow of PCI, and in 2024 he was named a PCI Titan of the Industry.

Clay Naito, PhD, PE, FPCI, is a professor of structural engineering at Lehigh University in Bethlehem, Pa., where he has taught for 22 years. Dr. Naito's research focuses on experimental and analytical evaluation of reinforced and prestressed concrete structures subjected to extreme events, including earthquakes, tsunamis, and intentional blasts. He has also conducted research studies for the Pennsylvania Department of Transportation, the Federal Highway Administration, and the Precast/Prestressed Concrete Institute on the performance of concrete bridge structures. Research topics include the performance of adjacent box-beam bridges, integration of electrically isolated tendons, use of self-consolidating concrete and ultra-high-performance concrete in bridges, and strand bond. He received the Distinguished Educator Award from PCI in 2015 and was elected Fellow of PCI in 2019.

Resources

- PTI/ASBI Specification for Multistrand and Grouted Post-Tensioning
- PTI Specification for Grouting of Post-Tensioned Structures, 4th Edition
- FHWA Replaceable Grouted External Post-Tensioned Tendons
- ASBI Construction Practices Handbook, 3rd Edition
- PCI Bridge Design Manual, 4th Edition
- PCI Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges

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