ASPIRE®

THE CONCRETE BRIDGE MAGAZINE

WINTER 2026

www.aspirebridge.org

Harbor Bridge
Corpus Christi, Texas

***ASPIRE®* BEGINS ITS 20TH YEAR**
by Dr. Richard Miller

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EDITORIAL

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AI Bridge Design and Construction?

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

Today, it seems like everyone is focused on this promising or menacing thing called artificial intelligence (AI). Are we ready for an AI-designed bridge? It's coming, or maybe it's already here.

So, how does AI-driven bridge design work? Do we just feed the environmental conditions, restrictions, constraints, materials, and performance requirements into a specialized bridge design AI tool and—"booyah!"—out comes a complete set of plans, covering everything from earthwork to environmental requirements, structural calculations, final design, and construction plans? Imagine that instead of taking years to develop, a project could be ready to be permitted and constructed in a matter of weeks.

In this accelerated scenario, what happens to the process of seeking public input about infrastructure projects? And what happens to our bridge design profession? Will AI push designers out to pasture by automatically adapting established solutions to fit the conditions of a selected site? Today, design and project engineers are a critical component of the concrete bridge industry. Are they (we) quickly becoming a thing of the past? If human engineers become obsolete, how do we ensure quality control, quality project delivery, and safety to bridge owners and the traveling public?

We've heard from some pundits that AI won't displace anyone. "You need humans to program the bots," they say. "Human experts are necessary to make AI work." Until when?

It is clear that contractors and construction equipment manufacturers in the concrete bridge industry are going to use AI tools to enhance jobsite construction. Personally, I thought it would take a little while longer for AI to play a central role in the preparation of engineering plans, but that time appears to be here. Designers are being asked by contractors to adjust details to facilitate unmanned assembly. This type of jobsite feedback is just the beginning. In the next few issues of *ASPIRE*®, let's start a discussion about the various strategies to consider while designing that hypothetical AI bridge, and how we can remain integral to the process.

In October, I attended a University of Texas Concrete Bridge Engineering Institute (CBEI) class on bridge deck construction, which involved going from classroom lecture to visiting the three-span bridge located at CBEI. On the third trip to the bridge site, I noticed that a motorized screed was running. It moved along the rails, over the partial-depth concrete deck panels with a single mat of reinforcement, to verify the adequacy of the concrete cover. We were instructed to begin taking deck and elevation measurements, move forward to take additional measurements, and then calculate the adjustments needed to finish the deck at the proper elevation as we neared the quarter point of the span.

This type of immersive training is an exceptional feature of the new CBEI curriculum. It emphasizes for participants how many things need to go right to achieve a smooth riding deck, the myriad of steps involved in this activity, and the distinctive types of tasks that can go wrong. Working through the logic of the beam deflecting from a transient screed load, and incorporating the newly added dead load from the partial cast-in-place slab, made the engineering estimate for camber and deflection real.

No one designs or desires the bump that can occur at the expansion joints or near the pier. Our instructor explained that concrete finishers commonly tend to deviate from the global screed rail alignment to finish the concrete at the expansion joint. It makes sense to use the joint as a bulkhead to control the top surface, but that action may create a bad ride. Today, humans have to verify the deck elevations. In the future, there may be an AI-driven solution to such challenges, and I have no doubt someone is already working on finding a way.

The global pace of AI is dizzying. The motivational force behind its use is tied to capitalizing along economic lines, and I get it. I'm still committed to innovation, but I caution against becoming a business of catalogued and ready-made solutions. Let's stay with human-centered technologies that feature tools that make sense. We have never been a one-size-fits-all profession. A

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Located in a region susceptible to hurricanes, the new Harbor Bridge in Corpus Christi, Texas, challenged the limits of precast concrete segmental design and construction. Photo: Harbor Bridge Project.

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CONCRETE CALENDAR 2026

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

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.

April 23–24, 2026
NCBC Prestressed Concrete Bridge Seminar
Austin Marriott South
Austin, Tex.

May 3–9, 2026
PTI Convention
Westin Long Beach
Long Beach, Calif.

June 15–17, 2026
International Bridge Conference
Gaylord National Resort
National Harbor, Md.

June 28–July 2, 2026
AASHTO Committee on Bridges and Structures
Charlotte, N.C.

September 9–12, 2026
PCI Committee Days
San Antonio, Tex.

September 13–16, 2026
AREMA Annual Conference & Expo
Kansas City Convention Center
Kansas City, Mo.

September 30–October 2, 2026
PTI Committee Days
San Antonio, Tex.

October 11–14, 2026
ACI Concrete Convention
Hilton Atlanta
Atlanta, Ga.

October 15–18, 2026
NRMCA ConcreteWorks
Gaylord Opryland
Nashville, Tenn.

February 1–5 2027
2027 PCI Convention at The Precast Show
Salt Lake City, UT

ASPIRE® Begins Its 20th Year

by Dr. Richard Miller

The first issue of *ASPIRE*®, the Concrete Bridge Magazine, was published in the winter of 2007. As we begin the 20th year of publication with this Winter 2026 issue, it is an appropriate time to look back at some milestones in the magazine's history, reflect on the impact the publication has made on the industry, and plan for its continued success. We are grateful for the input of three significant people—John Dick, *ASPIRE*'s first executive editor; Henry Russell, the first managing technical editor; and Reid Castrodale, managing technical editor emeritus—whose reflections over the last 20 years inform this article.

Origin Story

The first challenge *ASPIRE* faced was uniting designers, fabricators, and contractors in the concrete bridge area. As John Dick has noted, until the 1980s, there was no organization dedicated specifically to concrete bridges. Instead, each segment of the concrete bridge industry—for example, precast or cast-in-place concrete; reinforced, pretensioned, or post-tensioned systems; and slab, beam, or segmental construction—was focused on promoting their share of the market. But in 1987, John, who was working for the Precast/Prestressed Concrete Institute (PCI), and Dr. Basile Rabbat, who was employed by the Portland Cement Association, collaborated with representatives of two additional organizations—the Concrete Reinforcing Steel Institute and the National Ready Mixed Concrete Association—and founded the National Concrete Bridge Council (NCBC). From the beginning, NCBC has worked closely with the Federal Highway Administration (FHWA) (see the Perspective article in the Fall 2022 issue of *ASPIRE*).

There were challenges to overcome before the first issue of *ASPIRE* was published. Members of the concrete bridge industry were skeptical that a publication could promote concrete bridges, in general, rather than the specific types they designed, produced, and/or constructed. However, they were persuaded that a magazine promoting concrete bridges would increase the overall market share for such bridges, and as a result would increase the market share for each sector. PCI agreed to publish *ASPIRE* with financial support from various trade groups within the concrete industry and from advertising.

John was named as executive editor and asked Dr. Henry Russell to become *ASPIRE*'s first managing technical editor with Craig Shutt as the first managing editor. Mark Leader of Leader Graphic Design Inc. was hired to design *ASPIRE*, and he established the overall layout style and colors, some of which are still used today.

ASPIRE Launches and Evolves

In the inaugural Winter 2007 issue, John wrote in his editorial: "*ASPIRE* magazine will showcase how you and your peers are meeting challenges and expanding design boundaries with concrete bridge technology." Since then, the editorial staff of *ASPIRE* have continually worked to meet this challenge.

Henry Russell noted that in the early issues, it was difficult to persuade people to write articles for a completely unknown publication, and so the early issues relied on the editorial staff to produce much of the content. He shared that as *ASPIRE*'s visibility increased, external authors were willing to provide articles for the publication, and this remains true today. *ASPIRE* is indebted to the many engineers, designers, fabricators, contactors, suppliers, and academics who contribute the majority of the content for each issue.

The table of contents for the first issue reveals many article types that continue to be published today. For example, *ASPIRE* has always featured a broad range of project articles, spanning different concrete construction types, in each issue. These projects showcase how designers, fabricators, and constructors rise to the challenge of providing high-quality concrete bridges that meet the owners' need for economy, function, and speed of construction. The project articles frequently highlight why a concrete bridge was a preferred choice over other options. Over the years, highway bridges have made up the bulk of the featured projects; however, pedestrian, light rail, heavy rail, and airport bridges are also highlighted.

To complement featured projects from across the country, *ASPIRE* has included aesthetics commentary since the first issue. Frederick Gottemoeller focuses on one selected project in each issue, drawing attention to the beauty and elegance of concrete bridge structures.

ASPIRE has regularly published articles on the consultants and construction companies that design, build, inspect, and repair concrete bridges. These articles show how these companies make significant contributions to the concrete bridge industry and emphasize the innovative practices they employ.

Another precedent for future issues was an article featuring a state department of transportation (Minnesota). As often as possible, *ASPIRE* publishes articles profiling a state, local, or regional government agency and the important work they do in maintaining our infrastructure.

The first issue contained an article by Dr. Dennis R. Mertz on the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*. When asked if there were an *ASPIRE* article or series of articles that was especially memorable, John, Henry, and Reid all

The first meeting of the *ASPIRE* team, April 17, 2006. Front row: Mark Leader (left) and Craig Shutt; back row, from left: Henry Russell, Jim Ahtes, John Dick, and Roy Diez. Photo: John Dick.

noted the LRFD articles. In 2007, the AASHTO LRFD specifications were in their fourth edition, and states had only been required to use those specifications since 2000. Thus, many aspects of the AASHTO LRFD specifications were new and unfamiliar. Dr. Mertz's early involvement with the development of the AASHTO LRFD specifications made him the ideal person to explain the origin, meaning, and application of various provisions. As the AASHTO LRFD specifications were updated and improved, Dr. Mertz was there to provide insight and guidance to the design community. Unfortunately, Dr. Mertz passed away in 2016. Since then, the column has been written by another expert on the AASHTO LRFD specifications, Dr. Oguzhan Bayrak.

The first change in the *ASPIRE* leadership occurred in the summer of 2012, as John retired and William Nickas assumed the role of editor-in-chief. In the Winter 2015 issue, Dr. Reid Castrodale was welcomed as the new managing technical editor.

While *ASPIRE* continues to publish many of the types of features found in the first issue, the scope of *ASPIRE*'s content has also expanded over the past two decades. Concrete Bridge Technology articles were added just before Reid's tenure as managing technical editor began. In some cases, these articles expand on the technologies used in the featured projects. In other cases, the articles describe innovative or unusual analysis techniques, design processes, or construction methodologies.

ASPIRE also has perspectives, articles where members of the concrete bridge industry can provide information and share their experiences. These perspectives are written by a broad range of contributors who offer insight into areas such as new products, sustainability, research, policies, and ethics. Educators and other individuals with academic backgrounds are frequent contributors, describing how colleges and universities are contributing to the concrete bridge industry and the challenges of educating future bridge engineers.

With the Winter 2023 issue, Reid became managing technical editor emeritus, and Dr. Krista Brown assumed the role of managing technical editor until I came on board with the Winter 2025 issue.

ASPIRE's Impact

What is the impact of *ASPIRE*? Currently, we mail *ASPIRE* to approximately 14,000 hard-copy subscribers and the magazine has approximately 3,500 digital subscribers. We estimate that 25,000 individuals come into contact with each issue and that an average of 1.5 unique persons sees each paper copy. Some paper copies even reach 3 to 5 people. Anecdotally, members of the editorial advisory board often encounter readers who comment on the excellence of publication. The fact that so many professionals are willing to commit their valuable time to contributing articles indicates that they benefit from increasing the industry exposure of their companies and projects, and from what they learn by reading *ASPIRE*. from addition to the support of our readers, we are also incredibly thankful for our paid advertisers for their support of this knowledge transfer tool.

In 2023, a readers' survey was conducted. Of the 455 readers who responded, 76% rated the value of *ASPIRE* 7 out of 10 or higher. About two-thirds of the respondents said that *ASPIRE* helps them understand the latest advances in the concrete bridge industry and that the publication provides ideas for their own projects. The project case studies, Concrete Bridge Technology, and the perspective articles were the most highly rated features. (For more information on the survey, see the Perspective in the Summer 2023 issue of *ASPIRE*.)

Moving Forward—With Your Help

As *ASPIRE* moves into its 20th year, we are committed to delivering articles that help you in the conception, design, fabrication, construction, preservation, sustainability, and rehabilitation of concrete bridge structures of all types. We also want to expand *ASPIRE* to include more about workforce development, consistent with AASHTO efforts in that area, and address the ethical obligations of our profession.

But we can't do this without you. Do you have a concrete bridge project that would be of interest? While major projects are always welcome, *ASPIRE* is also looking for articles on "bread and butter" projects. Sometimes, seemingly simple projects involve innovative design or construction techniques or conquer constraints through cutting-edge solutions where the properties of concrete bridges shine.

Have you applied innovative design, analysis, or construction techniques that could be covered in a Concrete Bridge Technology, Creative Concrete Construction, Concrete Bridge Preservation, or Safety and Serviceability article? We are eager to share what you have learned with others, as that is how our industry grows.

So, if you have an idea you would like to share, please reach out. You can find contact information for the *ASPIRE* team in the masthead on page 2 of this issue, or you can contact us through the *ASPIRE* website: www.aspirebridge.com.

High Performing Concrete Bridges—From Rural To Urban

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The table of contents from the first issue of *ASPIRE*® (Winter 2007). Figure: PCI.

Building Information Modeling in Bridge Design and Construction

by Zhengzheng (Jenny) Fu, Paul Giuntini, and James Bodi, Kiewit Corporation

Building information modeling (BIM) has transformed how infrastructure projects are designed and delivered. In vertical construction, adoption of BIM has been rapid, providing architects, engineers, and owners with a shared digital environment to manage projects. In the bridge sector, adoption has been slower, but the use of BIM is steadily gaining momentum. BIM is not merely a visualization tool; it is a working platform that influences every stage of project delivery: planning, design, fabrication, construction, and eventual handover to owners for operation and maintenance. Owners, engineers, and contractors are tasked with developing and converting a digital model into a physical structure while balancing priorities related to time, cost, quality, and safety. This article explores BIM's impact on bridge design and construction through the lens of Kiewit as an engineer and contractor, focusing on benefits, challenges, and the road ahead.

Geographically correct three-dimensional (3-D) models are useful for visualization and planning. Figure: Kiewit/Trimble/Autodesk/Bentley Systems/Google Earth.

Integrated Building Information Modeling

At Kiewit, integrated delivery is more than a project strategy—it is how we operate. The appropriate use of BIM will depend on the project delivery type. On design-build (DB) and progressive design-build (PDB) bridge projects, our design and construction teams work side by side from project pursuit through execution, providing real-time constructability insights that improve design decisions, reduce rework, and drive more reliable outcomes in the field. This collaborative model allows us to optimize construction sequences and material selections, and align engineering strategies early, thereby maximizing value for clients. Because we control critical aspects of the scope by self-performing processes such as formwork, reinforcement, concrete, and other aspects of construction, we can translate digital BIM models into execution plans, with cost and schedule certainty built in from the start.

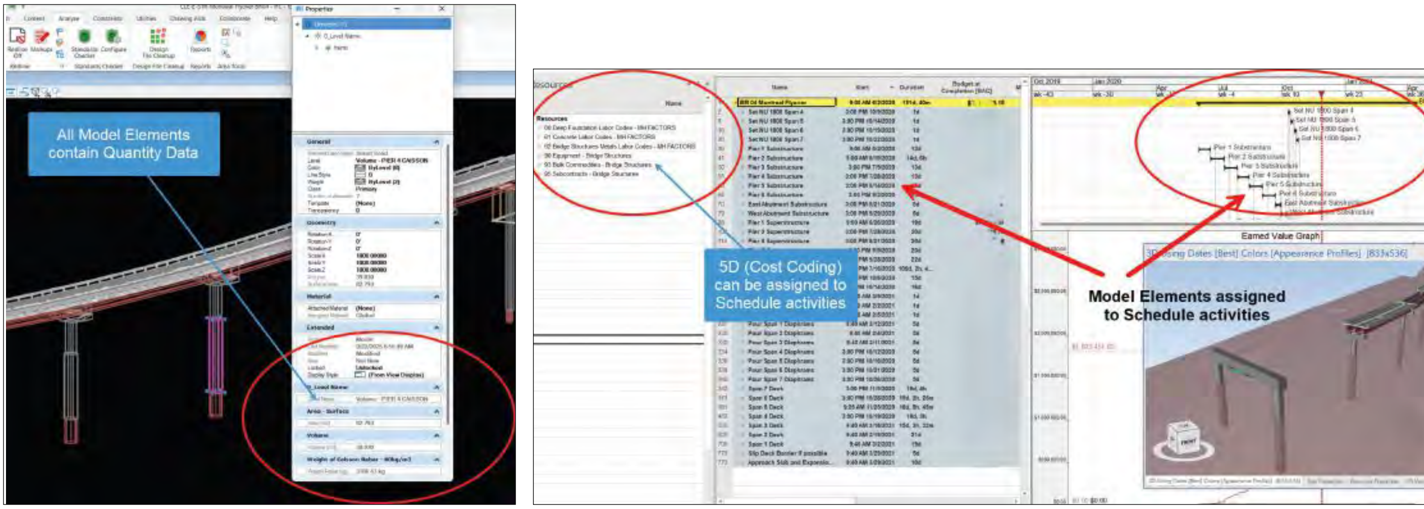
In construction manager at risk and construction manager/general contractor projects, BIM is most effective when it is used as a collaborative, decision-making tool from early design through construction.

In design-bid-build (DBB) projects, contractors have very limited involvement during the design stage. BIM models in DBB projects can balance the need for adequate details for bidding with flexibility for contractor innovation. However, one concern on DBB projects is BIM compatibility with contractor software; it is important to ensure that BIM models can be effectively used and shared in construction.

BIM Benefits

The following are key benefits of BIM in bridge projects:

- Safety planning: Safety is a top priority in bridge construction, especially when projects occur over waterways or live traffic. BIM supports safety planning by allowing contractors to simulate construction activities and identify hazards before work begins. By virtually performing crane lifts, girder placements, or temporary works, contractors can develop safer sequences and train crews more effectively.
- Constructability reviews: One of BIM's most immediate benefits is



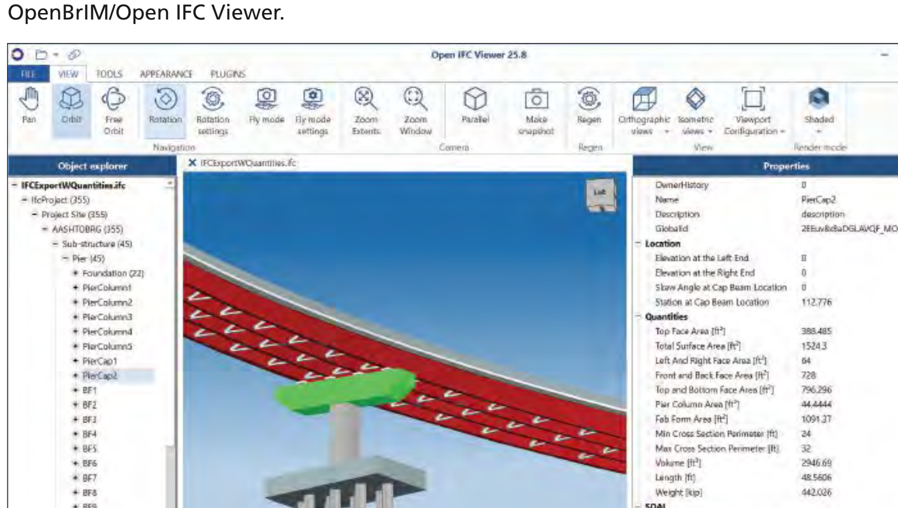
Example of a five-dimensional cost estimation. Figure: Kiewit/Bentley Systems.

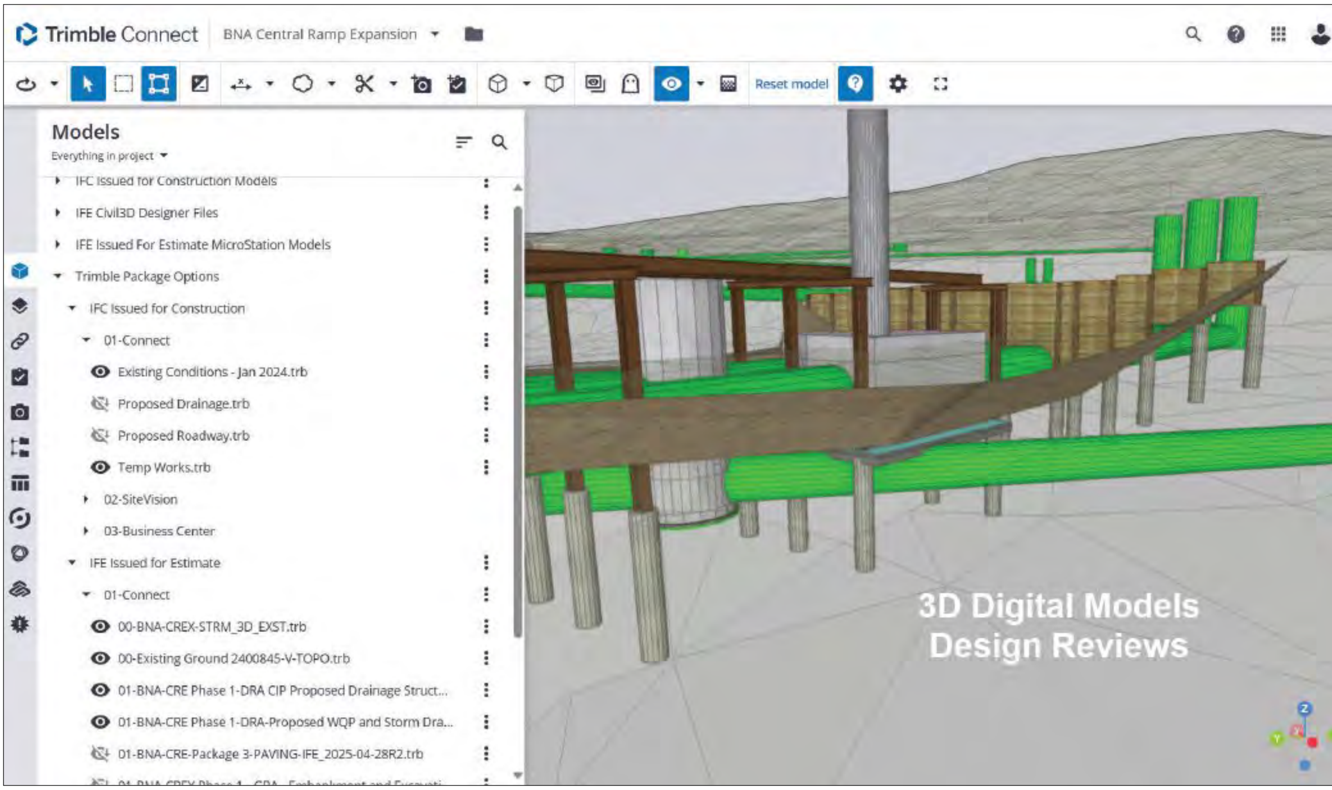
Linking three-dimensional models (upper left) to construction timelines can help with scheduling, construction staging, and the like. Figure: Kiewit/Bentley Systems.

the ability to assess constructability before construction begins. Bridges often feature complex geometries, multiple spans, skewed alignments, and varying foundation conditions. BIM allows engineers and contractors to detect clashes during the design phase. Early identification of conflicts reduces costly rework, change orders, and schedule delays.

- Four-dimensional (4-D) scheduling: BIM enhances scheduling by linking three-dimensional (3-D) models to construction timelines, creating what is known as 4-D BIM. For contractors, BIM can simulate construction staging, traffic detours, crane operations, temporary works, and equipment placement.
- Five-dimensional (5-D) cost estimation: Accurate cost estimation is central to a contractor's role. BIM enables quantity takeoffs directly from the digital model, improving the accuracy of estimates and reducing the risk of underestimation or double counting. With 5-D BIM, where cost is tied to the model, contractors can update cost estimates in real time as designs change. This feature is particularly valuable in DB projects, where rapid decision-making is essential to maintaining budget control.
- Collaboration and communication: Contractors often face communication gaps with designers and owners, especially on large and complex bridge projects. BIM's centralized digital model fosters transparency. Instead of relying solely on two-dimensional (2-D) drawings, all stakeholders can view and interact with the same 3-D model. For contractors, this use of BIM reduces misunderstandings, accelerates approvals, and supports smoother coordination with subcontractors.

Bridge model using the Industry Foundation Classes (IFC) standard. Figure: Kiewit/OpenBrIM/Open IFC Viewer.





Digital model reviews allow engineers and contractors to detect clashes during the design phase, which can reduce costly rework, change orders, and schedule delays. Figure: Kiewit/Trimble.

BIM Challenges and Limitations

While BIM offers clear benefits, the industry also faces significant barriers to effective adoption, including the following:

- Software interoperability: Designers, fabricators, and contractors often use different software platforms. Converting models between formats can lead to data loss, errors, or misalignment of geometry. A lack of interoperability forces some contractors to remodel portions of the design, reducing efficiency. To address interoperability concerns, the BIM for Bridge initiative at Kiewit has been focused on delivering bridge models in the Industry Foundation Classes (IFC) format, which is an open, global standard (ISO 16739[1]). See the Concrete Bridge Technology article, "BIM for Bridges and Structures Pooled-Fund Program," in the Fall 2024 issue of *ASPIRE*® for details on IFC.
- Investment costs: To use BIM, contractors must invest in software licenses, powerful hardware, and training programs. For smaller contractors, these costs may outweigh the perceived benefits, producing gaps in BIM adoption across the industry.
- Workforce resistance: Transitioning from traditional 2-D drawings to digital models requires a cultural shift. Sometimes, even highly experienced field personnel, owners, and design staff will resist adopting new technologies that are unfamiliar to them. We must dedicate time and resources to training and transforming management's view.
- Contractual and legal uncertainties: When BIM models are used, contractors should be cautioned to draft contract agreements carefully to ensure that they are not inadvertently assuming liability for design errors or deficiencies contained within the BIM models provided.
- Insufficient guidance regarding application of BIM models: Bridge models can be extremely large and complex. Such models are often difficult for contractors to use due to a lack of clear guidance on the level of development/detail or the level of information needs. This lack of guidance leads to uncertainty around the intended use, comprehensiveness, and accuracy of the models.

Conclusion

From Kiewit's perspective, BIM in bridge design and construction is both a valuable tool and a challenging commitment. Its benefits in constructability reviews, scheduling, cost estimation, safety, field planning, construction management, and collaboration are undeniable. However, owners, engineers, and contractors must also contend with software interoperability, high investment costs, cultural resistance, legal uncertainties, and data management issues. Despite these challenges, the trajectory of BIM in the infrastructure sector is clear: BIM is becoming an indispensable part of modern bridge delivery. For owners, engineers, and contractors, embracing BIM is not optional—it is the pathway to more efficient, safer, and more cost-effective projects. The bridge industry must continue refining standards, training, and contracts to ensure that BIM achieves its full potential in transforming bridge design and construction.

Reference

1. International Organization for Standardization (ISO). 2024. *Industry Foundation Classes (IFC) for Data Sharing in the Construction and Facility Management Industries*. ISO 16739-1:2024. Geneva, Switzerland: ISO.

PROJECT

U.S. Route 181 Harbor Bridge: Creating a New Coastal Icon for South Texas

by Joseph Briones, Texas Department of Transportation, Chris Ursery, Arup, and Justo Molina, Flatiron-Dragados LLC

Each precast concrete segment was fabricated off site and then delivered to its respective pylon, where a ground-based crane hoisted the segment to the bridge deck. A self-propelled modular transporter carried the segment along the southbound box girder to be installed at the cantilever front by a derrick crane. All Photos and Figures: Harbor Bridge Project.

The Harbor Bridge, located in the coastal city of Corpus Christi, Tex., carries U.S. Route 181 across the Corpus Christi Ship Channel. The name Harbor Bridge carries historical significance, honoring the bridges that preceded it and that helped spark and sustain the economic growth of the Coastal Bend. This important crossing has evolved from the original drawbridge of 1926 to a steel truss bridge, which opened in 1959 and was known as the Gateway to Corpus Christi, to the recently completed, signature precast concrete structure.

When it opened, the 1959 structure was considered an engineering marvel, at the cusp of innovation for bridge engineering, and it subsequently became a long-lasting icon for the local community. The Texas Department of Transportation (TxDOT) integrated several emerging technologies in that bridge that are still commonly used today, including the first application of prestressed concrete girders (for the approach spans to the main channel) and the first use of elastomeric bearing pads under girders in Texas.

As the years passed, maintenance costs for the Harbor Bridge rose due to the structure's deterioration in the harsh marine environment, traffic demands increased, and concerns about limited maritime accessibility grew. The combination of those factors led TxDOT to consider constructing a new bridge. In 2014, TxDOT accelerated efforts to replace the old Harbor Bridge with a taller, wider, and more durable structure capable of withstanding the region's demanding climate profile. The new bridge design would address TxDOT's priorities of improving regional mobility, maritime accessibility, and safety for motorists and pedestrians. Using the design-build-operate-maintain delivery model, TxDOT teamed with Flatiron-Dragados LLC and ultimately chose to replace the aged Harbor Bridge with a signature precast concrete segmental cable-stayed bridge. This option was selected over steel girder, cable-stayed proposals.

The new Harbor Bridge, which is located in a region susceptible to hurricanes, challenged the limits of precast concrete segmental design and construction. It achieved the longest precast concrete segmental main span ever constructed (1661 ft), as well as the widest delta-frame connected cross section (nearly 150 ft). Innovative materials were essential to protect the major structural components from the corrosive marine environment and meet TxDOT's sustainability goals. High-performance concrete mixture designs were engineered to achieve both the demanding 10-ksi design compressive strength requirement and the project's 170-year extended service life requirement, the pinnacle of sustainability for this project. Corrosion protection for the 270-ksi high-strength steel strand used for the stay cables was achieved by using epoxy-coated and filled strand, in which the internal voids among the strand wires are epoxy filled. This type of strand is relatively

profile

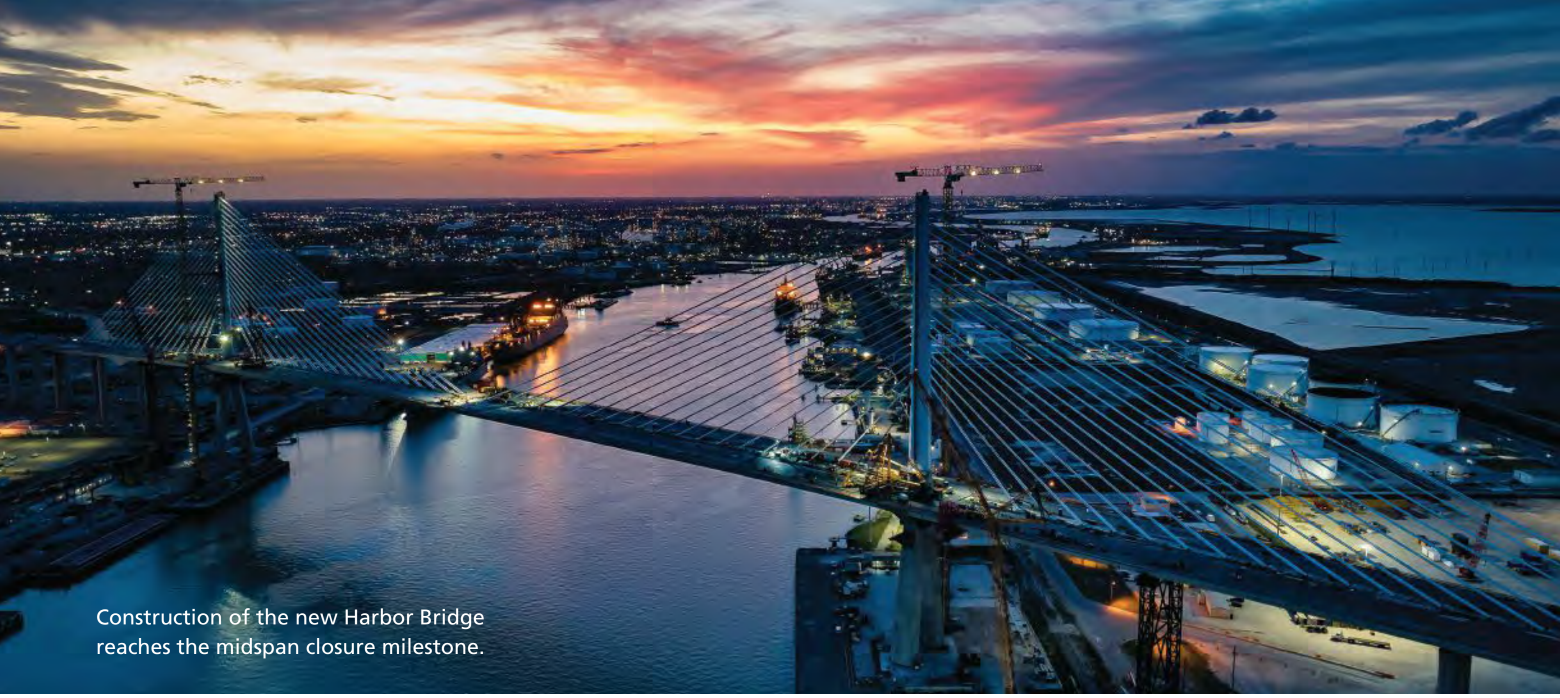
U.S. ROUTE 181 HARBOR BRIDGE / CORPUS CHRISTI, TEXAS

BRIDGE DESIGN ENGINEER: Arup & Carlos Fernandez Casado (CFC) – Design Joint Venture, Houston, Tex.

OTHER CONSULTANTS: Owner's engineers: HNTB, Kansas City, Mo., and Texas Department of Transportation Bridge Division, Austin; construction quality acceptance firm: Atlas Technical Consultants, Denver, Colo.; aesthetic lighting design: Reed Burkett Lighting Design Inc., St. Louis, Mo.

PRIME CONTRACTOR: Flatiron-Dragados LLC, Corpus Christi, Tex.

MATERIAL SUPPLIERS: Stay-cable system supplier and installer: DYWIDAG-Systems International (DSI), Long Beach, Calif.; post-tensioning suppliers: Structural Technologies (VSL post-tensioning products), Columbia, Md., and Williams Form Engineering Corp., Belmont, Mich.; reinforcement fabricator: Harris Supply Solutions, Seattle, Wash.; bearings and expansion joints: Mageba, New York, N.Y.; precast concrete segmental formwork: Ninive Casseforme, Garbagnate LC, Italy; derrick crane sleds: Somerset Engineering, Somerset, Pa.



Construction of the new Harbor Bridge reaches the midspan closure milestone.

A delta frame is installed using a custom support system.

new in the United States and is gaining popularity for stay cables and ungrouted external tendon applications.(For more information on epoxy-coated strands, see the Spring 2020 issue of *ASPIRE*®.)

Enhanced connectivity and safety improvements for motorists and pedestrians were key TxDOT requirements for the new bridge. The bridge has three lanes of traffic in each direction and includes 10-ft shoulders, a safety element missing from the old bridge. A protected 10-ft-wide shared-use path for pedestrians and cyclists is provided on the northbound side leading up to the scenic overlook at the center span, where visitors can observe unmatched views of this beautiful coastal region.

To accommodate the shared-use path, the northbound box girder is wider than its southbound counterpart, creating an asymmetrical cross section. The dual precast concrete box girders, connected transversely by precast concrete delta frames and a cast-in-place median slab, are supported by a central plane of twin, parallel stay cables. The cable-stayed portion of the bridge stretches 3295 ft with two 817-ft side spans and a 1661-ft center span. The navigational vertical clearance envelope for the new bridge has been increased to 205 ft (compared with 138 ft for the original bridge), allowing the passage of large modern cargo ships underneath.

The impressive, nearly 540-ft-tall, inverted Y-shaped pylons, which are the tallest structures in Texas south of San Antonio, have greatly enhanced the Corpus Christi skyline. The slenderness of the upper pylon allows the structure to seamlessly blend in with the surrounding built environment.

Arguably, concrete segmental bridges offer an enhanced aesthetic appeal when compared to conventional bridges. In a series of outreach events, the public selected "Corpus Christi: A Beacon of Coastal Beauty" as the aesthetic bridge theme. This concept identifies the public's preference that the bridge aesthetics be integrated with the built environment and the natural beauty of the greater Coastal Bend region. One highlight of the aesthetic design is the lighting system, which consists of fully addressable, dynamic LED devices installed on the towers, along the stay cables, and along the superstructure underside, providing an infinite number of color combinations for special lighting presentations.

TEXAS DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Signature cable-stayed bridge featuring a 1661-ft center span and 817-ft side spans, supported by a central plane of dual stay cables and two nearly 540-ft-tall inverted Y-shaped concrete pylons. The nearly 150-ft-wide cross section uses two post-tensioned precast concrete box-girder segments transversely connected with precast concrete delta frames provided at each deck-level stay-cable anchor.

STRUCTURAL COMPONENTS: 698 post-tensioned precast concrete box-girder segments, 84 post-tensioned precast concrete delta frames, and 76 pairs of stay cables to support the superstructure. Each stay cable is anchored at its prescribed precast concrete delta frame along the bridge deck and steel anchor box within the upper tower. The pylons, back-span piers, and transition piers use cast-in-place concrete. The pylons are founded on 10-ft-diameter and 4-ft-diameter drilled shafts while the back-span piers and transition piers are founded on 24-in. square precast, prestressed concrete piles.

BRIDGE CONSTRUCTION COST: $517.3 million (cable-stayed bridge only)

AWARD: 2025 American Segmental Bridge Institute Bridge Award for Excellence

Back-span cantilever at temporary pier tie-in.

Construction of the new Harbor Bridge tower and superstructure.

Analysis

The structural analysis of the bridge consisted of both local and global models, each with different modeling approaches for specific design checks. Local models using three-dimensional (3-D) brick elements were used to determine the transverse design deck effects. The primary global model, consisting of 3-D grillage elements, included the construction stage analysis. A central database was used to store model input and output data and served as the sole source of authoritative information for the design partners.

The construction engineering team used a local 3-D brick model for the nodal regions of the delta frame and box girders, two-dimensional shell elements for the thin slab portions of the box girders, and one-dimensional frames for the delta-frame main members. The transverse stiffness in the global model was calibrated to resemble the behavior observed from the more granular local model. The local model was essential to capture local effects from post-tensioning, stay force tensioning, local live load, and transverse bending of the median slab, and this model could quickly investigate the effects of heavy equipment during construction. Separate local models were used in regions such as the back-span pier segments, the expansion joint segments, the tower table nodal zone, and the stay-cable anchor boxes.

Given the high risk for hurricanes in the Gulf Coast region, the project required a rigorous wind-loading analysis. Wind tunnel testing confirmed the bridge's satisfactory behavior. Additional wind-buffeting analyses were performed based on the modal behavior and

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

Corpus Christi is in the flat Coastal Bend region of Texas's Gulf shore. Prominent landscape features are visible for miles. The Harbor Bridge stands slightly apart from the downtown, so the bridge occupies its own visual space, clear of the city's skyline. Even so, it is near important regional landmarks, including Corpus Christi's minor league baseball stadium, Whataburger Field. Indeed, the bridge dominates the view from left field. So, it is no surprise that the community wanted it to be a "beacon of coastal beauty." And, wow, is it ever.

The bridge owes its beacon status in large part to a combination of improvements in concrete segmental construction. The most visible of these is the unusually wide deck system featuring two segmental box girders connected by delta frames. The system allows support from the median by a pair of cable planes emanating from single centerline towers. Visual simplicity is always important in creating landmark bridges, and this deck system is as visually simple as it gets. It is easy to understand from nearby and from a distance, and even from below. Even fans at Whataburger Field can enjoy the elegance of the solution between innings. And the designers solved the problem of installing a shared-use path on just one edge of the bridge in the simplest way possible: they made one box girder a bit wider than the other.

The innovations do not end there. Because of their V-shaped bases, the towers appear to be striding across the channel. Vertical tapers on the legs and tops of the towers, combined with the diagonal placement of the legs' square cross sections and the hexagonal cross sections of the tops (which make those elements appear narrower), give the whole structure a sense of elegance. The two-box system also contributes at each pier line, requiring only two slim piers, made to look even slimmer by their octagonal cross sections.

The Harbor Bridge is a masterpiece. Its designers, the Texas Department of Transportation, and the community are to be congratulated on their achievement.

specific wind climate definitions for the completed bridge and for critical stages of construction.

Much of the complexity in the global analysis model involved developing the construction stage analysis. Each stage required specific boundary conditions and construction-load assumptions. The intent of the staged analysis was to capture all locked-in effects in the structure as the cantilever construction progressed and cables were stressed. A specialized tuning effort was performed to control stresses in the structure; thus, stay cables were tensioned at the time of installation and midway through the following cycle. To prevent undesirable stresses and deformations after the main span closure, a third phase of tensioning was executed in the final three pairs of stay cables.

Construction

Segmental construction accelerated the project's pace by allowing concurrent fabrication of the precast concrete segments during the construction of the pylons. Precast concrete delta frames were fabricated as full pieces at the precasting facility where the box girders were fabricated. Off-site segment fabrication also facilitated the geometric precision and quality control needed for this structure. After each segment was delivered to its respective pylon, a ground-based crane hoisted the segment to the bridge deck. A self-propelled modular transporter would then carry the segment along the southbound box girder to be installed at the cantilever front. Derrick cranes mounted on sleds atop the northbound box girder moved sequentially with the advancing structure, lifting and placing each segment into position. After a segment was aligned and epoxy was applied to the joint, high-strength post-tensioning bars locked the segment into the permanent structure. Because segments were not lifted from the shipping channel, access to the Port of Corpus Christi remained uninterrupted during the project.

Each side of the cantilever required 19 construction cycles, with each cycle consisting of an approximately 37-ft-long section having four northbound box-girder segments, four southbound box-girder segments, one delta frame, a cast-in-place median slab, and twin stay cables. In total, 698 precast concrete box-girder segments, 84 precast concrete delta frames, and 76 pairs of permanent stay cables were used to assemble the bridge. During peak production, construction crews streamlined the process to achieve an impressive 11-day cycle time, clearly demonstrating the efficiency of segmental construction.

A custom support system used for the delta-frame installation allowed the delta frames to be adjusted in all six degrees of freedom while hoisting. The delta frames were maneuvered to engage the shear keys, with their corresponding blockouts located within the webs of the adjoining segments. Minor manipulations were necessary to align the internal post-tensioning ducts and correctly position the stay-cable guide pipes. Placement of the cast-in-place concrete closures and tensioning of the continuity post-tensioning completed the assembly.

The post-tensioning design used center-span continuity tendons, back-span continuity tendons, and top-slab cantilever tendons. All tendons were composed of 0.6-in.-diameter strands. The center-span continuity post-tensioning used 62 tendons, with 19 to 27 strands per tendon, while the back-span continuity post-tensioning used 56 tendons in each of the two back

Underside view of twin box girders and delta frames.

The completed new Harbor Bridge overlooks Whataburger Field, a minor league baseball stadium, in Corpus Christi, Tex. The bridge opened to traffic in June 2025.

spans with 16 to 27 strands per tendon. Finally, the top-slab cantilever tendons were installed during the initial cantilever construction, before the cable stay installation and consisted of 20 tendons per cantilever in the 8 cantilevers for a total of 160 cantilever tendons with 25 to 27 strands per tendon.

Most of the stay-cable tensioning occurred in two phases: at the conclusion of an erection cycle and halfway through the next cycle. This sequence was necessary to control the tension generated in the top deck during cantilever construction and the tension in the bottom slab generated during stay tensioning. After the main-span closure, the final three cables had a third tensioning phase, as previously mentioned, to control stresses and deformations in the completed structure.

Construction Engineering and Geometry Control

The construction engineer created a comprehensive erection manual that provided the details necessary to achieve the required internal forces and geometry after completion of construction without overstressing any of the bridge components during construction. In lieu of a fully prescriptive manual, construction rules were developed to allow the contractor to make on-site adjustments to a typical erection sequence without further evaluation. Compared to typical fully prescriptive manuals, these rules added a significant number of analysis permutations; however, this approach provided the flexibility needed to achieve and maintain production goals.

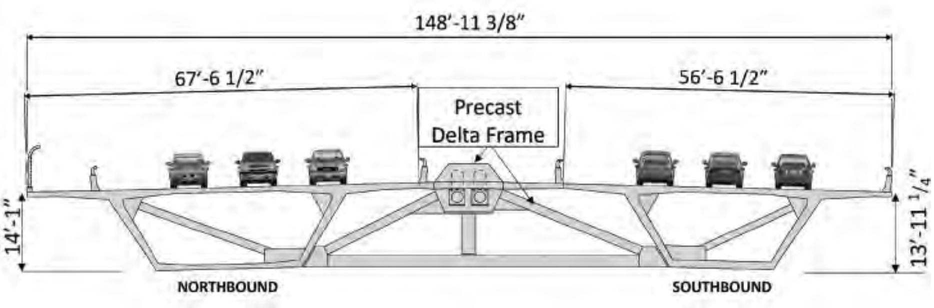
During construction, the box girders experienced multiple cycles of negative bending due to segment erection and positive bending due to stay-cable installation and tensioning. The critical location for peak flexural stresses was generally located approximately three cycles behind the leading edge. The optimum stay-cable installation forces and subsequent prestressing forces were calculated to keep the longitudinal tensile stresses within allowable limits.

Although much emphasis is placed on the assembly of bridge components, geometry control of the pylon and superstructure is of utmost importance and must be carefully monitored. Target geometry was set according to the design, using a reference condition of 70°F and 30,000 days after the end of construction to capture long-term effects.

To compensate for expected deformations, the tower pile cap foundations were designed to accommodate the predicted long-term settlement. The lower legs of the pylon compensated for longitudinal deflection, while the upper towers were constructed assuming a vertical precamber to preserve the distance between deck level and the upper stay anchors. Temporary towers were also installed halfway between the main towers and intermediate back-span piers to help stabilize the superstructure during construction. As for the box girders, the vertical and twist precambers were incorporated into the theoretical cambered geometry. Twist precamber was necessary to compensate for torsional deformation from the box girders being supported from a center plane of stays.

Recognizing that analysis models differ from on-site behavior, the

The delta frames were maneuvered to engage the shear keys, with their corresponding blockouts located within the webs of the adjoining segments (circled in the left photo with detail in the upper right photo). Precise manipulations were used to align the internal post-tensioning ducts and correctly position the stay-cable guide pipes (bottom right photo).



Typical cross-section geometry of the bridge with dual precast concrete box girders connected transversely by precast concrete delta frames and a cast-in-place median slab.

project team had to rely on a robust geometry control plan until the model stiffness could be adjusted to match the observed deflections during construction. Part of this plan involved weighing each segment, delta frame, and piece of large construction equipment. Early cycles included local surveys to ensure that the as-erected geometry reasonably agreed with the as-cast geometry established during fabrication. Global surveys were performed at night and provided a snapshot of the bridge's behavior for comparison with its corresponding construction stage. Stay-cable forces were measured during global surveys. Leading stays were measured using traditional liftoff procedures, while trailing stay forces were reported using the instrumentation installed at the top stay anchors.

Closures

The ultimate success of the geometry-control effort would be reflected when the cantilevers neared the back-span piers, transition piers, and center span. Although each closure had its own intricate set of constraints, the goal was to connect the superstructure within the established geometric and force tolerances.

The design allowed for some vertical and horizontal jacking, if needed. The temporary works for the closures were designed to resist all expected forces for short-term, critical stages of the closure operation. The precision and model confidence required at the phases just before each closure were paramount to achieving successful bridge alignment.

Conclusion

As home to both the oldest precast concrete segmental bridge in the United States (JFK Causeway, 1973, which is discussed in the Fall 2021 issue of *ASPIRE*) and now the longest precast concrete segmental span ever built (U.S. Route 181 Harbor Bridge, 2025), Corpus Christi represents more than five decades of progress in segmental bridge technology. As such, the Coastal Bend region is a beacon of transportation infrastructure excellence, bridge aesthetics, and sustainability. A

Joseph Briones is deputy district engineer for the Texas Department of Transportation in Corpus Christi. Chris Ursery is national segmental bridge leader for Arup in Houston, Tex. Justo Molina is project executive and project manager for Flatiron-Dragados LLC in Corpus Christi.

PROJECT

Laurel Fork Creek Bridge Replacement

by Jerry Pfuntner,
COWI North America Inc.

Main span completion over Laurel Fork Creek. Photo: Vannoy Construction.

When the existing Blue Ridge Parkway steel truss bridge over the Laurel Fork Creek in Ashe County, N.C., deteriorated to the point that it would no longer meet modern safety standards, the Eastern Federal Lands Highway Division of the Federal Highway Administration (FHWA) concluded that a full bridge replacement would provide the safest, most durable, and cost-effective solution. The Eastern Federal Lands Division developed a design for a new three-span (155, 235, 155 ft) precast concrete segmental bridge using a typical balanced-cantilever construction sequence with three segment end span units. The post-tensioning layout consists of internal cantilever tendons and a mix of internal continuity tendons anchored in bottom slab blisters and external continuity tendons anchored in the pier segment and routed through deviation segments.

Project Redesign and Construction Modifications

As is typical for a complex bridge, the successful bidder applied their means and methods to finalize the construction sequence so that it would best suit their equipment, experience, and schedule. Members of the construction engineering and contractor teams had just begun construction of a similar precast concrete segmental bridge—the Blue Ridge Parkway over Interstate 26 (I-26) in Buncombe County, N.C.—and the contractor realized that they could effectively reuse construction details from the I-26 bridge on the Laurel Fork project. As a result, several significant design and construction modifications were made on the Laurel Fork project. (For more information on the Blue Ridge Parkway Bridge, see the article in the Summer 2024 issue of *ASPIRE*®.)

Revision from Precast Concrete to Cast-in-Place Piers

The original design called for precast concrete segmental piers. However, the contractor determined that the benefits to the schedule of using a precast concrete approach did not outweigh the requirements for setting up precast concrete operations and the transportation costs. Therefore, the design team developed a cast-in-place design using the same dimensions as the original pier column to mimic the appearance of the existing bridge.

Revised Box-Girder Cross Section

The cross section for the Blue Ridge Parkway I-26 project was very similar to the Laurel Fork Bridge cross section. Both bridges have the same roadway width of 26 ft, but the Laurel Fork Bridge does not have a sidewalk so it is slightly narrower (30 ft 3$\frac{5}{8}$ in. wide) than the I-26 bridge. With minor modification to the existing casting machines from the I-26 project, a revised cross section for the Laurel Fork project was developed; its properties deviated from the original design by less than 1%. The new cross section also met project design requirements with the original post-tensioning layout and reinforcement design. (See the Spring 2025 issue of *ASPIRE* for more information about the precast concrete segments.)

profile

LAUREL FORK CREEK BRIDGE / ASHE COUNTY, NORTH CAROLINA

ORIGINAL BRIDGE DESIGN ENGINEER: Federal Highway Administration Eastern Federal Lands Division

BRIDGE DESIGN ENGINEER: COWI North America Inc., Tallahassee, Fla.

CONSTRUCTION ENGINEER: COWI North America Inc., Tallahassee, Fla.

PRIME CONTRACTOR: Structural Technologies/Vannoy Joint Venture, Jefferson, N.C.

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

Anchorage of an unducted continuity tendon. Photo: Vannoy Construction.

A revised precast concrete box-girder segment is lifted during erection. Photo: COWI North America.

Updated Post-Tensioning Details Using Diabolos

To simplify the casting of the concrete segments and post-tensioning installation, the original design for bent steel pipes was revised to use diabolos. Diabolos permit a wide range of tendon geometries from a single bell-shaped opening in the deviators. This decision also allowed for unducted epoxy-coated strand (ECS) to be selected and installed later in the project.

Adoption of Ground Crane Erection Methods

The original design assumed the use of segment lifters for the main span and erecting the back-span segments on falsework towers. The contractor chose to use a large-capacity crane to erect segments in full cantilever to minimize the requirement to create prepared ground surfaces in this environmentally sensitive project site. Based on the proposed modifications, the FHWA decided that the construction engineer would become responsible for the new bridge and serve as the engineer of record for the concrete segmental bridge portion of the project.

FHWA Demonstration Project: Unducted Epoxy-Coated Strand External Continuity Tendons

During the initial stages of construction, the FHWA approached the construction and bridge design engineer about the opportunity to use the Laurel Fork project as a demonstration for the use of unducted ECS as a substitution for the grouted external continuity tendons. (See the Fall 2025 issue of *ASPIRE* for more about the ECS demonstration project.) The traditional grouted external tendon system provides three levels of protection for the post-tensioning strand: the box girder, high-density polyethylene (HDPE) duct, and grout. An unducted ECS system provides two levels of protection: the box girder and the epoxy-coated sheathing on the strand. However, the ECS system mitigates the lack of a third protection level by allowing for direct inspection of the ECS. The unducted ECS tendon system employs epoxy coating on the exterior and interior of the steel strands that provides an impermeable barrier against moisture and corrosion, allowing strands to be left ungrouted and directly exposed within the protective enclosure of the box girder. This system offers considerable advantages:

- Direct inspection: Maintenance staff can visually monitor tendon conditions for corrosion or damage to the epoxy coating without costly nondestructive testing equipment or intrusive grout removal.
- Simplified replacement: Damaged tendons can be replaced efficiently and simply with significantly less cost and effort than would be needed to replace grouted external tendons.
- Reduced maintenance costs: Eliminating grout and ducts removes the risk for latent grouting defect issues. The strand epoxy coating can also be repaired in place at any time with minimal equipment.

Evaluation and Adoption of Epoxy-Coated Strand Tendons

As part of their due diligence before modifying the continuity post-tensioning design, the bridge design engineer undertook a comprehensive assessment of the ECS system, including a review of experiences in Japan with similar systems, which have been successfully used for more than 17 years. The assessment process also included meetings with ECS manufacturers and participation in an FHWA workshop on ECS.

Given that Laurel Fork Bridge primarily consists of bonded internal tendons, the design engineer determined that the project was an ideal candidate for demonstrating the feasibility and benefits of ECS use for external continuity tendons. The ECS tendon system can easily meet service and strength-level load requirements.

NATIONAL PARK SERVICE, OWNER

POST-TENSIONING CONTRACTOR: Structural Technologies, Columbia, Md.

OTHER MATERIAL SUPPLIERS: Bearings: CONSERV, Georgetown, S.C.; epoxy-coated strand: Sumiden Wire, Dayton, Tex.

BRIDGE DESCRIPTION: 545-ft-long, three-span, precast concrete segmental bridge

STRUCTURAL COMPONENTS: Sixty-two precast concrete box-girder segments, cast-in-place concrete piers, drilled shaft foundations

BRIDGE CONSTRUCTION COST: $29 million

During construction, before the closure pour, the cantilever is supported by temporary towers. Photo: COWI North America.

Design Adaptations for Epoxy-Coated Strand Tendons

Implementing the unducted tendon system entailed a few considerations for the modified design:

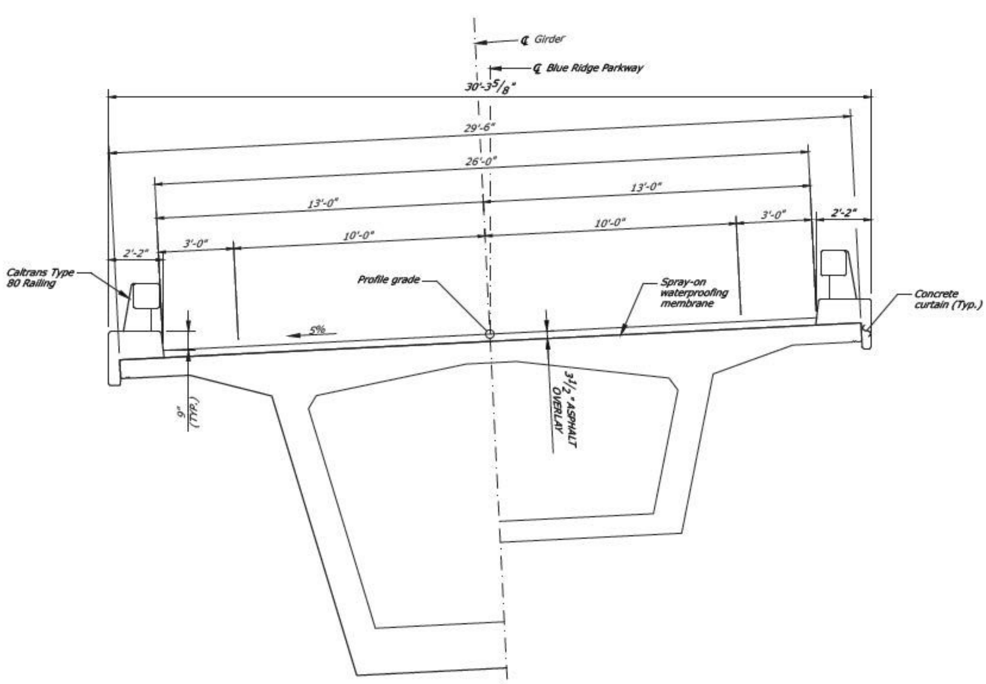
- Anchor-set increase: ECS requires a unique set of strand anchorage wedges to anchor each strand in the anchor head. The wedges must also "bite through" the epoxy coating into the post-tensioning steel. This requires anchorage wedges that are specifically designed for ECS and are typically ⅛ to ¼ in. longer than a standard wedge. Given the length between deviation points with the external tendons, this requirement had a small impact on the final tendon force after stressing.
- Coefficient of friction: Engineers in Japan have the most experience with unducted ECS post-tensioning systems, and they noted a higher coefficient of friction (up to 0.30) compared with grouted duct systems. The higher friction was considered in the Laurel Fork design; however, actual elongation measurements correlated with a coefficient of friction of 0.17, similar to that for HDPE duct. Design calculations predicted only a minor reduction (~2%) in residual midspan precompression due to increased anchor-set and friction effects, consistent with design experience in Japan. Field verification during initial tendon tensioning confirmed the anchor-set values, with actual elongations consistent with theoretical values, although there was a somewhat greater variation in the anchor set than would be typical for bare strand post-tensioning systems. The additional friction noted by Japanese engineers, however, was not observed, and a typical friction coefficient of 0.17 was consistent with the elongation results.

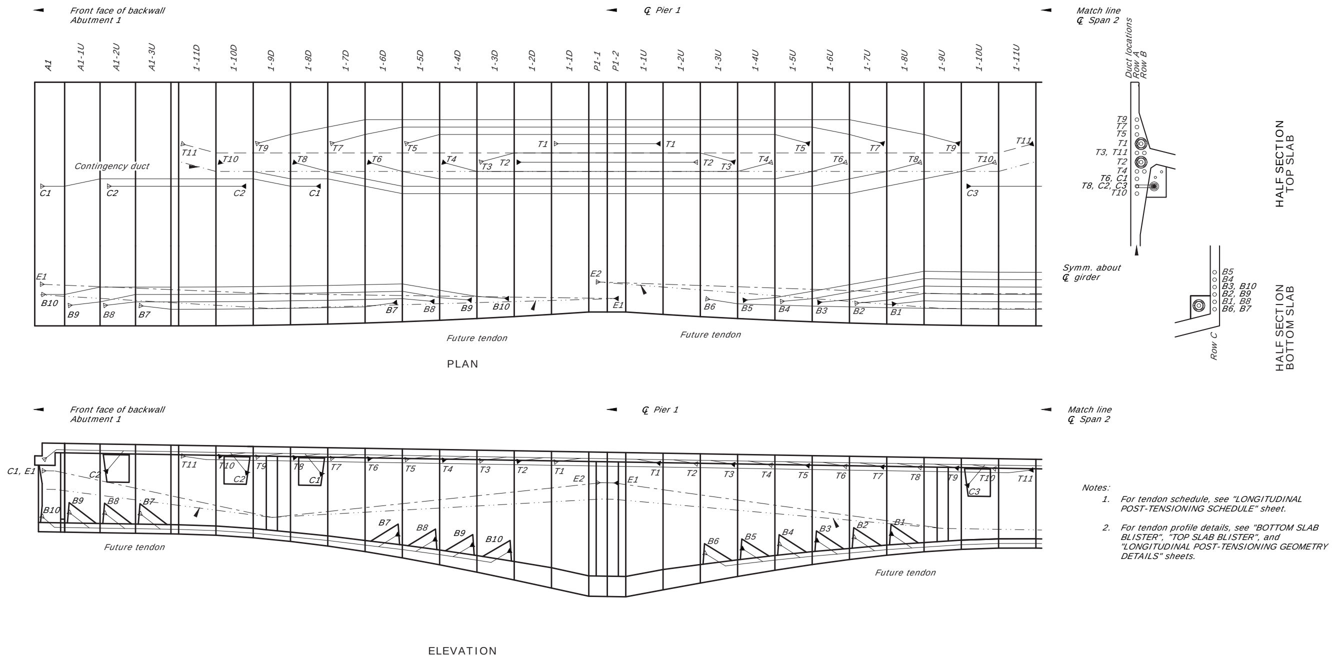
Tendon Vibration Assessment

Typically, unducted ECS tendons experience greater sensitivity to vibration after installation than grouted systems. Without the damping effect of grout, vibrations are more readily induced; for example, striking the tendon with just a fist produces noticeable vibrations of the strand bundle.

Because long-term fatigue due to vibration can jeopardize tendon integrity, the design engineer conducted dynamic analyses comparing the first vibration frequency of unbraced tendon lengths to the bridge's first vertical vibration frequency. Results showed that the tendon frequencies are approximately double those of the bridge span vibrations, demonstrating

Bridge typical section. Figure: COWI North America.





Post-tensioning layout for the Laurel Fork Bridge. Four types of tendons were used—top slab cantilever tendons, bottom slab continuity tendons, top slab tendons across the closure pour, and external tendons. Each tendon used 12 strands. Figure: COWI North America.

that span deflections will not induce resonant tendon vibrations.

Before the bridge was opened to traffic, in situ observations during construction vehicle crossings showed no significant adverse vibrations. Accordingly, the design engineer recommended against installation of intermediate tendon supports, which could introduce local restraint stresses on the ECS. Ongoing monitoring will evaluate long-term performance.

Conclusion

The Blue Ridge Parkway Laurel Fork project exemplifies how an effective concrete segmental bridge design allows the contracting team to adapt their methods and successfully complete the project. When owners, engineers, and contractors collaborate closely to achieve the best overall outcome, significant milestones can be reached. This project notably accomplished the successful implementation of unducted ECS for external tendons. This achievement, along with valuable lessons learned, demonstrates the usefulness of an additional post-tensioning option that can be incorporated into segmental and other bridge types.

Jerry Pfuntner is the Southeast Region technical director for COWI North America Inc. in Tallahassee, Fla.

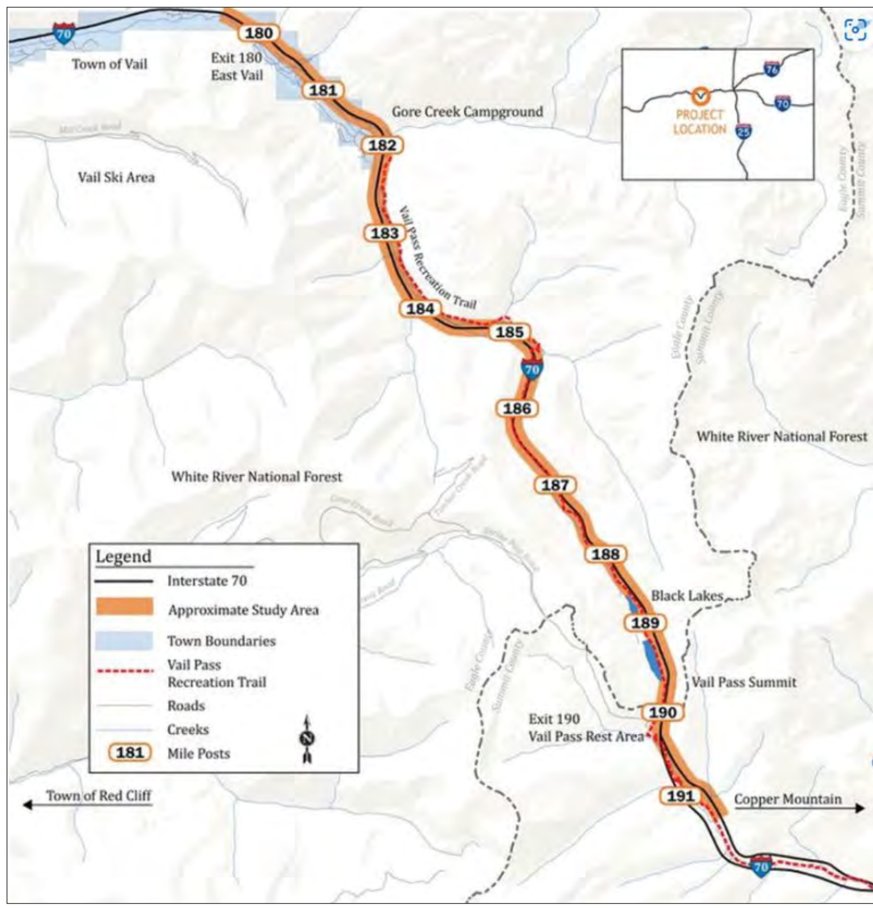
West Vail Pass Auxiliary Lanes

Interstate 70 over Polk Creek bridge replacements using precast, post-tensioned curved concrete U-girders

by Chad Hammond, RS&H, and Angela Tremblay

As part of the Interstate 70 (I-70) West Vail Pass auxiliary lanes project, the Colorado Department of Transportation (CDOT) replaced the bridge structures over Polk Creek in Summit County, Colo., near the town of Vail. The bridge replacements are part of improvements designed to enhance safety and reduce congestion through the steep mountain pass. The existing highway section is only two lanes in each direction, which often leads to unpredictable travel times as slow-moving trucks navigate the steep grades and tight curves. This portion of I-70 has one of the highest crash rates in Colorado, with more than 600 accidents on West Vail Pass between 2017 and 2021, and more than 1800 hours of full and partial closures during the same period.[1]

The West Vail Pass corridor is a vital link for people and freight moving across Colorado's Rocky Mountains. CDOT estimates an economic impact of $1 million per hour when the highway is closed.[2] Safety and capacity improvements for the 12-mile corridor have been studied and planned for more than 20 years. Some of the planned improvements include improving safety and operations on I-70 for the traveling public, maintenance staff, and emergency responders by adding a climbing lane, widening traffic lanes and shoulders, and modifying existing curves to meet current federal design standards. These upgrades also required the replacement of the Polk Creek bridges, which was accomplished under the construction manager/general contractor (CM/GC) project delivery method.



The Interstate 70 bridges over Polk Creek are at milepost 186.5 along the West Vail Pass auxiliary lanes project near Vail, Colo. Figure: Colorado Department of Transportation.

Project Delivery

CDOT structured the West Vail Pass project as a CM/GC project so the contractor and design consultant could work together through the design

profile

INTERSTATE 70 OVER POLK CREEK BRIDGES / VAIL, COLORADO

BRIDGE DESIGN ENGINEER: RS&H, Denver, Colo.

PRIME CONTRACTOR: Kiewit, Lone Tree, Colo.

PRECASTER: Plum Creek Structures, Littleton, Colo.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Structural Technologies LLC, Wheat Ridge, Colo.

OTHER MATERIAL SUPPLIERS: Custom formwork: Doka, Denver, Colo.

The Ten Mile Canyon National Recreation Trail, which crosses beneath the Interstate 70 bridges, remained open to cyclists and pedestrians during construction. The trail can be seen entering under the bridges at the bottom right-hand side of this photo, then it winds through the trees and climbs toward the top of the photo. All Photos: Kiewit.

process. The CM/GC process allowed the contractor, owner, and designer to collaborate on the complex issues that were known when planning this project and adapt quickly as issues arose.

For example, the initial plan was for twin 1200-ft-long twin bridges, constructed simultaneously outside the original highway footprint. However, during the constructability assessment, the contractor determined that such long bridges would be difficult to construct on the limited footprint of the jobsite. The project team revised the plan to reduce the bridge lengths and phase construction to build one bridge at a time on a roadway alignment closer to the existing I-70 alignment and adding embankment to shift the abutment locations. This facilitated the use of two bridges with 575-ft-long main structures over Polk Creek. The contractor quickly provided a cost estimate for the alternate solution to the CDOT team so they could make an informed decision and move forward without schedule delays. This collaborative approach helped the teams solve contract, scope, and risk issues together without stalling the project or deferring problems to be negotiated through change orders. A risk register was maintained for the project to define risks and clearly state who owned each risk before beginning the work.

Design Criteria

To enhance safety and bring the bridges and roadway geometry up to current federal standards appropriate for the 65-mph design speed, the radii of the horizontal curves were increased, and the bridges were widened to accommodate three 12-ft lanes and two 8-ft shoulders. Even so, the design still involved a 1680-ft-radius curve, and the curved geometry was a significant consideration for determining the bridge type.

Another important consideration was the historical significance of the I-70 corridor at Vail Pass. This segment of I-70 was originally constructed in the 1970s with the intent to integrate aesthetics into the various highway elements to honor the natural environment. In 2011, Vail Pass was declared historically significant and eligible for listing on the National Register of Historic Places as a linear historic district because of the way it was designed and constructed to "enhance the alpine environment."[3] As such, CDOT was bound to adhere to aesthetic and environmental commitments on the pass and honor the original design. As part of the aesthetic criteria, bridges were to portray a slim, curvilinear, and elegant appearance that would blend into the landscape. The bridges had to use box or tub girders on single-column piers, and curved structures could not use chorded, straight girders to approximate a curve.

Structure Type Study

After the initial roadway layout and constructability reviews, the design

The eastbound Interstate 70 bridge was erected between the new westbound bridge and the existing eastbound bridge, which were both open to traffic. As a result, sequencing and access for the new eastbound bridge were especially challenging.

COLORADO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Twin five-span post-tensioned, precast concrete simple-made-continuous tub girder bridges.

STRUCTURAL COMPONENTS: Three girder lines per five-span bridge for a total of 30 precast concrete U72 tub girders; an 8½-in.-thick cast-in-place concrete deck with 3½-in.-thick precast concrete deck panels; cast-in-place concrete semi-integral abutments and single-column piers supported on drilled shafts.

The completed westbound bridge (left) and the in-progress eastbound bridge (center) have improved roadway geometry compared with the existing eastbound bridge (right). The horizontal curves and shoulder widths were upgraded to current federal standards appropriate for the design speed of 65 mph.

team determined that the best solution for the bridges was to use a total length of approximately 550 to 575 ft on a constant horizontal curve. The out-to-out width was 55 ft to allow three traffic lanes, shoulders, and 1.5-ft-wide CDOT type 9 bridge railings. The team developed several alternative structure types and span configurations that would meet the aesthetic criteria to use curved tub or box girders, and they ultimately evaluated the following three options in detail:

- Four-span, spliced steel tub girders
- Four-span, spliced post-tensioned concrete tub girders
- Five-span, simple-made-continuous curved precast concrete tub girders

Traditionally, most multispan, post-tensioned concrete girders are spliced. However, because access and construction schedule were limited, the design team wanted to include an option that would eliminate the use of falsework towers and post-tensioning on site. Therefore, they developed a design that would use precast, post-tensioned concrete tub girders in a manner similar to that used for pretensioned girders, where girders are tensioned in the casting yard after they are removed from the forms but before they are shipped. For this project, the precast concrete tub girders are assumed to behave as simple spans for noncomposite loads applied before the deck cures, but continuous for loads applied to the composite section (superimposed dead and live loads).

The structure selection process involved an evaluation of all three options for aesthetics, cost, schedule, constructability, and serviceability. The spliced steel option promised a favorable schedule and constructability benefits as girders could be spliced in the air, eliminating falsework towers and closure pours that would be needed for spliced concrete girders. Cost and serviceability were major concerns with this option, as the cost was expected to be $2.2 million more than the lowest-cost option and bearings would be required at all supports, which would increase future maintenance costs for CDOT. There was also concern that compared with the concrete options, the steel design would produce a larger cyclical (temperature-based) movement that would be less favorable to the performance of expansion devices or require the use of larger expansion devices.

The spliced concrete option would cost less than the steel option, even after field work and larger cranes for picking concrete girders were considered. The major concern with this option was the schedule associated with building falsework towers, casting field splices for the girders, and post-tensioning the tendons. The contractor estimated that this option would add 10 weeks to the schedule for each bridge.

The bridge design includes 3.5-in.-thick precast concrete deck panels that were used as forms for an 8.5-in.-thick cast-in-place concrete deck. In this photo, the precast concrete deck panels have been placed, the continuity diaphragms have been formed, and reinforcement is being placed in preparation for the cast-in-place concrete deck placement.

The cast-in-place concrete deck placement is complete on the eastbound bridge. The deck will be topped with a waterproofing membrane and an asphalt concrete wearing surface to complete the driving surface as seen on the completed westbound structure.

The simple and elegant lines of the new bridges honor the original structures and complement the mountain environment. Design choices along the Vail Pass corridor were chosen to "enhance the alpine environment" consistent with the corridor's eligibility for listing on the National Register of Historic Places as a linear historic district.

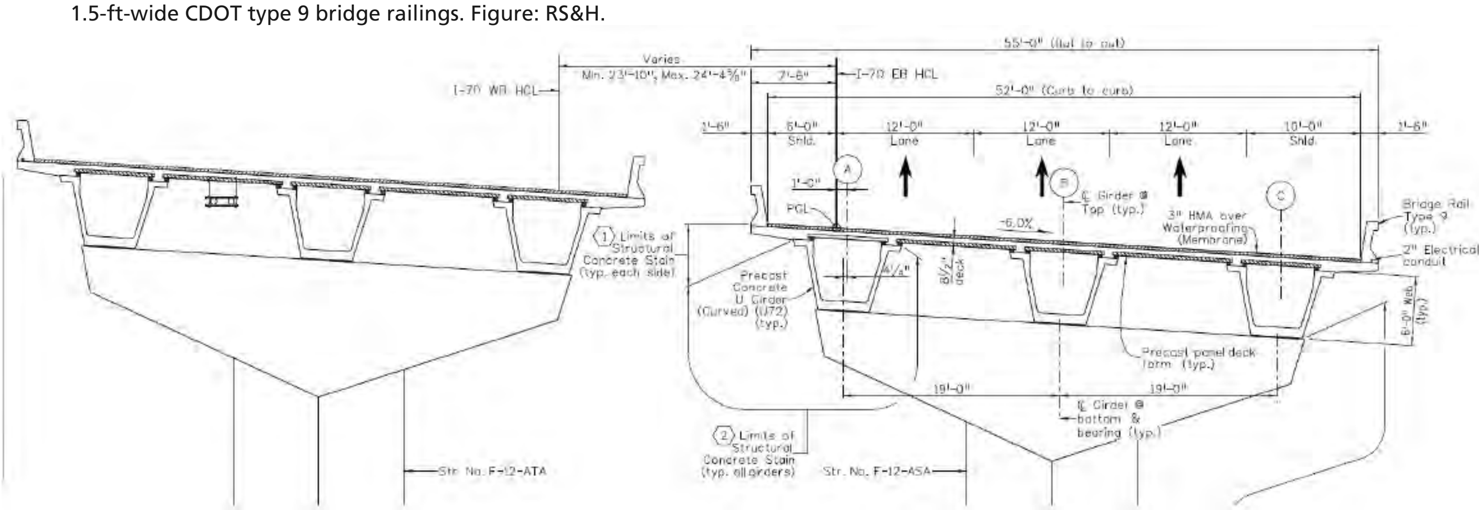
The simple-made-continuous for live load precast concrete girder option offered cost and schedule advantages. Despite adding a pier, this option would cost less than the other options, and the added construction time for the additional pier was minimal. These factors ultimately led the stakeholders to choose this option for the final design.

Design

The westbound I-70 structure over Polk Creek has span lengths of 86.5, 115, 115, 115, and 113.5 ft for a total of 545 ft, whereas spans for the eastbound bridge are 115, 131.58, 105.25, 105.25, and 115-ft long for a total of 572.08 ft. Three girder lines were used for each bridge. While these girder lines each have a different radius when laid out on paper, the design team decided to use the same radius for all the girders so that a single set of forms could be used. This decision saved labor and time in the casting yard. Because the girders have a constant radius, they are not perfectly parallel to each other or to the edge of deck and they do not have a constant offset distance between them and the edge of deck. Calculations showed that the difference in offset between the exterior girder and the edge of deck radius was only ½ in. at its maximum point and would be imperceivable to any observer. The deck consists of 3.5-in.-thick precast concrete deck panels, prestressed with ⅜-in.-diameter strands, that were used as forms for the 8.5-in.-thick cast-in-place concrete deck. Partial-depth precast concrete deck panels are used on many bridges in Colorado, and forming a soffit and placing shoring towers under the bridge was not cost or schedule efficient, so the precast concrete panels were a great fit for the project. All cast-in-place concrete for the superstructure was CDOT class DF concrete, which includes macro or hybrid polyolefin fibers to reduce shrinkage cracking and extend the service life of the structure. The concrete deck was topped with a waterproofing membrane and a 3-in.-thick asphalt wearing surface.

With the CM/GC contract and because the bridges were phased such that the westbound bridge was completed before construction began on the eastbound bridge, the contractor was able to give feedback on construction of the first bridge that could be applied to the design of the second bridge. One example of this was the contractor's request that the girders be designed to allow a large overhang from the support to the girder end during shipping. To facilitate this request, the girder design was modified to add a temporary post-tensioned monostrand to the girder top flanges. The monostrand was

The improved cross section for the bridges over Polk Creek has an out-to-out width of 55 ft to allow three traffic lanes, shoulders, and 1.5-ft-wide CDOT type 9 bridge railings. Figure: RS&H.



Temporary and permanent bracing is in place as the formwork and reinforcement for the continuity diaphragms at the piers are prepared.

The simple-made-continuous design uses precast, post-tensioned concrete tub girders in a manner similar to that used for pretensioned girders. The girders were tensioned in the casting yard after they were removed from the forms, but before they were shipped.

tensioned on the same day as all other prestressing, but it was tensioned last in the sequence. This additional post-tensioning limited the tensile stress induced in the top flanges by the large girder overhangs during shipping. The monostrand was detensioned after the girders were set on site.

The substructure consists of cast-in-place concrete semi-integral abutments and single-column piers with a diamond-shaped cross section. Each pier is supported by a pair of 48-in.-diameter drilled shafts, and the abutments are each supported by four 30-in.-diameter drilled shafts. The abutments are relatively tall, with an exposed height of 6 ft from the ground to the bearing seat and a height of 13 ft from the ground line to the top of abutment; therefore, the earth load behind the abutments was significant. To reduce the total load applied to the drilled shafts, crews built a basket-faced, mechanically stabilized earth wall behind the abutments to prevent the full lateral earth pressure from the backfill being applied to the abutments and foundations.

Construction

The logistics of the Vail Pass project differed significantly from those of projects on Colorado's Front Range. Working on a busy mountain pass, the construction crew faced many unique constraints.

- There were limited local trucking options, so the contractor had to use companies from farther away in Denver or Grand Junction to meet hauling needs.
- The construction season on the pass is very limited due to the harsh winters, and working through the spring is very slow due to muddy conditions from snow melt.
- The Ten Mile Canyon National Recreation Trail crosses the project site and needed to remain open to cyclists and pedestrians during construction.
- In addition to the high volume of vehicular traffic, large events and cycling competitions had to be accommodated.

Public safety was a priority—the team had a duty to protect cyclists, trucks, and cars moving through the project area. To promote safe travel, full-time flaggers were used and lane closures were limited.

In addition to maintaining safety, the team had to work through solutions to address environmental and site-access challenges associated with the project. The terrain and general logistics of the location made it difficult to ship materials to the jobsite. Cast-in-place concrete construction had to be carefully planned because the supplier was limited to 200 yd^3 of concrete per delivery. The plan to ship the girders from Littleton, Colo., to the jobsite near Vail Pass, a distance of roughly 98 miles, was also complex because there were very few alternative routes to I-70. Structurally deficient bridges had to be avoided, or the load had to be distributed so that the structures would not be overloaded.

The team designed custom haul trucks to transport girders on the planned route. This arrangement worked well for the westbound bridge construction because there was space for a staging area on the north side of the bridge that allowed the contractor to pick and place the girders with no interference.

However, the eastbound bridge was nestled between the new westbound bridge and the existing eastbound bridge, both of which were needed to maintain traffic; therefore, sequencing and access were especially challenging. The haul route had to be revisited after the westbound bridge was built and it came time to deliver the girders for the eastbound bridge. The detour used to move westbound girders around a deficient bridge was no longer viable when shipping the eastbound girders because there was another CDOT project underway along I-70. There were many transportation meetings to work through this issue. Eventually, the team determined that the best solution was to use the crane to pick the girders off the newly built westbound bridge with a lane closure in place. Then the girders could be placed directly into their final position, which reduced crane time and avoided double handling of the girders.

The curvature of the girders presented a challenge when it came to girder erection. The girders would tend to rotate without the full bracing of the deck in place and the dead load from above balancing out their weight and shape. To provide the needed stability during construction, temporary bracing was designed and installed. After the concrete deck was completed and cured, the bracing was removed. A similar issue applied to the bearings. When the girders were set, there were

A precast, post-tensioned concrete tub girder passes through the Vail Tunnel on its way to the bridge location over Polk Creek. The terrain and general logistics of the project made it difficult to ship materials to the jobsite.

gaps at the bearings. The application of the weight from the precast concrete deck panels and deck placement closed the gaps at the supports and shifted the girders back into their proper alignment.

Conclusion

Construction of the westbound I-70 bridge over Polk Creek was completed in 2023, and work on the eastbound bridge wrapped up in 2025. Precast concrete construction saved an incredible amount of time on this project. The innovative, simple-made-continuous precast concrete girder concept proved to be cost-effective and saved time in construction. Furthermore, the simple and elegant lines of the new bridges honor the original structures and complement the mountain environment. The bridge replacements are an important milestone in the West Vail Pass auxiliary lanes project, which is improving safety and operational capacity in the region.

References

1. Longwell, A. 2024. "Eagle County Governments Keep Pressure on CDOT to Complete Extra Lane in Vail Pass 'Narrows.'" *Vail Daily*, April 10, 2024. https://www.vaildaily.com/news/eagle-county-governments-pressure-cdot-vail-pass.
2. Colorado Department of Transportation (CDOT) "CDOT Receives $60.7 Million in Federal Funding for Improving Vail Pass." https://www.codot.gov/news/2020/june-2020/vail-pass-funding.
3. Jacobs. 2022. *Aesthetic Guidance for the I-70 Segment on West Vail Pass*. CDOT. https://www.codot.gov/projects/i70westvailauxiliarylanes/assets/23982_i70_wvp_aestheticguidance_final_110421.pdf.

On the Use of ASTM A722–Like and Non–ASTM A722 Alternative Post-Tensioned Bars

by Tim Christle, Post-Tensioning Institute

The Post-Tensioning Institute's *Recommendations for Prestressed Rock and Soil Anchors* (PTI DC35.1-14)[1] provides specific requirements for the use of prestressing steel bars that conform to ASTM A722, *Standard Specification for High-Strength Steel Bars for Prestressed Concrete*,[2] in prestressed rock and soil applications. However, there are only a limited number of suppliers of ASTM A722 bars, especially for larger diameters. There are high-strength bars that have similar tensile properties to ASTM A722–conforming materials but are made using different processes than those required by ASTM A722. These alternatives are referred to as "ASTM A722–like" and "non–ASTM A722" bars. ASTM A722–like and non–ASTM A722 bars will not behave in the same manner as fully conforming ASTM A722 bars when used in prestressed rock and soil anchors or similar post-tensioning (PT) bar applications.

PTI DC35.1-14 specifies the use of prestressing strand conforming to ASTM A416, *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*,[3] and/or prestressing bar conforming to ASTM A722 in prestressed rock and soil applications. However, Section 4.2.5 of PTI DC35.1-14 does allow for the use of special prestressing materials, provided those materials have tested properties that meet or exceed ASTM A416 or ASTM A722. A licensed design professional (LDP) must have a clear understanding of the properties of materials conforming to ASTM A416 or ASTM A722 to determine whether alternative types of strand or bars meet or exceed these requirements.

In June 2024, PTI issued Technical Notes 23[4] and 24,[5] which advise engineers on important differences between fully conforming ASTM A722 bars and ASTM A722–like or non–ASTM A722 bars. The main points made in the technical notes are as follows:

- ASTM A722 provides a specific process of cold stressing and stress relieving the bars to achieve specific properties. Alternative bars do not undergo this process.
- Alternative bars have some properties that are equivalent to ASTM A722–compliant bars, but the properties are not identical.
- Specifically, alternative bars may have greater relaxation than ASTM A722–compliant bars.
- Alternative bars may have a lower yield strength–to–ultimate strength ratio, which may cause an issue when stressing bars in the field.
- While using alternative bars is not recommended, if an LDP chooses to use them in prestressed rock and soil applications, the differences in properties must be accounted for in the design.

Technical Note 23, *Non-ASTM A722 Alternative Post-Tensioned Bar Considerations*, details the differences between fully conforming ASTM A722 bars and alternative bars for stress-strain behavior under tensile load, modulus of elasticity, and stress relaxation and creep. It also discusses corrosion considerations. Technical Note 24, *ASTM A722-Like Alternative Post-Tensioned Bar Considerations*, discusses the relaxation and creep properties in greater detail. Technical Note 24 also discusses accounting for the effects of increased relaxation on relaxation-sensitive applications and provides an appendix that discusses common approaches for force monitoring using instrumentation.

These PTI Technical Notes both indicate that ASTM A722 is a "process specification" that requires bars to be subjected to cold stressing to no less than 80% of the minimum tensile strength followed by stress relieving to produce the prescribed tensile properties. This process produces a high-strength, low-relaxation bar. While ASTM A722 does not contain relaxation requirements, typical test values for relaxation losses in ASTM A722–compliant bars are less than 4% when held at $0.70F_{pu}$ for 1000 hours, where F_{pu} is the specified minimum ultimate tensile strength of the bar. As noted in PTI Technical Note 24, this is consistent with relaxation standards for similar bars found in other international standards. ASTM A722–like material includes bars that may meet the yield strength, tensile strength, and elongation properties of ASTM A722 but are not manufactured using the cold-stress and stress-relief process. As a result, ASTM A722–like material will usually not have relaxation values close to those of an ASTM A722–compliant material.

The cold-stressing technique has additional benefits. As pointed out in Technical Note 23, the cold-stressing technique creates a material that has a linear stress-strain relationship up to yield. It also proof-stresses the bar, which greatly reduces the probability that a flaw in the bar will cause failure during tensioning in the field.

Technical Note 23 states that PTI DC35.1 allows a maximum design load of $0.60F_{pu}$ and a maximum test load not exceeding $0.80F_{pu}$. For alternative bar materials, the test load of $0.80F_{pu}$ may exceed the yield strength (F_y) of the material, leading to large deformations in the field.

Technical Note 23 concludes with the following:

> *PTI DC35.1 applies to prestressed ground anchors using prestressing steel conforming to ASTM A416 strands and ASTM A722 bars. While PTI DC35.1 does allow for special prestressing steel materials, the properties of that steel must be equal to or better than ASTM A416 or ASTM A722. This discussion describes the differences between using prestressing steel bars conforming to ASTM A722 and alternative steel bars that are being used in some post-tensioning applications. Direct use of PTI DC35.1 with alternative steel must be carefully considered by the LDP to avoid unsafe conditions and unexpected results during load testing and unexpected behavior during the design life of the structure.*

Technical Note 24 addresses the differences in relaxation between ASTM A722–compliant bars and alternative bars in greater detail. While using a prestressing bar that does not meet or exceed the requirements of ASTM A722 is not recommended by PTI DC35.1-14, should an LDP decide to specify that type of prestressing bar, the LDP must understand how the properties of the alternative bar differ from ASTM A722–compliant bars and adjust the design accordingly.

A section in Technical Note 24 accounts for the effects of increased relaxation on relaxation-sensitive applications. It states:

> *While establishing a specification for ASTM A722-like material is currently a topic of conversation under review by ASTM International, the PTI Committee DC-35, Task Group A722-Like Material, interim recommendations to Owners/Engineers fall under the following categories.*

Technical Note 24 then makes the following recommendations:

- Obtain specific bar relaxation properties from the bar manufacturer and adjust calculations accordingly.
- Specify the threshold of relaxation of the bar used.
- Lower the prestress level of the bar.
- Specify a monitoring and retensioning program (Appendix A of Technical Note 24 provides information on instrumentation for monitoring.).

Technical Note 24 concludes with the following statement:

> *This technical paper intends to provide awareness of the higher relaxation that is possible for high-strength ASTM A722-like bars. The use of this material may require further accommodation in estimating long-term losses and its impact on creep and creep testing methods currently described in PTI DC35.1-14.*
>
> *Design considerations include obtaining the expected relaxation loss from the manufacturer, specifying the maximum relaxation loss, reducing the stressing load, or force monitoring and/or re-tensioning.*

These important technical notes for high-strength, post-tensioned bar can be downloaded for free from the PTI website (https://www.post-tensioning.org/FAQTECHNICALNOTES). If you have any questions about this topic or would like additional information, please email technical.inquiries@post-tensioning.org for assistance.

The PTI DC-35 Prestressed Rock and Soil Anchor Committee will include the information found in these technical notes in their current update cycle for the DC35.1 publication. These revisions and others will be issued in the next version of these recommendations, which is planned for release as DC35.1-27.

References

1. Post-Tensioning Institute (PTI). 2014. *Recommendations for Prestressed Rock and Soil Anchors*. PTI DC35.1-14. Farmington Hills, MI: PTI.
2. ASTM International. 2018. *Standard Specification for High-Strength Steel Bars for Prestressed Concrete*. ASTM A722/A722M-18. West Conshohocken, PA: ASTM International.
3. ASTM International. 2024. *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*. ASTM A416/A416M-24. West Conshohocken, PA: ASTM International.
4. PTI. 2024. *Non-ASTM A722 Alternative Post-Tensioned Bar Considerations*. PTI Technical Note 23. https://www.post-tensioning.org/Portals/13/Files/PDFs/Education/PTI-TechnicalNote-23.pdf.
5. PTI. 2024. *ASTM A722-Like Alternative Post-Tensioned Bar Considerations*. PTI Technical Note 24. https://www.post-tensioning.org/Portals/13/Files/PDFs/Education/PTI-TechnicalNote-24.pdf.

A post-tensioned bar being tensioned in the field. Photo: Pete Speier, Williams Form.

Application of the Wood-Armer Method for Slab Design

by Matthew C. Wagner, Colliers Engineering & Design

Concrete slabs are among some of the most common structural components in modern construction. In many cases, slab design can be approached with a simple one-way analysis, such as the strip method, where the slab is assumed to act as a beam element that is bending about its major axis oriented normal to the direction of the primary reinforcement. This approach has proven efficient and effective for most situations, where the slab geometry, boundary conditions, and loading are straightforward. However, in some scenarios—such as designs with curved alignments or skewed supports—this approach can yield unconservative results. Under such conditions, both direct bending moments and twisting moments should be considered in design to ensure adequate safety margins against overload and satisfactory in-service response.

This article reviews the mechanics of direct and twisting moments and provides an example application of the Wood-Armer method[1] in the design of the Bend Bridge, a curved, multispan, continuous, reinforced concrete slab bridge that provides pedestrian access from the Glass City Riverwalk to the Martin Luther King Bridge in Toledo, Ohio (**Fig. 1**). (For more information, see the Project article in the Summer 2025 issue of *ASPIRE*®.)

The Wood-Armer method, which was introduced by R. H. Wood in 1968, is one of the most popular rational design methods to incorporate the effect of twisting moments on the slab. Wood and G. S. T. Armer developed their approach from the normal moment yield criterion (also known as Johansen's yield criterion[2]), which aims to prevent yielding in the reinforcement in all directions. Their method combines direct bending and twisting actions into equivalent ultimate design moments that act normal to the primary reinforcement. The ultimate design moments for each reinforcement direction can be easily checked to ensure that they do not exceed the resisting moments.

Direct Bending Moments

Direct bending moments are derived from one-way slab action. They are the flexural forces that cause a slab to bend like a beam about a single axis.

- Direct bending moments M_{xx} and M_{yy} are flexure about the orthogonal slab *x*- and *y*-axes that result in out-of-plane displacement and curvature of the slab (**Fig. 2**).
- The out-of-plane displacement and curvature due to bending create linear strain profiles across the slab depth, generating compression on one face and tension on the opposite face. Reinforcement is required in regions of tensile stress.
- Direct or primary bending moments typically govern the slab's design for ultimate strength, crack control, and long-term deflection.

In conventional one-way slab designs, loads are distributed into strips and the resulting direct moments are checked against the resistance of the reinforcement. However, this approach ignores the twisting effects and resultant in-plane shear stresses that develop when a slab experiences two-way bending action.

Twisting Moments

A twisting moment M_{xy} arises when slab elements rotate about an in-plane axis due to shear forces acting on the slab surface. Description and derivation of the twisting moments can be found in any textbook on plate analysis.

- A twisting moment is effectively a torque within the plane of the slab.
- Unlike direct bending, twisting does not directly cause flexural cracking, but it induces in-plane shear stresses that reinforcement must balance.
- Twisting moments are particularly significant near corners, discontinuous edges, and skewed or curved support conditions, where high stress concentrations build concurrently in both primary axes.

Neglecting twisting moments can lead to inadequate reinforcement in high-stress

Figure 1. The Wood-Armer method was used for the design of the Bend Bridge, a curved, multispan, continuous, reinforced concrete slab bridge. Photo: Metroparks Toledo.

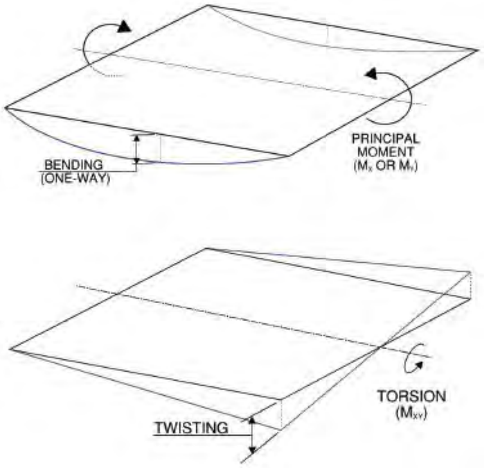


Figure 2. Basic bending and twisting moment diagrams. Figure: Colliers Engineering & Design.

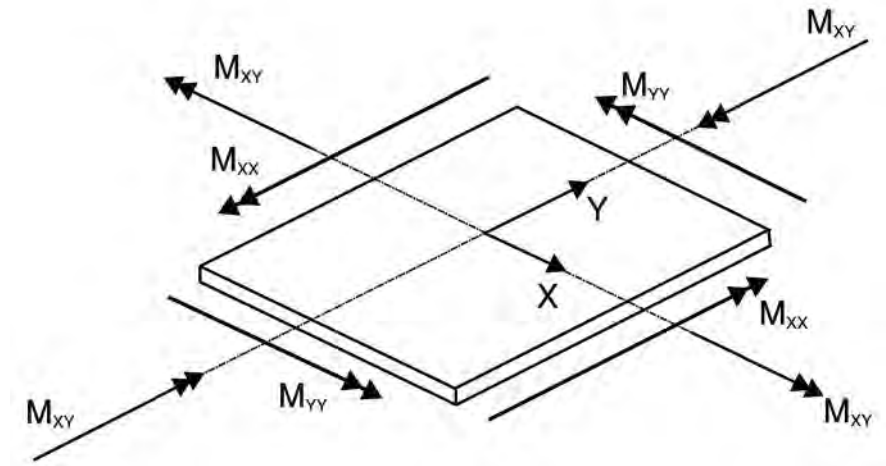


Figure 3. Notation and axis system used by R. H. Wood for plate direct bending and twisting moments. Figure: Colliers Engineering & Design.

regions, resulting in excessive cracking, serviceability concerns, and increased maintenance. Two-way slabs resist load through biaxial bending action (that is, loads are shared between orthogonal directions). The stress state results from a triad consisting of M_{xx}, M_{yy}, and M_{xy}.

- Biaxial action: Bending occurs about both the x and y axes, combined with twisting about the x-y plane.
- Load distribution: This interaction produces efficient structures but requires more sophisticated design than one-way strips.
- Reinforcement implications: Orthogonal reinforcement must simultaneously resist both direct and twisting contributions.

The challenge is to convert this triad into equivalent design moments for reinforcement, which is precisely the function of the Wood-Armer equations.

The Wood-Armer Method

Wood's paper "The Reinforcement of Slabs in Accordance with a Pre-determined Field of Moments" established a systematic approach for incorporating twisting moments into slab design. **Figure 3** shows the notation and axis system used by Wood for plate direct bending and twisting moments. The method, derived from Johansen's step yield-line criterion, has since been incorporated into many design guides, such as the American Concrete Institute's ACI 447R-18,[3] and finite element postprocessing tools. Some of the key principles of the method are as follows.

- Conversion of twisting moments: Twisting moments M_{xy} and direct bending moments are translated relative to the direction of the primary reinforcement for structural design.
- Design moments: For each slab face and primary reinforcement direction, the ultimate design moments are determined (**Fig. 4**).
- Efficient reinforcement layout: By resolving combined effects into orthogonal layers, the method avoids over- or underreinforcement for individual moment components.
- Applicability to skewed slabs: Extensions of the equations account for principal moment directions inclined relative to reinforcement axes, which facilitates application of the method to skewed bridge decks and irregular geometries.

Figure 5 shows example software output from the Bend Bridge design. For Wood-Armer moments, the reinforcement directions are defined relative to a reference axis:

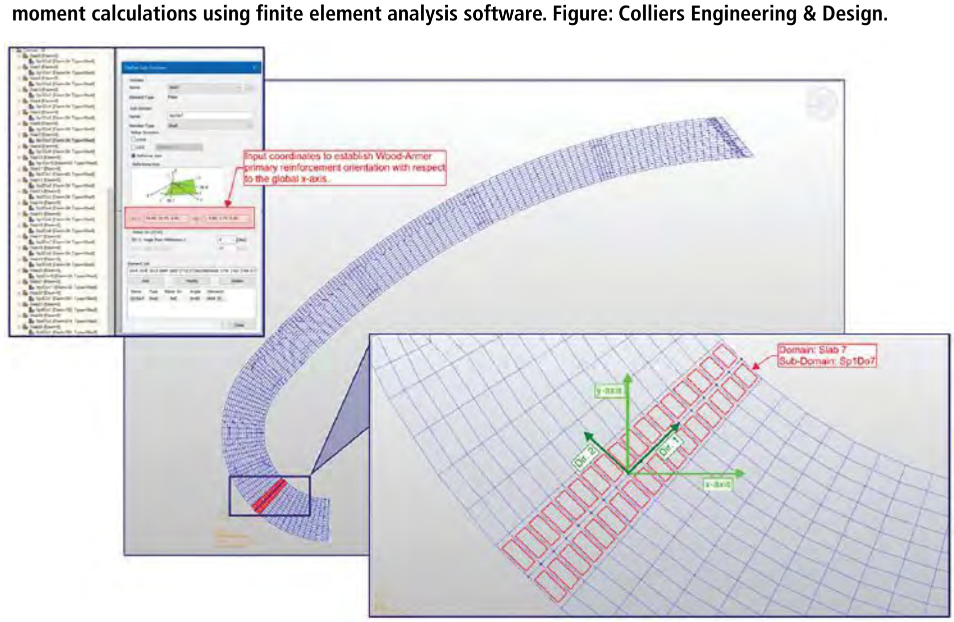
- W-A Moment, Top, Dir. 1 and W-A Moment, Bottom, Dir. 1 (defined as the slab top and bottom transverse reinforcement, respectively)
- W-A Moment, Top, Dir. 2 and W-A Moment, Bottom, Dir. 2 (defined as the slab top and bottom longitudinal reinforcement, respectively)

Integration with Finite Element Analysis

Most current finite element analysis (FEA) packages output M_{xx}, M_{yy}, and M_{xy} at nodes or elements. While these values represent the linear-elastic response of the plate or slab element, they cannot be used directly for reinforcement design unless the reinforcement is also aligned on the same coordinate system.

The Wood-Armer technique provides a rational method to link analysis and design, converting complex moment triads into ultimate design moments in the direction of the primary

Figure 4. Example of defining reinforcement directions relative to a reference axis for Wood-Armer moment calculations using finite element analysis software. Figure: Colliers Engineering & Design.



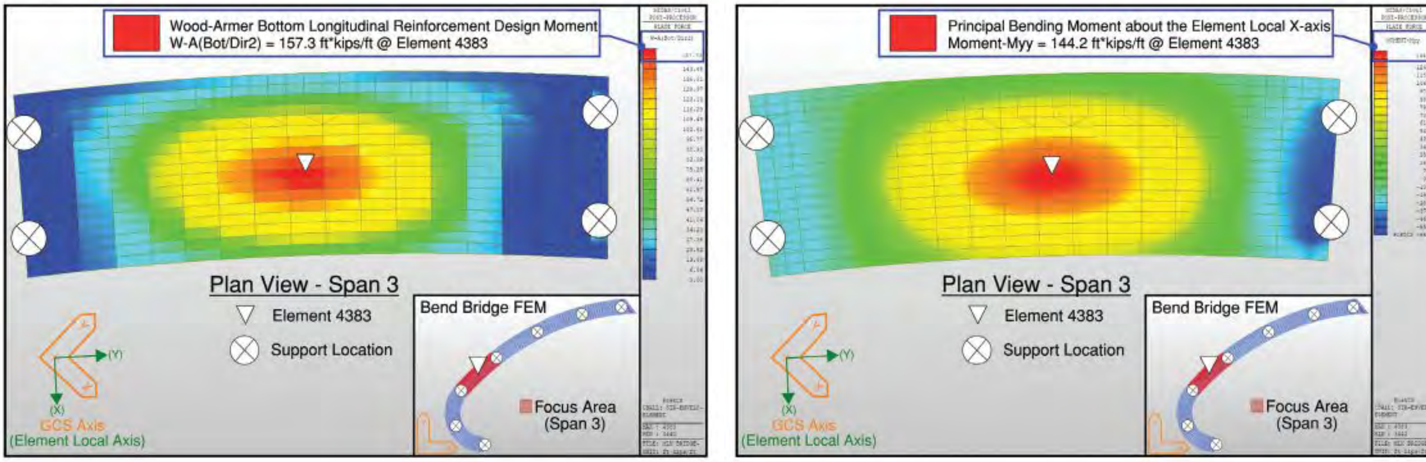


Figure 5. Comparison of Wood-Armer moments (left) and primary local bending moments (right) for the bottom longitudinal reinforcement design. If the primary local bending moment were used to design the bottom longitudinal reinforcement, the design would have been unconservative. Figure: Colliers Engineering & Design.

reinforcement and with respect to the location (top or bottom face) in the slab section. Without this step, there is potential for underreinforcement (if torsion is ignored) or overreinforcement (if moments are simply summed without redistribution).

Advantages of Wood-Armer Method with Finite Element Analysis

The use of the Wood-Armer method with FEA offers several benefits.

- Comprehensiveness: The method explicitly accounts for both direct bending and twisting moments that are neglected using strip-method design approaches.
- Design-oriented results: The output produces design moment contours aligned with the directions and locations of the primary reinforcement within the structural slab section.
- Efficiency: The method reduces unnecessary reinforcement by distributing twisting moments into equivalent bending moments.
- FEA design foundation: This technique forms the basis for slab reinforcement design modules in many current FEA software packages.

Limitations of Wood-Armer Method

Several caveats must be considered for this method:

- Manual complexity: Calculations are labor intensive if performed by hand. However, many software packages have integrated calculations that can be implemented directly.
- Assumptions: The method is based on linear elasticity and small deformations and does not capture nonlinear effects due to cracking.
- Structure type and material: The method is only applicable for reinforced concrete structural slabs.
- Potential for unconservative design: Research indicates that results may be unconservative in slabs with high reinforcement ratios (greater than 0.75%) under large torsion near restrained corners.
- Software output interpretation: Engineers must competently interpret contour plots and slab moments to avoid misapplication.

Final Thoughts

More than 50 years after its introduction, the Wood-Armer method remains relevant, particularly as analysis software advances. The base concepts are still relevant as a primary approach to break down complex analysis into an output format that engineers can understand and use for slab reinforcement design. When twisting moments are considered in addition to direct bending moments, the design and detailing of reinforcement, especially near corners and at discrete support points, are refined. The associated gains in serviceability and margins of safety demonstrate the power of using the Wood-Armer method for the design of structural slabs.

References

1. Wood, R. H. 1968. "The Reinforcement of Slabs in Accordance with a Pre-Determined Field of Moments." *Concrete* 2 (2): 69–76 (with discussion by G. S. T. Armer).
2. Johansen, K. W. 1962. *Yieldline Theory*. London, UK: Cement & Concrete Association.
3. American Concrete Institute (ACI). 2018. https://www.concrete.org/Portals/0/Files/PDF/Previews/447R-18_preview.pdf.

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The completed Bend Bridge in Toledo, Ohio, provides a pedestrian connection from the Glass City Riverwalk to the Martin Luther King Bridge in Toledo, Ohio. Figure: Kokosing Construction Co.

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.bimforbridgesus.com
This is a link to the BIM for Bridges and Structures website, which was developed as part of the Transportation Pooled Fund (TPF) project TPF-5(372). The pooled fund's goal was to develop an open, national standard for exchanging building information modeling (BIM) information necessary for bridge design, construction, and maintenance, and this website offers many resources related to BIM for bridges. The Perspective article on page 7 discusses how Kiewit is using BIM for bridge projects.

https://harborbridgeproject.com/about-the-bridge/project-overview
The Harbor Bridge project in Corpus Christi, Tex., is the subject of the Project article on page 10. Using the design-build-operate-maintain delivery model, the Texas Department of Transportation teamed with Flatiron-Dragados LLC to replace the aged Harbor Bridge with a signature precast concrete segmental cable-stayed bridge. This is a link to the project website, which provides a project overview, maps, and photos of the bridge development and construction, and much more.

https://www.codot.gov/projects/i70westvailauxiliarylanes
The Interstate 70 West Vail Pass auxiliary lanes project website can be found at this link. As part of that project to enhance safety and reduce congestion through the steep mountain pass, the Colorado Department of Transportation replaced the bridge structures over Polk Creek in Summit County, Colo., near the town of Vail. The bridge replacements are the focus of the Project article on page 20.

https://www.aspirebridge.com/magazine/2015Summer/ASPIRESupplementSummer2015.pdf
The Polk Creek bridges discussed in the West Vail Pass Project article on page 20 feature an innovative design that incorporates curved precast, post-tensioned concrete U-girders. A supplement to the Summer 2015 issue of *ASPIRE*®, found at this link, tracks the development of the U-girder.

https://my.mech.utah.edu/~brannon/pubs/7-2009BrannonLeelavanichkulSurveyConcrete.pdf
The Concrete Bridge Stewardship article on page 32 discusses a study to develop assessment techniques and repair guidance for prestressed concrete girder bridges subjected to overheight vehicle strikes. As part of the study, finite element modeling was used to evaluate the damage response of prestressed concrete girders. This is a link to a report comparing theory and implementation of some of the concrete constitutive models used in the study.

https://www.researchgate.net/publication/390421082_RELAXATION_TESTING_OF_ASTM_A722_AND_A722-LIKE_BAR_A_LIMITED_BLUESTONE_DAM_CASE_STUDY
The Concrete Bridge Technology article on page 26 discusses the differences in structural behavior between ASTM A722, ASTM A722–like, and non–ASTM A722 prestressing bars. The article also references the Post-Tensioning Institute's Technical Notes 23 and 24 regarding the important differences among these types of bars. This is a link to a case study and material testing involving ASTM A722 and ASTM A722–like bars.

https://www.concrete.org/education/freewebsessions.aspx
The National Concrete Bridge Council (NCBC) member spotlight on page 36 focuses on the American Concrete Institute (ACI) and its mission to advance knowledge of concrete and its use. This link takes you to a webpage where you can browse through a catalog of hundreds of free ACI educational presentations from 2018 to the present.

https://asbi-assoc.org/wp-content/uploads/2023/07/2021-July-Webinar-Corven.pdf
The LRFD article on page 43 discusses the upcoming changes to the American Association of State Highway and Transportation Officials' *Manual for Bridge Evaluation* regarding the load rating of segmental concrete bridges. This is a link to slides from a 2020 American Segmental Bridge Institute convention and webinar presentation that gives the history and background for load- and resistance-factor rating.

https://www.ncdot.gov/helene-recovery/Pages/default.aspx
In September 2024, Hurricane Helene produced record rainfall across western North Carolina and severely affected critical transportation corridors. The State article about North Carolina on page 40 discusses recovery efforts and how the North Carolina Department of Transportation (NCDOT) is using lessons learned from the hurricane to inform emergency response and long-term resiliency planning. This is a link to the NCDOT Hurricane Helene recovery page, where you can find project information, videos, and links to other resources.

Numerical Investigation and System-Level Resilience of Prestressed Concrete Girder Bridges in Overheight Truck Impacts

by Mohamed A. ElGawady, Haitham AbdelMalek, Francis Ashun, Mohanad Abdulazeez, and Ahmed Gheni, Missouri University of Science and Technology, and Ahmed Ibrahim and Mohamed Elshazli, University of Idaho

Vehicle collisions into bridges remain a major concern for transportation infrastructure, as they often lead to costly repairs, traffic disruptions, and safety risks. The National Highway Traffic Safety Administration (NHTSA) reports that about 15,000 bridge collisions occur annually in the United States.[1,2] Overheight truck impacts on prestressed concrete girders are among the most critical of these incidents that can significantly weaken a bridge's structural integrity. Recent incidents of overheight vehicle impacts include the Lordsburg Bridge in New Mexico and the State Route 410 White River Bridge in Washington State, with both structures suffering major damage after being struck by overheight vehicles. The cost of repairing damaged structures can reach a substantial portion of the expense required for full replacement, creating a heavy financial burden for transportation agencies. With more than 600,000 bridges in the United States, developing reliable and economical methods for damage assessment and repair has become essential to maintaining a safe and resilient transportation network.

Despite advances in testing and simulation, there is no unified framework to evaluate impact-induced damage, quantify residual flexural strength, and guide repair decisions. To address that gap, investigators for the Transportation Pooled Fund TPF-5(462) study, *Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts*,[3] used an integrated framework combining full-scale testing, finite element modeling, and repair evaluation to develop standardized procedures for assessing and repairing impacted girders. This article focuses on the analytical investigation of the TPF-5(462) study, whereas a future *ASPIRE®* article will present the experimental evaluation and repair of prestressed concrete girder bridges subjected to overheight truck impacts. The efforts of this study will provide a foundation for advancing concrete bridge stewardship, thereby enhancing safety and improving resilience across the nation's bridge network.

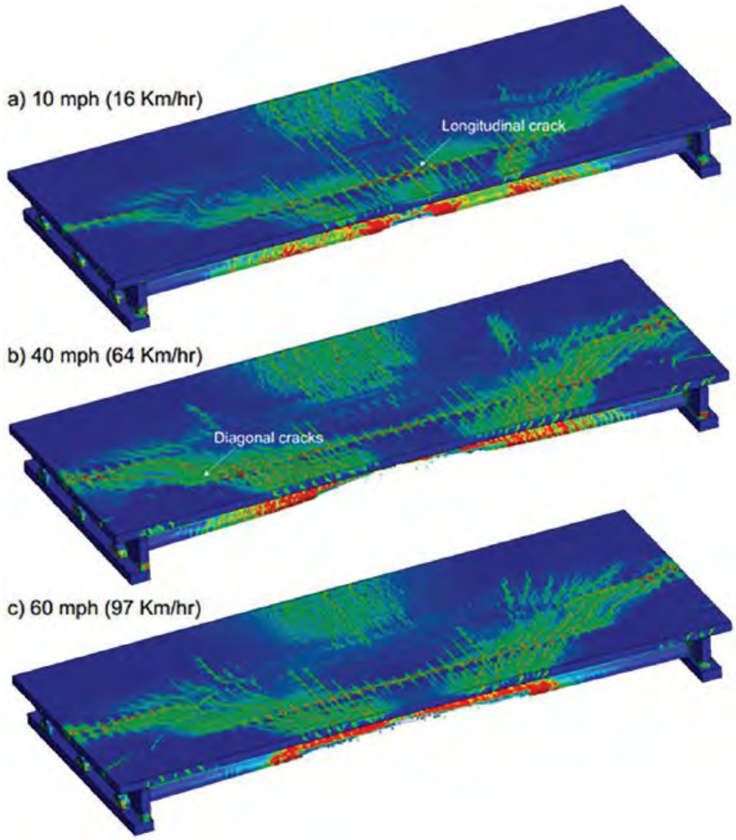
Modeling

The numerical modeling framework was developed with finite element modeling software using the nonlinear explicit analysis. Prestressed concrete girders, bridge decks, and diaphragms were modeled using a combination of solid, shell, and beam elements, whereas vehicle impacts were represented through moving rigid and deformable bodies, with impact-force transfer, through contact algorithms.

Four concrete constitutive models were evaluated: the continuous surface cap model (CSCM), Karagozian & Case concrete (KCC) model, Winfrith concrete model, and concrete damage plasticity model. Among these, the KCC and CSCM models were selected for most analyses because of their superior predictive accuracy and robust handling of strain-rate effects and element erosion. Both models captured triaxial concrete confinement, strain-rate sensitivity, and post-peak softening—features essential for simulating high-energy impacts. Material parameters were calibrated through laboratory compression and tension tests and benchmarked against established data in the literature.[4,5]

Both mild steel reinforcement and prestressing strands were modeled using plastic-kinematic formulations incorporating strain rate–dependent hardening. For the 270-ksi low-relaxation strands, stress-strain behavior was experimentally characterized through Split-Hopkinson tensile bar tests, which indicated a 5% to 15% increase in ultimate strength under impact strain rates. These findings

The experimental testing setup at Missouri University of Science and Technology. All Photos and Figures: Missouri University of Science and Technology.



Results of the finite element analyses illustrate the overall damage patterns of the prestressed concrete girder bridges when impacted at different speeds.

provide direct experimental validation for incorporating dynamic increase factors in both design assessment and numerical simulation.

Prestressing was introduced into the models using a thermal stress-relaxation procedure that accurately reproduced the initial pretensioning stresses and subsequent stress redistribution following impact. Bond-slip behavior was neglected in the localized region of impact, where damage and material degradation dominated the overall response.

Validation

Investigators conducted a comprehensive, multiscale validation program using laboratory and field data at the materials, component, and system levels.[3] At the materials level, the CSCM was validated against compression and impact tests on concrete cubes. The simulations reproduced the measured stress-strain response and strain-rate enhancement with close agreement, confirming the model's reliability for representing concrete behavior under dynamic loading.

Because full-scale dynamic impact tests of prestressed concrete girders are limited, component-level experimental validation used static four-point bending of prestressed concrete girders and drop-weight impact testing on reinforced concrete beams. Both the KCC and CSCM models accurately captured load-deflection behavior, crack development, and localized damage mechanisms, with peak responses deviating from experimental measurements by less than 10% to 12%.

At the system level, comparisons with full-scale bridge impact experiments conducted by the Iowa Department of Transportation[6] verified the accuracy of global load-sharing behavior, diaphragm action, and deck-girder interaction under impact loading. Furthermore, mesh-sensitivity analyses confirmed numerical convergence for 1- to 2-in. element sizes in critical regions while maintaining hourglass energy within acceptable limits. This comprehensive validation established a robust foundation for the parametric and analytical investigations.

Bridge Prototype Modeling and Scenarios

A comprehensive set of impact scenarios was analyzed using more than 100 models, covering vehicle speeds from 10 to 90 mph and impact weights between 4 and 80 kips. The study included three girder types—Missouri Department of Transportation (MoDOT) Type II, MoDOT Type VI, and Nebraska University (NU) 35—to capture the range of geometries commonly used in regional highway bridges.

The baseline bridge model consisted of a 45-ft-long, 54-in.-deep MoDOT Type II girder with a system-level configuration that included three girders spaced at 6 ft, an 8-in.-thick reinforced concrete composite deck, and reinforced concrete diaphragms and supporting elements to simulate realistic load-sharing and boundary conditions.

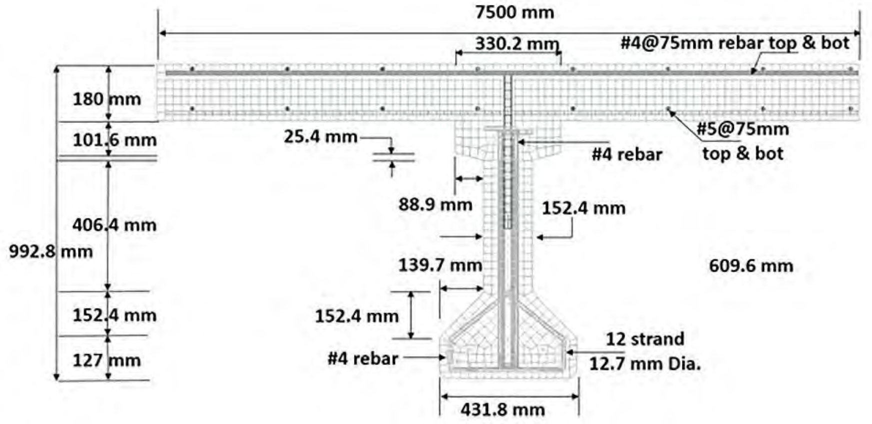
A standard tractor-trailer, with a gross vehicle weight ranging from 55 to 80 kips, was used to simulate impact events at various speeds and heights. To expand the parametric database, a simplified rigid-cylinder impactor was also used to isolate the influences of vehicle speed, mass, impact location, and diaphragm configuration.

Dynamic Response: Global versus Local Behavior

The finite element simulations revealed two distinct behavioral regimens:

- Low-velocity impacts (30 mph or lower): Global flexural and torsional

Structural damage induced on a model of a prestressed concrete bridge with a 2-in.-thick concrete deck by the impact of a tractor-trailer truck traveling at 80 mph (for illustration).



A comprehensive set of impact scenarios was analyzed using more than 100 models, covering various vehicle speeds, impact weights, girder types, and system configurations. This figure shows a Missouri Department of Transportation Type II girder used in the analysis models.

deformation dominated the response, with minimal concrete spalling or localized damage.

- High-velocity impacts (greater than 30 mph): Localized shear-plug formation, web crushing, and concrete fragmentation developed at the impact zone, leading to pronounced material degradation.

Peak simulated impact forces ranged from 170 to 341 kips, with up to 93% of the total kinetic energy dissipated within the impacted girder. This concentration of energy confirmed that localized repair strategies can be both effective and economical. Full-bridge models produced slightly higher peak forces than isolated girders—227 versus 201 kips—due to increased lateral stiffness and composite deck restraint. The collision duration in the full-bridge model was approximately four times longer, as impact energy propagated through diaphragms and adjacent girders.

At an impact velocity of 70 mph, damage maps indicated web shear fractures, bottom-flange spalling, and rupture of up to 20% of the prestressing strands. Erosion visualization closely matched the damage patterns documented in post-impact field inspections, validating the predictive capability of the numerical model.

Diaphragms and System Resilience

Based on the finite element analyses, intermediate diaphragms proved to be among the most effective design features for mitigating impact-induced damage.

- Reinforced concrete diaphragms reduced impact-induced lateral midspan deflection and cracking by approximately 25%.
- Steel-channel diaphragms provided comparable performance but exhibited localized yielding under severe impacts.
- Dual-diaphragm configurations positioned at one-third span locations offered an optimal balance of stiffness and energy dissipation for the 45-ft-long girder that was investigated.

Diaphragms also played a crucial role in redistributing impact energy across adjacent girders, reducing stress concentrations by nearly half and preserving partial load-carrying capacity even after localized damage. These results emphasize the importance of diaphragm installation, maintenance, and retrofit—particularly in regions where bridge strikes are frequent—to enhance overall system resilience and post-impact performance.

Equivalent Static Force: Simplifying Impact Loads

While detailed dynamic analyses are invaluable for research, bridge owners and transportation agencies often require simplified tools for rapid assessment of post-impact residual flexural strength. To address this need, the investigators developed an equivalent static force (ESF) method—a practical approach for representing transient impact loads with static forces that generate comparable structural effects.

A 25-millisecond moving-average filter was applied to the dynamic force–time histories to obtain ESF values. Across all nine scenarios, the mean ESF was approximately 128 kips (with a standard deviation of 25 kips), which is about 14% higher than the 112 kips specified in Table 4.2 of Eurocode EN-1991-1-7(2006)[7] for bridge impacts. This finding suggests that U.S. bridges, which are subjected to heavier truck loads and distinct clearance geometries, may require regionally calibrated ESF values to achieve accurate post-impact assessments.

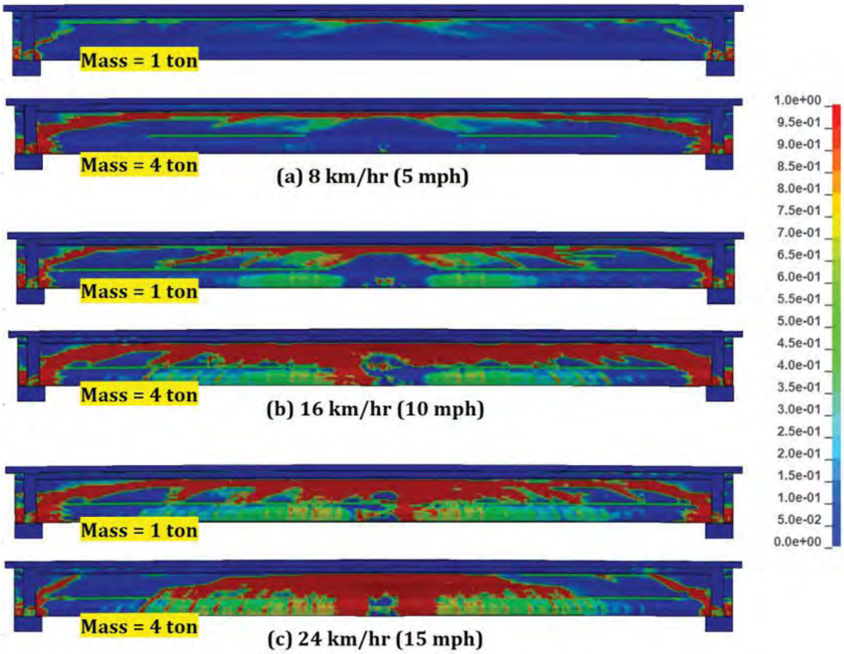
Residual Flexural Strength and Post-Impact Assessment

Beyond the immediate damage phase, the residual flexural strength of impacted girders is an essential consideration when determining whether a bridge can remain open to traffic. Analytical studies of a 120-ft-long AASHTO BT-72 girder with 48 prestressing strands quantified the effects of asymmetric strand rupture—a realistic condition when impacts sever strands on one side of the section.[3] The analyses considered various combinations of damage scenarios, including the loss of 12.5% to 50% of the number of prestressing strands and concrete section reductions up to 56%.

The results from the analysis of the BT-72 girder indicated the following:

- Flexural strength was reduced up to 60% for combined strand and concrete damage.
- Stiffness was reduced between 10% and 40%, and the ductility loss was between 20% and 45%.
- The American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[8] overestimated residual flexural strength by 11% to 18% under asymmetric conditions.
- Biaxial effects caused by accidental lateral eccentricity reduced flexural capacity by approximately 15%.
- The live-load distribution factor of the interior girder increased by up to 27% under a 50% stiffness reduction in the exterior girder caused by strand loss and its asymmetric pattern.

Based on these findings, the following method is recommended to evaluate the residual flexural strength of impact-damaged girders. Design engineers should first calculate the flexural strength of the damaged girder using only the remaining undamaged prestressing strands. To account for the effects of asymmetry, biaxial bending, and residual stress redistribution resulting from strand loss, a residual-strength factor Ψ_{IM} of 0.85 should then be applied to this calculated strength.



Effective plastic damage patterns of the prestressed concrete girder bridges at different impact weights and speeds. Effective plastic strain values quantify the amount of plastic deformation that a material undergoes beyond its elastic limit under loading conditions.

Practical Implications and Concluding Remarks

The validated finite element analysis framework provides a design-ready basis for assessing and mitigating bridge impacts with engineering accuracy. Based on the results of this study, investigators recommend the following guidance for bridge engineers, owners, and asset managers:

- Assessment: Use a lateral ESF of approximately 128 kips to represent the static effect of the impact when evaluating prestressed concrete girders for rapid load posting and preliminary safety evaluations.
- Design: Beyond the factors prescribed in the AASHTO LRFD specifications, apply a residual-strength factor Ψ_{IM} = 0.85 to account for asymmetric strand rupture and biaxial interaction effects observed under impact conditions.
- Mitigation: Install or retrofit diaphragms to reduce lateral displacements by 10% to 70% and improve load redistribution.
- Inspection and policy: Incorporate nondestructive testing (for example, radar or ultrasonic methods) calibrated to numerical damage maps within risk-based inspection programs.
- Asset management: Because more than 90% of the impact energy is confined to the struck girder, targeted repair is typically more economical than full superstructure replacement.

Collectively, these findings advance concrete bridge stewardship by providing simplified yet robust tools for impact evaluation and post-event decision-making. The integration of ESF loading, Ψ_{IM} factor, and dynamic increase factors bridges the gap between high-fidelity modeling and practical field application.

A subsequent article in *ASPIRE* will present the experimental findings, including full-scale impact tests, post-repair performance, and the effectiveness of strengthening methods that use carbon-fiber-reinforced polymers.

Acknowledgment

Special thanks go to the Pooled Fund Study (PFS) TPF-5(462), with contributors from the departments of transportation in Missouri, Alaska, Idaho, Mississippi, Ohio, and Texas, along with the Federal Highway Administration. Their financial support, vision, and commitment to advancing innovative concepts have been instrumental in pushing the boundaries of current practices. Part of the numerical analyses in this project was conducted using the Foundry (supercomputing) cluster at Missouri University of Science and Technology and was thereby supported in part by the National Science Foundation (NSF) under Grant No. OAC-1919789.

References

1. Cook, W., P. J. Barr, and M. W. Halling. 2015. "Bridge Failure Rate." *Journal of Performance of Constructed Facilities* 29 (3): 04014080. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000571.
2. Dunne, R., and E. Thorkildsen. 2020. *Case Study: Response to Bridge Impacts—An Overview of State Practices*. FHWA-HIF-20-087. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/bridge/preservation/docs/hif20087.pdf.
3. AbdelMalek, H., F. Ashun, M. Elshazli, M. Abdulazeez, A. Gheni, A. Ibrahim, and M. ElGawady. 2025. *Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts*. Transportation Pooled Fund TPF-5(462) Final Report. Jefferson City: Missouri Department of Transportation. https://rosap.ntl.bts.gov/view/dot/86972.
4. Abdelkarim, O., and M.A. ElGawady. 2017. "Performance of Bridge Piers Under Vehicle Collision." *Engineering Structures* 140: 337–352. https://doi.org/10.1016/j.engstruct.2017.02.054.
5. Abdelkarim, O., and M.A. ElGawady. 2015. "Design of Short Reinforced Concrete Bridge Columns Under Vehicle Collision." *Transportation Research Record* 2592 (1): 27–37. https://doi.org/10.3141/2592-04.
6. Klaiber, F., T. Wipf, F. Russo, R. Paradis, and R. Mateega. 1999. *Field/Laboratory Testing of Damaged Prestressed Concrete Girder Bridges*. Final Report for Iowa Department of Transportation Project HR-397. https://publications.iowa.gov/17339/1/IADOT_hr397_Field_Lab_Testing_Damaged_Prestressed_Concrete_Girder_Bridges_1999.pdf.
7. European Commission. 2006. *Eurocode 1: Actions on Structures - Part 1-7: General Actions - Accidental Actions*. https://eurocodes.jrc.ec.europa.eu/EN-Eurocodes/eurocode-1- actions-structures.
8. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.

ACI Joins NCBC to Strengthen Collaboration, Advance Concrete Bridge Technology

by Dr. Trey Hamilton, American Concrete Institute

In early 2025, the National Concrete Bridge Council (NCBC) welcomed the American Concrete Institute (ACI) as its newest member. This membership aligns with ACI's mission to advance knowledge of concrete and its use, and ACI brings to NCBC valuable expertise for the continual improvement of concrete bridge technology.

"ACI's membership in NCBC will create synergies between ACI's broad expertise in concrete standards and education and NCBC's industry-specific focus on advocacy, research, and policy development," stated then-ACI President Michael J. Paul in January 2025. "Together, ACI and NCBC can drive improvements in bridge safety, durability, and sustainability, while enhancing workforce skills and industry knowledge. ACI's strategic alignment with the NCBC will not only amplify its influence in the bridge sector but also ensure that concrete bridges remain a cornerstone of modern infrastructure."

A Shared History of Influence

ACI has long been a driving force in developing concrete design practices. The institute's leadership in load- and resistance-factor design (LRFD) methodologies laid the foundation for modern strength-based approaches to structural design. The American Association of State Highway and Transportation Officials (AASHTO) incorporated these principles into its bridge design specifications in the 1970s and ultimately adopted LRFD in 1994.

With these aligned efforts, ACI and AASHTO have historically worked in parallel, with ACI focusing on buildings and materials and AASHTO focusing on bridges and transportation structures. By joining NCBC, ACI takes an important step toward greater collaboration, ensuring that expertise from both communities is effectively shared and applied where needed.

Advancing Bridge-Focused Knowledge

ACI maintains more than 120 technical committees addressing every aspect of concrete design and construction. Four of those committees are directly focused on bridges: ACI 341 Performance-Based Seismic Design of Concrete Bridges; ACI 342 Evaluation of Concrete Bridges and Bridge Elements; ACI 343 Concrete Bridge Design (a joint committee with the American Society of Civil Engineers); and ACI 345 Bridge Construction and

The Interstate 74 Mississippi River Bridge in Bettendorf, Iowa, won first place in the 2023 ACI Excellence in Concrete Construction Awards. Photo: ACI Excellence in Concrete Construction Awards.

The Los Angeles Bureau of Engineering's Sixth Street Viaduct is a cast-in-place concrete network tied arch that sets a new threshold for seismic safety and expands the utility of urban bridges. Photo: ACI Excellence in Concrete Construction Awards.

Preservation. Additionally, many other ACI committees develop knowledge and standards relevant to bridge design and maintenance. For example, the work of ACI 440 Fiber-Reinforced Polymer Reinforcement on internal and external reinforcement has supported bridge strengthening and new construction practices.

The expertise of ACI's volunteers, many of whom work in bridge design, construction, or research, extends well beyond the formal bridge committees. Through NCBC, these experts will now have a stronger path to engage with AASHTO's Committee on Bridges and Structures, fostering the direct exchange of knowledge and addressing gaps in technical guidance.

NCBC and ACI: Working Together to Benefit the Bridge Community

By combining their distinct yet complementary missions, ACI and the other members of NCBC can achieve substantial synergies. ACI's role as a professional organization and thought leader in the global concrete industry aligns well with NCBC's advocacy and efforts to promote concrete bridges as a sustainable and reliable solution for public infrastructure. Through collaboration, ACI joins the other members of NCBC in leveraging their shared commitment to advance concrete knowledge and innovation while addressing the specific needs of the concrete bridge community.

Together, NCBC member organizations work to ensure that concrete bridges continue to meet the highest standards of safety, durability, and environmental sustainability. ACI's global technical expertise, professional education, and certification programs can support the NCBC's efforts to enhance the skills of engineers, contractors, and owners in the bridge sector. At the same time, NCBC's focus on bridge-specific issues and industry advocacy can help ACI members stay informed about the latest trends, research, and policies affecting the concrete bridge industry. The following key points highlight the strategic advantages and collaborative benefits of ACI's membership in NCBC for the concrete bridge industry:

- Strategic alignment: ACI's strategic plan emphasizes the dissemination and advancement of concrete knowledge, with a particular focus on building mutually beneficial alliances. Membership in NCBC aligns with ACI's goal to enhance its influence and effectiveness within the concrete bridge industry.
- Enhanced collaboration: NCBC's established relationships with the Federal Highway Administration (FHWA) and AASHTO present a strategic opportunity for ACI. AASHTO's preference for a unified voice from the concrete industry through NCBC underscores the importance of ACI's participation to ensure that the institute's expertise and standards are available to assist AASHTO in its development of standards and guidance related to concrete bridge design, construction, and maintenance.
- Mutual benefits: NCBC's broad industry network and influence will improve the visibility and applicability of ACI's extensive expertise and resources, which will be of mutual benefit to ACI and the concrete bridge community. ACI's membership in NCBC will ultimately support both organizations' goals of advancing concrete bridge technology and elevating the performance and reliability of infrastructure systems.

The History of ACI

Established in 1904 as the National Association of Cement Users and renamed the American Concrete Institute in 1913, ACI is a 501(c)(3) nonprofit organization that was created to bring consistency, safety, and technical guidance to the growing use of concrete in construction. From its earliest building regulations for reinforced concrete to the internationally adopted *Building Code Requirements for Structural Concrete* (ACI 318), the institute has shaped how concrete is designed, specified, and built worldwide.

Headquartered in Farmington Hills, Mich., with a regional office in Dubai, and resource centers across the United States, ACI serves more than 40,000 members in over 120 countries through 90 chapters and 350 student chapters. For more than a century, ACI has been a leading global authority for the development, dissemination, and adoption of consensus-based standards, technical resources, and educational, training, and certification programs.

Looking Ahead

By joining NCBC, ACI formalizes its role as a collaborative partner in advancing the state of practice for concrete bridges. Together, NCBC and ACI are well positioned to influence standards, foster innovation, and improve the durability and performance of the nation's bridge infrastructure. Thank you to NCBC for welcoming ACI to the council. We look forward to the opportunities that this partnership will bring to our member organizations and the entire bridge community.

Dr. Trey Hamilton is senior engineer for the American Concrete Institute. Hamilton is past chair of ACI Technical Activities Committee and ACI Committee 423 Prestressed Concrete. Retired from the University of Florida, Hamilton is a fellow of both the American Concrete Institute and the Post-Tensioning Institute.

Teaching Students to Read and Interpret Construction Specifications and Drawings

by Dr. George Okere, University of Cincinnati

The outcome of careful and detailed design efforts for construction projects is the creation of construction specifications and drawings. These documents are used for cost estimating and scheduling, and they become the input for constructing concrete structures.

Despite the emphasis on construction specifications and drawings in the construction industry, many engineering and construction management graduates are ill-equipped as to how to read these documents when they enter the industry. One might assume that because reading and interpreting these documents are essential skills in the construction industry, students preparing for careers in that industry would learn these skills in college. The truth is that many interns and recent graduates lack a strong understanding of how to read and interpret construction drawings because they were never taught, while most employers assume that new hires are sufficiently prepared.

State of the Curricula in Construction-Related Programs

Reviewing the curricula of civil engineering, construction management, and construction engineering programs reveals gaps in current practices. Most students in these programs gain some experience reading construction specifications and drawings if they take a cost-estimating course.[1]

The Accreditation Board of Engineering and Technology (ABET) establishes the curriculum standards for accreditation of university engineering, technology, and applied science programs.[2,3] However, universities can choose to surpass these ABET requirements. Let's review the requirements for construction engineering, civil engineering, and construction management programs.

- For an accredited construction engineering curriculum, ABET requires the application of "knowledge of construction methods, materials, equipment, planning, scheduling, safety, and *cost analysis*" (emphasis added).
- For an accredited civil engineering curriculum, ABET does not require the application of construction cost analysis for all students.
- For an accredited construction management curriculum, ABET requires knowledge of "cost estimating, including types, levels, and accuracy."

The American Society of Civil Engineers' (ASCE's) Civil Engineering Body of Knowledge[4] does not list cost estimating as a required area of knowledge for civil engineers. However, the required Civil Engineering Body of Knowledge does include engineering economics.

We know that many construction engineering and construction management graduates are employed by contractors. These employees were probably exposed to cost estimating and related construction specifications and drawings while in college. However, civil engineering graduates may not have been exposed to those same project documents in college. We can all agree that the ability to read and interpret specifications and drawings is an essential skill for a variety of roles in engineering and construction, without which many graduates will struggle within their first year.

Building Students' Foundational Knowledge

In academia, there is a reason we have prerequisites. They are designed to help students gain the foundational knowledge they need to be well prepared for upper-level courses.

We should think of reading and interpreting construction specifications and drawings as an important type of prerequisite knowledge. Instead of covering these foundational concepts only in upper-level courses, introducing this knowledge in prerequisite classes could prepare students for courses such as cost estimating and project scheduling where their skills could be reinforced through practice. Furthermore, the prerequisite knowledge can help students see how what they learn in their design courses translates to project specifications and drawings.

Civil engineering programs should consider the future of their students who choose to work in the field. These students must complete many design requirements to graduate, but they may never apply them day to day. Such students would benefit from college instruction and practice in reading and interpreting construction specifications and drawings, as they will need this foundational knowledge to work effectively in the industry.

How to Bridge the Gap

As I previously mentioned, students are typically exposed to reading specifications and drawings if they take a cost-estimating course. However, civil engineering students at some universities do not have that option, or they may not elect to take cost estimating.

The civil engineering program at the University of Cincinnati offers construction cost-estimating courses to its students, but we still face challenges such as getting students to take the appropriate cost-estimating courses and teaching plan-reading skills to students who choose not to take a cost-estimating course.

Possible strategies to overcome the gap in students' education about specifications and drawings include the following:

- Emphasize to students the importance of taking a cost-estimating course.
- Expand coverage of project documents in courses on construction materials and methods. It has been shown that this type of course can be modified to include exercises in reading and interpreting construction specifications and drawings.[5]
- Find opportunities in every design course to showcase how designs are translated and represented for use in the construction phase. For example, mini case studies could be presented in each design course to help students build their awareness of what specifications and drawings look like and how to read and interpret them.
- Include reading, understanding, and preparing construction documents in the design capstone course that is required in ABET-accredited programs.
- Direct students to checklists for reading construction specifications and review a table of typical drawing elements based on items of work. **Figure 1** shows typical sections of specifications for the purpose of organizing checklists.

Conclusion

In academia, we sometimes fail to adequately prepare students in construction-related programs to read and interpret construction specifications and drawings. This knowledge is critical for success in their careers. In some cases, students gain exposure to this fundamental knowledge through cost-estimating courses. However, ABET accreditation does not require cost analysis for civil engineering programs, and ASCE does not include the topic as a core knowledge area. The reality is that our graduates need this knowledge to excel in the field. While cost-estimating courses are important, design courses could also incorporate brief case studies to demonstrate the relationship between design decisions and construction specifications and drawings.

References

1. Okere, G., and C. Souder. 2023. "An Approach in Designing and Teaching Hands-on and Immersive Construction Cost Estimating Course," paper presented at 2023 ASEE Annual Conference & Exposition. Baltimore, MD, June 25, 2023. https://peer.asee.org/42611.
2. Accreditation Board of Engineering and Technology (ABET). 2025. "Criteria for Accrediting Engineering Programs, 2025–2026." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026.
3. ABET. 2025. "Criteria for Accrediting Applied and Natural Science Programs, 2025–2026." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-applied-and-natural-science-programs-2025-2026.
4. American Society of Civil Engineers (ASCE). 2019. *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer*. Reston, VA: ASCE. https://doi.org/10.1061/9780784415221.
5. Okere G. 2021. "Modifying the Syllabus on Construction Materials and Methods to Better Prepare Construction Students for Upper-Level Courses, Co-ops, or Internships," paper presented at the 2021 ASEE Annual Conference & Exposition (virtual), July 26, 2021. https://peer.asee.org/37515.

Figure 1. Specification review checklist sections. Figure: University of Cincinnati.

Scope of Work	+	Coordination	+
Submittals	+	Regulations	+
Standards	+	Access Restriction and Constraints	+
Products and Materials	+	Related Sections	+
Named Responsible Party	+	Contract Pay Item	+
Construction Requirements and Quality of Workmanship	+	Incidental Work	+
Quality Control	+	Measurement and Payment	+
Off-Site Fabrications	+	Commentary - Construct if Included in the Contract	+
Activities (Work Tasks)	+	Commentary - Make No Assumptions	+

STATE

North Carolina

North Carolina continues to invest in infrastructure while exploring innovative construction and repair methods to extend the lifespans of concrete bridges.

by Nicholas Pierce, Aaron Earwood, and Tyler Rogers, North Carolina Department of Transportation

Construction of the new $450 million Alligator River Crossing in eastern North Carolina began in early 2025 and is expected to take four years. More than 700 square precast, prestressed concrete piles are being driven into the Alligator River to support the new bridge. All Photos: North Carolina Department of Transportation.

As the third most hurricane-prone state in the United States, just behind Florida and Texas, North Carolina regularly experiences heavy winds, flooding, storm surge, and tornadoes. North Carolina's coast is especially vulnerable to the effects of hurricanes because it extends into the ocean. However, all areas of the state, from the coast to the mountains, have been affected by hurricanes in the past 20 years.

Hurricane Helene Damage and Recovery

In September 2024, Hurricane Helene produced record rainfall across western North Carolina. Some areas received more than 30 in. of rain, triggering catastrophic flooding and landslides that resulted in more than 100 deaths and an estimated $60 billion in damage to businesses, private property, and transportation infrastructure. Hurricane Helene severely affected critical transportation corridors. The North Carolina Department of Transportation (NCDOT) determined that 674 bridges and 712 culverts were damaged.[1]

Rebuilding in the aftermath of Hurricane Helene presented significant challenges for NCDOT engineers. The widespread destruction and extensive damage to critical infrastructure led to an intense demand for materials, equipment, contractors, and inspectors to support recovery efforts. One of the greatest hurdles during the earliest phases was access, as washed-out roads and bridges made it extremely difficult to reach impacted areas and deliver construction materials and equipment.

As emergency repairs began, the restoration of connectivity gradually made deliveries more feasible, allowing recovery efforts to accelerate. The focus during the initial response was on installing temporary bridges and roadways to restore emergency access for isolated communities and homeowners.

Over time, priorities following the hurricane shifted toward planning and constructing resilient, permanent infrastructure. Balancing the urgency of quickly installing temporary bridges with the long-term need to reconstruct permanent ones was a key challenge. In some cases, temporary structures could be offset from the original alignment to preserve space for future permanent construction; however, in other instances, site constraints required temporary bridges to be built directly on the original footprint, which complicated the transition to permanent solutions.

Close collaboration among NCDOT, the Federal Highway Administration, transportation agencies in neighboring states, industry partners, and local stakeholders proved essential to set western North Carolina firmly on the path to recovery. Lessons learned from this disaster are already influencing how NCDOT approaches emergency response and long-term resilience. By refining strategies for rapid access, resource coordination, and the balance between temporary and permanent solutions, the department will be better prepared to respond swiftly and effectively to future challenges.

Corrosion-Resistant Alternatives

Given the severe coastal environment and the high likelihood of storms affecting the state, NCDOT continues to invest in research and other efforts to increase resiliency, such as ways to prevent and curtail the onset of corrosion in concrete structures. Measures to protect concrete components exposed to chlorides from seawater splash, saltwater spray, or the briny atmosphere include substituting silica fume for a portion of the cement, using corrosion-inhibiting admixtures such as calcium nitrite, and maintaining proper concrete cover.

NCDOT is reviewing the corrosion policy to allow increased use of nonferrous alternative materials to steel reinforcement, including

The new Harker's Island Bridge opened in 2023 and provides improved access to and from the island in emergencies and during hurricane evacuations. The structure is the first in North Carolina to feature carbon-fiber-reinforced polymer strand and glass-fiber-reinforced polymer reinforcement bars.

types of fiber-reinforced polymers (FRPs). Because materials such as glass-fiber-reinforced polymer (GFRP) and carbon-fiber-reinforced polymer (CFRP) are both durable and resistant to corrosion induced by saltwater and harsh environments, their use extends the lifespans of bridges.

The Harker's Island Bridge replacement project was the first bridge entirely reinforced with FRP reinforcing bars and prestressing strand in North Carolina. (For more information on this project, see the Fall 2023 issue of *ASPIRE*®). Given the success of the Harker's Island project, NCDOT has specified FRP reinforcement on other projects, including a bridge replacement over the Alligator River in the Outer Banks region.

Alligator River Bridge Replacement

Currently under construction, the 3.2-mile-long Alligator River Bridge will carry U.S. Route 64 over the Alligator River between the Outer Banks of North Carolina and the mainland. For this project, NCDOT selected a construction manager/general contractor project delivery method to accelerate the schedule.

The new structure, which replaces a swing-span bridge that is more than 60 years old, has a high-rise, fixed span over the navigation channel with a horizontal clearance of 140 ft and a vertical clearance of 65 ft. The new cross section consists of two 12-ft-wide travel lanes with 8-ft shoulders for a total width of 40 ft.

The bridge consists of 134 spans with lengths ranging from 80 to 170 ft over the channel. Precast, prestressed concrete girders and a cast-in-place concrete deck comprise the superstructure, and concrete link slabs are specified to eliminate joints. Corrosion-resistant design features include CFRP prestressing strands in the precast concrete piles and GFRP reinforcement in the cast-in-place concrete substructure. The square precast concrete piles are 24, 36, and 54 in. with lengths that range from 89 to 125 ft. The design also incorporates GFRP reinforcement in the concrete deck.

Marc Basnight Bridge

The 14,800-ft-long Marc Basnight Bridge, which serves the Outer Banks, is another example of corrosion-resistant design. (See the Fall 2019 issue of *ASPIRE* for a Project article about the Marc Basnight Bridge.) For the first time in North Carolina, stainless steel was used in place of traditional carbon steel reinforcement, specifically in the cast-in-place concrete bridge deck and the post-tensioning bars. In conjunction with the stainless steel reinforcement, advanced concrete mixtures and precast concrete components were used to help achieve the design goal of a 100-year service life. The concrete mixture proportions used for the Marc Basnight Bridge were selected for maximum durability against saltwater exposure. Calcium nitrite corrosion inhibitor coupled with supplementary cementitious materials, including fly ash, slag, and silica fume, decrease the permeability of the concrete and help delay the onset of corrosion in the steel reinforcement.

Sampson County Bridge No.3 is the first North Carolina example of a retrofit application using the prestressed, mechanically fastened, fiber-reinforced polymer system. The repair of six beams was completed in five days, and the bridge reopened immediately after installation of the repair.

Beyond Coastal Corrosion

The "belt and suspenders" approach of corrosion protection for bridges along the coast makes sense, but there are other areas of the state that can benefit from additional measures to protect bridges from corrosion. For example, structures in locations that require deicing agents in the winter are also at risk for corrosion-related damage. For this reason, NCDOT is evaluating the use of FRP bars in concrete bridge decks statewide.

NCDOT has constructed four bridges using FRP materials for reinforcement, with two more under construction. Currently, NCDOT is giving contractors on awarded projects the option to substitute FRP bars for steel reinforcement in concrete decks, when feasible, while the development of design guidance is completed. The new guidelines will include deck design tables for use by designers and a flowchart that demonstrates when FRP should be a priority to achieve a minimum service life of 75 years. This approach promotes the use of FRP instead of carbon steel for both strand and reinforcing bar in known corrosive environments and ensures that bridge decks are protected. For bridges in corrosive areas, the flowchart indicates that all prestressed concrete girders shall be designed for zero tension in the precompressed tensile zone to minimize cracks.

The Marc Basnight Bridge is designed to resist corrosion in the harsh saltwater environment of coastal North Carolina. To meet the 100-year service life, the design team chose stainless steel reinforcement for the cast-in-place concrete deck.

Mapping Corrosive Environments

The NCDOT Structure Management Unit Manual[2] includes a Corrosive Areas Map that delineates both "corrosive" and "highly corrosive" lines along the coast and inland to the Albemarle Sound. NCDOT is trying to clearly locate corrosive environments in the state and identify when to use corrosion-resistant materials such as GFRP.

A 2022 research project[3] by the University of North Carolina at Charlotte examined whether the specified cover requirements, use of fly ash and silica fume, and corrosion-inhibitor dosage rates described in the NCDOT's Structures Management Unit Manual were consistently delaying the onset of corrosion in coastal concrete bridges. The study proposed further evaluation of the current method of delineating high-corrosion zones.

Beyond coastal areas, NCDOT can use in situ testing to pinpoint potentially corrosive environments. The follow-up research aims to develop improved corrosion mitigation strategies for long-term durability, possibly by analyzing water samples to assess chloride exposure and site aggressiveness.

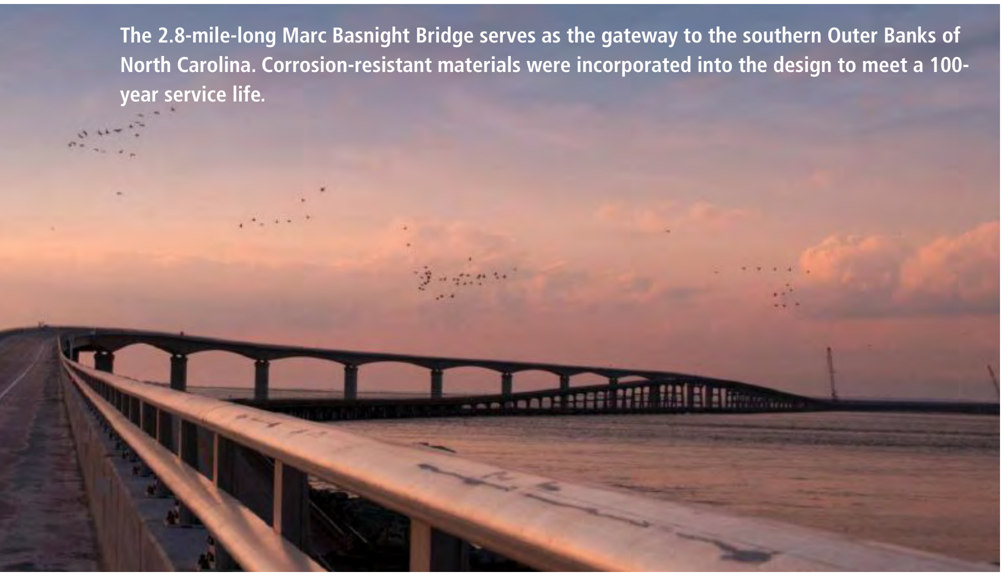
Rapid Repair of Prestressed Concrete Bridge Beams

In conjunction with North Carolina State University (NCSU), NCDOT has examined innovative approaches to restore the integrity of concrete bridges with corroded prestressing strands. The prestressed, mechanically fastened, fiber-reinforced polymer (MF-FRP) system has been used primarily on prestressed concrete channel and cored-slab beams to provide a type of temporary repair that can be rapidly completed to extend the structure's use until it can be replaced.

In November 2020, six channel beams on Sampson County Bridge No. 3 were retrofitted with the prestressed MF-FRP system as a temporary solution for a deteriorated structure. The bridge is a three-span prestressed concrete channel structure built in 1966 across Branch Six Run Creek, and the retrofit was designed to restore prestressing forces lost due to corrosion of internal steel strands. The cost-effective repair allowed the bridge to be reopened immediately; the bridge's condition was then continuously monitored until the structure was replaced. The new bridge opened to traffic in 2023.

Similar repairs were performed on Franklin County Bridge No. 80 and Wake County Bridge No. 180. These projects demonstrate that with a small NCDOT crew, many structures can be repaired and kept in service, typically with an increased load posting, until a permanent solution can be implemented.

NCSU continues to study the MF-FRP system by evaluating the repaired girders as they become available when retrofitted bridges are replaced. Specifically, the investigators can determine the residual strength in the repaired girders after being in service for typically two to three years. With that information, NCDOT should be better able to determine the extended service life of the repaired components. The research team is salvaging the six retrofitted channel beams from Sampson County Bridge No. 3 that were in service for approximately 21 months. Two additional beams from the bridge will serve as controls for comparison at the laboratory. The MF-FRP rapid-repair system is discussed in detail in the Fall 2024 issue of *ASPIRE*.



The 2.8-mile-long Marc Basnight Bridge serves as the gateway to the southern Outer Banks of North Carolina. Corrosion-resistant materials were incorporated into the design to meet a 100-year service life.

Conclusion

NCDOT faces a variety of challenges when designing and constructing resilient concrete bridges. North Carolina's existing infrastructure, including its bridges, is susceptible to damage from exposure to corrosive environments as well as flooding and high-water events. The agency uses innovative techniques to repair existing concrete structures and design new bridges to withstand environmental impacts.

References

1. North Carolina Office of State Budget and Management (OSBM). 2024. *Hurricane Helene Recovery—Revised Damage and Needs Assessment*. Raleigh, NC: OSBM. https://www.osbm.nc.gov/hurricane-helene-dna/open.
2. North Carolina Department of Transportation (NCDOT). 2023. *Structures Management Unit Manual*. Raleigh, NC: NCDOT. https://connect.ncdot.gov/resources/Structures/StructureResources/SMU%20Design%20Manual.pdf.
3. Tempest, B., T. Cavalline, R. Newsome, K. Violette, and T. Al-Salihi. 2022. *Evaluating Corrosive Sites Policy for Concrete Bridges at the North Carolina Coast*. Raleigh, NC: NCDOT. https://connect.ncdot.gov/projects/research/RNAProjDocs/RP2019-22%20Final%20Report.pdf.

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AASHTO LRFD Bridge Design Specifications: Updates to AASHTO's *Manual for Bridge Evaluation*

by Dr. Oguzhan Bayrak, University of Texas at Austin

This article provides an overview of one agenda item that updates the American Association of State Highway and Transportation Officials' *Manual for Bridge Evaluation* (AASHTO MBE)[1] for load rating of segmental bridges. The "Perspectives on Structural Behavior and Redundancy" series of articles, published in *ASPIRE*® in 2021, serves as a primer to the changes in this working agenda item that was approved in June 2025. The approved changes to the AASHTO MBE explain the logic behind load ratings of segmental bridges, help ensure the safety of such bridges, and give due consideration to the cost-effectiveness of the engineering solutions. With that stated, let's focus on the newly approved 15-part working agenda item for the upcoming changes in the AASHTO MBE.

Part 1

The consideration of the temperature gradient *TG* when evaluating segmental bridges is clearly explained by replacing the second paragraph in Article C6A.2.3.6, as follows:

For segmental concrete box girder bridges, TU *and* TG *shall be considered at the service limit state at the design-load inventory level. The corresponding load factors,* γ_{TU} *and* γ_{TG}*, shall be taken as 1.0 and 0.5, respectively, when live load is considered.*

Part 2

Commentary language is added to Article C6A.2.3.6 to clarify intent, as follows:

Corven Engineering (2004)[2] *and Popok et al. (2024)*[3] *have established that when assessing bridge designs for Strength Limit State, the impact of thermal gradients need not be considered. Inventory Ratings, which are as reliable as new designs, should account for thermal gradients at the Service Limit State as per LRFD guidelines.*[4] *However, the likelihood of the maximum live load and the peak thermal gradient occurring at the same time is minimal. Therefore, during Inventory Ratings, only half the thermal gradient value (0.5*TG*) is considered alongside the design live load at service. Operating Ratings exclude thermal gradient effects at both Service and Strength Limit States due to their negligible influence and the minor consequences of limit exceedance.*

Typically, the longitudinal expansion and contraction in concrete bridges are managed by sliding or flexible bearings, which minimally affect the superstructure. However, when superstructures are fixed to substructures, the forces from thermal expansion and contraction (TU) *must be taken into account. These forces are only factored in at the Service Limit State for Inventory Ratings, with a factor of* γ_{TU} *= 1.0, as including them at the Strength Limit State does not substantially alter the core reliability of the structure and could lead to unnecessary work. Similarly, for Operating Ratings, the effects of thermal expansion and contraction are considered negligible, and the repercussions of surpassing the limit are not significant.*

Part 3

To provide clarity, the following language is added to Article 6A.4.2.2:

In Table 6A.4.2.2-2, the application of the live load factor of 1.0 does not extend to segmental concrete box girder bridges, designed using gross sections and utilizing time-step methods in the time-dependent prestress loss calculations rather than the refined estimates as specified in LRFD Design Article 5.9.3.4. The live load factor of 0.8 should be applied for Service III load combination for segmental concrete box girder bridges at the design-load inventory level.

Part 4

Commentary to Article 6A.4.2.2 (C6A.4.2.2) is expanded to include the following explanation:

For segmental concrete box girder bridges, a live load factor of 0.8 at the design-load inventory level is calibrated for the Service III limit state to achieve a target reliability index, β_T*, of 1.0, corresponding to a one-year return period (Popok et al., 2024).*[3]

Part 5

The second row of Table 6A.4.2.2-2, "Load Factors for Live Load for the Service III Load Combination, γ_{LL}, at the Design-Load Inventory Level," is revised to read:

Prestressed concrete components rated using the refined estimates of time-dependent losses as specified in LRFD Design Article 5.9.3.4 in conjunction with taking advantage of the elastic gain	1.0

Part 6

The third row of Table 6A.4.2.2-2 is revised to read:

All other prestressed concrete components, including segmental concrete box girders	0.8

Part 7

Article 6A.5.11.3 is revised to read:

For the Multiple Presence Factors [MPFs] in segmental concrete bridges, the following table is recommended for spans up to 400 ft.

Table 6A.5.11.3—Multiple Presence Factors for Segmental Bridges

Number of Loaded Lanes	MPF
1	1.20
2	1.00
3	0.75
4 or more	0.60

For the transverse operating load ratings of the top slab of segmental concrete box girders, the factor of 1.20 specified in Table 6A.5.11. for one loaded lane shall be limited to a maximum of 1.00.

Part 8

Article C6A.5.11.3 is expanded by adding the explanation below:

The multiple presence factors derived for segmental concrete bridges are based on actual WIM [weigh-in-motion] *data which has at least hundredth of a second timestamp. Truck traffic simulations and probabilistic modeling are used to capture the load effects created by the cross-lane multiple presence events. It is found that the MPFs are affected by two major factors: truck loads and probability of multiple presence events. Truck loads can be further defined as the mean and standard deviation of loads on each lane, and the covariance of the load effects across the lanes. The probability of multiple presence events is related to average daily truck traffic, and the distribution of the traffic (Lou et al., 2023).*[5] *For spans up to 400 ft, the current AASHTO LRFD is reasonably conservative for the single-lane and two-lane factor, while three-lane and four-or-more-lane factors are decreased to account for the low probability of side-by-side events based on WIM data.*

Part 9

Article 6A.5.11.4 is revised as follows:

The Strength I and both the Service I and the Service III limit states shall be checked for the design-load rating of segmental concrete bridges. For the Service III limit state, the number of live load lanes shall be taken as the number of design lanes for both inventory and operating ratings. The live load factor of 0.65 shall be used for operating rating. For segmental concrete bridges, the Service III limit state specifically includes the principal tensile stress check of LRFD Design Article 5.9.2.3.3.

To offer clear guidance, Article 6A.5.11.5.1 is revised to read:

Both the Service I and Service III limit states are mandatory for legal load rating of segmental concrete box girder bridges. For the Service III limit state, the number of live load lanes shall be taken as the number of design lanes, and the live load factor of 0.65 shall be used. For segmental concrete box girder bridges, the Service III limit state specifically includes the principal tensile stress check of LRFD Design Article 5.9.2.3.3.

Article 6A.5.11.5.2 is revised as follows:

Both the Service I and Service III limit states are mandatory for permit load rating of segmental concrete box girder bridges. For the Service III limit state, the number of live load lanes shall be taken as the number of design lanes, and the live load factor of 0.65 shall be used. For segmental concrete box girder bridges, the Service III limit state specifically includes the principal tensile stress check of LRFD Design Article 5.9.2.3.3.

Part 10

The Commentary Article C6A.5.11.4 is revised to read:

The principal tensile stress check is necessary to verify the adequacy of webs of segmental box girder bridges for longitudinal shear and torsion.

The use of a live load factor of 0.65 for operating rating derived from the calibration of the service limit states conducted by Popok et al. (2024)[3] *and distinguishes the operating rating from the inventory rating, where a live load factor of 0.8 is appropriately used. The lesser load effects resulting from the reduced live load factor for the operating rating acknowledges a lower target reliability index for operating rating as opposed to inventory.*

The strength limit states are calibrated to achieve target reliabilities, β_T, of 3.5 and 2.5 for inventory and operating evaluation levels, respectively. For the Service III limit state, the live load factors of 0.8 for inventory and 0.65 for operating rating evaluation levels are calibrated to achieve target reliabilities, β_T, of 1.0 and 0, respectively, for the return period of one year (Popok et al., 2024).[3]

Part 11

A new article, 6A.5.11.5.3—Stress Limits for Concrete, is added as follows:

The limits in Table 6A.5.11.5.3 shall apply for compressive and tensile stresses at the Inventory and Operating Ratings in segmentally constructed bridges.

Table 6A.5.11.5.3—Stress Limits in Concrete at the Inventory and Operating Ratings for Segmental Bridges

At the Service Limit State after losses	Stress Limit INVENTORY Rating	Stress Limit OPERATING Rating	Source of Criteria
Compression (Longitudinal or Transverse): Compressive stress under effective prestress, permanent load, and transient loads	$0.60\phi w f'_c$	$0.60\phi w f'_c$	LRFD Table 5.9.2.3.2a-1 LRFD Article 5.6.4.7.2c
Longitudinal Tensile Stress in Precompressed Tensile Zone: (Intended for Segmental and similar construction) • For components with bonded prestressing tendons or reinforcement that are subject to not worse than: For (a) an aggressive corrosion environment and (b) moderately aggressive corrosion environment	$0.0948\lambda\sqrt{f'_c} \le 0.3$ ksi tension	$0.24\lambda\sqrt{f'_c}$ ksi tension	LRFD Table 5.9.2.3.2b-1 and FDOT[6] no distinction for Environ't
• For components with unbonded prestressing tendons only	No tension	No tension	LRFD Table 5.9.2.3.2b-1
Longitudinal Tensile Stress through Joints in Precompressed Tensile Zone: (Intended for Segmental and similar construction) • Type A joints with minimum bonded auxiliary longitudinal reinforcement sufficient to carry the calculated longitudinal tensile force at a stress of $0.5f_y$; for internal and/or external PT (e.g., cast-in-place construction) For (a) an aggressive corrosion environment and (b) moderately aggressive corrosion environment	$0.0948\lambda\sqrt{f'_c} \le 0.3$ ksi tension	$0.24\lambda\sqrt{f'_c}$ ksi tension	LRFD Table 5.9.2.3.2b-1 Seg. Guide Spec. 9.2.2.2[7] FDOT no distinction for Environ't
• Type A joints without the minimum bonded auxiliary reinforcement through the joints; internal and/or external PT (e.g., match-cast epoxy joints or unreinforced cast-in-place closures between precast segments or between spliced girders or similar components.)	No tension	No tension	Ditto and FDOT Seg. Rating Criteria[8]
• Type B joints (Dry-joints without epoxy. These bridges use external tendons only.)	0.1 ksi min comp.	No tension	Seg. Guide Spec. 9.2.2.2 FDOT Seg. Rating Criteria
Transverse Tension, Bonded PT: • Tension in the transverse direction in precompressed tensile zone calculated on basis of uncracked section (i.e., top prestressed slab) For (a) an aggressive corrosion environment and (b) moderately aggressive corrosion environment	$0.0948\lambda\sqrt{f'_c} \le 0.3$ ksi tension	$0.19\lambda\sqrt{f'_c}$ ksi tension	Seg. Guide Spec. 9.2.2.3 LRFD Table 5.9.2.3.2b-1 FDOT no distinction for Environ't FDOT Seg. Rating Criteria
Tensile Stress in Other Areas: • Areas without bonded reinforcement	No tension	No tension	Seg. Guide Spec. 9.2.2.4 LRFD Table 5.9.2.3.2b-1
• Areas with bonded reinforcement sufficient to carry the tensile force in the concrete calculated on the assumption of an uncracked section is provided at a stress of $0.5f_y$ (<30 ksi)	$0.19\lambda\sqrt{f'_c}$ ksi tension	$0.19\lambda\sqrt{f'_c}$ ksi tension	Seg. Guide Spec. 9.2.2.4 LRFD Table 5.9.2.3.2b-1
Principal Tensile Stress at Centroidal Axis in Webs (Service III): • All types of segmental or beam construction with internal and/or external tendons.*	$0.110\lambda\sqrt{f'_c}$ ksi tension	$0.110\lambda\sqrt{f'_c}$ ksi tension	LRFD 5.9.2.3.3 FDOT LRFR Rating Criteria[9]

**Principal tensile stress is calculated for longitudinal stress and maximum shear stress due to shear or combination of shear and torsion, whichever is the greater. For segmental box, check centroidal axis. For composite beam, check at centroidal axis of beam only and at centroidal axis of composite section and take the minimum value. Web width is measured perpendicular to the place of web. For segmental box, it is not necessary to consider coexistent web flexure. Account should be taken of vertical compressive stress from vertical PT bars provided in the web, if any, but not including vertical component of longitudinal draped post-tensioning—the latter should be deducted from shear force due to applied loads.*

Check section at H/2 *from edge of bearing or face of diaphragm, or at end of anchor block transition, whichever is more critical.*

For the design of a new bridge, a temporary principal tensile stress of $0.142\lambda\sqrt{f'_c}$ *may be allowed during construction—per AASHTO Seg. Guide Spec.*

Initial load ratings for new design should be based upon specified concrete strength.

Load rating of an existing bridge should be based upon actual concrete strength from construction or subsequent test data.

Part 12

A new commentary Article C6A.5.11.5.3 is added as follows:

The initial stress limits for concrete, as outlined in Table 6A.5.11.5.3, were predominantly established by Corven Engineering (2004).[2] Furthermore, these limits were also specified in the work of Popok et al. (2024),[3] which used the 2004 study by Corven Engineering as a reference point.

Part 13

Table 6A.5.11.6-1 is revised to read:

Table 6A.5.11.6-1—System Factors for Post-Tensioned Segmental Concrete Box Girder Bridges

Bridge Type	Span Type	# of Hinges to Failure	System Factors (ϕ_s)[a] No. of Tendons per Web: 1/web[b]	2/web	3+/web
Balanced Cantilever, Type A Joints or Cast-in-Place	Interior Span	3	1.00 (0.95)	1.20 (1.05)	1.20 (1.05)
	End or Hinge Span	2	0.95 (0.90)	1.10 (0.95)	1.10 (0.95)
	Statically Determinate	1	n/a	0.95	0.95
Precast Span-by-Span, Type A or B Joints	Interior Span	3	n/a	1.20 (1.05)	1.20 (1.05)
	End or Hinge Span	2	n/a	1.10 (0.95)	1.10 (0.95)
	Statically Determinate	1	n/a	n/a	0.95

[a]*When two values are presented, the first entry refers to the case where one span is loaded (i.e., side-by-side vehicles); the second, in parentheses, refers to two adjacent spans loaded (i.e., multiple vehicles in the same lane).*

[b]*For sections with 1 tendon per web, if three or more webs are present, increase by 0.10 (0.05). This increase applies only for the case of 1 tendon per web.*

Part 14

Commentary Article C6A.5.11.6 is revised to read:

In the context of post-tensioned segmental box girders, the system factor must account for a few significant and important aspects different than other types of bridges. In particular, for a post-tensioned segmental bridge, the system factor, ϕ_s, must properly and appropriately account for:

- *longitudinally continuous versus simply supported spans,*
- *inherent integrity afforded by the closed continuum of the box section,*
- *multiple-tendon load paths,*
- *number of webs per box, and*
- *types of details and their post-tensioning.*

System Factor may vary significantly from one post-tensioned segmental box structure to the next and depends on a variety of factors including bridge geometry, number of spans, span continuity, boundary conditions, number of webs, number of tendons per web, prestress steel area, effective level of prestress, how live load is applied on the structure, as well as other parameters. Thus ideally, System Factors are calculated specifically for the structure under consideration, following the procedure outlined in NCHRP 406.[10] This procedure generally requires a 3-dimensional nonlinear finite element analysis. Such an analysis should account for the change in behavior of the structural system as a component fails and the accompanying redistribution of external load as well as internal forces. In lieu of such an analysis, System Factors for longitudinal flexure at the Strength Limit State may be taken from Table 6A.5.11.6-1. As system factors account for behavior at load levels much beyond those considered for service evaluation (i.e., from component to complete system failure), they are not to be used for service limit states.

Span type and No. of Hinges to Failure refers to the number of plastic hinges needed to form a collapse mechanism. That is to say, 1 hinge for a simple span or statically determinate structure; 2 hinges for the end span of a continuous unit; and 3 for an interior span or monolithic portal frame. The same reasoning applies whether a bridge is built using span-by-span or balanced cantilever construction. Hence a "statically determinate" cantilever bridge (i.e., two cantilevers with a suspended "drop-in" span) is to be treated as a simple span bridge.

The Table lists two values for continuous multi-span structures: a value for one span loaded, such as the case when a single very heavy truck or two heavy trucks in adjacent lanes load the bridge; and a value for two adjacent spans loaded, such as when two heavy vehicles in the same lane load the structure, where the vehicles are separated such that each is on an adjacent span. The two values given are not to be interpreted as use for rating positive or negative moment regions separately; the same System Factor applies to the entire structural system and should be used for both cases. Rather, which System Factor is most appropriate will depend on the local traffic pattern, which will determine the governing load case. Here the concern is what load configuration is most likely to cause failure of the structural system. If this traffic information is unavailable, the following guidance may be used: in general, the two adjacent spans loaded case tends to govern only on longer-span bridges, such as those with each span on the order of 300 ft and longer. For shorter spans, the single span loaded scenario is most likely to control, and in this case the corresponding System Factor may be used. The values in Table 6A.5.11.6-1 were developed from bridges with typical segmental box sections. For other structural types, such as those with significant curvature (approaching a radius of curvature of 800 ft or less), suspension bridges, or other unique characteristics, a System Factor analysis is recommended.

System Factors were developed from the conceptual approach described in NCHRP 406,[10] where factors are a function of the redundancy ratios of system to component capacity. For multi-girder bridges, the focus of NCHRP 406,[10] a component is defined as an individual girder. However, the definition of a component must be reconsidered when segmental bridges are analyzed. For longitudinal flexure, System Factors are meant to account for three types of behavior: longitudinal continuity, the integrity of the box section, and multiple tendon paths. As such, components must be defined to recognize these effects. Thus, in terms of longitudinal continuity, a component is *a potential plastic hinge necessary for bridge failure; for section integrity, a component is an individual web; and when considering multiple tendon load paths, a component is a tendon.*

For consideration of bridge type, the live load on the bridge used for System Factor evaluation ranges from first tendon yield to ultimate capacity and is significantly higher than service loads. As such, distinction between different types of construction (balanced cantilever vs cast-in-place) or joint type (A or B), which generally becomes important for consideration of service rather than strength limit states, was not made for System Factor determination. As such, the System Factors for all bridge types are identical when values are presented. A distinction is made between two broad categories of construction, however: a) balanced cantilever, Type A joints or cast-in-place; and b) precast span-by-span, Type A or B Joints. This distinction is made to separate recommended and/or existing from non-recommended/non-existing designs, depending on the number of tendons per web. For example, there is no known case of span-by-span construction with only one external tendon per web. This consideration led to the insertion of "n/a" in the Table (meaning "not applicable" or "not allowed"). A System Factor analysis is recommended if such a case is found to exist.

In general, the analysis indicated that structures with greater longitudinal continuity tended to have greater System Factors. For these cases, System Factor was nearly always governed by ultimate capacity analysis (rather than functionality or damage), where first component failure was almost always tendon yield.

It was further found that one of the most significant effects of live load placement in System Factor determination was how many spans of a continuous structure were loaded, where it was generally observed that loading two adjacent spans rather than a single span could result in significantly lower System Factors.

System factors are based on evaluations of ultimate system capacity, functionality, and component damage. For the structures considered, the analysis indicated that the component damage evaluation did not govern for any of the cases where System Factors are provided. Thus, values for 2 or 3 tendons per web are identical. An exception is the case of 2 tendons per web for statically determinate span-by-span construction, which is given a system factor of "n/a" due to the impracticality of this case.

Due to the inherent lack of redundancy with only 1 tendon per web, however, System Factors were lowered for the 1 tendon/web case to 1.0 for interior spans (and to 0.95 for adjacent spans loaded), even though the analysis suggests no change in System Factor from the 2 tendon per web case is required. This reduction is also to account for wider structures than those considered in the analysis, where loads with greater eccentricity to the damaged side may lower System Factors further than those found in the analysis. Similarly, system factors were lowered to 0.95 (0.90 for adjacent spans loaded) for the 1 tendon/web case for end or hinge spans. Because 3 web cases were found to have higher System Factors than 2 web cases, an increase of 0.10 (0.05 for 2 spans loaded) was allowed for the case of 1 tendon/web only. This increase of 0.10 applies only to sections that have three or more webs; it does not increase further for sections with more than three webs.

For longitudinal shear and shear torsion, the system factor is taken as 1.00 for the strength limit state for all circumstances.

With transverse post-tensioning of the deck slab, a segmental box is simply a prestressed concrete structure. Therefore, the system factor for transverse flexure of 1.00 is appropriate, regardless of the spacing of tendons; likewise for the local detail of a transverse beam support to an expansion joint device, although the possibility of having only one tendon in the effective section is recognized by reducing the system factor to 0.90.

For local details involving local shear and/or strut-and-tie action or analysis where the resistance is provided by local post-tensioning tendons or bars, a system factor of 1.00 is considered appropriate for two or more tendons. A reduced factor of 0.90 should be used where only one tendon or bar provides the resistance.

Part 15

The references from Corven Engineering[2] and Popok et al.[3] are added to the references section of the AASHTO MBE.

Conclusion

Collectively, the changes detailed herein establish a more definitive guideline for the inclusion of *TU* and *TG* effects in segmental bridges, specifying the limit states, rating levels, and associated load factors. The revised provisions introduce a clear direction to use a live load factor of γ_{LL} = 0.8 for segmental concrete box girders at the design-load inventory level, calibrated as an outcome of the NCHRP 12-123 project (with a final deliverable of NCHRP Report 1128),[3] as opposed to γ_{LL} = 1.0 applied for prestressed concrete components rated using the refined estimates of time-dependent losses as specified in Article 5.9.3.4 of the AASHTO LRFD specifications. The revised multiple presence factors decrease the factor for three loaded lanes from 0.85 to 0.75, and the factor for more than three loaded lanes from 0.65 to 0.6, as compared to AASHTO LRFD Table 3.6.1.1.2-1. The factors for one loaded lane and two loaded lanes remain the same as LRFD Table 3.6.1.1.2-1. With the newly adopted revisions, the use of the number of striped lanes has been replaced with the number of design lanes, but incorporating a live load factor of 0.65. It is important to recognize that the current system factors in AASHTO MBE are based on engineering judgment and experience. The newly adopted factors were developed from analyses based on the conceptual protocol outlined in NCHRP Report 406,[10] with appropriate modifications for the segmental bridges.

References

1. American Association of State Highway and Transportation Officials (AASHTO). Forthcoming. *The Manual for Bridge Evaluation*. 4th ed. Washington, DC: AASHTO.

2. Corven, J., and A. Moreton. 2013. *Post-Tensioning Tendon Installation and Grouting Manual*. Version 2.0. FHWA-NHI-13-026. Washington, DC: Federal Highway

Administration. https://www.fhwa.dot.gov/bridge/construction/pubs/hif13026.pdf.

3. Popok, K., A. Nowak, P. Hurtado, J. Chmielewski, R. Barnes, H. Nassif, P. Lou, C. Yang, S. Hanbay, F. Menkulasi, C. Eamon, F. Cakmak, B. Bhaktha, J. Corven, E. He, and B. Morris. 2024. *Load Rating of Segmental Bridges*. National Cooperative Highway Research Program (NCHRP) Research Report 1128. Washington, DC: National Academies Press. https://doi.org/10.17226/28597.
4. AASHTO. 2024. *AASHTO LRFD Bridge Design Specifications*. 10th ed. Washington, DC: AASHTO.
5. Lou, P, C. Yang, and H. Nassif. 2023. "Live Load Multiple Presence Factors for Design and Evaluation of Short-to-Medium Span Highway Bridges." *Journal of the Transportation Research Board* 2677 (10). https://doi.org/10.1177/03611981231160529.
6. Florida Department of Transportation (FDOT). 2025. *FDOT Structures Manual.* FDOT Design Office Topic No: 625-020-018. Tallahassee, FL: FDOT. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/structures/structuresmanual/currentrelease/2025/2025-structures-manual.pdf?sfvrsn=f658fd25_1.
7. AASHTO. 1989. *Guide Specifications for Design and Construction of Segmental Concrete Bridges.* 1st ed. Washington, DC: AASHTO.
8. FDOT. 2023. *FDOT Bridge Load Rating Manual.* FDOT Topic No. 850-010-035. Tallahassee, FL: FDOT. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/maintenance/str/lr/oom_20230103_fdotloadratingmanual.pdf?sfvrsn=e0dd89fa_2.
9. FDOT. 2004. *New Directions for Florida Post-Tensioned Bridges, Volume 10A: Load Rating Post-Tensioned Concrete Segmental Bridges*. Tallahassee, FL: FDOT. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/structures/posttensioning/newdirectionsposttensioningvol10a.pdf?sfvrsn=58c828bc_0.
10. Ghosn, M., and F. Moses. 1998. *Redundancy in Highway Bridge Superstructures*. NCHRP Report 406. Washington, DC: National Transportation Research Board. https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_406.pdf.

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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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