ASPIRE®

THE CONCRETE BRIDGE MAGAZINE

FALL 2020

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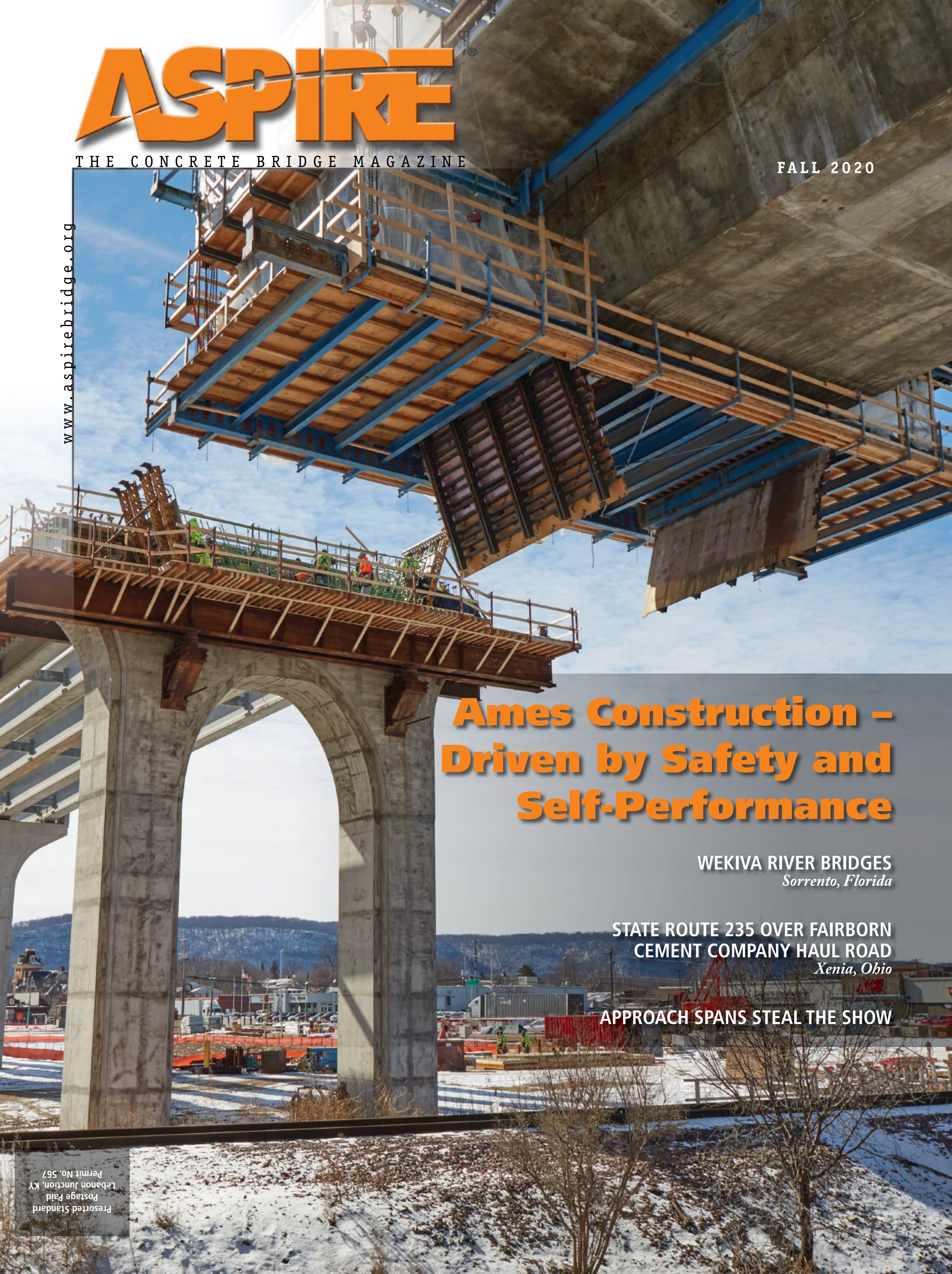

Ames Construction – Driven by Safety and Self-Performance

WEKIVA RIVER BRIDGES
Sorrento, Florida

STATE ROUTE 235 OVER FAIRBORN CEMENT COMPANY HAUL ROAD
Xenia, Ohio

APPROACH SPANS STEAL THE SHOW

Photo: Superior Construction Company Southeast.

Photo: LJB Inc.

Photo: Dale Thomas.

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Photo: Superior Construction Company Southeast.

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EDITORIAL


Photo: PCI.

Interesting Times Provide Time for Reflection

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

These last eight months or so have been challenging, to say the least. Our communities, our industry, and all of us personally have been forced to adjust our daily routines to meet the demands of this new environment. Slowly, as we began to understand the limitations, restrictions, and safety protocols, we made the necessary adjustments that allowed us to continue to accomplish our work.

Zoom meetings, conference calls, and remote work suites are now the norm. And I found another tool that this pandemic uncovered: time for reflection. We'd been moving at such a hectic pace that this "forced inactivity" actually provided an opportunity to look back and recall the tenets that shape all engineers.

T.Y. Lin and Ned Burns dedicated their 1955 book, *Design of Prestressed Concrete Structures* (republished in 1963 and 1981 by John Wiley & Sons Inc.), to "engineers who, rather than blindly following the codes of practice, seek to apply the laws of nature." The need for such engineers is greater today than at any time in our history.

We continue to see unprecedented man-made and environmental disasters. Bridge stewards (owners), along with researchers, students, designers, contractors, and material suppliers, realize that making simple changes to existing specifications or design criteria will not meet our future needs or demands. Our challenge is therefore to "apply the laws of nature," leverage new and emerging technologies, build stronger, more resilient communities, and provide state-of-the-art assets that enhance the lives of our customers and of society at large.

One constant in this drive toward a successful future must remain the quality of the engineering design team we assemble. We must select the right project lead and build a design team around the lead to manage the client's expectations while achieving the desired results. Establishing the right and best team from the outset is key to a successful outcome.

Tim Keller, Ohio Department of Transportation, in his Perspective on page 56 of this issue, "A Call to Action for All Bridge Engineers," discusses the significance of trust. We must build design teams with trust at the forefront. Design leads must have the freedom of action to push the design based on sound engineering principles and established, tried-and-true methods, all backed by the detailed mathematics that our industry demands.

This trust, built over time, establishes our credibility and enhances our profession. When disaster strikes, it is this trust that allows our political leadership to look to us to lead our communities through these events.

Love from my quarantined office to yours,

William

Readers Response

William & Reid:

I'm reading through my summer 2020 ASPIRE issue and I feel the need to compliment you and your staff on what a great magazine this is. This issue is the most informative and relevant publication with "useful" information for all levels of bridge engineers I think I have ever read.

Great Job and Keep it up!!

Regards,

Jerry

Jerry M. Pfuntner is a principal with Finley Engineering Group in Tallahassee, Fla.

Cover
The Highway 43 Mississippi River Crossing in Winona, Minn. Photo: Ames Construction.

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CONCRETE CALENDAR 2020–2021

The events and dates listed were accurate at the time of publication but may change as local guidelines for gatherings continue to evolve.

October 19–23, 2020
The International Bridge Conference
Virtual Event

October 25–29, 2020
ACI Fall 2020 Convention
Virtual Event

October 27–28, 2020
ASBI 32nd Annual Convention and Committee Meetings
Virtual Event

January 5–29, 2021
100th Transportation Research Board Annual Meeting
Virtual Event

January 13–15, 2021
International Symposium on Pavement, Roadway, and Bridge Life Cycle Assessment
Davis, Calif.

January 19–22, 2021
World of Concrete
Las Vegas Convention Center
Las Vegas, Nev.

February 23–27, 2021
PCI Convention with the Precast Show and National Bridge Convention
Ernest N. Morial Convention Center
New Orleans, La.

March 28–April 1, 2021
ACI Spring 2021 Convention
Hilton & Marriott Baltimore
Baltimore, Md.

April 18–21, 2021
PTI 2021 Convention & Expo
Westin Indianapolis
Indianapolis, Ind.

July 11–15, 2021
AASHTO Committee on Bridges and Structures Annual Meeting
Indianapolis, Ind.

September 22–25, 2021
PCI Committee Days and Technical Conference
Loews Chicago O'Hare Hotel
Rosemont, Ill.

December 8–10, 2021
International Accelerated Bridge Construction Conference
Miami, Fla.


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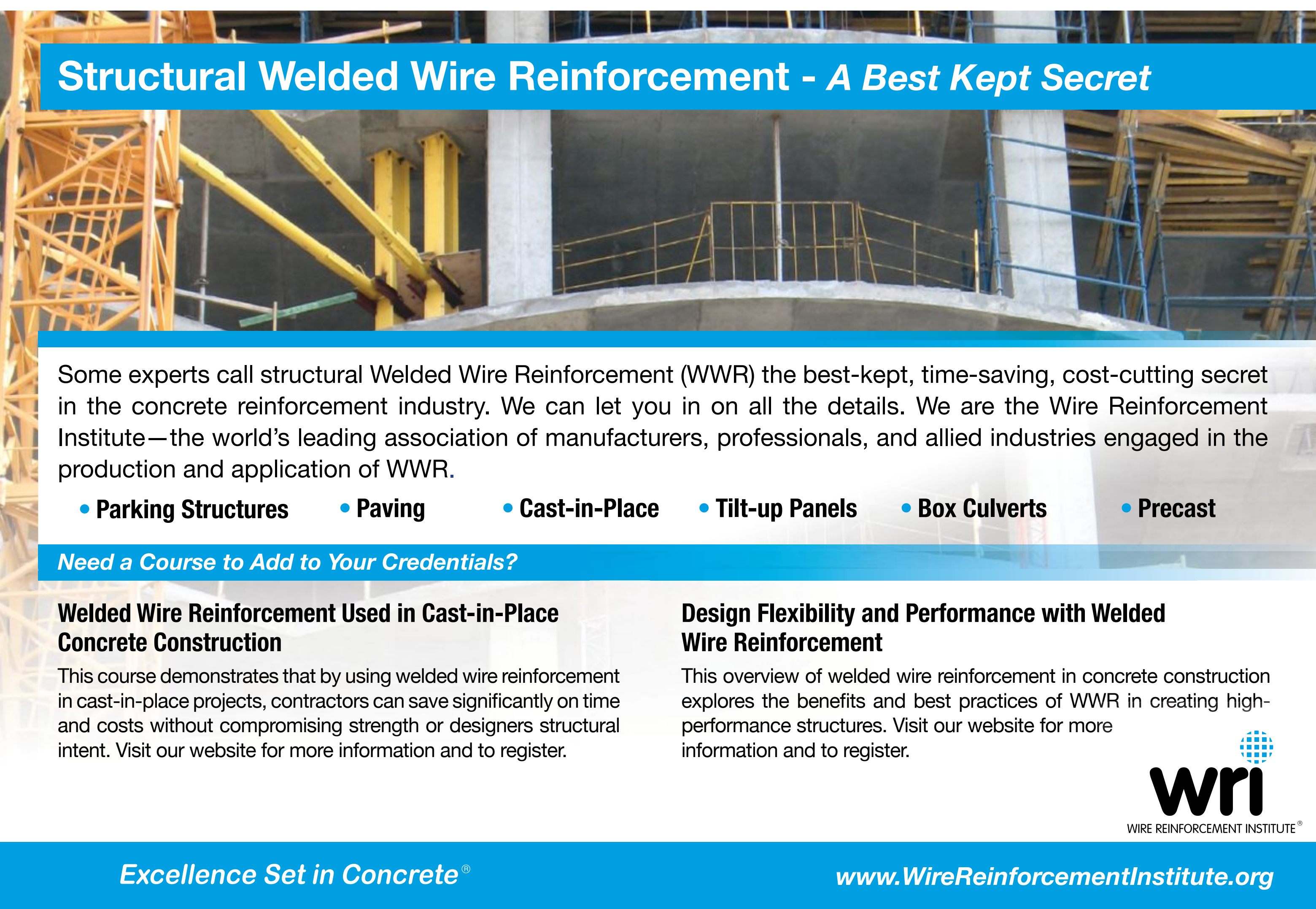
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Midwestern Family Mindset Drives Safety and Self-Performance

From heavy/civil earth moving to a major bridge construction company, Ames keeps it all in the family

by Monica Schultes

Currently ranked 74th out of the top 400 contractors in the United States by *Engineering News-Record*, Ames Construction succeeds by performing to the best of its ability every day and on every project. Since its inception as a family business in the Midwest in 1962, Ames has upheld a reputation for providing superior construction services to a wide range of clients across the midwestern and western United States.

Culture of Loyalty

Being a family-owned company makes a difference. Though many employers say that their people are their most valuable asset, Ames Construction is set apart by the dedication of many lifelong employees and its history of company loyalty.

According to Justin Gabrielson, executive Midwest region vice president, the company values at Ames inspire a culture of commitment to customers and each other. Unsurprisingly, many employees are the second or third generation of their families to work for Ames.

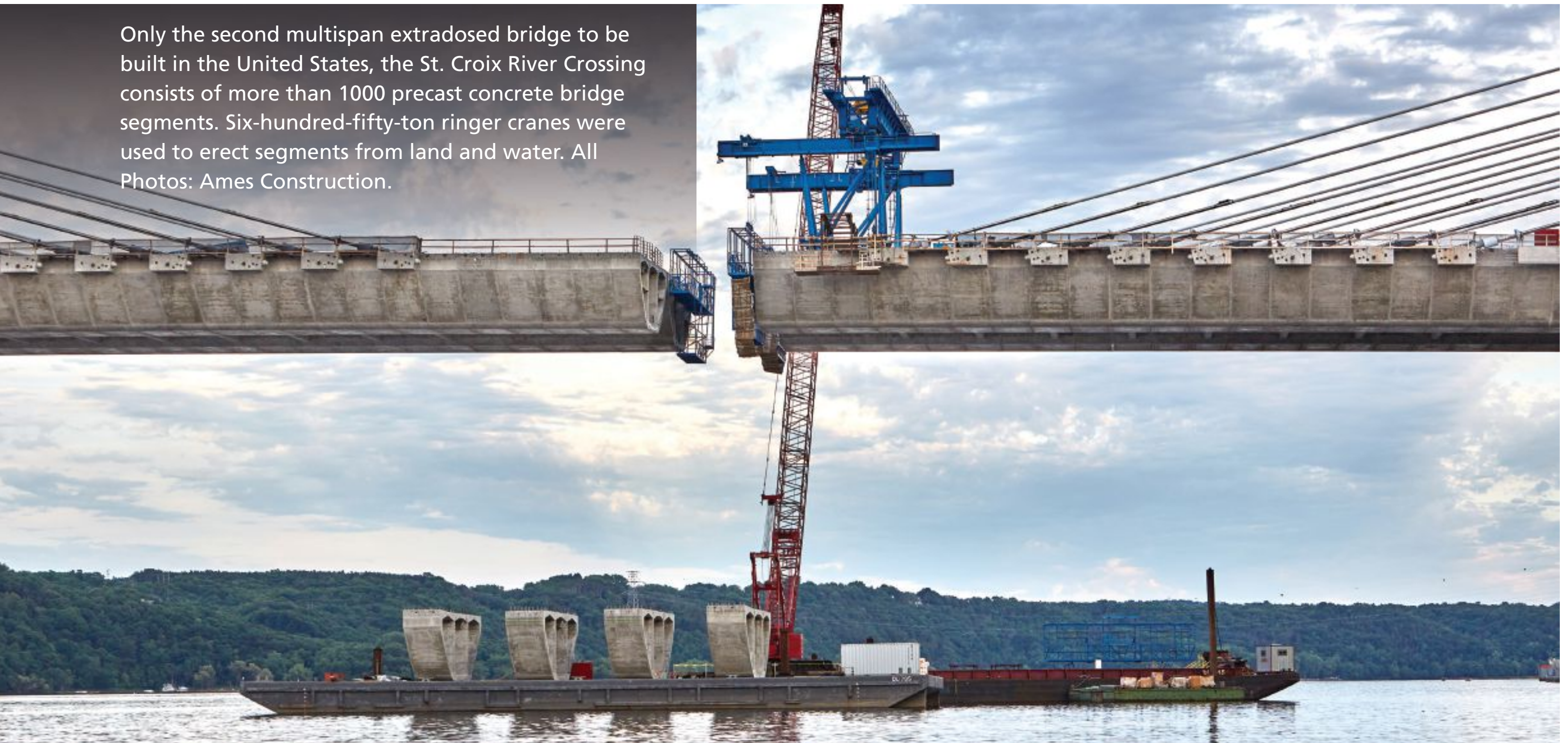
Gabrielson believes that the company's success with employee retention is home grown. "We have been very fortunate to continue to grow as a company, which creates opportunities for coworkers who want to grow with us. There are always positions and opportunities with more responsibilities—we treat them right and respect the work that they do," he explains.

Nick Ruba, vice president of alternative delivery, adds, "It is more than that. They are our company. It is our core belief to develop and grow our people. When we do that right, the rest follows."

Workforce Excellence

In many areas of the United States, construction companies struggle to find an adequate number of skilled workers, but this is not a major issue at Ames. "We are fortunate to not suffer from a severe labor shortage," explains Gabrielson. "We are proactively always looking to add value to our team. Our philosophy is to add people for a career and not just a job," he adds. The company frequently celebrates milestones of lifelong employees who have served 40 or more years with the family business.

Another challenge plaguing the construction industry is its aging workforce. Unlike other vocations that tend to attract a younger pool of talent, the construction industry continues to age. "We put a lot of effort and care into employee development," says Gabrielson. "The bottom line is to attract and keep the right people. There are extensive mentor and internship programs for both tradespeople and project managers. Luckily, the average age of our workforce is trending down with the addition of young employees."



Only the second multispan extradosed bridge to be built in the United States, the St. Croix River Crossing consists of more than 1000 precast concrete bridge segments. Six-hundred-fifty-ton ringer cranes were used to erect segments from land and water. All Photos: Ames Construction.

Self-Performance

Self-performing the majority of its work, rather than hiring subcontractors, helps Ames with many achievements that are important to the company's success: efficiency, risk reduction, and cost control, to name a few. "We self-perform for the main reason that we control our destiny," says Ruba. "For us, it all starts with safety—if you can control your part of the work, it improves the safety of your people," he adds. "While we don't cast our own precast concrete girders, we try to do as much as possible with our own forces. On mega projects that are $400 million or more, we try to team with local firms or joint ventures to parse out the work efficiently."

"We self-perform for the main reason that we control our destiny."

The ability of Ames to self-perform work in the bridge arena is becoming increasingly critical, according to Jerry Volz, vice president of bridges and structures. Project contract durations are being compressed to minimize the impact of construction activities on the traveling public, freight movement, and local businesses. "By self-performing a majority of the work we contract, Ames Construction meets these challenges by reducing our reliance on subcontractors and increasing our control of the workforce," explains Volz. "While our self-performance approach to construction is critical to meet today's project requirements, it also translates into confidence experienced by our clients. They understand that our team is handling their project correctly and that they will receive a successfully delivered project in the end," he adds.

Safety

Construction continues to be one of the most dangerous industries in the United States. With Ames self-performing most of its work, the company places heavy emphasis on safety. Managing safety is crucial to mitigating risk.

Roger McBride, executive vice president of safety and risk management, emphasizes that safety is a core value at Ames Construction. "Working safely is something we take very seriously. Safety is rooted in our daily decisions, which means that we take the time to plan before the actual work begins. We look for innovative ways to reduce risks to our employees. We use engineering and preplanning to eliminate unnecessary hazards, and then we train our workforce how to do the work as safely as possible."

Embedded safety professionals ensure safe operations with on-site safety training, preshift meetings, and dedicated programs to mitigate safety issues and minimize injury and illness incidence rates. "Having a skilled and trained workforce is critical to our project success. Sending workers home safe each day has its own sense of reward," McBride points out.

"Having a skilled and trained workforce is critical to our project success. Sending workers home safe each day has its own sense of reward."

Three Major Concurrent Projects

A defining moment for Ames was when the firm tackled three major river crossings concurrently. With an estimated average workforce of approximately 400 people for the three projects combined, they worked through the Minnesota winters to beat completion dates for the Dresbach, Winona, and St. Croix bridge projects.

On the Dresbach Interstate 90 Crossing over the Mississippi River project, Ames constructed two cast-in-place, balanced-cantilever concrete segmental box-girder bridges while

A cast-in-place closure pour for the Dresbach bridge. Stainless steel reinforcement was used in the deck, and epoxy-coated reinforcement was used in the box-girder webs and bottom slab. Post-tensioning ducts at the bottom of the web and anchorages for multistrand slab tendons are also visible.

To facilitate the project schedule, the Minnesota Department of Transportation chose Ames Construction as construction manager/general contractor to construct the Highway 43 Mississippi River Crossing in Winona, Minn. The approaches are prestressed concrete girder units, and the four-span main unit is a cast-in-place, balanced-cantilever segmental bridge featuring a concrete box-girder design.

The precast concrete bridge segments for the St. Croix bridge were cast in two locations: The smaller segments were made on site and were handled with a self-propelled modular transporter. The larger segments were cast and stored on Grey Cloud Island, downstream from the project. Segments were surveyed three times in the casting yard by two different parties to ensure accuracy of casting.

As part of a public-private partnership with the Arizona Department of Transportation, Ames Construction and its joint venture partners completed the South Mountain Freeway (Loop 202) around Phoenix, Ariz. One of the largest projects in the state's history, the 22-mile project includes more than 40 bridges.

keeping the highway, waterway, and rail routes open for the duration of construction (see an article on the project in the Summer 2016 issue of *ASPIRE*®). The project's 508-ft-long main span achieved a new Minnesota record for concrete main span length. Construction was kept to the smallest footprint possible to protect the environment, and the bridge was built on four fronts at once using balanced cantilever construction. The bridge was completed and fully opened to traffic in 2016.

Ames also worked with the Minnesota Department of Transportation (MnDOT) to construct the Winona Bridge over the Mississippi River, MnDOT's first project using the construction manager/general contractor (CM/GC) delivery method. A concrete box-girder structure type was selected because the graceful lines of the haunched segemental box girder struck the desired aesthetic notes and was also the most cost-effective solution. Through collaboration and partnership efforts, Ames not only completed construction ahead of the already aggressive schedule but also helped MnDOT realize significant cost savings that brought the project in under budget (see the project article in the Winter 2017 issue of *ASPIRE* for additional details).

Opened to the public in the summer of 2017, the striking mile-long St. Croix River Crossing was constructed by an Ames joint venture. The main unit is an extradosed bridge that combines cable stays with a precast concrete segmental box-girder design—the second multispan extradosed bridge to be built in the United States. The innovative design was selected to minimize the structure's environmental impact by using fewer piers in the water, and its shorter cable-stay towers are below the bluff's line of sight (for more details, see the project article in the Fall 2018 issue of *ASPIRE*). At the peak of construction for the three river crossings, more than 600 skilled and dedicated workers were on jobsites.

Project Delivery Methods

Ames has extensive experience with design-build and the firm's business using the CM/GC delivery method is growing. "I think the biggest value [clients] see is selecting the best ideas and innovations from all proposals to create an optimized solution," Ruba notes. For example, during the early CM/GC phase of the Winona segmental bridge over the Mississippi River, Ames worked closely with MnDOT and FIGG, the designer. Volz recalls, "The challenge was that we needed to start casting segments a short five months after contract award. The collaboration allowed us to incorporate the form travelers and post-tensioning components, which streamlined the process." As a result, the bridge opened months ahead of schedule.

In Ruba's opinion, especially with mega projects, Ames's strength is optimized with the progressive design-build process, which is primarily based on qualifications, and owners see the value from early collaboration between designers and builders. "For us, it encourages the team to be proactive. Projects are becoming more complex and yet continue to compress schedule and budget. In the past, our contracts included calendar days and schedule goals. Now, the owner provides only a completion date and you have the

The St. Croix River Crossing is one of three major bridge projects which Ames worked on concurrently. At the peak of construction for the three river crossings, more than 600 skilled and dedicated workers were on the job.

flexibility to accelerate or shut down during winter as needed," he explains.

For its first public-private partnership (P3), the Arizona Department of Transportation (ADOT) selected an Ames joint venture to construct the South Mountain Freeway (also known as Loop 202). Using the innovative P3 approach for the South Mountain Freeway reduced costs and resulted in completion three years sooner than would have been possible with a more traditional approach. The 22-mile freeway opened to the public in late 2019 and includes more than 40 bridges. Two half-mile structures over the Salt River feature the longest precast concrete bridge girders (175 ft) ever used in Arizona.

No matter what project approach is taken, Ames emphasizes the relationships the company has with clients. "We have had success in both public and private sectors," says Gabrielson. "That stems from having established good working relationships with the owners and delivering on our promises."

Technology

Ames is always on the lookout for the latest technology. A dedicated team researches and vets new devices with the goal of improving workflow or enhancing worker safety. One area of interest is wearable technology, including smart helmets with fall-impact detection and smart vests with GPS.

"If they are viable and make us better, we adopt the new technology," says Ruba. A side benefit is that technology appeals to young employees, who expect to use tablets, cloud-based platforms, and other data-sharing tools. Digital workflow attracts younger project managers and engineers. New hires out of college don't want to review plans on paper. They want to be able to visualize their work with 3-D and ultimately 4-D models, and collaborate with others.

In the future, Ames anticipates greater use of building information modeling (BIM) for bridges, which it frequently uses during the proposal stage but does not yet incorporate into day-to-day operations. "On future projects, the sequence drawings from the BIM model can be incorporated into a 4-D schedule, which would be a very useful tool for managing project schedules," says Volz.

"To win the Third Avenue Bridge concrete arch project over the Mississippi River in Minneapolis, we looked to BIM modeling with help from our construction engineer, Finley Engineering," Volz recalls. "For this CM/GC project, we collaborated with the engineer of record to depict a stage-by-stage approach to the removal and reconstruction of the concrete deck, spandrel columns, and caps of this historic bridge. That tool helped us win the contract and became invaluable throughout the design phase, as it demonstrated each piece of concrete that was removed in a sequence that kept the bridge arches within the design stress tolerances," he explains.

Looking Forward

"While earthwork and underground infrastructure projects are out of sight, bridges are on display for all to see," says Volz. "We take special pride in providing a visual and aesthetically pleasing final product on all of our bridge projects. In our experience, concrete provides a longer-lasting, more durable, and more sustainable bridge product, and it is typically more economical."

"While earthwork and underground infrastructure projects are out of sight, bridges are on display for all to see."

Ames continues to look for opportunities to expand geographically and develop new markets. The firm is actively investigating multiple sectors and segments for viable projects.

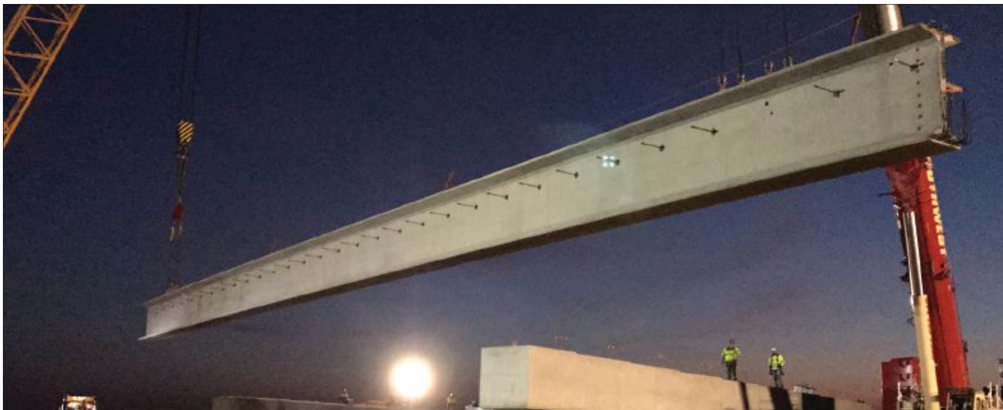
History and Growth

From one man with a used bulldozer in 1962 to a major heavy/highway firm, Ames Construction provides heavy civil and industrial construction services to the transportation, mining, and power industries, mainly in the Midwest and West. To fuel geographical expansion, Ames family members started satellite operations in Colorado, Arizona, and Utah in addition to the original Minnesota location. "As we moved into a new state, we started with earthwork projects and everything was grown organically," says Gabrielson. "Over the years, each region has grown considerably, until we now have reached $1.2 billion in annual revenue."

With a reputation as one of the top earth-moving general contractors in the country, the Ames company took pride in moving dirt. "The family made the decision to diversify into bridge construction to avoid waiting for others to create infrastructure to support hauling their dirt," recalls Volz. "When they hired me in 2002 to grow their bridge portfolio, we started with 'cookie-cutter' bridges and avoided river crossings. However, in 2006, we built our first bridge across the Mississippi River in Sterns County, Minn." Since then, Ames has grown into one of the country's top bridge-building contractors with many segmental, precast concrete girder, post-tensioned box-girder, and concrete extradosed bridges in their portfolio.

The company thrives by building strong relationships and is driven by a commitment to not only do things right but to do the right thing. Ames takes pride in maintaining the highest safety and quality standards, knowing that the family name is associated with every project it delivers.

The South Mountain Freeway Bridge over the Salt River features the longest precast concrete bridge girders (175 ft) ever used in Arizona.



PERSPECTIVE

Making the Case for Resilient Design—Part 2

by Evan Reis, U.S. Resiliency Council

In a recent *ASPIRE*® article, "Making the Case for Resilient Design," I argued that true sustainability cannot be measured only by our impact on the environment; we must also consider the impact the environment has on us.[1] In other words, what we think of as "green" design is only half of sustainability—the other half is resilience (**Table 1**). Resilience is an indicator of how a system responds to shock. Systems can include communities, companies, families, individuals, and physical assets. Shocks can be chronic, such as ongoing and long-term weather conditions, or acute, such as natural and human-made disasters. The resilience of our physical infrastructure is measured in terms of the infrastructure's durability and capacity to remain functional or to recover quickly regardless of the type and severity of shock.

Case Study: Seismic Resilience

I worked for several years at a San Francisco–based engineering firm whose expertise is the design of seismic-, blast-, and fire-resistant buildings and infrastructure. During my time there, the replacement eastern span of the San Francisco–Oakland Bay Bridge was completed alongside the existing span, which was more than 75 years old. I drove over the new span many times as the old steel truss structure was disassembled girder by girder. During those drives, I would think back to when, as a young engineer in San Francisco, I watched the TV coverage of the damage to the original bridge caused by the 1989 Loma Prieta earthquake, which killed one person.

That seismic event spurred a decades-long effort to design a replacement bridge that would be built for resilience. Using sophisticated simulation analysis methods, engineers designed the bridge and its approach spans, which were constructed from segmental concrete box girders, to meet the severe ground motions that would be expected in an event comparable to the Loma Prieta earthquake or the even more powerful 1906 San Francisco earthquake. The bridge typically sees traffic of about 260,000 vehicles daily. Consequently, the resilience of the entire Bay Area and the region's capacity to recover after a major disaster are both highly dependent on the ability of this bridge (and others) to remain safe and usable. As the California Department of Transportation's Brian Maroney explained to a reporter in 2013, "The [new] Bay Bridge is built for those motions we expect to occur once every 1,500 years."[2]

Table 1. Objectives of Resilient and Green Designs

Resilient Design	Green Design
Preserve lives	Use renewable materials
Produce longer-lasting structures	Use fewer natural resources
Build stronger communities	Lower energy use
Faster economic recovery	Produce less waste
Incur less damage in disaster, therefore producing less debris	

Source: U.S. Resiliency Council

Social and Economic Benefits of Resilient Design

In a 2010 Department of Homeland Security report on the aging U.S. infrastructure, one contributor wrote, "Resiliency is the foundation of preparedness.... A resilient society can face the challenges of the upcoming decades."[3] Unfortunately, the transportation infrastructure (our nation's roads and bridges) is often taken for granted. We only have to look to the Interstate 35 West bridge collapse in Minneapolis, Minn., in 2007, or collapses caused by flooding or landslides such as in Cedar Rapids, Iowa, and Big Sur, Calif., to see that, while often ignored, the performance of bridges is an essential link in the chain that allows a community to function during and following natural or accidental disasters.

Whereas a building might house 1000 people, a bridge might serve 1000 buildings. The centrality of our bridge infrastructure to the functioning of our communities before and after a disaster means the resilience of these assets is a social and economic imperative that goes far beyond the potential costs of maintaining or replacing bridges if they are damaged in such a disaster.

The concrete industry's efforts to make the case for concrete bridges by using the prevailing mindset that sustainability is about "green" design is not new. For example, in a 2009 presentation for the Construction Research Congress, Raymond Paul Giroux stated, "By almost any measure concrete is a 'green' bridge material." He went on to cite some of the advantages of concrete as a sustainable bridge material, such as the lower energy cost of production per unit mass of concrete compared with steel (2.5 GJ/t and 30 GJ/t, respectively), low solar reflectance, and recyclability of concrete and reinforcing steel.[4]

One of the U.S. Resiliency Council's most important missions is to encourage owners, builders, and governments to extrapolate the value of resilient design beyond the confines of first costs, long-term maintenance, and green design. The value of resilient design is realized only when we fully quantify the benefits it has for society as a whole. An important consideration for the concrete industry is to develop ways to quantify the social and economic benefits of concrete structures in terms that decision makers can use to justify the selection of a structural system. In a Perspective article in the Spring 2019 issue of *ASPIRE*, Jeremy Gregory of the Massachusetts Institute of Technology made a strong case for the industry's ability to measure the resilience of bridges and encouraged readers to rethink how we describe sustainability. According to Gregory, "Many aspects of a structure, including its future economic impact and the environmental consequences of construction, repairs, or replacement, affect its sustainability. Our research finds that quantitative assessment of these factors can lead to alternatives that improve a structure's sustainability."[5]

Making the Economic Case for Resilient Design

To calculate resilient design's return on investment (ROI), bridge designers and builders can use available analytical and engineering tools. The straightforward equations, starting with that used to calculate risk, are:

$$Risk = Probability \times Vulnerability \times Consequence$$

It is important to decision makers that risk be an objective and quantified metric that allows for direct comparison of strategies, investments, and outcomes. Probability is the likelihood over the life of a bridge that a natural or human-made hazard event will occur. Vulnerability is the resulting damage and loss of function that the bridge will incur when subjected to that hazard. Consequence is the cost to repair that damage as well as the lost social and economic output caused by the loss of the bridge for a time.

The ROI is the savings in risk achieved through resilient design divided by the additional cost, if any, to achieve that resilience:

$$ROI = \frac{Risk_{Standard\ Design} - Risk_{Resilient\ Design}}{Cost_{Resilient\ Design} - Cost_{Standard\ Design}}$$

The ROI of resilient design is a metric that all government entities should use to evaluate new bridge projects. Often, however, they don't operate in these terms; instead, they focus on what is the lowest bid that meets the minimum project requirements. Moving beyond this short-term assessment standard is imperative for the long-term health of our communities.

The U.S. Resiliency Council encourages the bridge and transportation industries to invest in research that quantifies the performance of bridge structures in natural hazards. This is the first necessary step to making the case that using resilient materials such as concrete more than pays for itself in the short and long term by reducing the social and economic impacts of disasters on the communities served by these structures.

Conclusion

The COVID-19 pandemic is clearly the largest and most difficult challenge to face our country in many decades. We must take advantage of the opportunity it has afforded us to think more deeply about the inevitability of natural and human-made hazards and the need to invest in resilience and preparedness. It is a matter of when, not if. Because our transportation infrastructure is expected to last at least 50 to 100 years, society today must not have a short-term outlook on the challenges we will face tomorrow.

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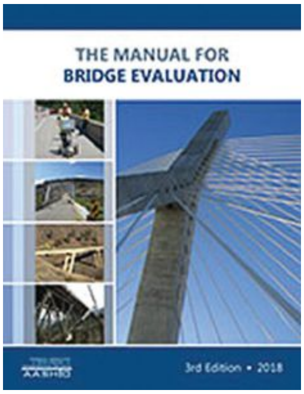
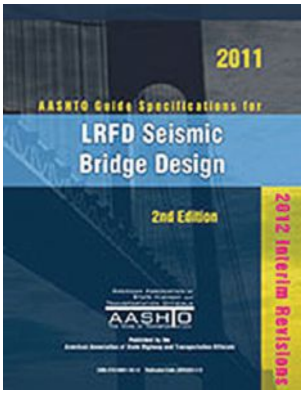
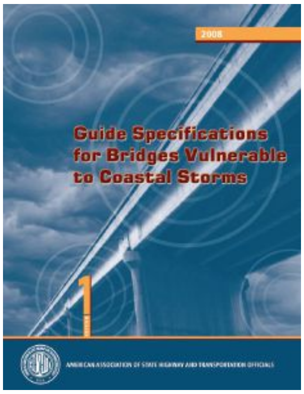






EDITOR'S NOTE

Our community of bridge professionals has systematically responded to extreme events for decades with deemed-to-satisfy and probability-based specifications that fill knowledge gaps in the technical arena. Evan Reis has now presented a holistic approach that moves beyond the last decade's sustainability concepts. The new concept of infrastructure resiliency is emerging as a holistic view that also considers risks and community impacts. Bridge professionals need to understand this much broader framework and then become engaged with leadership to help frame the ongoing conversation.

Evolution of the Buy America Requirements for Highway Bridge Projects

by Dr. Timothy R. Wyatt, Esquire, Conner Gwyn Schenck PLLC

Federally assisted highway construction projects are subject to the Buy America statute codified at 23 U.S.C. §313. In conjunction with associated regulations issued by the Federal Highway Administration (FHWA) at 23 C.F.R. §635.410, this Buy America provision requires practically all steel or iron products used on such projects to be manufactured in the United States.

The FHWA Buy America provision originally enacted by Congress in November 1978 permitted only domestic materials and domestic manufactured products to be used on FHWA-funded projects. However, the provision only applied to projects whose total cost exceeded $500,000. Also, waivers were available for public interest, nonavailability, and price differential exceptions. (Price differential waivers could be requested when using foreign material would result in cost savings of at least 10%.) Eleven days after the legislation was enacted, FHWA issued "emergency regulations," which included a public interest waiver for *all* materials and products *except* structural steel, significantly limiting the scope of FHWA Buy America requirements.

The price differential exception was examined in *Wampler v. Goldschmidt,* a 1980 federal case involving the Richard I. Bong Memorial Bridge (replacement for the Arrowhead Bridge) between Minnesota and Wisconsin, which had been segmented into 14 prime contracts. In *Wampler*, the U.S. District Court for Minnesota upheld a waiver allowing foreign steel on the main span because it resulted in a more than 10% cost savings for that contract, although the cost savings was much less than 10% of the entire $60 million project. The court concluded that the only reasonable application of the price differential exception was to a single contract, not the overall project; otherwise, foreign steel could never be used on an FHWA-funded bridge project.

In January 1983, Congress enacted legislation significantly revising the FHWA Buy America provision, requiring *all* steel, cement, and manufactured products used on FHWA-funded contracts to be domestic. The 1983 legislation retained waivers for public interest, nonavailability, and price differential. However, to obtain a price differential waiver, foreign material must result in cost savings of at least 25%, a significant increase from the earlier 10% threshold, making a waiver much less likely.

As in 1978, 11 days after enactment of the 1983 legislation, FHWA again issued emergency regulations, granting a public interest waiver for *all* manufactured products other than steel and cement. In November 1983, FHWA permanently adopted this manufactured products waiver, which specifically exempted asphalt from FHWA Buy America requirements. Congress exempted cement from FHWA Buy America requirements in 1984.

Congress added iron to the FHWA Buy America provision in 1991. Therefore, with the manufactured products waiver still in place, the FHWA Buy America provision has since 1991 been effectively limited to steel and iron. The regulations adopted by FHWA in 1983 require all manufacturing processes to take place in the United States, which is understood to require steel and iron to originate from a smelting furnace at a domestic steel mill, with all subsequent processes such as rolling, machining, bending, cutting, drilling, or coating taking place in the United States. In 1995, FHWA issued a waiver allowing certain foreign constituent materials (including pig iron, iron ore, or alloys containing insubstantial amounts of steel or iron) to be introduced in the initial melt at the domestic steel mill. However, aside from those express exceptions, steel or iron used on FHWA-funded projects cannot incorporate ferrous material that has undergone any manufacturing process outside the United States, such as scrap steel originally smelted at a foreign steel mill.

The 1983 legislation eliminated the $500,000 project cost threshold, expanding FHWA Buy America requirements to all FHWA-assisted contracts. However, the regulations adopted by FHWA in 1983 include a minimal use exception, permitting a minimal amount of foreign steel or iron, where the cost does not exceed 0.1% of the contract price or $2500, whichever is greater.

Notwithstanding the manufactured products waiver, FHWA has long taken the position that steel or iron components of manufactured products must be domestic. However, in a 2012 memo, FHWA reexamined the manufactured products waiver and concluded retroactively that it exempted all steel and iron components of manufactured products, except in predominantly steel or iron products. The 2012 FHWA memo defined a predominantly steel or iron product to consist of at least 90% steel or iron. The implication was that any manufactured product consisting of less than 90% steel or iron was exempt from FHWA Buy America requirements.

However, in December 2015, in *United Steel v. FHWA*, the U.S. District Court for the District of Columbia invalidated significant portions of the 2012 FHWA memo. The court determined that FHWA improperly waived Buy America requirements for all products with less than 90% steel or iron content by issuing the 2012 FHWA memo without following the required rule-making process. However, the court did not disturb the 2012 FHWA memo's conclusion that the manufactured products waiver permits the use of foreign steel and iron components of manufactured products that are not predominantly steel or iron.

In 2016, as a result of *United Steel*, FHWA proposed a new nationwide waiver for commercially available off-the-shelf (COTS) products with steel or iron components. The proposed COTS waiver would have waived FHWA Buy America requirements for manufactured products broadly used in construction, notwithstanding steel or iron content. At the same time, FHWA proposed a list of specific products *not* covered by the COTS waiver, to which FHWA Buy America requirements would still apply. The list of products excluded from the COTS waiver included structural steel, steel or iron products used in bridges (such as anchor bolts or prestressing strand), and reinforcing steel, including steel fibers for ultra-high-performance concrete (UHPC).

However, the COTS waiver was not adopted, due in part to an April 2017 executive order requiring federal agencies to minimize waivers of Buy America requirements. Accordingly, after *United Steel*, there is no clear rule for determining whether a manufactured product is predominantly steel or iron. This could result in inconsistent treatment, as different FHWA divisions may reach different conclusions regarding whether the manufactured products waiver applies to a given product. FHWA's rule-making efforts to better define the manufactured products waiver, such as the proposed 2016 COTS waiver, have proven controversial and have been effectively abandoned.

This assessment of FHWA efforts to clarify what constitutes acceptable foreign steel or iron content of manufactured products is not to be construed as a criticism. FHWA's regulations, waivers, and guidance over the years (including the 2012 FHWA memo canceled in the wake of *United Steel*) reflect earnest efforts to balance the FHWA Buy America provision with the realities of manufacturing in today's global economy. Congress imposed an impossible requirement on FHWA in 1983 by requiring all steel and manufactured products to be domestic, and Congress exacerbated the problem in 2005 and 2012 by practically eliminating the price differential exception for bridge projects.

Although the *Wampler* decision in 1980 had endorsed FHWA's policy of applying the price differential exception to individual contracts, Congress stated in the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) reauthorization bill that the FHWA Buy America provision requiring domestic steel unless foreign steel would result in cost savings of 25% applies to an entire bridge project—*not* individual contracts. This was in response to a California Department of Transportation (Caltrans) plan to apply the price differential exception to the eastern span contract of the Bay Bridge between Oakland and San Francisco, which would allow use of foreign steel. After SAFETEA-LU, Caltrans elected to defederalize the eastern span contract so FHWA Buy America requirements would not apply. Congress responded in the 2012 Moving Ahead for Progress in the 21st Century Act (MAP21) reauthorization bill by extending FHWA Buy America requirements to all contracts in a project eligible for FHWA assistance if FHWA helped fund *any* contract in the project.

Following MAP21 and *United Steel*, there are limited options for using foreign steel or iron on FHWA-funded projects. To use a predominantly steel or iron product that has had any manufacturing process performed outside of the United States, the minimal use exception must be satisfied or FHWA must issue a project-specific nonavailability waiver. Nonavailability waivers are typically granted within a couple of months after the waiver request is published on FHWA's Buy America Notice of Waiver Request website (https://www.fhwa.dot.gov/construction/contracts/waivers.cfm), provided no domestic sources are identified in the subsequent 15-day public comment period. However, if comments opposing the waiver are received, there may be a months-long delay while FHWA determines whether the commenter has identified a viable domestic source, in which case a nonavailability waiver is not appropriate and will be denied.

For example, prior to 2014, the use of UHPC on FWHA-funded projects was limited because the steel-fiber reinforcement used in the UHPC mixture was not manufactured domestically. UHPC could not be used on a project unless the steel fibers satisfied the minimal use exception or FHWA issued a project-specific nonavailability waiver. In 2014, FHWA identified a domestic supplier that could produce UHPC steel-fiber reinforcement commercially that would be available to all potential purchasers and indicated that nonavailability waivers for UHPC are not appropriate. FHWA has not granted any nonavailability waivers for UHPC since that time, although FHWA divisions may allow foreign-sourced UHPC fibers based on a minimal use exception.

In summary, notwithstanding the actual text of 23 U.S.C. §313, the FHWA Buy America provision has never, in practice, prevented the use of foreign manufactured products that are not predominantly steel or iron. However, the FHWA Buy America provision has proven to be very effective in ensuring that steel and iron construction materials used on FHWA-funded highway construction projects are manufactured in the United States and entirely of domestic content. For specialty products used in bridge construction, the key unanswered question is how to determine whether the product is predominantly steel or iron for purposes of the FHWA Buy America provision.

Dr. Timothy R. Wyatt is a construction lawyer with Conner Gwyn Schenck PLLC in Greensboro, N.C.

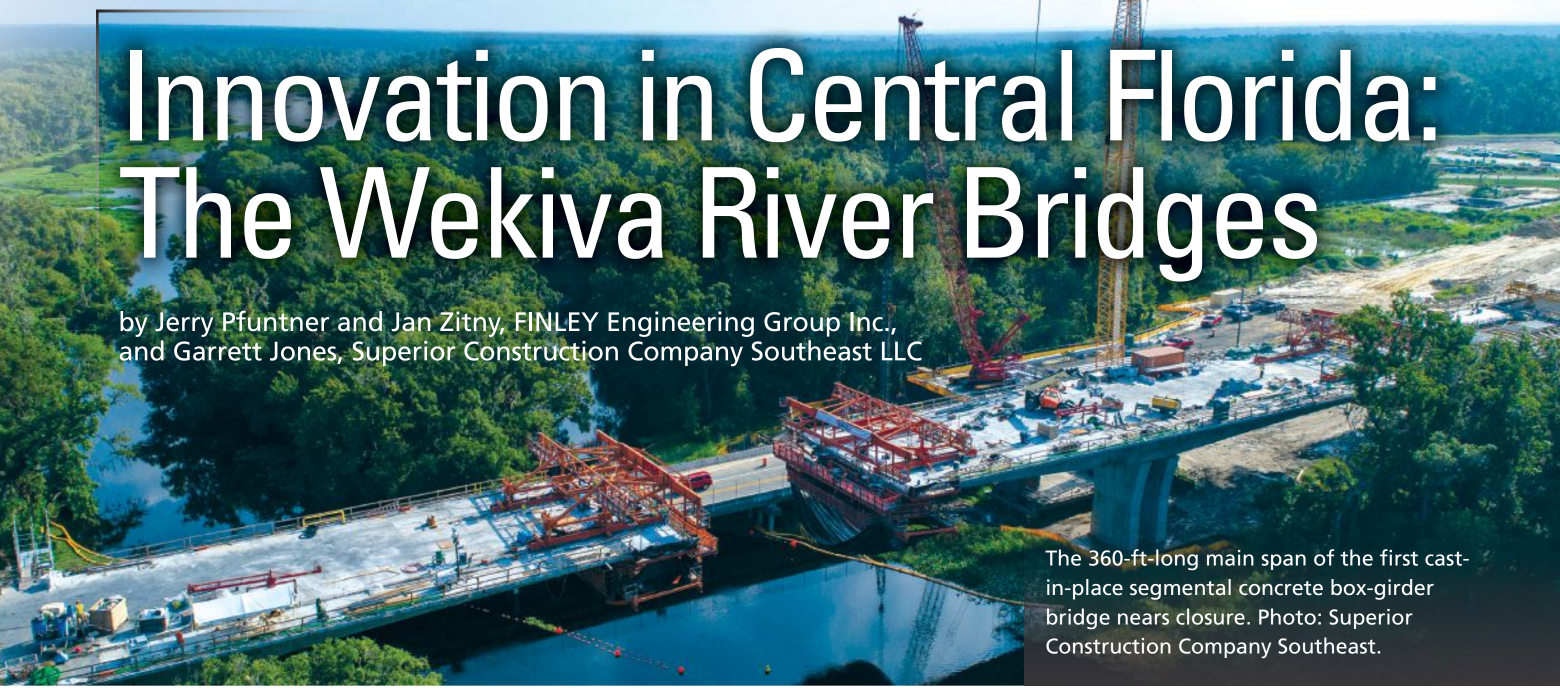
EDITOR'S NOTE

Dr. Timothy R. Wyatt is the author of the National Cooperative Highway Research Program (NCHRP) Legal Research Digest 80, titled **Buy America Requirements for Federal Highway Projects,** *which was published in April 2020. The 52-page report provides a complete discussion of this topic and references to documents mentioned in this article. The report is available at https://doi.org/10.17226/25799.*

PROJECT

Innovation in Central Florida: The Wekiva River Bridges

by Jerry Pfuntner and Jan Zitny, FINLEY Engineering Group Inc., and Garrett Jones, Superior Construction Company Southeast LLC



The 360-ft-long main span of the first cast-in-place segmental concrete box-girder bridge nears closure. Photo: Superior Construction Company Southeast.

In the heart of central Florida forests, the Wekiva River meanders within a fragile and unique setting, attracting many outdoor enthusiasts, many of whom appreciate this region's beauty from the water. The new Wekiva Parkway will span across this river with three new parallel cast-in-place, segmental concrete box-girder bridges with a main span length of 360 ft. The three-span bridges complement the surrounding environment and enhance the beauty of this pristine waterway.

The segmental bridges and the prestressed concrete Florida I-beam approach spans have been designed to minimize their impact on the local environment and wildlife. The height and length of the new structures will allow wildlife to follow their natural movement patterns without having to cross the widened Wekiva Parkway. Meeting transportation needs, promoting wildlife safety, and achieving aesthetic goals were among the challenges set forth by the Florida Department of Transportation (FDOT) for this design-build project.

Design-Build Procurement with a Twist

For this project, FDOT incorporated a new twist into the design-build procurement process. Traditionally, a technical proposal submission is the only document needed to communicate the design-build team's approach to the project. However, in this case, FDOT required teams to submit an initial bridge aesthetics and constructability package, which FDOT had to approve before a team could move forward with the final technical and cost proposal. FDOT placed particular value on the aesthetic and environmental concerns, and this early submission package ensured that the finalist teams would provide acceptable aesthetics, as well as a construction scheme that would maintain the existing site conditions, vegetation, and water access. This initial submittal was also required within three months of short listing, so the design-build teams had to immediately focus on the design and construction of the project's segmental portion.

For the initial submission, the bridge design engineer who ultimately led the project immediately began modeling the structure to develop the bridge design requirements and sizing the foundation and substructure elements. The bridge design firm directly coordinated the design modeling with its prime contractor to develop the construction sequence and temporary works concepts required to present the overall sequencing of the new bridge construction.

The conceptual demolition plan of the existing bridge also had to be included with the initial plans, and the team had to develop and commit to solutions to overcome the project's environmental impact, such as containment of saw cuttings and strategies to reduce turbidity during the removal of existing piles. The submission included an exceptionally detailed environmental impact strategy, including a tree survey

profile

WEKIVA RIVER BRIDGES FOR WEKIVA PARKWAY SECTION 6 / SORRENTO, FLORIDA

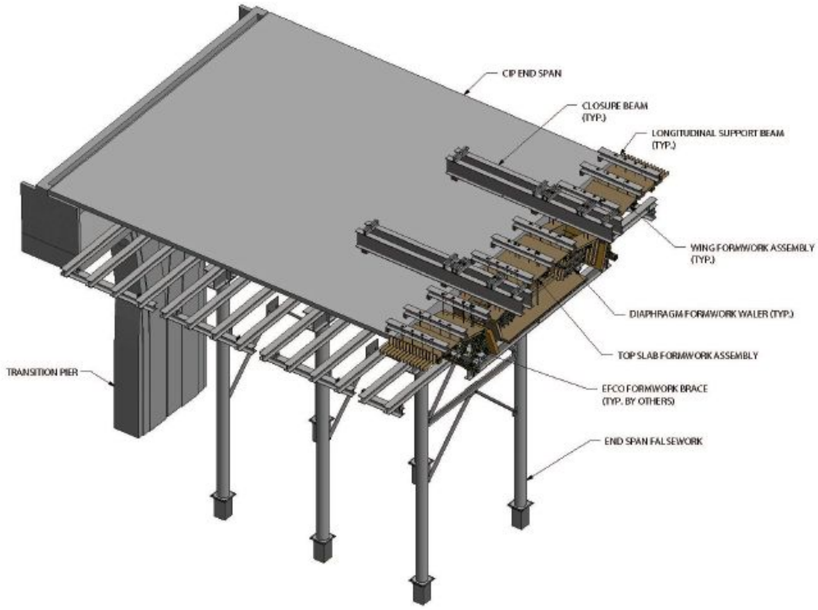
PRIME CONSULTANT: WGI, Orlando, Fla.

SEGMENTAL BRIDGE DESIGNER/CONSTRUCTION ENGINEER: FINLEY Engineering Group Inc., Tallahassee, Fla.

APPROACH SPAN DESIGNER: Arcadis, Jacksonville, Fla.

PRIME CONTRACTOR: Superior Construction Company Southeast LLC, Jacksonville, Fla.

GIRDER PRECASTER: Dura-Stress, Inc. Leesburg, Fla.—a PCI-certified producer



Three-dimensional model showing the end span falsework. Bridge information modeling technology allowed stakeholders to visualize constructability issues and possible conflicts, which could then be solved during the design process. Figure: FINLEY Engineering Group.

and a tree removal drawing to define the exact number of trees that would be removed, trimmed, or left intact.

Preparing this submittal was a uniquely detailed and exhaustive process. It gave the design-build team the opportunity to present a comprehensive plan that offered specific solutions to critical issues well before the technical proposal was written and the final prebid design, drawings, and quantities were produced. The design-build team's process ensured that its final submittal would meet project requirements and be acceptable to FDOT.

Innovations

Each project brings a unique set of challenges, which can bear the fruit of innovation. These new Wekiva Parkway bridges exemplify innovation in the design and construction of concrete segmental bridges, as several unique features have been incorporated into the three-span segmental structures.

Specifically, FDOT has developed a new approach to enhancing the durability of its post-tensioned structures and now requires the use of flexible fillers for continuity post-tensioning (PT) (see the article in the Winter 2017 issue of *ASPIRE*®). With this approach, the tendons may be removed and replaced at any time in the future. Additionally, the continuity tendons must be a combination of internal tendons and draped external tendons. For this project, the internal tendons contained twenty-two 0.6-in.-diameter strands and the external tendons used nineteen 0.6-in.-diameter strands. Combining unbonded PT strand and bonded mild reinforcement increases the complexities of strain compatibility and geometric analyses to determine the correct stresses in the strand at ultimate loading. These analyses go well beyond typical bridge design and analysis software design capabilities.

This project also built on the successful implementation of diabolos that the bridge design engineer had developed for the FDOT District 6 Palmetto Section 5 project, which was the first use of diabolos in Florida. The external PT tendons for the Wekiva River Bridge project all use diabolos for the deviation of the external tendons, allowing standardized deviation segment formwork and diabolo details (see related article in the Fall 2015 issue of *ASPIRE*).

For this project, the designers incorporated an innovative bridge information modeling (BIM) approach, where bridge information databases were introduced into the planning, design, and construction processes using advanced engineering software.

Side view of cantilever construction of the main span with form travelers. Span closure is ready for concrete placement at the form traveler on the right. Photo: Superior Construction Company Southeast.

FLORIDA DEPARTMENT OF TRANSPORTATION AND NATIONAL PARK SERVICE, OWNERS

OTHER MATERIAL SUPPLIERS: Formwork: EFCO, Orlando, Fla.; form travelers: NRS, Oslo, Norway; reinforcement fabricator: CMC Rebar, Kissimmee, Fla.; bearings: RJ Watson Inc., Alden, N.Y.; expansion joints: mageba LLC, New York, N.Y.; post-tensioning: Structural Technologies, Pompano Beach, Fla.

BRIDGE DESCRIPTION: Design-build project including three cast-in-place segmental concrete box-girder bridges built in balanced cantilever with span lengths of 260, 360, and 260 ft. Approach spans were constructed using prestressed concrete Florida I-beams.

STRUCTURAL COMPONENTS: Cast-in-place segmental bridges built in balanced cantilever with form travelers, prestressed concrete I-beams, prestressed concrete piles

BRIDGE CONSTRUCTION COST: Approximately \$60 million (\$160/ft^2)

Aerial view of segmental bridge construction in several stages: The completed first bridge (on the right) is open to traffic; construction on the outer bridge (on the left) is progressing from two main piers; and foundation construction has begun on the center bridge after demolition of previous bridge. Photo: Superior Construction Company Southeast.

The designers used general aspects of BIM for bridges and advanced software to develop the project workflow for integrating analysis models in SOFiSTiK with computer-aided design and drafting production models in Autodesk.

This integration enabled the design team to work more efficiently and reduced the efforts by project engineers as each member was able to work simultaneously on multiple facets of the project, including bridge design, construction analysis, geometry control, the construction manual, and superstructure shop drawings. This increased consistency and reduced the time spent on repeated efforts between analysis models and drawing production; in addition, this smooth workflow significantly increased the overall quality of the final project.

For the Wekiva River Bridges, it was critical that the design and construction engineering activities were nearly concurrent. With BIM, as changes were made in the analysis model, the construction model was also updated. Similar efficiencies were achieved in the integrated three-dimensional (3-D) bridge model that was used for the construction manual, as the falsework towers in the integrated bridge model would update with any changes and follow through in every drawing sheet of the construction manual, significantly reducing errors and drawing production effort. Using the construction models with the bridge visualization simplified the fabrication of the temporary falsework towers, resulting in 3-D isometric views and falsework drawings that were very similar to the physical product.

In general, 3-D BIM allows for greater understanding of constructability issues and possible conflicts, which can be solved with relative ease during the design process, helping to avoid delays at the construction site or in the casting yard. Sometimes, it is a true challenge to clearly show intricate details of the reinforcing bar cage in two-dimensional drawings. Using the BIM method, designers could share the integrated 3-D segmental model with the prime contractor's staff, thereby preventing confusion and preempting questions during construction. (For more details on BIM, see the Concrete Bridge Technology article in the Winter 2019 issue of *ASPIRE*.)

Conclusion

The requirements for the new Wekiva River Bridges dictated that the design-build team go above and beyond the conventional proposal submittal process for a new FDOT project because of the project's location in a fragile and diverse ecosystem. The design-build team focused on innovative and definitive planning to give FDOT the confidence to move forward with the team's proposal, which included design modeling concepts through the use of BIM technology, environmental impact strategies, and well-conceived construction sequences. Implementation of these plans ensured the eventual success of the project.

Jerry Pfuntner is principal and technical director and Jan Zitny is a bridge engineer, both with FINLEY Engineering Group Inc. in Tallahassee, Fla. Garrett Jones is assistant project manager with Superior Construction Company Southeast LLC in Orlando, Fla.

A dual-shaft pier was used to stabilize the pier segment. Photo: Superior Construction Company Southeast.

External post-tensioning tendons passing through diabolos in a deviator segment. Because flexible filler is used, the tendons may be removed and replaced in the future. Photo: Superior Construction Company Southeast.

Executive Overview:

From the busy streets of Manhattan to the Golden Gate Bridge, America's iconic cities and their roads have come to a standstill since the COVID-19 Pandemic struck in March 2020 with its mandated stay-at-home orders. As a result, the US felt a crash similar to the financial crisis of 2007, with an economy and job market quickly crumbling. Taking advantage of the empty railways and streets, state authorities such as New York Governor, Andrew Cuomo to Florida Governor, Ron DeSantis are expediting roadwork and transportation developments to help recover the economy, while avoiding the crowding and traffic that usually increase with these large-scale projects.

"We remain committed to improving our transportation infrastructure through strategic innovation, by significantly relieving traffic congestion, this reconstruction project will provide motorists a more effective way to travel through the region. Additionally, it will add capacity for future growth and improve connectivity for Tampa's residents, businesses and visitors." Governor DeSantis.

As our essential supply chain from manufacturing, logistics, all the way through to O&M, slowly starts to prevail, these foundational businesses are working hard to support contractors who are looking at ways to properly maintain state guidelines and practices of social distancing, while ensuring project deadlines and critical operations stay on track.

With advanced technology evolving to create safer and more efficient jobs for end-users, contractors are beginning to bring in more of these tools to help overcome the labor shortage, rotational shifts, and also minimize job site injury. To help overcome and efficiently adapt to these new challenges, MAX USA, Corp. is working with contractors and developers to sustain core business functions, in the field, by deploying the TwinTier as an enhancement to rebar tying operations. As an alternative to hand tying or inefficient tools, the TwinTier is delivering a multitude of benefits to contractors from cost-savings in materials and time, increased productivity, and overall safer job site operations that align with the COVID-19 guidelines.

Download White Paper

Read whitepaper on Road and Bridge Contractor's Best Practice for Sustaining Business During the COVID-19 Pandemic | http://cloud.maxusaproducts.com/covid-19whitepaper

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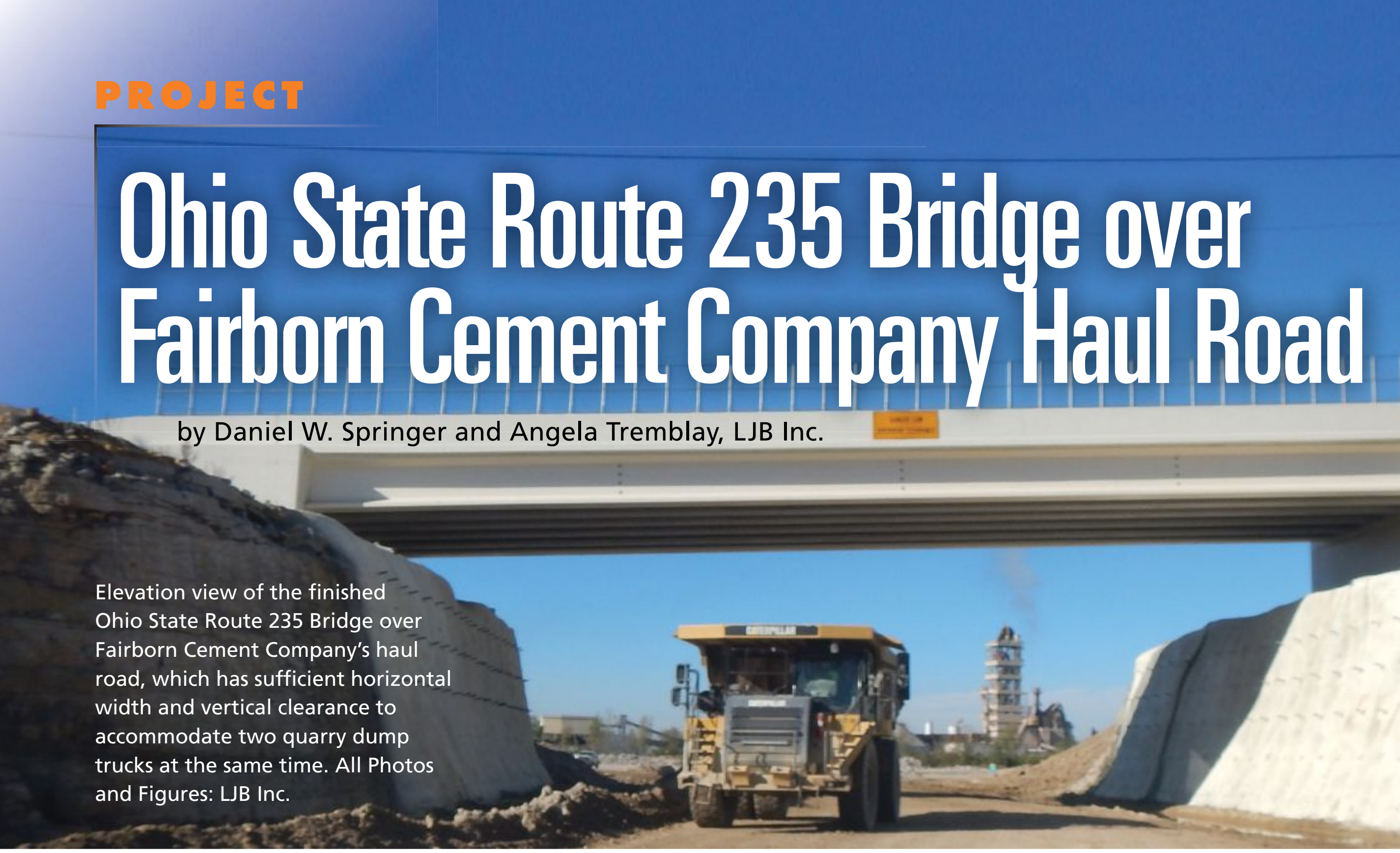
PROJECT

Ohio State Route 235 Bridge over Fairborn Cement Company Haul Road

by Daniel W. Springer and Angela Tremblay, LJB Inc.



Elevation view of the finished Ohio State Route 235 Bridge over Fairborn Cement Company's haul road, which has sufficient horizontal width and vertical clearance to accommodate two quarry dump trucks at the same time. All Photos and Figures: LJB Inc.

In December 2018, a new Ohio State Route 235 (SR 235) bridge opened about 10 miles north of Xenia, a small city in Greene County, Ohio. The bridge allows a new haul road beneath SR 235 to connect Fairborn Cement Company's existing quarry on the west side of SR 235 to a new quarry east of SR 235. With this underpass, Fairborn Cement Company can extend its mining operations for at least the next 30 years. The project also keeps the vehicular traffic associated with mining activities and large rock-hauling trucks off public roadways, minimizing impacts on the surrounding community and improving safety along SR 235.

Unique Project Delivery

Very few privately funded projects have been completed on state routes in Ohio. This project required unique project management and presented design and construction challenges for the entire project team, including coordination of a large, diverse design team, a bridge maintenance agreement between the Ohio Department of Transportation (ODOT) and Fairborn Cement Company, ODOT-permitted closure of SR 235, and meeting Mine Safety and Health Administration (MSHA) requirements.

Because this was a privately funded project, there was a lot of flexibility in the procurement process of contractor selection. Therefore, the project was delivered using the designer-led design-build approach, where the lead bridge designer held the contract for both design and construction work. The first phase of the project included all preliminary coordination and engineering necessary to decide where the bridge would be constructed, and determination of the most cost-efficient structure type. This phase involved field survey, geotechnical investigations, environmental review, preliminary roadway and traffic design, and a structure-type study.

In the second phase, the bridge designer completed the engineering and design plans, which were approved by ODOT and then issued to five contractors for competitive bidding. Because the project was privately funded, the bidding process included contractor interviews as well as estimates of construction costs. After contractor selection, the project team proceeded with final coordination, design adjustments, and project management services during construction.

Fairborn Cement Company established a maintenance agreement with ODOT specifying that Fairborn Cement will maintain the bridge as long as the company exists. ODOT will provide the

profile

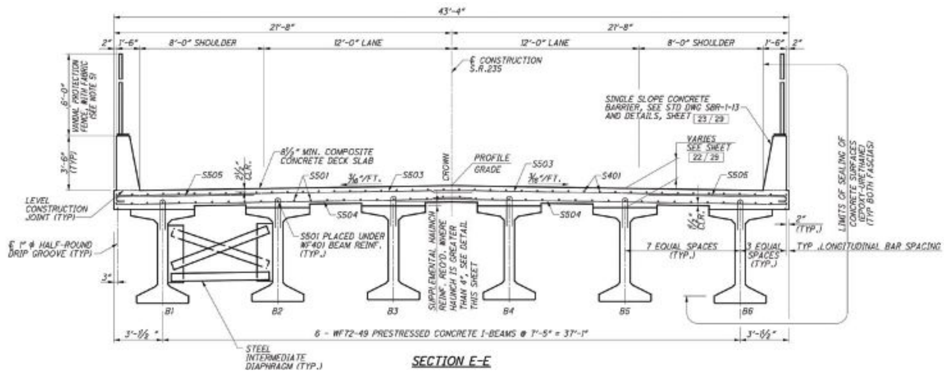
STATE ROUTE 235 OVER FAIRBORN CEMENT COMPANY HAUL ROAD / XENIA, OHIO

BRIDGE DESIGN ENGINEER: LJB Inc., Miamisburg, Ohio

OTHER CONSULTANT: Rock Stabilization Design Engineer: Resource International Inc., Columbus, Ohio

PRIME CONTRACTOR: Eagle Bridge Company, Sidney, Ohio

PRECASTER: Prestressed Services Industries LLC, Decatur, Ind.—a PCI-certified producer



Typical section of the bridge with ODOT-standard WF72-49 prestressed concrete I-beams spaced at 7 ft 5 in. with a composite 8.5-in.-thick cast-in-place, reinforced concrete bridge deck for the 145-ft-long span bridge.

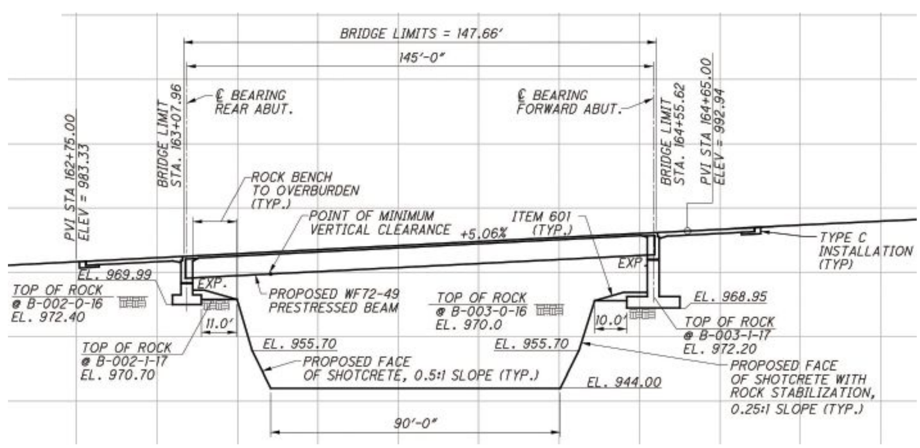
annual bridge inspection services as required by ODOT for all bridges in the state, issue reports to Fairborn Cement Company, and offer maintenance and repair recommendations. Any necessary bridge repairs will be coordinated between the two parties.

Selecting Bridge Location and Structure Type

Determining where to construct a bridge on SR 235 to create a new quarry haul road was a critical aspect of the project. SR 235 is approximately 50 ft above the quarry floor, and when the preliminary design began, the western floor excavation ended about 200 ft west of SR 235. The initial field survey and geotechnical exploration were important in finding a bridge location that would not only provide a convenient alignment for the haul route but also minimize the height of the bridge abutments above the underlying bedrock.

After several options were presented to Fairborn Cement Company, a structure-type study was completed and coordinated with ODOT to determine the final location and bridge type for the project. The structure-type study included initial construction and life-cycle costs and determined that a 145-ft-long single-span bridge with wide-flange precast, prestressed concrete I-beams was the most cost-efficient structure to meet the requirements of the 90-ft-wide haul road with a minimum 35-ft vertical clearance. The haul road width allows two large CAT-775F dump trucks to safely pass beneath the bridge at the same time, and the vertical clearance allows the trucks to safely pass beneath the bridge with their beds fully extended upward. A shorter (60 ft) span that would allow only one truck to pass beneath the bridge at a time was considered, but an economic analysis determined that the greater initial cost of a longer bridge would be offset by increased efficiency in the mining operations over the next 30 years. Because Fairborn Cement Company had the expertise and equipment required for rock excavation, it performed much of the blasting and excavation work to cut the haul road, which reduced its total cost for bridge construction.

The 72-in.-deep beams were produced with semi-lightweight concrete (125 lb/ft³) to reduce the shipping weight. The beams were placed using one crane on the quarry floor and one crane above on State Route 235.



Bridge profile showing the significant height difference between the two abutments, which is due to the relatively level bedrock elevations and the 5.06% grade of State Route 235. The semi-integral abutments on spread footings were set back from the rock face to allow access for bridge inspections.

OHIO DEPARTMENT OF TRANSPORTATION, OWNER
(CONSTRUCTION PRIVATELY FUNDED BY FAIRBORN CEMENT COMPANY)

BRIDGE DESCRIPTION: Single-span, 145-ft-long, wide-flange prestressed concrete I-beam bridge with composite reinforced concrete deck on semi-integral, reinforced concrete wall-type abutments supported by spread footings on underlying bedrock stabilized with post-tensioned rock bolts and nontensioned rock anchors supporting a reinforced shotcrete wall

STRUCTURAL COMPONENTS: Six ODOT WF72-49 prestressed concrete I-beams, 8.5-in.-thick cast-in-place concrete deck with epoxy-coated reinforcement, cast-in-place concrete spread footings, wall-type abutments, and reinforced shotcrete walls

BRIDGE CONSTRUCTION COST: $2.9 million

AWARD: 2020 American Council of Engineering Companies of Ohio Honor Award

Substantial wall-type abutments were constructed with cast-in-place concrete and epoxy-coated reinforcing bars to support the 145-ft-long single-span superstructure. The spread footings are founded on underlying bedrock.

The 40-ft bridge roadway width was coordinated with ODOT to ensure that it adhered to ODOT's design guidelines and specifications for a rural principal arterial route with average daily traffic of 4720 vehicles and a design speed of 60 mph. The bridge is on a tangent alignment and was strategically designed with no skew to simplify the design and construction. The 5.06% straight profile grade was designed to match the existing grade along SR 235 to limit the bridge approach roadway work and minimize overall construction costs for the project.

Superstructure Design

The bridge was designed for the American Association of State Highway and Transportation Officials (AASHTO) HL-93 live loading and a future wearing surface of 60 lb/ft^2, as required by ODOT. Six ODOT-standard 72-in.-deep WF72-49 prestressed concrete I-beams spaced at 7 ft 5 in. were used for the 145-ft-long span. The beams were designed with a draped strand pattern using 0.6-in.-diameter 270-ksi low-relaxation prestressing strands, a minimum concrete compressive strength of 6 ksi at transfer, and a final design strength of 7 ksi. Local precasters were consulted early in the design process to verify that routes were available to ship the large beams to the site. Semi-lightweight concrete (125 lb/ft^3) was recommended, and ultimately specified, to reduce the shipping weight of the beams by more than 16%. ODOT does not have a standard practice for using semi-lightweight concrete for prestressed concrete beams, but the material has been approved for previous value-engineering proposals. Material specifications and testing requirements were coordinated with ODOT and based on similar local projects.

The bridge cross section incorporated a composite 8.5-in.-thick cast-in-place, reinforced concrete (4.5-ksi) bridge deck with Grade 60 epoxy-coated reinforcement, which is the standard for bridge decks in Ohio. ODOT standard single-slope concrete barriers were used on each side of the 40-ft bridge roadway width, creating an overall bridge width of 43 ft 4 in. A 6-ft-tall vandal-protection fence was installed on top of the barriers.

Bridge Abutments and Rock Stabilization

The bridge structure-type study concluded that using spread footings founded on and keyed into the underlying bedrock for the cast-in-place, reinforced concrete wall-type abutments was more cost effective than using drilled shafts socketed into bedrock. The rear and forward abutments are 15 ft and 24 ft tall, respectively—the significant height difference is due to the relatively level bedrock elevation and the 5.06% grade of SR 235. The team used semi-integral construction at the abutments where the ends of the I-beams are supported by elastomeric bearings and the beams are encased in a 3-ft-6-in.-wide reinforced concrete end diaphragm that is rigidly connected to the bridge approach slab. The semi-integral end diaphragms connected to the approach slabs allow the bridge superstructure to expand and contract with respect to the abutments while eliminating joints at the ends of the span, thereby increasing the durability of the structure. The abutment footings were strategically placed a minimum of 10 ft horizontally from the top of the slope, which was more than the offset required for the bearing capacity, to enable annual ODOT abutment inspections to be completed more safely.

The poor quality of the underlying bedrock meant rock stabilization was required to support the spread footings. Rock stabilization was also essential to improve safety for the construction personnel working near the top of the rock slope. The top 5 ft of bedrock was laminated and required post-tensioned rock bolts, anchors, and wire netting to stabilize the laminated rock. Beneath this layer, nontensioned rock anchors were used in the competent bedrock as a conservative, long-term stability measure. After the rock was stabilized, geocomposite drainage curtains, reinforcing steel, and welded-wire reinforcement were placed on the rock face and covered with an 8-in.-thick layer of shotcrete. For added protection, an epoxy-urethane concrete sealer was applied to the entire shotcrete face.

Conclusion

From the outset, this project's critical success factors included providing a cost-efficient bridge solution, maintaining Fairborn Cement Company's budget, adhering to ODOT design specifications, ensuring safety during construction, meeting MSHA's safety guidelines for the quarry, and completing the project by the end of 2018. The design team met all objectives.

Concrete bridge construction provided a low-maintenance, durable, and long-term solution for the quarry haul road beneath SR 235—it not only allows Fairborn Cement Company to expand its mining operations but also improves safety for the community and residents in Greene County, Ohio, for many years to come.

Daniel Springer is a principal, project manager, and senior bridge engineer and Angela Tremblay is a senior bridge engineer with LJB Inc. in Miamisburg, Ohio.

Post-tensioned rock bolts, anchors, and wire netting were used to stabilize the upper layers of laminated rock. The remainder of the wall was connected to the rock using nontensioned anchors. An 8-in.-thick shotcrete facing with reinforcement was then placed on the rock face and sealed with an epoxy-urethane sealer for added corrosion protection.

Approach Spans Steal the Show

Three cast-in-place approach structures take the spotlight by creating new public spaces

by Frederick Gottemoeller, Bridgescape LLC, Nelson Canjura, HDR Inc., Jeff Cavallin, Parsons, and Clint Krajnik, RS&H

Bridges where the vertical clearance below allows plenty of room for a standard precast concrete girder are usually pretty straightforward to design. The same is true for bridges of constant width that are straight or have gradual curvature: conventional girder layouts will do. Designers, fabricators, and contractors can apply familiar materials and techniques, and the structure will be stiff enough to control deflections.

However, if the profile of the bridge approaches the existing grade too closely, or if the bridge varies in width, or if it must accommodate a severe skew or curvature, a branching ramp, or critical drainage conditions, then conventional girder layouts become a challenge. Or, if there is a need to use the space under the bridge for civic purposes, which in turn requires an improved appearance of the underside, the dark, uninviting recesses and pigeon perches created by typical girder systems are not appropriate.

Where these circumstances occur, cast-in-place (CIP) concrete slab spans can address them all. This article describes three such bridges.

Belleair Beach Causeway Bridge Replacement, Largo, Fla.

The Belleair Beach Causeway Bridge was completed in 2009 to provide a 3350-ft-long high-level replacement for an aging bascule bridge crossing Belleair Bay and the Intracoastal Waterway. The 324-ft main span, with its spliced, haunched bulb-tee girders, is one innovative feature of this bridge. But this article concentrates on another feature: the two 660-ft-long CIP post-tensioned concrete slab structures that are the east and west approaches for the bridge. (For details of the entire bridge, see the Summer 2010 issue of *ASPIRE*®.)

The approaches to the previous bascule bridge were across narrow causeways. On the east approach, Pinellas County had developed the north side of the causeway into a busy public boat ramp and the south side into "Dog Beach," a popular area for exercising pets. Both were so popular that the county was looking for ways to expand them. That meant providing more space for parking and maneuvering boat trailers on the east causeway (**Fig. 1**). To provide still more space for activities, the county also wanted to enlarge an existing small park on the west causeway to create areas for exercising pets and for launching canoes and kayaks.

To get above the Intracoastal Waterway, the new bridge's profile had to start rising well to the east and west of the existing parks. Supporting the approaches on embankments would have wiped out both facilities, as well as any possibility of expansion. Placing the approaches on structures was the obvious solution. However, with people under the approaches at all times, the underside surfaces of the bridges needed to be smooth, light colored, and without dark recesses, so that daylight would be reflected under the bridge and the area below the bridge would be easy to light at night.

How a Concrete Slab Addressed the Conditions

Selection of concrete slab structures for both approaches met the project goals (**Fig. 2**). The span lengths of the post-tensioned slab structures were

Figure 1. View of the Belleair Beach Causeway Bridge with the east approach structure in the foreground, showing Dog Beach and the new boat ramps. Photo: HDR Inc.

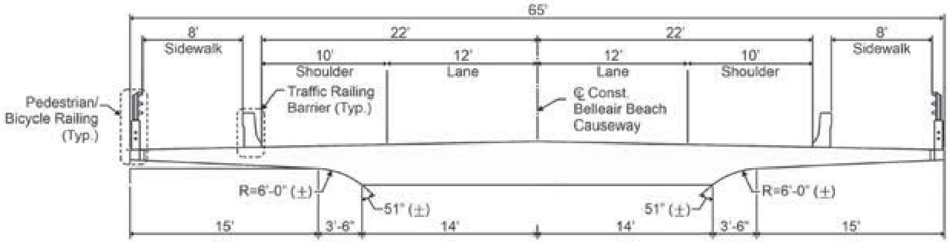


Figure 2. Typical cross section of post-tensioned concrete slab for the east and west approaches to the Belleair Beach Causeway Bridge. Figure: HDR Inc.

coordinated with the parking layout below the bridges to accommodate boat trailers. The 660-ft-long post-tensioned slab structures were divided into nine spans (eight spans at 75 ft and one end span at 60 ft at the abutments).

Integrating two different structural systems into one bridge requires some coordination so that the final result doesn't look like two different bridges mashed together. To that end, the same pier shape was used throughout the bridge: two closely spaced columns with an arched connection between them. On the approaches, the two columns support the concrete slabs; on the high-level spans, the two columns support a pier cap with cantilevered ends. At the two piers where the approaches join the high-level unit, the cantilevered pier cap ends support overlooks, which visually punctuate the junctions while obscuring the structural differences.

Construction and Design Challenges

The CIP concrete slab structures for the east and west approaches were originally designed to be constructed on falsework. This technique would have required a wide construction area, creating a large environmental impact on the seagrass beds to the northeast of the bridge and interfering with the maintenance of traffic on the causeways. Also, it was questionable whether the poor soils of the causeways could support the falsework. To resolve these issues, the contractor decided to use incremental launching for the entire 660 ft of concrete superstructure on each approach (**Fig. 3**). The casting beds were supported on piles behind each abutment, which eliminated settlement issues. The launching system used strand cables to pull the slabs forward. The technique improved quality control, because all segments were cast at the same location, and accelerated construction, which averaged one 37.5-ft-long segment per week. Most important, the contractor pointed out, "Of course, incremental launching saves time and money, but safety is the biggest benefit. Our workers were always on the ground, instead of 50 feet in the air."

Results

The Belleair Beach Causeway proved that incremental launching of concrete slabs can be a cost-effective method of accelerated bridge construction. Considered to be the largest single project awarded in Pinellas County Public Works Department's history, and managed by Pinellas County Public Works staff, the entire causeway was completed with just a 5.8% increase in construction time and a 0.06% increase in construction cost. The contractor estimated that the various savings resulting from adopting the incremental launching method of construction reduced costs by $250,000. It was a truly successful project for both the county and the general public. The Belleair Causeway Bridge became the fourth bridge constructed with the incremental launching method in the United States and the first one using this method for post-tensioned concrete slabs.

In the years since the 2009 completion of the bridge, the eastside boat ramp and Dog Beach have become busier than ever, and the westside pet park and launching ramps have become equally popular.

U.S. Route 61 over the Mississippi River and Second Street, Hastings, Minn.

Hastings is a historic river port. The south approaches to the U.S. Route 61 (U.S. 61) bridge cross over the city's Second Street shopping district, with its 19th-century buildings, with minimal vertical clearance. The street also hosts antique car rallies and other events during the summer. U.S. 61 joins Hastings's street system just one block south of Second Street, leaving no possibility of raising the roadway to create additional clearance. The steel girders of the previous bridge had rendered the space below the bridge dark and uninviting, which discouraged the extension of shopping and community activities west of U.S. 61.

How a Concrete Slab Addressed the Conditions

Selection of a CIP concrete slab for the south approach maximized the vertical clearance under the structure. The slab structure also allowed the span length over Second Street to be increased so the piers could be located behind the

Figure 3. Schematic showing the incremental launching sequence for the Belleair Beach Causeway Bridge post-tensioned concrete slab approach spans. Figure: HDR Inc.

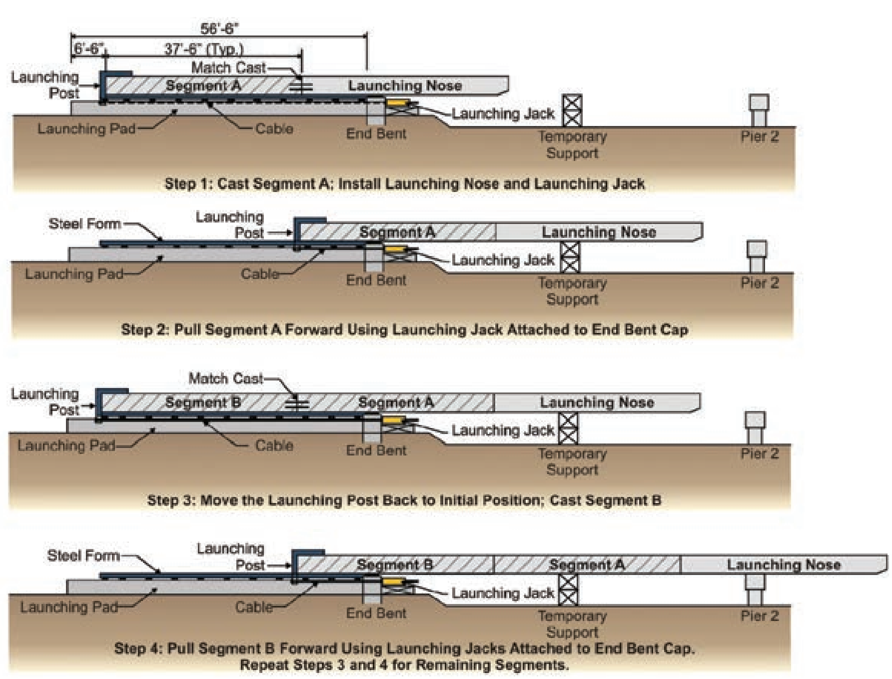


Figure 4. Parking area located under the south approach spans looking from Second Street toward the U.S. Route 61 bridge over the Mississippi River. Covers were later installed over the conduits mounted on the bridge. Photo: Dale Thomas.

line along the face of the buildings on each side of the street, so that the approach piers do not impinge on the width of the street and sidewalks. The slab span was also increased from the south building line on Second Street to the south abutment, enlarging the space under the bridge and making it more useful for civic activities. Finally, the spans from Second Street (**Fig. 4**) north to the river were optimized for parking under the bridge, better serving retail visitors to Second Street.

The smooth bottom soffit of the concrete slab replaces the utilitarian appearance of the typical multibeam and deck structure while eliminating the pigeon perches created by the girder flanges and exposed bracing of its predecessor. Instead, the slab provides a smooth and light-colored undersurface that reflects daylight into the space under the bridge, and which is uplighted at night to provide indirect lighting that illuminates activities under the bridge.

The south approach is 550 ft long with span lengths varying from 65 to 138 ft. **Figure 5** shows the typical cross section for this approach for northbound traffic, which is carried on a 52-ft-wide slab that includes a 12-ft-wide shared-use path. Southbound traffic is carried on a 39-ft-wide slab. Each slab has a typical thickness of 5 ft, which tapers to 3 ft 6 in. over Second Street to meet vertical clearance requirements. The transition between slab depths is accomplished by an aesthetically pleasing arched taper in the soffit. At its north end, the slab rests on the south pier of the main span that crosses the Mississippi River.

Construction and Design Challenges

The slab superstructure is post-tensioned in both the longitudinal and transverse directions to meet the owner's design requirement of 50-psi residual compressive concrete stress under service loads at the top of the structural slab. Post-tensioning was accomplished with longitudinal tendons, each containing thirty-one 0.6-in.-diameter strands, that run the full length of the slab structure. Transverse post-tensioning consists of tendons containing four 0.6-in.-diameter strands that are regularly spaced along each span, with additional transverse post-tensioning concentrated at the abutment and pier locations. Time-dependent post-tensioned concrete analysis models were used for design, and a finite element model was used to evaluate the effects of shear lag at the support locations at each column and for the transverse design of the slabs.

The CIP slabs were constructed on traditional falsework. Concrete was placed full depth in longitudinal segments with volumes of up to 1200 yd^3. Full-width shear keys were provided at each vertical construction joint. Special attention was given to the vertical reinforcing bars so they could serve multiple functions—post-tensioning duct support, robust "standee" support for the top layer of reinforcement that was more than 4 ft above the bottom layer, post-tensioning anchorage-zone reinforcement at end supports, and transverse reinforcement in pier regions (**Fig. 6**).

Results

Expansion of the under-bridge area created space for a plaza with benches and a natural stone mural on the south abutment wall (**Fig. 7**). This work depicts the history of Hastings in variously colored natural stones. Unusual for efforts of this type, the mural was the result of a collaboration between the design-build contractor,

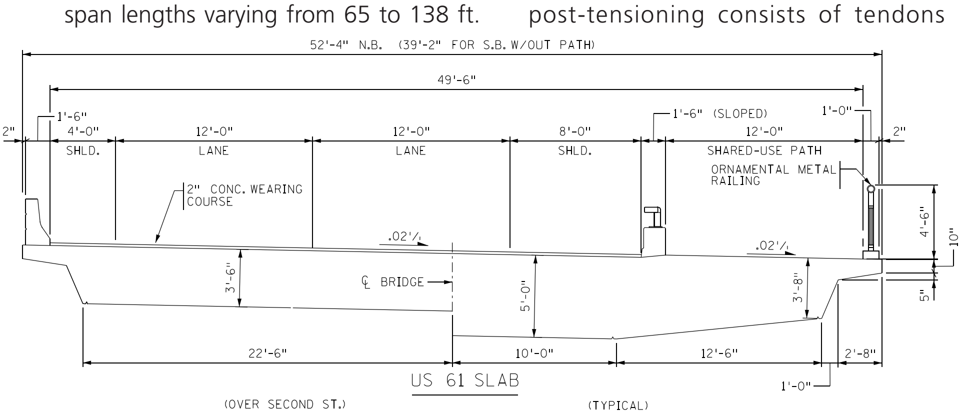


Figure 5. Typical cross section of the U.S. Route 61 south approach bridge carrying northbound traffic on the typical 5 ft depth (right) and the reduced depth over Second Street (left). Figure: Jeffrey Cavallin.

Figure 6. Longitudinal post-tensioning ducts in the bottom of the slab, transverse post-tensioning ducts in the top of the slab, and other mild reinforcement for the south approach slab of the U.S. Route 61 bridge. Note the use of both stainless steel and epoxy-coated reinforcement in the slab. Photo: Jeffrey Cavallin.

Figure 7. Civic plaza and mural at the south abutment of the U.S. Route 61 bridge. Lights illuminate the bottom soffit of the slab, which makes the whole plaza area bright and welcoming at night. A transition line is visible in the overhang, which is the taper for the reduced slab depth as the bridge crosses Second Street. Photo: Frederick Gottemoeller.

an artist retained by the contractor, and the Citizens Advisory Committee. The U.S. 61 Hastings bridge replacement project was very well received by both the community and the Minnesota Department of Transportation. At its dedication in the fall of 2013, Hastings mayor Paul Hicks said, "Our new bridge is a landmark that we look to with a sense of pride." Among the first of the project's many awards was the 2014 Midwest Best Project of the Year in the Highways/Bridges category of *Engineering News-Record*.

Grand Avenue Bridge, Glenwood Springs, Colo.

The Grand Avenue Bridge connects Interstate 70 (I-70) and U.S. Route 6 (U.S. 6) to downtown Glenwood Springs and points south. From north to south, the structure spans the parking lots for Glenwood Springs' hot springs, I-70, the Colorado River, the Colorado mainline of the Union Pacific railroad, and finally Seventh Street, where it enters downtown. South of Seventh Street, the alignment is centered on the Grand Avenue street right-of-way (ROW), with barely 15 ft of horizontal clearance to the historic retail buildings on either side, and the bridge spans a plaza used informally for seating and community events.

As it crosses Seventh Street, Grand Avenue is about 20 ft above the street level. From there it slopes down to join the street system at Eighth Street. An alley crosses the alignment halfway between Seventh and Eighth Streets. The city wanted to establish the alley as a pedestrian connection through downtown, which required moving the south abutment of the bridge about 50 ft farther south to allow direct passage under the bridge (**Fig. 8**). At that point, the vertical distance between the bridge roadway and the Grand Avenue sidewalks is just 11 ft. A typical girder structure would require a depth of 5 ft, leaving just 6 ft of headroom at the abutment.

How a Concrete Slab Addressed the Conditions

The Grand Avenue Bridge was designed and constructed as two units. Unit 1 of the bridge crosses the hot springs' parking lots, I-70, the river, and the railroad tracks. This article focuses on the three-span (60, 77, and 60 ft) unit 2, which extends from the south ROW line of the railroad to the south abutment, where the vertical clearance is most limited. Selecting a CIP concrete slab with a depth of only 3 ft for unit 2 increased the headroom at the abutment from 6 ft to 8 ft. To create still more headroom at the sidewalks, the edges of the slab are tapered to 9 in., increasing the minimum headroom there to 10 ft (**Fig. 9**). Under the bridge, the pavement of the plaza was lowered 2 ft by adding a row of steps parallel to each edge of the bridge, so the minimum headroom throughout the plaza is 10 ft. The tapered edge of the slab also makes it difficult to judge the full depth of the slab, so the bridge appears thinner than it really is. The underside of the slab includes 9-in.-deep recesses (coffers) in a rectangular pattern. They reduce the slab's weight and create an attractive "ceiling" pattern for the space under the bridge.

Units 1 and 2 join at the pier on the railroad's south ROW line, where the box girders from unit 1 are supported by three separate octagonal columns and the slab is supported on the dapped ends of the girders. To create visual continuity between units, all columns are octagonal, and all are faced with the same red/pink sandstone that is found on many of the town's historic buildings.

Construction and Design Challenges

Because of public concern about the closure of Grand Avenue, the construction of unit 2 had to be completed within a 95-day window. With that in mind, the Colorado Department of Transportation (CDOT) brought the contractor onto the team at the beginning of design, using the construction manager/general contractor (CM/GC) method of project delivery. As a result, the design team could weigh each feature of unit 2 against schedule and budget (see the article in the Summer 2020 issue of *ASPIRE*).

The tapered overhangs, coffers, and integral columns produced a departure from typical slab behavior. The two longitudinal ribs between the columns are the primary load-carrying elements. The use of simple scaffolding-style falsework, combined with prefabricated

Figure 8. Cast-in-place concrete slab structure of the Grand Avenue Bridge at Seventh Street as it descends toward the south abutment. Photo: Davis Deaton.

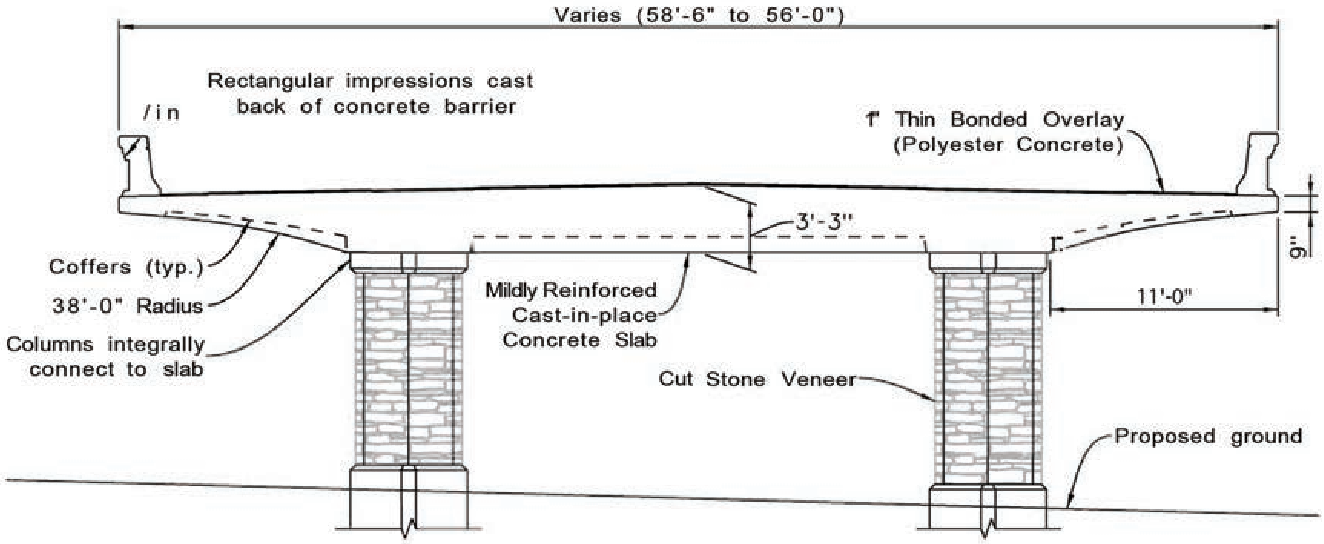


Figure 9. Typical cross section of unit 2 of the Grand Avenue Bridge. Figure: RS&H.

forms for the coffers and overhangs, accelerated construction. Rather than illuminating each coffer, widely spaced downlights simplified the conduit layout within the CIP slab (**Fig. 10**). Opting for a slab with mild reinforcement (no post-tensioning) also accelerated construction. The slab was cast in one continuous 15-hour placement of about 940 yd^3. Unit 2 was finished 10 days ahead of schedule.

Results

The plaza underneath the Grand Avenue Bridge had always been noisy. However, 3 ft of solid concrete deadens a lot of sound. At the dedication ceremony in 2018, Colorado Governor John Hickenlooper made his remarks standing in the plaza under the bridge, with 18 wheelers traveling 10 ft above his head. Listeners could hear every word.

The finished bridge is a civic success story. The plaza underneath is playing a key role in helping adjacent restaurants struggling with reduced seating capacity in the wake of COVID-19 shutdowns. "The city is now allowing restaurants to use the plaza space for additional outdoor seating, which for some restaurants may completely offset the loss in indoor capacity," noted Roland Wagner, who served as the project manager for CDOT. "The bridge created this public space, and it's been rewarding to see its positive impact in a time of need."

Conclusion

All three of these concrete slab approach structures met very tight vertical clearance requirements while at the same time creating outstanding public spaces below the structures. The owners, designers, and contractors of all three projects were willing to innovate and apply locally unfamiliar but proven techniques. While none of these examples confronted extreme skew, width variations, or other geometric complications, several of the coauthors have designed bridges using CIP concrete to efficiently address such requirements.

Where there is a tight schedule, or traffic must be maintained below the bridge, using CIP concrete might seem counterintuitive. But the incremental launching used at Belleair Beach proceeded quickly enough that the contractor termed it an example of accelerated bridge construction. The entire Grand Avenue slab was completed 10 days ahead of the allowed 95-day construction window. At the U.S. 61 and Grand Avenue structures, the contractors were able to use economical scaffolding-style falsework, and, at U.S. 61, to still maintain traffic on Second Avenue. At Belleair Beach, the limited footprint required for incremental launching allowed traffic on the causeways to be maintained throughout construction. An additional advantage of CIP concrete is that it does not require the use of large cranes. That can be a decisive criterion where space is limited.

Whenever an unusual method of bridge construction is proposed, questions are always raised about whether there will be a "premium" cost compared to a more conventional structure. When considering bridges like the three described in this article, that question is, to some degree, irrelevant. No conventional structure could meet the requirements that these three bridge approaches had to meet. With that in mind, none of the designers attempted cost comparisons of alternative structural systems.

Even when looking at the construction contracts, it is difficult to determine what the approach structures themselves cost. To start with, all three are relatively small components of much larger projects. Also, the U.S. 61 structure was a design-build project and Grand Avenue was a CM/GC project, so separate cost figures were not available

Figure 10. Restaurant seating in the public area below the Grand Avenue Bridge. Photo: Davis Deaton.

from the contractors. However, none of the contractors raised objections to the CIP concrete or complained that it imposed unbearable cost burdens. Indeed, the Belleair Beach contractor even cites his project as an example of cost-effective accelerated bridge construction! So, it does not make sense to assume that CIP concrete will impose an unnecessary or unreasonable cost premium on a project.

These three examples prove that CIP concrete slabs deserve consideration for bridges with tight vertical clearance restrictions or geometrical complications, or where the owner needs to provide for public uses in the areas below the structure, or even where there is a need to dampen noise intrusion below the bridge.

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CONCRETE BRIDGE TECHNOLOGY

Strut-and-Tie Modeling for Bridge Design

by Daniel J. Baxter, Emily Thomson, and Dr. Francesco M. Russo, Michael Baker International

This article, which follows up on a Spring 2020 *ASPIRE*® article on the use of strut-and-tie modeling (STM) for existing pier assessments, provides further thoughts on the use of STM for bridge design. Beginning with interim revisions to the seventh edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* and continuing to the current ninth edition,[1] there has been a heightened need to understand and apply STM principles to the design of concrete structures. Article 5.1 of the AASHTO LRFD specifications states,

> The provisions of this Section characterize regions of concrete structures by their behavior as B- (beam or Bernoulli) Regions or D- (disturbed or discontinuity) Regions, as defined in Article 5.2. The characterization of regions into B-Regions and D-Regions is discussed in Article 5.5.1.

Whereas Article 5.2 provides a definition, Article 5.5.1.2.1 provides a clear picture of what constitutes a D-region:

> D-Regions shall be taken to encompass locations with abrupt changes in geometry or concentrated forces. Based upon St. Venant's principle, D-Regions may be assumed to span one member depth on either side of the discontinuity in geometry or force.

The simply supported beam shown in **Fig. 1** illustrates this concept. On either side of each concentrated load or geometric discontinuity, a D-region exists. Considering a typical pier cap or footing, which is loaded primarily by point loads and includes cap-to-column and footing-to-column joints, nearly the entire pier cap and footing, including connections to the columns, will be classified as a D-region. This is illustrated for a typical pier in **Fig. 2**.

For this pier, extending out a distance equal to the depth of the pier cap *D* from each beam line results in the entire cap being defined as a D-region. Similarly, extending from the cap downward and from the footing upward by a distance *W*, the regions at each end of the columns are also defined as D-regions. For the footing, every line of piles is like a beam reaction and the entire footing becomes a D-region as well.

The characterization of this pier as containing primarily D-regions represents a change in approach for most engineers. The design process for bridge piers has nearly always involved a frame analysis considering vertical and lateral loads, the creation of shear and moment envelopes for various load combinations, and the design of elements using conventional methods. Because STM procedures require the creation of a truss or truss-like model, and each load case might require a unique truss, adoption of the new AASHTO requirements has been slow and inconsistent. In several recent projects, our team has employed STM approaches for the design of single- and multicolumn piers, and some of our approaches are highlighted in this article.

For the single-column pier shown in **Fig. 3**, design of the cap is the focus. The cap design is driven by the selection of the angle between the top tension tie and the compression strut. Selection of the column nodal locations is somewhat arbitrary, but it is always prudent to use a model with a direct and logical flow of forces. Simple trigonometry provides the force in the top tension tie and the compression strut as a multiple of the exterior beam reaction. The intent of this model is to determine the magnitude of the tie force and thus the quantity of tension steel needed for the design. The transverse steel must simply meet the minimum reinforcement requirements of AASHTO LRFD Article 5.8.2.6, Crack Control Reinforcement. Sketches showing the relationship between the transverse stirrups and longitudinal cap side-face reinforcement to the distribution reinforcement required by AASHTO are shown as an inset in Fig. 3, which has been adapted from the AASHTO LRFD specifications.[1] A preliminary estimate of the cap depth can be obtained by solving AASHTO LRFD specifications Eq. (C5.8.2.2-1) for the cap depth *d*.

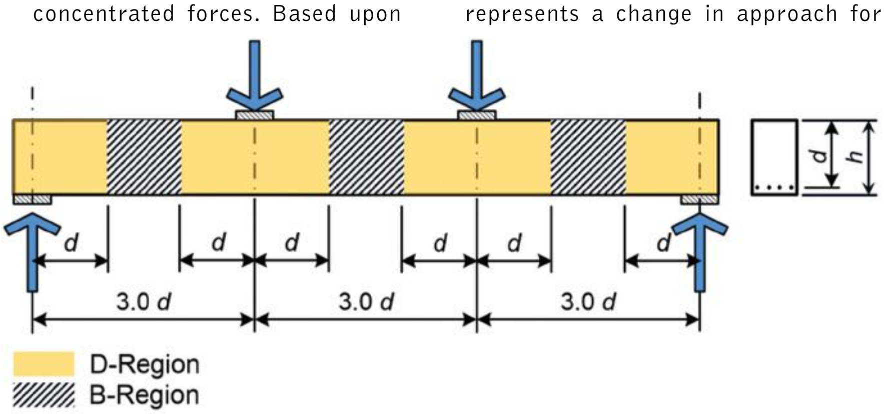

Figure 1. Definition of D-regions for a simply supported beam. Figure: Michael Baker International.

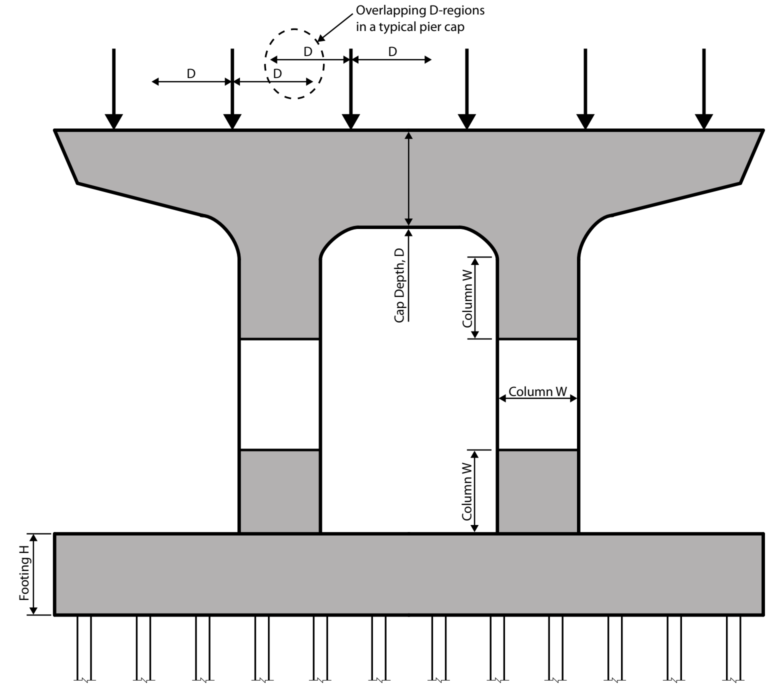

Figure 2. Definition of D-regions (shaded areas) for a pier cap in a typical framed pier. Figure: Michael Baker International.

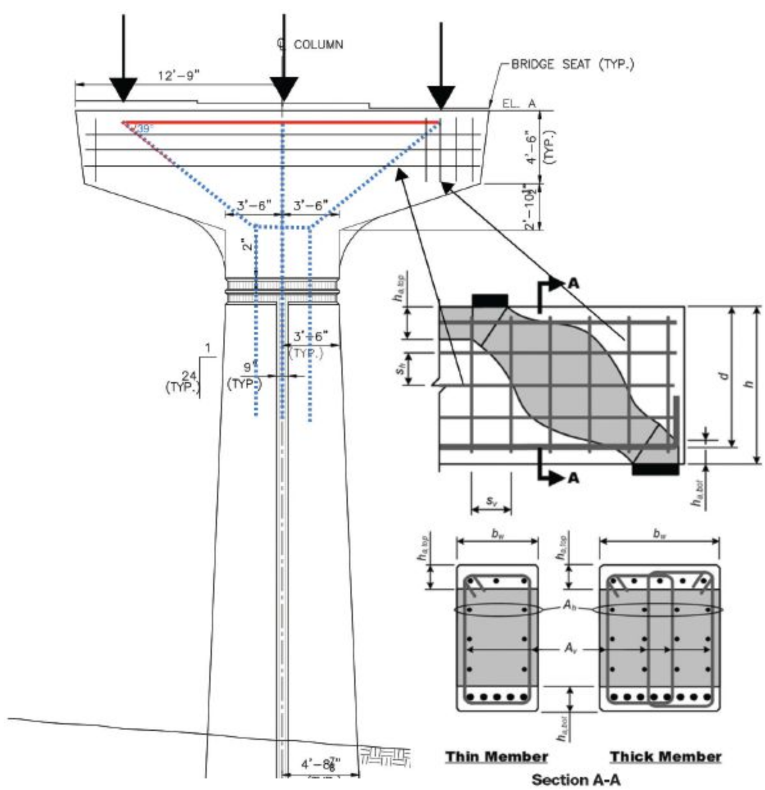

Figure 3. Strut-and-tie model for a hammerhead pier cap with inset illustrating the generalized concept of the strut and reinforcement details. Figure: Michael Baker International.

In the case of unbalanced beam reactions, which is common for pier caps, a variation of this model would also include a moment connection between the column and cap. Although this nuance would have no bearing on the top tie forces, it is a complication worth exploring. Transferring moment between the cap and column, or between the column and footing, can be a challenge. For additional guidance on this subject, the reader is referred to a complete design example (specifically, design example 3) in the manual for an STM course offered by the National Highway Institute.[2] In that example, a frame is analyzed for a critical load combination using traditional two-dimensional frame analysis tools. At *d* below the cap (that is, the transition between the B- and D-regions), a free body section is cut and an STM model of the cap and a portion of the columns is developed and solved (**Fig. 4**). The column axial load and bending moment at *d* below the cap have been resolved into tension and compression forces, and the shear in the column is shown as a horizontal reaction. The complete STM solution can be used for what would have typically been the shear and moment design of the cap, design of the top of the column, and any special considerations for joint design.

In efforts to automate the analysis of pier caps using the STM method, various approaches have been explored to couple the traditional frame model used for global pier analysis and the STM needed for the design of the cap as well as the cap-to-column joints.

Figure 5 presents an example of an STM model for a three-column pier cap. An approach has been developed and refined in which various load cases can be applied in a model where the web diagonals are assigned compression-only capability, shown in the top part of Fig. 5. As various loads are placed on the cap, the analysis software adjusts the model in an iterative way to only allow compression in the diagonals.

There are some sensitivities to this approach. Providing six points of vertical support to the cap, two at each column-to-cap connection, and analyzing the model that way with a general purpose finite element analysis program makes the cap indeterminate, and thus the member sizes become important. This approach also does not reflect the flexibility associated with the connected columns. Because the members in an STM model are truly notional (that is, not physical), they are only intended to provide a force path, and it is difficult to assign a rational member size. Instead, a more rational approach is an STM model with only two supports in a "cap-only" model and statically equivalent nodal loads applied to complete the force transfer to the columns, shown in the bottom part of Fig. 5. Attempts to link the STM model to the frame model using rigid links and constraints have only been partially successful, again owing to the indeterminate nature of the truss portion of the model.

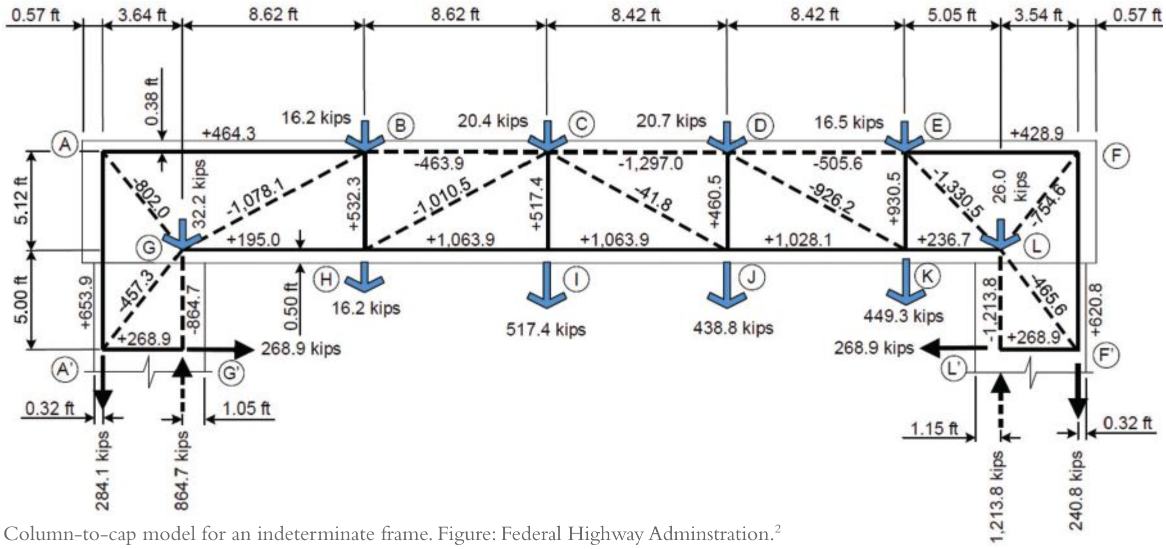

Figure 4. Column-to-cap model for an indeterminate frame. Figure: Federal Highway Adminstration.[2]

Conclusion

For preliminary engineering of all piers, and for final design of a single-column pier, the STM approach is a quick and accurate tool for pier cap design. Though the selection of node locations is somewhat arbitrary, simply sketching a model will quickly identify a logical flow of forces. Once the preliminary geometry has been established, the governing forces are quickly determined and the sizing of pier caps for service and strength limit states is easily achieved.

For more complex piers, fully automated solutions that couple STM and frame analysis have not yet been found. However, the process can be semiautomated to include a conventional frame analysis to determine the STM boundary forces and a separate model for the force flow in the cap itself. The challenges of STM deployment are met with practical solutions. Given the time involved in building and checking such models, it is strongly recommended that engineers not focus on the thousands of load cases that come from commercial software packages; instead, engineers should step back and again think about the design and what is critical. They will find that no more than a handful of loads and load combinations govern the design. This limited number of critical load cases is easily managed with the approaches highlighted in this article.

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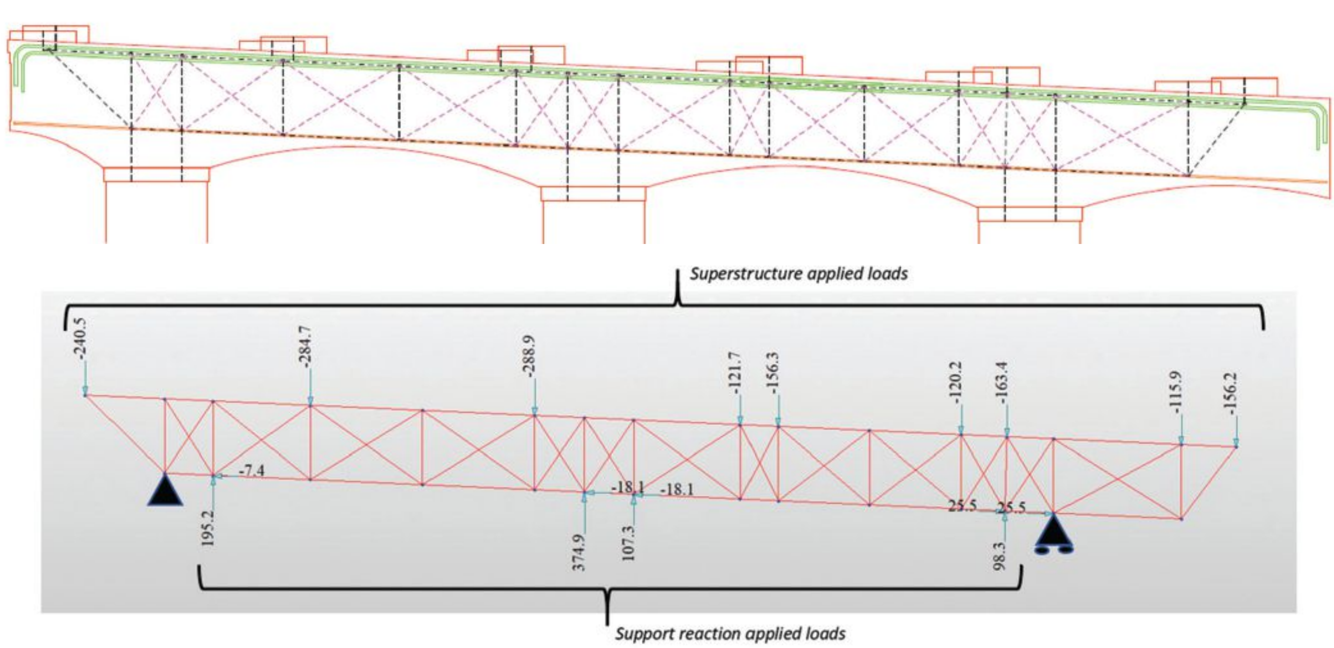


Figure 5. Strut-and-tie models for a multicolumn pier cap. Top: Indeterminate model in a general purpose finite element analysis program. Bottom: The same pier cap model with equivalent nodal loads applied at the columns results in a statically determinate model. Figure: Michael Baker International.

Strength of Structures with Struts Crossing Cold Joints—Beginning the Discussion

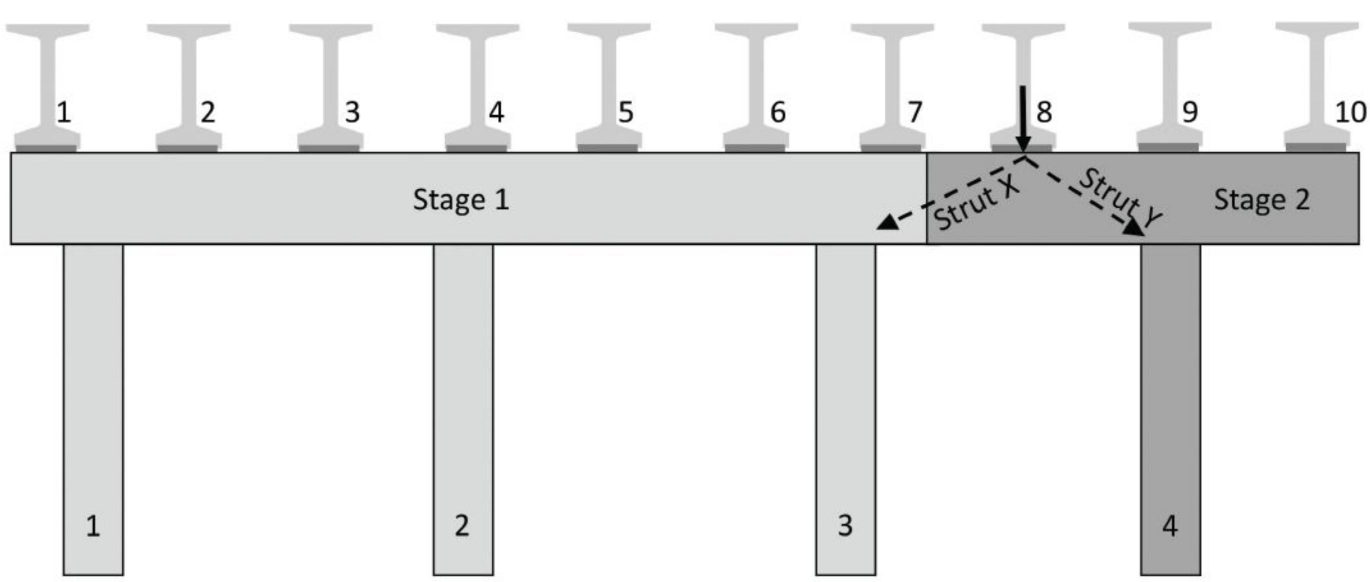
by Dr. Oguzhan Bayrak, University of Texas at Austin

This article addresses some of the challenges that arise in calculating the capacities of reinforced concrete structural components constructed in multiple phases and, hence, possessing cold joints. Staged construction, roadway expansion projects, and retrofitting old substructure components for increased load demands necessitate constructing new structural elements connected to the older components. To better define this concept, let us focus on the two examples shown in **Fig. 1** and **2**.

Figure 1 shows the staged construction of a multicolumn bent. The entire bent cap shown in this figure can be classified as a D-region, or a region of discontinuity, because loads introduced by each beam line and those from the supporting columns create disturbed regions. Such regions of discontinuity are to be designed in compliance with the strut-and-tie modeling (STM) provisions in Article 5.8 of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] Figure 1 shows seven beam lines supported on three columns that are constructed as part of the first phase. The need to expand the roadway supported on this multicolumn bent necessitates adding three beam lines and an additional column, which is supported on a separate foundation (foundations are not shown in Fig. 1 for simplicity). Each beam line introduces concentrated loads at the location of the bearing pads shown supporting the bottom flanges of the beams. Focusing on beam line 8, it can be observed that the load introduced into the bent cap by this beam line must flow into columns 3 and 4 through struts X and Y.

Analysis of strut Y, per the AASHTO LRFD specifications, is straightforward because struts are checked at the strut-to-node interface. Strut X, on the other hand, crosses a cold joint on its path to column 3. Shear friction of this strut must be checked in accordance with the commentary of Article 5.8.2.2 in the AASHTO LRFD specifications: "Where a strut passes through a cold joint in the member, the joint should be investigated to determine that it has sufficient shear-friction capacity." The actual geometry of the strut at the interface can be conservatively assumed to be equal to the width of the strut at the location where it frames into a nodal region. More specifically, averaging the width of both ends of strut X and assuming that compression does not spread through the depth of the cap would provide a conservative, well-justified solution. Research is ongoing to determine more

Figure 1. Multicolumn bent constructed in two phases shows a strut crossing a cold joint. All Figures: Dr. Oguzhan Bayrak.



refined and appropriately conservative approaches for analysis of a strut crossing a cold joint. The geometry, in conjunction with the intensity of the axial load in the strut, will drive the necessity to provide a shear key or roughened surface at the cold joint. This necessity is determined by analyzing the demand on and the capacity of the cold joint for transferring the load.

A similar, albeit more complex, scenario is presented in Fig. 2. This figure depicts the retrofit of a bridge foundation to accommodate additional loads. The original footing is supported on four drilled shafts (DS 1 through 4 in Fig. 2). Increased column loads, which are anticipated to be transferred through the footing, necessitate the installation of 10 additional drilled shafts and the expansion of the original footing (retrofit shown in dark gray in Fig. 2). Similar to the example discussed in Fig. 1, struts will form between the column and the new drilled shafts as compression fields form in the footing. Each one of these new struts will cross a cold joint, and therefore shear friction capacities of those struts must be checked. Once again, it is possible to determine the geometry of the struts crossing the cold joint, determine the capacity and demand, and make decisions on roughening the surfaces of the original footing or providing shear keys to enable the force transfer across the cold joint.

For the examples presented in Fig. 1 and 2, the interface shear resistance must be checked using the provisions of AASHTO LRFD specifications Articles 5.7.4.3 and 5.7.4.4.

Current design provisions in the AASHTO LRFD specifications do not directly address this issue. In an effort to emphasize the importance of this capacity calculation, AASHTO Technical Committee T-10 Concrete Design is currently considering clarifying or modifying the mandatory language in the AASHTO LRFD specifications and providing additional commentary. Once those deliberations are finalized and a formal vote is taken, our team at *ASPIRE*® will provide a detailed explanation of any upcoming changes developed and adopted by the AASHTO Committee on Bridges and Structures.

In conclusion, recognizing the issue, current related activities, and the number of questions being raised on this topic, the intent of this article is to draw the attention of our readers to this technical issue, the applicable provisions of the AASHTO LRFD specifications, and the ongoing consideration of additional design provisions to address it.

Reference

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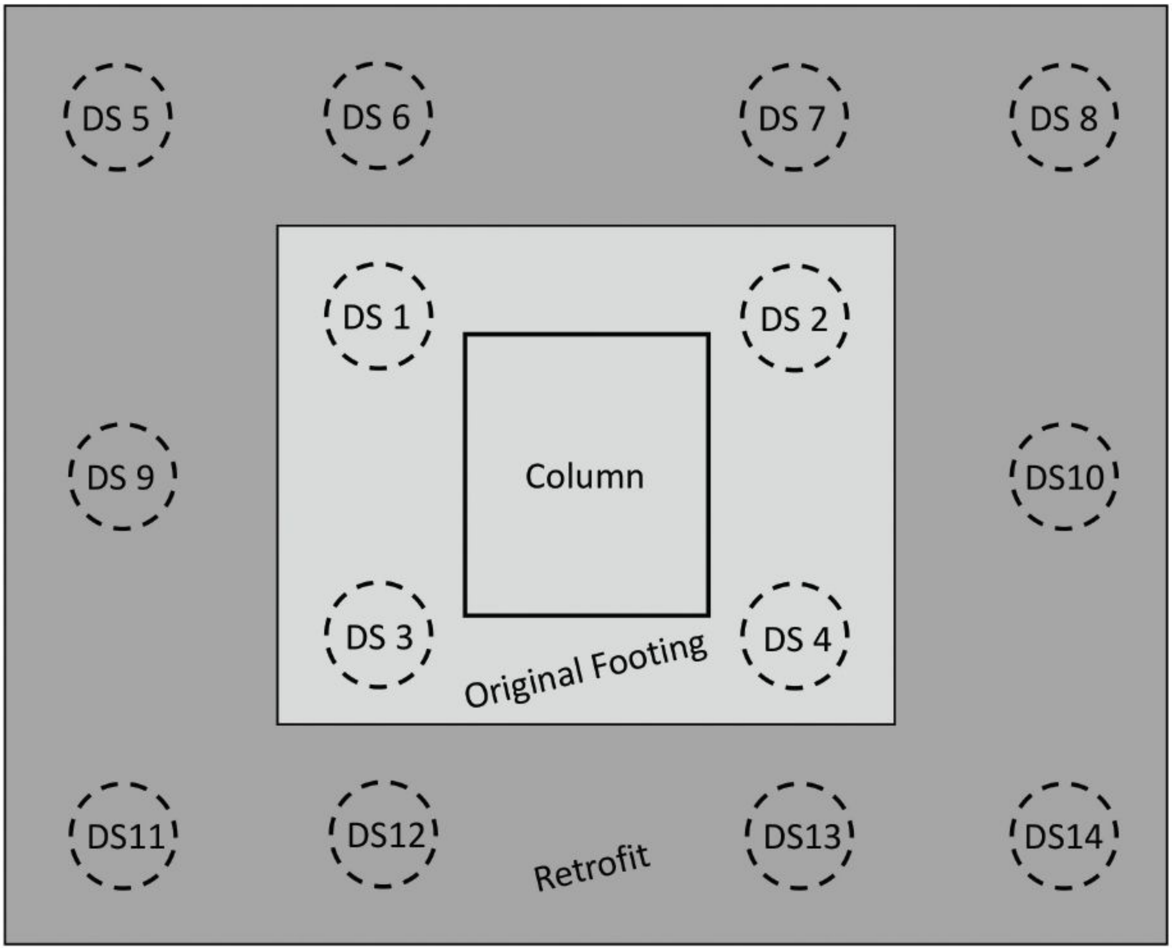
Figure 2. Structural retrofit of an existing footing supported by drilled shafts that requires a larger footing and more drilled shafts to accommodate increased column loads (plan view).



Bridge Deck Protection Systems

by Dr. Bijan Khaleghi, DeWayne Wilson, and Anthony Mizumori, Washington State Department of Transportation

This article focuses on Washington State Department of Transportation (WSDOT) concrete deck protection systems and the challenges WSDOT has encountered in increasing the longevity of bridge decks.

Figure 1 shows a typical concrete bridge deck deterioration curve. WSDOT uses information like this to assess bridge deck condition for repair, rehabilitation, and protection systems. Bridge decks are assigned to condition categories as follows:

- Good: 0% deterioration of total deck surface.
- Fair: Between 1% and 2% total deck surface deterioration. Decks in this group are considered for monitoring.
- Poor: 2% to 5% total deck surface area has patching and spalling. Prioritization for an overlay is triggered.
- Excessive: Over 5% total surface deck deterioration. The deck is considered "past due" and requires either major deck rehabilitation or deck replacement.

Figure 2 presents the distribution of deck protection systems based on deck area for all bridges managed by WSDOT. About half of WSDOT's bridges have decks with bare concrete without any overlay. For new bridges, WSDOT uses epoxy-coated reinforcement for both the top and bottom layers of reinforcement to protect the bridge deck from corrosion-induced damage.

Prior to the use of epoxy-coated reinforcement, which began in the early 1980s, WSDOT bridge decks typically remained in good condition for the first 20 years of service, reached fair condition around 30 years, and fell to poor condition around 35 years.

WSDOT revamped the bridge deck concrete material specifications in an effort to ensure durability and eliminate or reduce early-age restraint cracking in bridge decks. Bridge decks constructed with this revised performance-based concrete mixture specification are commonly referred to as performance-based bridge decks. Based on the recommendations of WSDOT-funded research,[1] the most significant change in the revamped specifications was the removal of the prescriptive requirement for a

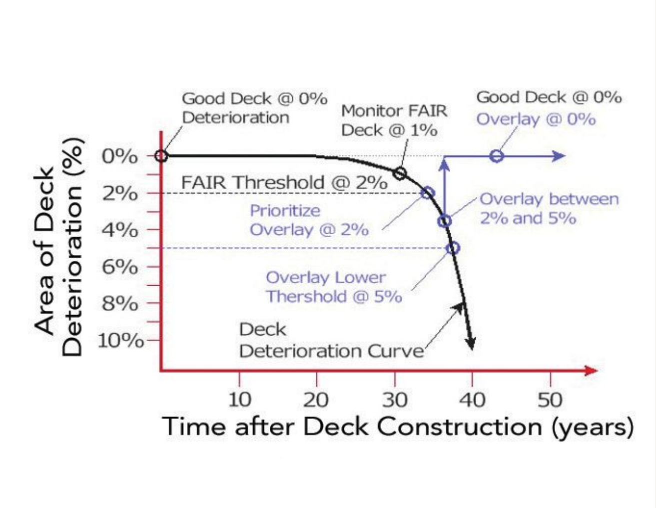


Figure 1. Typical concrete bridge deck deterioration curve. All Figures: Washington State Department of Transportation.

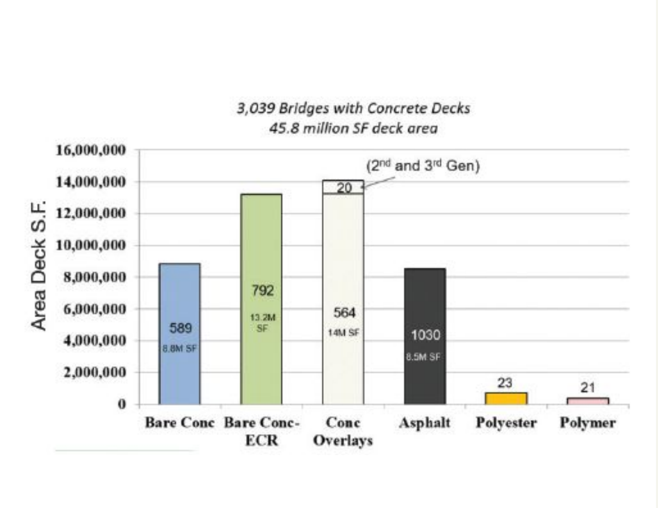


Figure 2. Total area of deck protection systems for bridges managed by Washington State Department of Transportation. Note: ECR = epoxy-coated reinforcement.

minimum cementitious content for bridge deck concrete, termed Class 4000D. Also, the specification includes a performance limit on drying shrinkage of 0.032% at 28 days based on American Association of State Highway and Transportation Officials requirements.[2] Another significant change was to increase the nominal maximum aggregate size from ¾ in. to 1½ in.

Deck Protection Systems

WSDOT uses five deck protection systems to improve the longevity of concrete decks.

Type 1

A Type 1 deck protection system is used for cast-in-place (CIP) concrete slab bridges, deck replacements, and the widening of existing decks. Notable features of this system are:

- A minimum of 2½ in. concrete cover over the top bars of deck reinforcement for CIP decks. The cover includes a ½ in. wearing surface and ¼ in. tolerance for the placement of the reinforcing steel. The concrete cover for the bottom layer of reinforcement is 1 in. minimum.
- Both the top and bottom mats of deck reinforcement are epoxy coated.
- Girder stirrups and horizontal shear reinforcement do not require epoxy-coated reinforcement.

Decks with epoxy-coated reinforcement (**Fig. 3**) are performing well compared with decks with uncoated (black) steel, which tend to exhibit corrosion-related damage.

Bridge decks using partial-depth precast, prestressed stay-in-place concrete deck panels are considered to have a Type 1 protection system; however, the reinforcement and prestressing strand in the partial-depth deck panels need not be epoxy-coated if they do not extend into the CIP portion of the deck.

Type 2

A Type 2 protection system consists of cementitious and polymer-based overlay on new or existing bridge decks. WSDOT requires new bridges to be designed for a 35 lb/ft^2 future wearing surface. Details of the three categories of overlays in this system follow.

Figure 3. Use of epoxy-coated reinforcement to protect the bridge deck from corrosion-induced damage.

1½ in. Modified Concrete Overlay

Concrete overlays are generally described as a 1.5-in.-minimum unreinforced layer of modified concrete. Overlay concrete is modified to provide a low permeability that slows or prevents the penetration of chlorides into the bridge deck and also has a high resistance to abrasion or rutting from snow tire studs. Ideally, the concrete cover to the top layer of reinforcement should be 2.5 in. For new structures, the deck reinforcement is epoxy coated.

These overlays were first used by WSDOT in 1979 and have an expected life between 20 and 40 years. As of 2010, there were more than 600 WSDOT bridges with concrete overlays. As the preferred overlay system for deck rehabilitation, these overlays provide long-term deck protection and a durable wearing surface. In construction, an existing bridge deck is hydromilled ½ in. prior to placing the 1.5-in. overlay (for more information on hydrodemolition, see the Concrete Bridge Preservation article in the Summer 2018 issue of *ASPIRE*®). This requires the finished grade to be raised 1 in.

The modified concrete overlay specifications allow a contractor to choose a latex, microsilica, or fly ash modified mixture design. Construction requires a deck temperature between 45°F and 75°F with a wind speed less than 10 mph. Traffic control can be a significant concern because the time required to cure these types of concrete overlays is 42 hours.

¾ in. Polyester Modified Concrete Overlay

These overlays were first used by WSDOT in 1989 and have an expected life between 20 and 40 years. As of 2010, there were more than 20 of these overlays in Washington. Currently, they are performing well, as expected.

The polyester modified concrete overlay uses specialized equipment and polyester materials to provide an overlay that normally cures in 4 hours. Construction requires dry weather with temperatures above 50°F. This overlay may be specified in special cases when rapid construction is needed.

3 in. Concrete Class 4000D Overlay

These overlays have a nominal 3-in. thickness and are placed after the existing bridge deck is scarified down to the top mat of bridge deck reinforcement. A minimum thickness of 2 in. is required to accommodate the larger aggregate in Concrete Class 4000D.

These overlays were first used in the mid 2010s on bridges that had previously received a modified concrete overlay. Second-generation modified concrete overlays were seen to suffer from debonding, which may have been due to microcracks in the substrate concrete caused by rotary milling machines and other percussive equipment used to scarify bridge decks in the past. The increased depth of removal using hydromilling equipment ensures the removal of bruised or microcracked concrete in the existing bridge deck.

Type 3

A Type 3 protection system consists of a hot mix asphalt (HMA) overlay wearing surface and requires the use of a waterproofing membrane. HMA overlays provide a lower level of deck protection and introduce the risk of damage by planing equipment during resurfacing.

Asphalt overlays with a membrane were first used on a WSDOT bridge in 1971, and about one-third of WSDOT structures have HMA overlays. When properly constructed, bridge deck HMA has an expected life equal to the expected life of roadway HMA. However, unlike roadway surfaces, the HMA material collects and traps water carrying salts and oxygen at the concrete surface of the bridge deck. Given this additional stress to an epoxy protection system or a bare deck, a waterproof membrane is required to mitigate the penetration of salts and oxygen into the concrete. **Figure 4** shows the removal of a HMA overlay from a segmental bridge in Washington, and **Fig. 5** shows the completed bridge after application of waterproof membranes and the new HMA overlay.

HMA overlays may be used in addition to a Type 1 protection system for new bridges to match roadway pavement materials. New bridge designs using HMA wearing surfaces have an overlay depth of 3 in. to allow future resurfacing contracts to remove and replace 1¾ in. of HMA without damaging the concrete cover or the waterproof membrane.

WSDOT prohibits the use of a Type 3 (HMA overlay) protection system for prestressed concrete slab-girder (voided slabs) or deck-girder bridges managed by WSDOT, which have connections between the adjacent precast concrete members. Exceptions may be made for pedestrian bridges and for widening existing similar structures with an HMA overlay. The HMA overlay with membrane provides some protection to the connections between girders, but it can be prone to reflective cracking at the joints. Voided slabs may fill with water and aggressively corrode the reinforcement. Other prestressed concrete members with a Type 3 protection system have a minimum concrete cover of 2 in. over a top mat of epoxy-coated reinforcement.

Type 4

A Type 4 protection system is used for adjacent prestressed concrete members and requires a minimum 5 in. CIP topping with at least one mat of epoxy-coated reinforcement. This system eliminates wheel distribution problems on girders and provides both a quality protection system and a durable wearing surface. It is commonly used on prestressed concrete slab-girder systems that are connected with grouted keyways that only carry shear forces. For these systems, epoxy coating is not required for the top mat of reinforcement in the prestressed concrete member, but the reinforcement must have a minimum concrete cover of 1 in.

Type 5

A Type 5 protection system requires a 3 in. concrete cover that is constructed using a layer of monolithically cast concrete and a modified concrete overlay for double protection. This system is also used on all segmentally constructed bridges to protect construction joints and provide minor grade adjustments during construction. This system is also used for segmental bridges and bridge decks with transverse post-tensioning in the deck because deck rehabilitation due to premature deterioration is very costly. Details of the Type 5 protection system are:

- The deck is constructed with 1¾-in. concrete cover.
- Both the top and bottom mats of deck reinforcement are epoxy coated.
- Girder web stirrups and horizontal shear reinforcement are not required to be epoxy coated.
- The deck is scarified ¼ in. prior to the placement of a modified concrete overlay. Scarification with

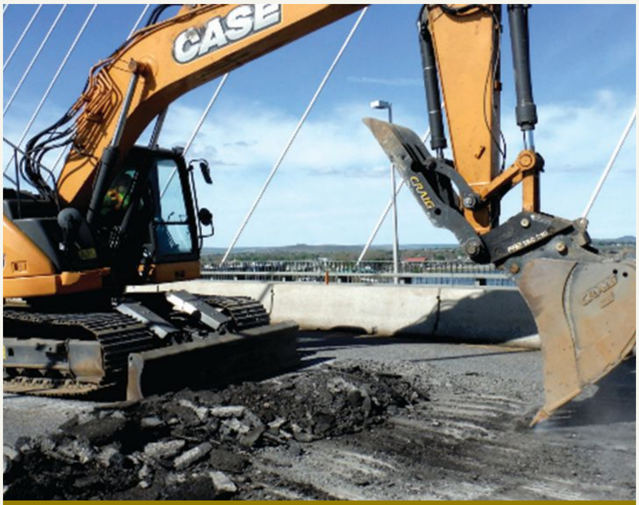


Figure 4. Removal of a hot mix asphalt overlay.

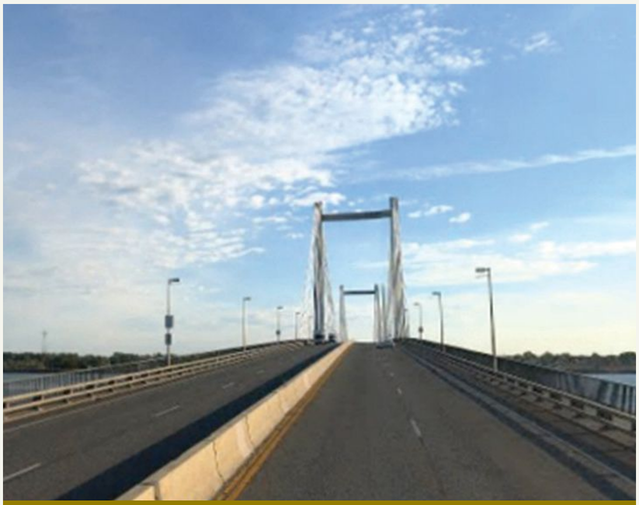


Figure 5. Completed bridge with a hot mix asphalt overlay.

diamond grinding to preserve the integrity of the segmental deck and joints is considered.
- A 1½-in. modified concrete overlay is placed as a wearing surface.

Discontinued Overlay Systems

A rapid-set latex-modified concrete (RSLMC) overlay uses special cement. RSLMC is mixed in a mobile mixing truck and applied like a regular concrete overlay. Like polyester, this overlay cures in 4 hours. WSDOT has discontinued the use of RSLMC due to its poor performance.

Thin polymer overlays are built-up layers of a polymer material with aggregate that is broadcast by hand. The first thin overlay was placed in 1986, and, after placing 25 overlays, they were discontinued in 1998 due to poor performance.

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Dr. Bijan Khaleghi is the state bridge design engineer, DeWayne Wilson is the bridge asset management engineer, and Anthony Mizumori is a concrete specialist, all with the Washington State Department of Transportation Bridge and Structures Office in Olympia.

EDITOR'S NOTE

Overlay system performance can vary because of local conditions, material specifications, and installation requirements. Although WSDOT reports that the discontinued overlay systems have not performed well for its projects, they have been used successfully for projects in other states.

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AASHTO THE VOICE OF TRANSPORTATION

PCI Precast/Prestressed Concrete Institute

Headed Reinforcement

by Dr. Henry G. Russell, Henry G. Russell Inc.

The traditional method of terminating reinforcing bars in tension is to provide a development length beyond the section where the reinforcing bar is no longer needed. This development length may consist of a straight length or a hooked anchorage. Hooks usually have 90- or 180-degree bends. There are, however, situations where there is insufficient length available to accommodate a straight development length or a hook. There are also locations, such as column-to-bent connections, where reinforcement can become very congested, particularly where hooks are used. These are ideal situations for considering the use of headed reinforcement. The benefits of headed reinforcement include:

- Simplified bar placement by reducing congestion
- Easier concrete placement
- Reduced detailing by using a standard product

Headed Bars Defined

The American Concrete Institute (ACI) defines a headed bar as "a steel reinforcing bar that has steel head(s) on one or both ends with the purpose of anchoring the bar in concrete."[1]

ASTM A970, *Standard Specification for Headed Steel Bars for Concrete Reinforcement*, addresses deformed steel reinforcing bars with a head attached to one or both ends.[2] Various methods are used to form the head. The scope of ASTM A970 includes the following methods for forming the head:

- Welding according to the standards of the American Welding Society.
- Integrally hot forging the head from the reinforcing bar.
- Attaching an internally threaded head to matching threads at the end of the bar. The threads may be straight or tapered. Thread specifications and standards are generally selected by the manufacturer.
- Cold swaging an externally threaded or plain coupling sleeve or headed sleeve onto the reinforcing bar. Radial compression of the swaged sleeve on the reinforcing bar creates a mechanical interlock with the bar deformations.
- Cold extruding an external coupling sleeve onto the reinforcing bar.
- Attaching a coupling sleeve to the end of the reinforcing bar by means of a ferrous filler medium.
- Using a separate threaded nut to secure the head to the reinforcing bar.

The head may be round, elliptical, or rectangular, and it may be forged, machined from bar stock, or cut from steel plate. The purchaser must either specify head dimensions or accept head dimensions supplied by the manufacturer prior to use. Headed deformed reinforcing bar manufacturers may also offer products made from a variety of stainless steel alloys, and some headed deformed bars are offered with epoxy or galvanic coatings.

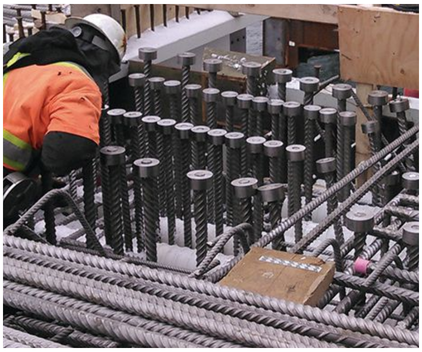
Structural Design

The American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* Article 5.10.8.3, Development by Mechanical Anchorages, allows the use of mechanical anchorages if the device is capable of developing the strength of the reinforcement without damage to the concrete.[3] Performance of mechanical anchorages must be verified by laboratory testing, and complete details must be shown in the contract documents.

The AASHTO LRFD specifications also allow the development of reinforcing bars to consist of a combination of mechanical anchorage and the additional development length of reinforcement between the point of maximum bar stress and the mechanical anchorage. In practice, most heads provide a strength greater than that of the reinforcing bar being anchored.

The AASHTO LRFD specifications provide few design details. However, design provisions for headed deformed reinforcing bars are included in Section 25.4.4 of ACI's *Building Code Requirements for Structural Concrete* (ACI 318-19).[4] These requirements allow the use of headed reinforcing bars in tension when the following conditions are satisfied:

- Bars conform with ASTM A970.
- Bar size does not exceed size no. 11.
- Net bearing area of the head is at least four times the area of the bar.
- Normalweight concrete is used.
- Clear cover for the bar is at least twice the bar diameter.



ASTM A970, *Standard Specification for Headed Steel Bars for Concrete Reinforcement*, lists seven methods of forming heads on headed reinforcing bars. Examples of three forming methods are shown here: (top) heads integrally hot forged from the reinforcing bars, (middle) internally threaded heads attached to matching threads at the end of the reinforcing bars, and (bottom) cold swaged headed sleeves on reinforcing bars. Photos: Headed Reinforcement Corp. (top); Dextra America (middle); BarSplice Products Inc. (bottom).

Congestion in a pile-to-pile cap connection was eliminated by using field-installed heads to replace hooked bars. Photo: Headed Reinforcement Corp.

- Center-to-center spacing between bars is at least three times the bar diameter.

The net bearing area is defined as the area of the head projected onto a plane orthogonal to the longitudinal axis of the bar minus the bar cross-sectional area. This area represents the contact surface between the head and the concrete where the bar tensile force is transferred to the concrete through compressive stress.

ASTM A970 requires tensile testing of the full-size reinforcing bar with a head attached to one end. The tensile properties of the headed bar shall conform to one of the following classes:

- Class A: Required to develop the minimum specified tensile strength of the reinforcing bar
- Class B: Required to develop both the minimum specified tensile strength and the minimum specified elongation of the reinforcing bar
- Class HA: Required to develop the minimum specified tensile strength of the reinforcing bar and to satisfy specific requirements for head dimensions

Note that ASTM A970 requires headed bars to develop 100% of the minimum specified tensile strength of the reinforcing bar, whereas the AASHTO LRFD specifications Article 5.10.8.4.2b requires mechanical couplers to develop 125% of the specified yield strength. ACI 318-19 Subsection 20.2.1.6 requires the use of Class HA head dimensions, but Subsection 25.4.5.1 also permits the use of any other type of mechanical anchorage capable of developing the yield strength of the reinforcing bar, provided it is approved by the building official.

Concluding Remarks

Headed reinforcing bars provide a solution to develop reinforcement in tension when the use of straight bars or hooked bars is neither practical nor economical. Further information about their use is available from the Concrete Reinforcing Steel Institute, ACI, ASTM International, and manufacturers' literature.

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Dr. Henry G. Russell is an engineering consultant and former managing technical editor of ASPIRE®. He has been involved with applications of concrete for bridges for over 45 years and has published many papers on the applications of high-performance concrete.

Bridge Bundling—A New Old Idea

by David Unkefer and Romeo Garcia, FHWA

Bridge bundling using the more advanced practices promoted in the Federal Highway Administration (FHWA) Every Day Counts (EDC)–5 Project Bundling initiative provides cost savings as great as 50% for design and up to 15% for construction, along with other benefits. This article defines bundling, introduces advanced practices, and shares examples of benefits that agencies have experienced as they make bundling a more strategic and consistent part of program delivery.

Bundling is awarding a single contract for similar preservation, rehabilitation, or replacement projects. When designed as a program, multiple bundles of projects are carefully chosen to accomplish larger agency goals, such as reducing the number of bridges classified as poor condition. Early and strategic bundle selection coupled with alternative contracting methods, such as indefinite delivery/indefinite quantity (IDIQ), design-build (DB), and construction manager/general contractor (CM/GC) project delivery, capitalizes on economies of scale throughout project delivery and supports greater collaboration.

With this approach, agencies can streamline design, contracting, and construction to reduce delivery costs and time, effectively decrease transportation project backlogs, and rapidly address agency asset management and system performance goals. Congress recognized the potential of bundling by including it in the Fixing America's Surface Transportation (FAST) Act (23 U.S.C. 144 (j)),[1] and FHWA also incorporated it in the Competitive Highway Bridge Program.[2]

Why Bundle?

The U.S. transportation system is aging, with many states seeing an increasing number of highways and bridges that need immediate attention. As a result, system performance is reduced, leading to adverse impacts on quality of life, mobility, travel time, freight movements, and emergency response times. Data from the National Bridge Inventory showing total values and values for bridges in good and poor condition appear in **Table 1**. The poor condition bridges need immediate attention. Often, the most pressing needs are found in local systems, as evidenced by bridges that are being posted for reduced loads. Bridge bundling offers an excellent approach to addressing these needs rapidly and effectively, and the same approach can also be used for other project types.

The following are some reasons that agencies employ bundling:

- To deliver transportation benefits to the public faster and with fewer disruptions
- To maximize use of existing funding and take advantage of financing opportunities
- To use existing agency staff efficiently and augment staff when needed
- To improve project and program delivery time
- To reduce design and construction costs

A comprehensive study completed by the Indiana Department of Transportation (INDOT) in 2018 compared project bundling to individual contracts in a sample that covered 10 years of construction and nearly 8800 projects.[3] The sample included the full range of typical transportation projects, from bridges and roads to traffic and utility projects. The study confirmed the following:

- Economies of scale resulted in reduced unit costs as project size increased.
- Bundling reduced per-project costs in bridge and road projects.
- Competition was maximized when two to four related projects were included in the bundle.
- Maintenance-of-traffic costs were reduced on bundled projects of all types, with roadway projects experiencing the greatest benefit.

INDOT has since worked to institutionalize bundling into its standard planning and programming and expects $50 million in savings per year.

The Pennsylvania Department of Transportation (PennDOT) used bridge bundling to address local bridge needs in a pilot project that was executed in three contracts (**Fig. 1**). The bundling projects rebuilt, replaced, or removed 40 county-owned structures in three counties for $25 million, resulting in 25% to 50% savings on design and 5% to 15% savings on construction. Only bridge projects (seven bridge replacements, 12 superstructure replacements, 18 rehabilitations, and three removals) with very similar details were chosen for the three contracts awarded. In addition to the cost savings, design and construction were performed in 18 months. Because of the savings achieved in this pilot bundling project, PennDOT chose to waive the local public agency (LPA) contribution; thus, PennDOT provided "no-cost" bridges for the local agencies while addressing critical bridge needs and supporting the local economies (see the Perspective article in the Winter 2020 issue of *ASPIRE*).

Other examples of successful project bundling include:

- The Delaware Department of Transportation uses a series of bundling contracts to address preservation issues on bridges and culverts. The bridge management section prioritizes the work, and the maintenance districts

Table 1. Bridge condition ratings data from the Federal Highway Administration's National Bridge Inventory as of June 2, 2020

		All Bridges		Locally Owned Bridges	
National bridge count	Total	618,411		307,309	
	Good condition	278,507	(45.0%)	141,309	(46.0%)
	Poor condition	44,978	(7.3%)	29,509	(9.6%)
National bridge deck area (m^2)	Total	396,259,573		90,027,336	
	Good condition	173,862,848	(43.9%)	41,823,240	(46.5%)
	Poor condition	20,571,497	(5.2%)	6,623,054	(7.4%)
Average age		44.9 years		43.4 years	

Note: The National Bridge Inventory Data can be accessed using the FHWA InfoBridge portal, which was described in the Winter and Spring 2020 issues of ASPIRE®.

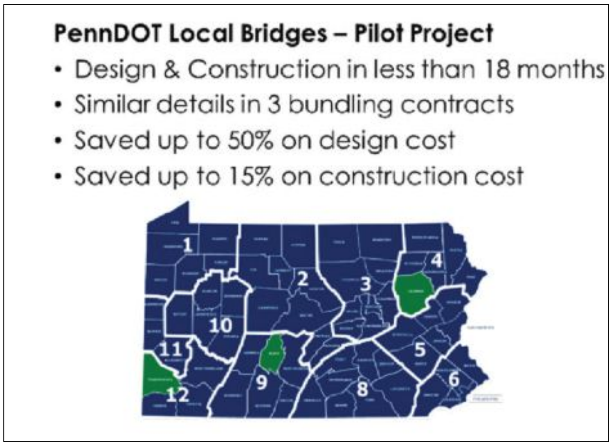

Figure 1. Pennsylvania Department of Transportation pilot bundling project for local bridges. Projects were located in counties highlighted in green. Figure: PennDOT.

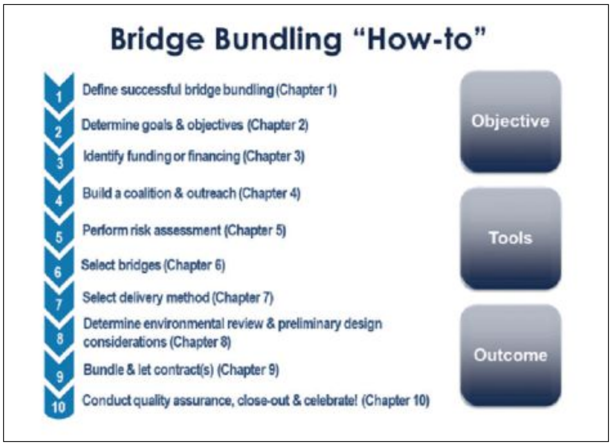

Figure 2. Ten-step bridge bundling process from *Bridge Bundling Guidebook*.[4] Figure: FHWA.

administer the contracts. Scopes include deck sealing, bridge painting, deck patching, joint repair, and culvert replacement.

- The Ohio Department of Transportation Bridge Partnership Program replaced or rehabilitated 220 county bridges over three years by bundling two or three bridges per contract; this program was funded through $120 million in Grant Anticipation Revenue Vehicle (GARVEE) bonds and toll credits.
- The Georgia Department of Transportation Design-Build Bridge Replacement Program, which began in 2016, replaced 25 local bridges in bundles of five to seven bridges within 1095 calendar days through new revenue available under the state's Transportation Funding Act of 2015.
- The Oregon Department of Transportation's $1.3 billion State Bridge Delivery Program replaced or repaired 271 bridges using 87 project bundles.
- The Missouri Department of Transportation (MoDOT) $685 million Safe & Sound Bridge Improvement Program replaced or rehabilitated 802 state-owned bridges over 3.5 years, including 554 bridges replaced through a single DB contract.
- FHWA's Central Federal Lands Division used bundling on a $49 million emergency contract to repair and replace 10 miles of roadway and 12 bridges. The procurement used a design-bid-build best-value, single-award task order contract.

How to Bundle?

Drivers of Bundling

There are two primary approaches to bundling: project-based and initiative-based. Both methods have valid objectives: Bundling on a project basis benefits an agency's standard program by strategically and efficiently combining projects. Bundling on an initiative basis achieves a specific initiative or performance goal, or makes the case for one.

The project-based approach may be executed in one of two ways:

- An agency's existing program is reviewed for project opportunities to bundle.
- Asset management activities are conducted to identify projects that will help achieve performance goals; project locations are identified by similar work types and bundled to take advantage of efficiencies.

Some of the departments of transportation taking this approach are INDOT, MoDOT, and the Michigan Department of Transportation.

The initiative-based approach is also used in two ways:

- To deliver a specially funded program or agency initiative, such as with the American Recovery and Reinvestment Act (ARRA) emergency relief projects, and some tribal examples
- To justify or make the case for an initiative to secure additional funding for projects, such as to address poor-condition bridges

Examples of the initiative-based approach include Kentucky's Bridging Kentucky program (see the State article in the Fall 2019 issue of *ASPIRE*), the Ohio Bridge Partnership Program (see the State article in the Winter 2016 issue of *ASPIRE*), and Nebraska's County Bridge Match Program.

Selecting Bridges to Bundle

States that implement advance bundling use screening criteria and best practices to fully leverage bundling to meet their goals. For example, INDOT has developed business rules to rank and select bundles and to standardize the process.[3]

Examples of INDOT's screening criteria for selecting project bundles are:

- Geographic location and proximity
- Road type, geometry, traffic, and work zone control
- Bridge size
- Similar bridge types
- Similar work types
- Environmental permitting
- Hydrology and hydraulics
- Geotechnical conditions
- Utilities or third parties
- Right-of-way
- Railroads

Bridge Bundling Guidebook

The FHWA's recently published *Bridge Bundling Guidebook*[4] outlines a 10-step process for implementing a bundling program based on best practices from around the United States (**Fig. 2**). It also outlines advanced bundling practices developed through a national study and provides case studies of bundling's benefits and how various agencies have strategically deployed project bundling. The guidebook is available, along with other bundling resources, at the FHWA Office of Innovative Program Delivery website. In addition to the guidebook, the EDC-5 Project Bundling Initiative will soon be completing a bundling "quick start" reference, a database of resources, and a self-assessment tool to assist agencies with implementation.

For more information on technical assistance available through EDC-5, contact Romeo Garcia (Romeo.Garcia@dot.gov) or David Unkefer (David.Unkefer@dot.gov).

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SAFETY AND SERVICEABILITY

Alkali-Silica Reaction: Testing Demonstrates Unexpected Capacity

by Dr. Oguzhan Bayrak, University of Texas at Austin

Although there are a number of causes for the early deterioration of transportation structures, this article focuses specifically on one concrete durability problem, alkali-silica reaction (ASR), and my experience with it at the University of Texas.

ASR takes place when reactive aggregates are subjected to a high-alkali pore solution in concrete. The third, and necessary, ingredient for this chemical reaction is water or high internal relative humidity (~80% or higher) in concrete. When these three ingredients are all present, ASR takes place. The reaction product, a hygroscopic gel, absorbs water and expands. Expansion results in cracking of concrete, raising concerns about structural integrity as well as the durability of the structural component.

Since joining the faculty at the University of Texas nearly two decades ago, I have conducted research on damage caused by ASR and delayed ettringite formation (DEF), among other concrete durability problems. This work has focused on the structural implications of ASR damage, considering also the deleterious effects of ASR on concrete material properties, for several projects sponsored by the Texas Department of Transportation (TxDOT) and, more recently, the nuclear power industry. In some cases, my research group fabricated specimens with ASR-prone concrete mixtures for laboratory testing to understand structural performance under varying levels of ASR damage.[1] In other cases, where field testing was possible and practical, we evaluated the structural performance of damaged concrete structures or their components through destructive testing.[2–4]

I would like to share some of what we learned while performing field tests on high-mast illumination pole (HMIP) drilled-shaft foundations in Houston, Tex. HMIPs are commonly used in urban areas to illuminate intersections, direct connectors, and highways. **Figure 1** shows that under strong winds, HMIPs experience substantial loads. Potential failure of foundations—more specifically, the anchor rods in the concrete supporting the HMIPs—during hurricane-level winds prompted TxDOT to contract with the University of Texas to study the structural performance of deep anchor rods embedded in ASR-affected drilled-shaft foundations with significant cracking. **Figure 2** is a close-up view of typical ASR cracks that were present in one of the drilled shafts tested. One of the additional concerns in the investigation was the presence of below-grade cracking, with ASR cracks serving as conduits to the reinforcing cage in the foundations that could allow water and other corrosive agents to penetrate the foundations. In addition to the structural implications of ASR, the owner was concerned about potential corrosion of the steel reinforcement within the drilled shafts.

Field tests were performed on six drilled shafts with substantial ASR damage to provide a basis for evaluating the structural adequacy of hundreds of other foundations with similar, or lesser, levels of damage and the same structural details as those tested. **Figure 3** shows the test setup.

The overall strength and stiffness implications for shafts damaged by ASR have been previously discussed in great depth.[2–4] A complete review of these issues is beyond the scope of this article. In our tests, foundations with ASR cracks performed adequately and the capacities of the anchor rods were not compromised by severe cracking resulting from ASR-induced expansions with the reinforced detail used by TxDOT. Furthermore, reinforcing bars located slightly above, at, or below grade in concrete with extensive ASR cracking showed no signs of corrosion despite frequent exposure to rainstorms. Reinforcing bar corrosion was not observed because the highly alkaline (high pH) levels in the pore solution in ASR-affected concrete cause passivation on the surface of reinforcing bars and therefore create an environment that may not promote corrosion of typical ASTM A615 carbon steel reinforcing bars. In general, the corrosion rate of reinforcing

Figure 1. Florida Department of Transportation photo showing high-mast illumination pole during a high wind. All Photos adapted from Reference 2.

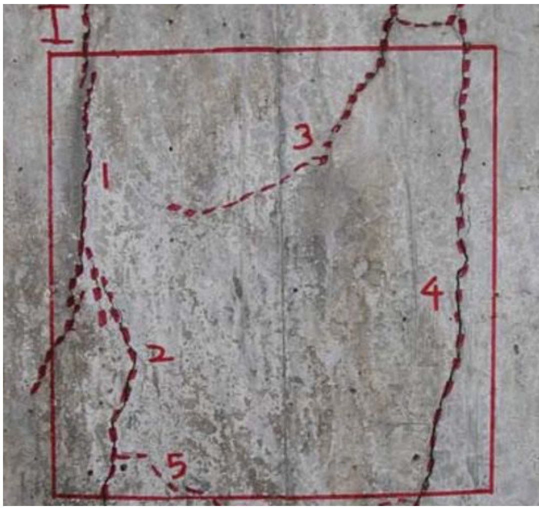

Figure 2. Cracks caused by alkali-silica reaction in the drilled-shaft foundation of a high-mast illumination pole.

Figure 3. Setup for field testing the deep anchors in the ASR-damaged drilled-shaft foundation of a high-mast illumination pole.

bars made with carbon steel decreases as pH values increase.

Advanced levels of ASR can significantly reduce the compressive and tensile strength as well as the modulus of elasticity of plain (unreinforced) concrete.[5] However, in the study of the performance of deep anchors in drilled shafts, the confinement provided by the reinforcing bar cage (longitudinal steel confined with spiral reinforcement as shown in **Fig. 4**) compensated for the adverse effects of ASR on the mechanical properties of plain concrete.[2] A recognition of the beneficial effects of confinement reinforcement was necessary to explain why the substantial reduction in observed mechanical properties of the ASR-damaged concrete had no discernable effect on the structural performance of the deep anchors. More specifically, the tensile and compressive loads on the deep anchor rods were transferred to the neighboring longitudinal reinforcing bars with the help of the spiral (confinement) reinforcement. Simple strut-and-tie models were used to explain the structural response.[4] The viability of the load transfer relied on the integrity of the struts forming in the structural core and the presence of the confining reinforcement providing restraint against radial blowout forces.

Figure 4. No corrosion of the reinforcement was evident in the drilled shafts having significant cracks likely caused by ASR.

As a result of the favorable structural test results and observed behavior that could be explained on the basis of first principles, many ASR-affected drilled-shaft foundations of HMIPs were kept in service. The lack of observed corrosion in reinforcing bars and anchor rods contributed to this decision.

As our nation's transportation infrastructure continues to age, most bridge engineers will be involved with the assessment of the existing structure inventory. The good news is that we will find most of the concrete bridge inventory is in excellent shape, ready to serve our communities for many decades to come. In some cases, as in the case of the ASR problem discussed in this article, the body of knowledge developed in the United States and around the world will help us evaluate our bridges, and may allow us to keep them in service, possibly with repairs if necessary, and thus use our resources judiciously. Above all, we must all aspire to use available resources in a responsible manner. (For more information on ASR and DEF, see articles in the Summer 2018 and Spring 2019 issues of *ASPIRE*®.)

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Mass Concrete

by Dr. Henry G. Russell, Henry G. Russell Inc.

The American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] defines "structural mass concrete" in Article 5.2 as "any large volume of concrete where special materials or procedures are required to cope with the generation of heat of hydration and attendant volume change to minimize cracking."

Though the AASHTO LRFD specifications provide a definition, they do not include guidance on addressing issues related to mass concrete. The references and additional resources at the end of this article provide further information on this topic.

It is generally accepted that concrete is considered to be mass concrete when the maximum temperature in the placement exceeds the typical industry standard limit of 160°F or when the temperature difference between the interior of the placement and a point that is 2 to 3 in. below or inside the center of a nearby surface exceeds the typical industry standard limit of 35°F .[2]

The definition in the AASHTO LRFD specifications is often interpreted to apply when the least dimension of a member is greater than 3 or 4 ft or 1 meter. However, this assumption can be misleading because the heat of hydration is affected by many factors other than the size of the member. Members with a thickness of 1 ft or more and a high cementitious materials content can achieve temperatures in excess of 160°F.

High concrete temperatures and high temperature differences between the interior and surface of a mass concrete member can be controlled by a variety of techniques. These include lowering the heat of hydration using supplemental cementitious materials, lowering the initial temperature of the fresh concrete with the use of ice or liquid nitrogen, insulating the forms, and internal cooling of the concrete through the use cooling pipes.

Failure to control the temperature in concrete can result in cracking and undesirable chemical reactions. Project specifications should require that the contractor develop a thermal control plan showing how temperature rise and thermal cracking will be controlled in applicable elements. Internal concrete temperatures can then be monitored to ensure adherence to the plan.

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Additional Resources

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EDITOR'S NOTE

The Texas Department of Transportation (TxDOT) offers free ConcreteWorks software to aid in the design and construction of mass concrete on its engineering software page: https://www.txdot.gov/business/resources/engineering-software.html.

CONCRETE CONNECTIONS

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

IN THIS ISSUE

http://www.aspirebridge.com/magazine/2018Fall/PROJECT-StCroisRiverCrossing.pdf
The mile-long St. Croix River Crossing has the second extradosed bridge to be built in the United States as its main unit. The structure was constructed by a joint venture of Ames Construction, which is featured in the Focus article on page 6. The link leads to the Project article in the Fall 2018 issue of *ASPIRE*® that describes in detail the St. Croix Crossing structure.

azdot.gov/projects/central-district-projects/loop-202-south-mountain-freeway
As mentioned in the Focus article on page 6, Ames Construction was a partner in a joint venture for the first Arizona Department of Transportation public-private-partnership project, the construction of the South Mountain Freeway (Loop 202). This website has details and photos of the project.

www.fema.gov/media-library-data/1557508353169-d67f745e88e04e54a1f40f8e94835042/FEMA_P-58-6_GuidelinesForDesign.pdf
The Perspective article on resilient design on page 10 discusses the benefits of resilient design and how it differs from sustainability or green design. The Federal Emergency Management Agency's *Guidelines for Performance-Based Seismic Design of Buildings* (FEMA P-58-6) can be downloaded from this website. Although the publication addresses seismic performance of buildings, the principles are also applicable to transportation structures and any hazard event.

www.wekivaparkway.com/project-6.php
This website has a video showing a bird's eye view of the construction progression of the Wekiva Parkway Bridges, including those featured in the Project article on page 14.

http://www.aspirebridge.com/magazine/2018Fall/PERSPECTIVE-BenefitsOfTheFHWA-NHI.pdf
The Concrete Bridge Technology articles on pages 28 and 32 discuss design and construction details of strut-and-tie models. This link is to an article from the Fall 2018 issue of *ASPIRE* that explains the fundamentals of strut-and-tie modeling.

www.fhwa.dot.gov/ipd/pdfs/alternative_project_delivery/bridge_bundling_guidebook_070219.pdf
Bundling of bridge projects is discussed in the Federal Highway Administration (FHWA) article on page 42. FHWA's recently published *Bridge Bundling Guidebook* can be downloaded from this website.

www.fhwa.dot.gov/innovation/everydaycounts/edc_5/docs/project-bundling-webinars-resource.pdf
Based on a fall 2018 webinar, this FHWA document provides resources on project bundling. Bridge bundling is the subject of the FHWA article on page 42.

www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm
This Texas Department of Transportation website contains standard drawings for bridge construction, including prestressed concrete beams and railing details. The use of standard details as a cost-effective measure is mentioned in the State article on page 50.

www.pci.org/AnchoringToConcreteImp
As mentioned in the LRFD article on page 54, Article 5.13 of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* has adopted the provisions for concrete anchorage from the American Concrete Institute's *Building Code Requirements for Structural Concrete* (ACI 318-14) *and Commentary* (ACI 318R-14). Under the sponsorship of the National Cooperative Highway Research Program, PCI developed a five-part webinar series for bridge engineers on the requirements for designing, detailing, and installing concrete anchors. This link provides access to a Dropbox folder that contains the recorded webinar series, course handouts, and resources.

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Texas

by Graham Bettis, Michael Hyzak, and Bernie Carrasco,
Texas Department of Transportation Bridge Division

Everybody knows that Texans like to brag about big numbers, and the state's bridge inventory is no exception: With over 55,000 state and locally owned structures, Texas has the largest inventory in the United States. But Texans take even greater pride in a small number: 1.3%. That is the current percentage of poor-condition bridges in the state, compared to a national average of 7.5%.

The condition of Texas' bridges was not always so well ranked. In 2001, 6.6% of all bridges in Texas were rated as structurally deficient, as were 14.8% of locally owned (off-system) bridges in the state. (**Fig. 1**). To reduce those numbers, the Texas Department of Transportation (TxDOT) developed a deliberate and calculated plan. All poor-condition ("structurally deficient" is no longer a term used in the National Bridge Inventory) bridges in the state, not just the state-owned (on-system) structures, were identified, and a prioritized list for rehabilitation and replacement was generated. TxDOT did not focus solely on bridges owned and maintained by the state because the top priority was (and is) the safety of the traveling public.

Leveraging the Benefits of Precast Concrete

As a government agency, TxDOT has a responsibility to be a good steward of the tax dollars it receives. Concrete and, in particular, precast concrete have played a major role in drastically reducing the percentage of poor-condition bridges over the past two decades.

TxDOT engineers enjoy big, complex, signature structures as much as anyone, but the bulk of the department's bridge work involves building structures with essentially the same puzzle pieces over and over again. Those puzzle pieces are made up primarily of precast concrete.

When it comes to options for precast concrete, TxDOT's catalog includes a wide range of standard shapes and designs. TxDOT builds, on average, about 350 new bridges a year. That includes roughly 250 bridges to replace other structures, most of them rated as poor condition. Roughly 95% of span-type bridges (nonculvert structures) are designed and constructed with prestressed concrete superstructures. In addition to bulb tees (typically called Tx girders), TxDOT precast concrete standard drawings include options for slab beams, box beams (adjacent or spread), U-beams, and decked slab beams. In recent years, TxDOT has expanded its use of spliced precast concrete girders to construct spans up to several hundred feet in length, using a combination of pretensioning and post-tensioning.

TxDOT also has standard drawings for other precast concrete components such as abutment caps, bents, piling, and MASH-compliant railing. The decks on almost all prestressed concrete bridges are constructed using stay-in-place prestressed concrete subdeck panels. Standard drawings for precast concrete columns are currently being developed, and once those are in place, TxDOT will routinely be designing bridges from the ground up using essentially 100% precast concrete elements.

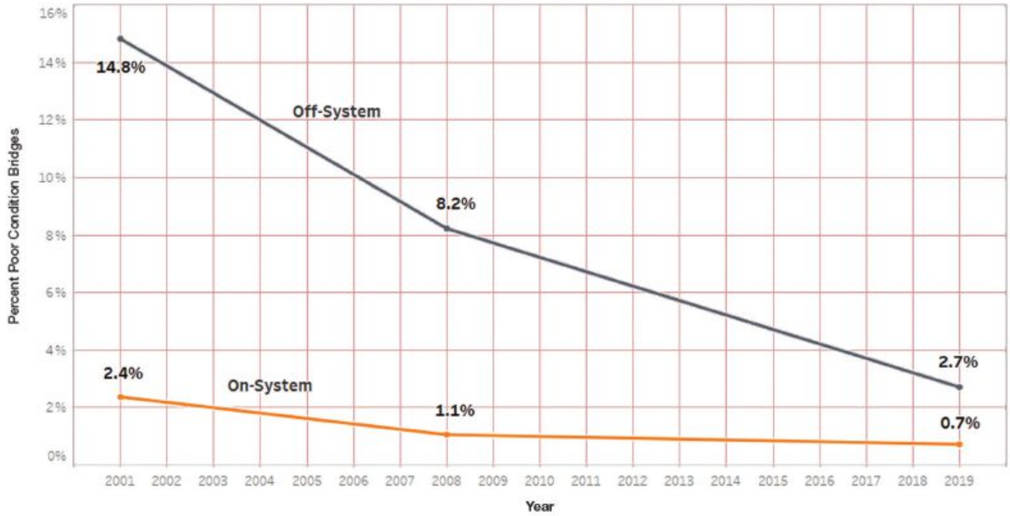
Increasingly, TxDOT has found that using precast concrete standards allows contractors to build new bridges at such low prices that it can be more cost effective to replace existing bridges instead of rehabilitating them. Texas routinely has some of the lowest unit-rate construction costs for new bridges in the United States. That allows the state to stretch the available dollars and maximize the number of poor-condition bridges it can replace.

Partnering with Local Owners

For state-owned structures, prioritizing replacement of poor-condition bridges has been straightforward. TxDOT simply made rehabilitating or replacing them a priority and went about it.

The bigger challenge has been addressing the poor condition of locally owned bridges because many counties and cities face funding

Figure 1. Percentage of poor-condition bridges in Texas, 2001–2019. Figure: Texas Department of Transportation Bridge Division.



challenges when it comes to infrastructure maintenance. Currently, locally owned bridge replacement projects are usually funded by 80% federal, 10% state, and 10% local government funds. However, the State of Texas developed a process that gives local governments two options: the locality can pay its 10% portion for a bridge replacement or the State will cover the local portion if the local government can demonstrate a 10% match spent on bridge maintenance activities elsewhere in its jurisdiction.

The latter arrangements, which are referred to as participation-waived projects, are carried out via the Equivalent Match Project (EMP) Program. Local agencies can use their 10% match on other bridges to improve structural capacity, improve hydraulics (including low-water crossings), increase bridge roadway width, or provide adequate bridge railing and approach guardrails. This program is highly beneficial for everyone. Local governments can stretch their infrastructure funding and have greater incentive to perform proactive maintenance activities on their bridges. Additionally, the EMP Program allows TxDOT to make progress on its goal of reducing the number of poor-condition bridges in the state. Most importantly, the EMP Program improves the safety of Texas roadways for the traveling public.

Ten of the fifteen spans of the RM 2900 Lake Lyndon B. Johnson Bridge at Kingsland, Tex., were washed out during an October 2018 flooding event. A replacement bridge comprised of prestressed concrete standard Tx34 bulb-tee girders and other standard components including partial-depth precast concrete panels, elastomeric bearing pads, and railings, allowed the bridge to be opened in May 2019. Photos: Texas Department of Transportation Austin District.

Relying on Standards

In addition to working with local governments, TxDOT collaborates frequently with contractors and precast concrete fabricators to ensure continual improvement of methods. The message from contractors has been clear: Keep bridge construction simple, and keep it repetitive. That is a mantra that TxDOT has also adopted. It applies not only to standard bridge construction but also to emergency projects. Texas has more than the usual share of overheight vehicle impacts, barge impacts along the coast, and flash flooding that can cause extensive damage to bridges and their approaches. Unique accelerated bridge construction techniques such as slide-in or self-propelled modular transporter moves are great when the construction team has time for a lot of advanced planning and preparation—but not when responding to emergencies. With that in mind, TxDOT designers typically stick with standards when a bridge must be rapidly replaced due to an emergency. Two recent examples of that approach are highlighted here.

Damaged main span of eastbound Interstate 10 over State Highway 304 at Gonzales, Tex., after an overheight vehicle collided with it. Photo: Texas Department of Transportation Yoakum District.

RM 2900 Lake Lyndon B. Johnson Bridge

In October 2018, a historic flood caused the typically docile Lake Lyndon B. Johnson to become a raging river. Consequently, ten of the fifteen spans of the 1200-ft-long RM 2900 Bridge over the lake were completely washed out when the rising water inundated the beams and deck.

Fortunately, TxDOT personnel recognized the hazards associated with the rising water and closed the bridge before it washed out. But the closure required a 45-minute detour in a bustling community (Kingsland is a popular retirement and recreation area northwest of Austin). Therefore, it was critical that the replacement bridge be designed and constructed as quickly as possible.

Considerations for span length, superstructure type and depth, substructure type, hydraulic performance, design simplicity, construction economy, and total construction duration made a prestressed concrete bulb-tee bridge the logical choice. The plans developed for this project included the following specific features and improvements:

The replacement of the damaged span of eastbound Interstate 10 was completed in 11 days. The Texas Department of Transportation opted to replace the entire span rather than repair or replace only the damaged section. Photo: Texas Department of Transportation Yoakum District.

- Whereas the original structure had 40-in.-deep beams, the new bridge used shallower 34-in.-deep beams with 80-ft spans with bents placed to avoid existing foundations and debris. Two of the fifteen spans were offset by 15 ft to avoid original bent locations.
- The replacement bridge has drilled-shaft foundations with permanent casings and extensions into hard granite layers that the original multiple steel H-pile foundations did not have. Extending the foundations into the granite took significant effort and time, but it was judged to be critical to prevent future washouts if similar flooding occurs.
- The replacement structure has modern TxDOT partial-depth precast concrete subdeck panels.
- Options for precast concrete bent caps and precast concrete deck overhangs helped expedite construction.

By using precast concrete standards, TxDOT engineers were able to complete the design in a matter of days. TxDOT has an emergency certification process that allows plan development and letting to occur in an expedited fashion for emergencies like this. Many different disciplines within TxDOT contributed to advance the project from the onset of the event to 100% plans and emergency letting within two weeks of the washout.

Even with challenges posed by removing the extensive debris (including the washed-out bridge) and by extending the foundations into the solid granite base, the bridge was opened to traffic only seven months after the washout occurred. The expediency of this project can be directly associated with the use of TxDOT precast concrete design and construction techniques.

Interstate 10 over State Highway 304 Span Replacement

Because large vehicles are necessary to support the Texas energy and heavy construction industries, overheight vehicle impacts to Texas bridges are a frequent occurrence. In April 2020, the eastbound Interstate 10 bridge over State Highway 304 near Gonzales, a town between San Antonio and Houston, sustained significant damage when a vehicle transporting a large pressure vessel struck the middle span.

Two options were considered to address the damage. One proposal was to saw cut the deck and repair and replace the damaged beams within the span while maintaining one lane of traffic. The alternative plan was to temporarily move traffic onto the frontage road and completely replace the damaged span.

It did not take much time for TxDOT to conclude that complete span replacement was the preferable option. The contractor could perform the work more quickly, and construction and inspection personnel would not have to work immediately adjacent to traffic.

Within one week of the event, plans were completely developed and let to contract using TxDOT's emergency certification and letting process. The precast concrete industry responded by prioritizing production and having replacement girders ready within one week of contract award. The single open lane on the eastbound bridge was closed to allow the contractor to perform demolition and span replacement. By expediting the construction process while using almost entirely standard bridge elements (girders, deck, and railing), the span demolition and replacement were completed in only 11 days, and traffic was fully restored within one month of the collision.

Looking to the Future

TxDOT looks forward to finding ways to keep its percentage of poor-condition bridges at or near the lowest in the country, both for state and locally owned structures. At the same time, TxDOT will continue developing new standards that allow bridges to be constructed quickly, at low cost, and with long service life. Precast concrete is a huge part of both those initiatives. TxDOT has relied on precast concrete for over 60 years, and will continue to do so for new bridges, replacement bridges, and emergency response. TxDOT welcomes the opportunity to collaborate with owners, contractors, and fabricators from around the country to further refine the state's already extensive use of precast concrete in all facets of bridge design and construction.

Graham Bettis is the Texas state bridge engineer, Michael Hyzak is a bridge design supervisor who frequently leads the design efforts for emergency bridge replacements, and Bernie Carrasco is the director of bridge management, overseeing state and local project prioritization and funding for bridge rehabilitation and replacement. All are with the Texas Department of Transportation in Austin.

Anchors in Concrete: The Tools to Find Acceptable Concrete Anchors—Part 2 of a four-part series

by Dr. Donald F. Meinheit

This article is part 2 in a four-part series addressing concrete anchorage in the reorganized Section 5 of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] published in 2017. Part 1 (see the Summer 2020 issue of *ASPIRE*®) outlined a PCI educational program sponsored by the Transportation Research Board to educate bridge engineers on the implementation of the new provisions adopted from the American Concrete Institute's *Building Code Requirements for Structural Concrete* (ACI 318-14) *and Commentary* (ACI 318R-14).[2] This article focuses on the qualification of post-installed concrete anchors.

Traditionally, state highway authorities (SHAs) have published their own materials and testing standards. AASHTO has published a collection of individual standards as the *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* since 1931.[3] However, SHAs have abandoned some of the individual AASHTO materials specifications for lack of use or have substituted standards from other organizations, usually ASTM International (formerly the American Society for Testing and Materials).

The AASHTO materials specifications are separated into three types:

- Materials (M series)
- Practice (R series)
- Testing (T series)

Standards in each series are numbered consecutively: M 1–334, R 1–84, and T 1–378. Currently, there are 134 M standards, 72 R standards, and 232 T standards.

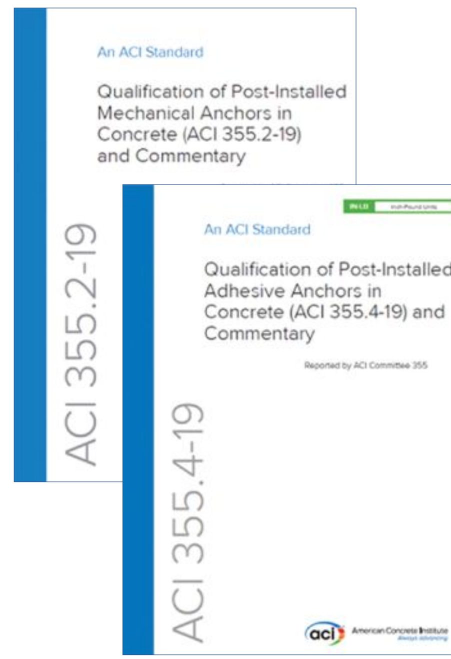
One standard in the AASHTO collection addresses concrete anchors: M 314-90 (2018), *Standard Specification for Steel Anchor Bolts*.[4] This standard does not address post-installed anchors for concrete, which should perhaps trigger a need in the AASHTO materials standards to create a specification for post-installed concrete anchors. However, it is the consensus of the concrete anchorage community of experts (designers, researchers, installers, and suppliers) that it is not necessary to have any additional AASHTO or SHA standard for the qualification of post-installed steel anchors because a qualification protocol already exists as an ACI standard.

In the United States, there are no ASTM standards for qualifying concrete anchors. The standards writing body for concrete anchor qualification is ACI. Specifically, ACI Committee 355, Anchorage to Concrete, writes and updates anchor qualification testing protocols. ACI assumed responsibility for writing the qualification standard in 2002, when the first ACI code requirement appeared in ACI 318-02.[5] The ACI standards for qualifying concrete anchors are modeled on and consistent with the qualification documents in Europe.

Qualification Standards for Anchors

Voting membership on the ACI 355 Committee includes anchor manufacturers, users, and individuals with a general interest (academics). One might think that having anchor manufacturer representatives on the committee is like having a fox watching the henhouse. However, the anchor qualification standards need to be rigorous, and the testing required by the ACI standards, as approved by ACI 355, indicates that the anchor manufacturers agree to comply with the requirements.

The International Code Council Evaluation Service (ICC-ES) is a nonprofit company that performs technical evaluations of building products and materials and publishes an evaluation service report (ESR) for products. (For a directory of these reports, visit https://icc-es.org/evaluation-report-program/reports-directory.) ICC-ES has a for-profit subsidiary that tests products per ICC-ES acceptance criteria (AC).



There are two ACI standards for qualifying anchors, which prescribe testing programs and evaluation requirements in accordance with ACI 318. One standard is for mechanical anchors: ACI 355.2, *Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary*,[6] which includes torque-controlled wedge anchors, torque-controlled sleeve anchors, concrete screws, and undercut anchors and was updated in 2019. The other is for polymeric adhesive anchors: ACI 355.4, *Qualification of Post-Installed Adhesive Anchors in Concrete and Commentary*,[7] which addresses anchors embedded in a polymeric adhesive and was also updated in 2019. Earlier versions of these two standards were in place when the eighth edition of the AASHTO LRFD specifications added Article 5.13 on anchors. The 2019 versions of the ACI standards for concrete anchors are discussed in this article because the standards did not substantially change but now include additional anchor types like concrete screws. Anchors embedded in cementitious grout do not yet have a qualification standard.

Anchor manufacturers submit test results for their products performed per the requirements of the AC to ICC-ES for evaluation and reporting, which are performed for a fee. The test protocols established by ICC-ES are AC193 for mechanical anchors (torque-controlled wedge anchors, torque-controlled sleeve anchors, concrete screws, and undercut anchors) and AC308 for adhesive (polymeric) anchors. These ACs address anchor qualification requirements given in the ACI qualification standards: AC193 for ACI 355.2 and AC308 for ACI 355.4.

Qualification Standard Tests

Within each of the ACI or AC qualification test protocols, testing is separated into four parts:

- *Identification tests* evaluate the anchor's compliance with critical manufacturing characteristics, which can include, but are not limited to, dimensions and tolerances, constituent materials (mill test reports for steels used in the product), surface finishes, coatings, fabrication techniques, the marking of the anchors and components (nuts and washers), a fingerprint of the adhesive, and the classification of the steel anchor elements as ductile or brittle, as this makes a difference in the strength reduction factor ϕ assigned for the design of the anchor.
- *Reference tests* establish the baseline strength performance against which subsequent mechanical tests to investigate the reliability and service conditions are compared. Both cracked and uncracked concrete conditions are tested. These tests are essential in establishing the anchor performance category (1, 2, or 3) for designing the anchor.
- *Reliability tests* are performed in both cracked and uncracked concrete to establish whether the anchor is safe and will perform acceptably under normal and adverse conditions. Tests are conducted during installation and in service and are intended to assess the sensitivity of the anchor to various adverse installation conditions, different strengths of concrete, performance under repeated load (but not fatigue loading), installation in a concrete crack and subsequent cycling of the crack width, and verification if brittle behavior exists under a tensile load.
- *Serviceability tests* are service-condition tests to evaluate the performance of the anchor under expected service conditions, such as the minimum member thickness in which the anchor can function; how close to a corner the anchor can be installed and still carry the same load as when away from the corner; and the minimum spacing that can be tolerated between anchors such that the concrete does not crack due to installation. Finally, if post-installed anchors are used in moderate- or high-seismic design categories, they must pass a simulated seismic test to be qualified.

Grading Anchor Performance

The primary purpose of the qualification standard is to confirm an anchor's reliability and place it in the appropriate category based on its performance. The anchor category is an index of the anchor's sensitivity to conditions of installation and use. Criteria for determining the anchor category for mechanical anchors and adhesive anchors are contained in ACI 355.2 and ACI 355.4, respectively. The assigned anchor category carries with it a ϕ-factor set by the ACI 318 design code. For mechanical anchors, the category is numerically evaluated using the smallest ratio of the various reliability tests to the corresponding reference test from the ACI document. **Table 1** conceptually shows how the anchor category is assigned for mechanical anchors.

Assigning the anchor category for an adhesive anchor follows the same concept of comparing the reliability tests to the reference tests, but is somewhat more complicated. Adhesive anchor performance is more sensitive to hole cleaning, moisture in the drill hole, mixing effort of the adhesive, and whether the adhesive will work if the concrete is saturated or under water. Therefore, ACI 355.4 (AC308) includes a series of reliability tests that are compared to reference test results. The ratios of results of these reliability tests to reference tests, called α-values, are compared to a table of required α-values, α_{req}. If the test α-value is below the required α-value in the table, the category number increases and, consequently, the ϕ-factor decreases to reflect poorer performance.

The characteristic tension bond stress is also determined by how well or poorly the adhesive performs in other reliability and service-condition tests, which include assessments for long-term temperature exposure (α_{lt}), short-term temperature exposure (α_{st}), durability (freezing/thawing) (α_{dur}), durability of the anchor system to environmentally aggressive chemicals and crack-width cycling (α_{o}), the coefficient of variation of test results (α_{COV}), regional concrete variations (α_{conc}), and a reduction if the anchor system is in category 3, the lowest capacity category (α_{cat3}). The last reduction on bond stress is a factor accounting for the reliability tests that were used to determine the anchor category (β). All of these reduction factors are applied to the nominal characteristic tension bond stress ($t_{k,nom\ (cr,uncr)}$)

Table 1. Anchor categories for mechanical anchors from ACI 355.2.[6]

Smallest ratio of characteristic capacities	Anchor category
$0.80 \le \frac{N_{b,r}}{N_{b,o}}$	1
$0.70 \le \frac{N_{b,r}}{N_{b,o}} \le 0.80$	2
$0.60 \le \frac{N_{b,r}}{N_{b,o}} \le 0.70$	3
If $\frac{N_{b,r}}{N_{b,o}} < 0.60$	Anchor is unqualified

Note: $N_{b,r}$ = the characteristic tension capacity (5% fractile) in the reliability tests; $N_{b,o}$ = the characteristic tension capacity (5% fractile) in the reference tests.

$$\tau_{k\,(cr,uncr)} = t_{k,nom\,(cr,uncr)}\ \beta\ \alpha_{lt}\ \alpha_{st}\ \alpha_{dur}\ \alpha_{\varrho}\ \alpha_{conc}\ \alpha_{COV}\ \alpha_{cat3}$$

Equation 10-12 from ACI 355.4-19[7] for determining characteristic tension bond stress for cracked or uncracked conditions accounting for numerous reduction factors defined in text.

to determine the value of the characteristic design tension bond stress (τ_k) for cracked (*cr*) or uncracked (*uncr*) conditions using the equation shown above.

From this detailed evaluation process, it is clear that the design stress for the adhesive anchor system failing in bond is taken seriously. The design tension bond strength must also incorporate the appropriate ϕ-factor and any other modification factors as found in Section 17.4.5.2 and other provisions of Chapter 17 of ACI 318-14.

All the geometric requirements (such as edge distance, minimum anchor spacing, and concrete thickness) and installation recommendations for a specific concrete anchor or adhesive, plus the performance of the anchor in concrete breakout and pullout/pull through, and the steel strength, are summarized for the designer in a downloadable ESR from ICC-ES.

Part 3 of this four-part series on concrete anchors will focus on specifications and procurement of concrete anchors.

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PERSPECTIVE

A Call to Action for All Bridge Engineers

by Tim Keller, Ohio Department of Transportation

The article "Why Didn't They Just Close the Road?" in the Spring 2020 issue of *ASPIRE*® is a call to action for the bridge industry. One of the points of the article is that it takes strong leadership to make difficult decisions. Strong leadership, both politically and technically, must be evident for those affected to accept and understand the decision. The political leadership must have trust in the technical staff. "Trust is not given, but earned" is a statement that all bridge engineers should embrace. Trust is not given because of a person's title. Trust is earned over time as relationships are developed. Trust must exist before a crisis so that the "pushback" described in the article is not a roadblock or delay to a difficult decision. Trust must exist to push fear out of the decision process.

The concurring statement by National Transportation Safety Board (NTSB) vice chairman Bruce Landsberg on page 106 of the NTSB highway accident report on the 2018 pedestrian bridge collapse at Florida International University[1] should be read by everyone in the bridge industry. It stung the first time I read it. Powerful and basic, it is a call for our industry to learn from this failure. Elsewhere in the report, the NTSB issued recommendations specifically to the Federal Highway Administration (FHWA), Florida Department of Transportation (FDOT), American Association of State Highway and Transportation Officials, and the Engineer of Record. I believe these recommendations are meant for all of us in the industry.

My fellow state bridge engineers, as bridge owners, please join me in evaluating your state practices and processes with Landsberg's message in mind. You may find, as I did, that the complacency that he described has crept into some of your practices. With FHWA and our industry partners, we must continue to improve our specifications and the understanding on how to implement them. We all should take care that the training recommended in the accident report is not limited to how to make a shear calculation. The training we all are entrusted with is key to the future of bridge design. We have the responsibility to invest in people, so that future lessons learned are not a result of loss of life.

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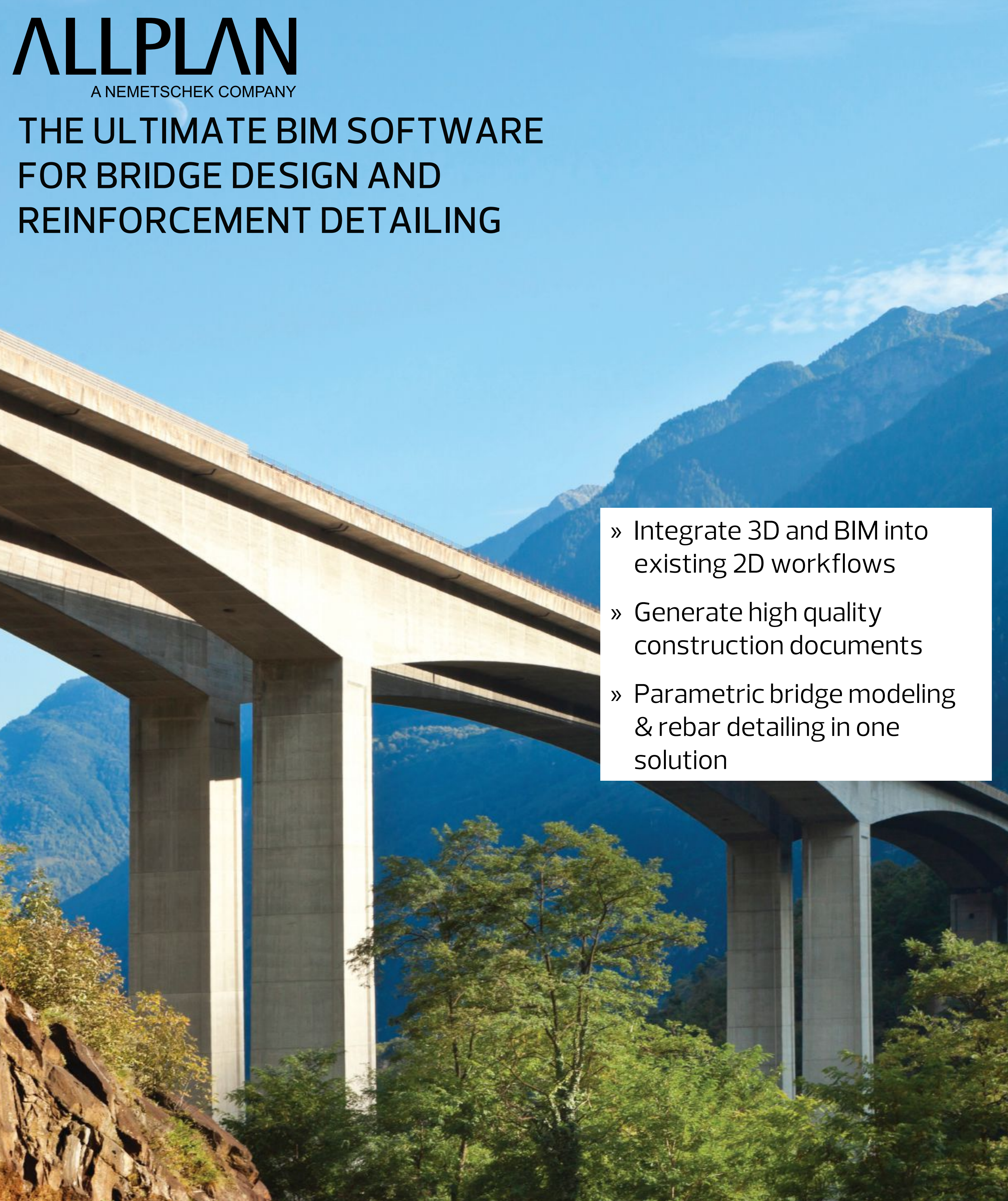
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