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
FIGG Bridge Group is a family of companies specializing in bridge services for all types of delivery methods.

- **Design-Bid-Build (Design for Owner)**
- **Construction Engineering & Inspection (CEI for Owner)**
- **Design-Build (Design for Contractor)**
- **Construction Engineering & On-Site Support (CE for Contractor)**
- **Construction Quality Control (QC for Contractor)**
- **Construction Manager/General Contractor (CMGC) (Design for Owner: Construction Engineering and Field Support for Owner/Contractor)**

FIGG’s experienced team brings benefits to owners and contactors from design through construction of major concrete bridges.

**Over 42 years of DELIVERING CONCRETE BRIDGE SOLUTIONS across the United States with proven services**

- **CMGC | DESIGN | ON-SITE CONSTRUCTION ENGINEERING**
- **New I-35W Bridge, Minnesota**
- **Honolulu Rail Transit Project, West Oahu / Farrington Highway and Kamehameha Highway Sections, Hawaii (10 miles)**
- **I-76 Allegheny River Bridge, Pennsylvania**
- **Victory Bridge, New Jersey**

Follow us on LinkedIn!

figgbridge.com
CONTENTS

Features
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 6

Innovation in Central Florida:
The Wekiva River Bridges 14

Ohio State Route 235 Bridge over Fairborn Cement Company Haul Road 18

Approach Spans Steal the Show 22

Departments
Editorial 2
Concrete Calendar 4
Perspective—Making the Case for Resilient Design—Part 2 10
Perspective—Evolution of the Buy America Requirements for Highway Bridge Projects 12
Concrete Bridge Technology—Strut-and-Tie Modeling for Bridge Design 28
Concrete Bridge Technology—Strength of Structures with Struts Crossing Cold Joints—Beginning the Discussion 32
Concrete Bridge Preservation—Bridge Deck Protection Systems 34
Creative Concrete Construction—Headed Reinforcement 39
FHWA—Bridge Bundling—A New Old Idea 42
Safety and Serviceability—Alkali-Silica Reaction: Testing Demonstrates Unexpected Capacity 44
Creative Concrete Construction—Mass Concrete 46
Concrete Connections 47
Buyers Guide 48
State—Texas 50
LRFD—Anchors in Concrete: The Tools to Find Acceptable Concrete Anchors—Part 2 of a four-part series 54
Perspective—A Call to Action for All Bridge Engineers 56

Advertisers’ Index
ALLPLAN . Inside Back Cover
Cresset Chemical . . . . 21
FIGG . Inside Front Cover
Hamilton Form Company . . . . 3
HDR . Back Cover
Helter Industries . . . . 21
MAX USA CORP . . . . 17
PCI . . . . 38, 41, 46, 47, 53
Poseidon Barge Ltd . 27
Stalite . . . . 5
Williams Form Engineering . . 31
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 1965 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 leader 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 36 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.
Hamilton Form has long been recognized for high quality, custom engineered forms built to exacting dimensions. The FM 457 Bridge Replacement Project highlights our commitment toward innovation and finesse in forms to deliver a successful project.

The focus of this project was the construction of a Dual Corkscrew Bridge to replace an obsolete swing bridge over the Gulf Intercoastal Waterway in Matagorda County, TX. Precast was supplied by Bexar Concrete Works, Inc in San Antonio, Texas. Hamilton Form designed and fabricated forms to produce Modified TX96 girders, haunch girders with end blocks, drop-in sections with end blocks, and the bent caps. Along with all the formwork, Bexar Concrete Works also looked to Hamilton Form for the required Modified TX96 embed plates, splice girder embed plates, and erection hanger assemblies.

The next time you need innovative formwork and ingenious equipment solutions, call on Hamilton Form. We’re here to fulfill your requests and deliver the complete package with the best service possible. Contact us at 817 590-2111 or sales@hamiltonform.com
CONTRIBUTING AUTHORS

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

Romeo Garcia is a bridge construction engineer in the Federal Highway Administration (FHWA) Office of Preconstruction, Construction, and Pavements, where he leads the advancement of highway bridge construction activities with transportation agencies and private industry.

Tim Keller is the administrator of the Office of Structural Engineering and the state bridge engineer for the Ohio Department of Transportation.

Dr. Donald F. Meinheit is a retired structural engineer who worked for Wiss, Janney, Elstner Associates Inc. He has been an active PCI member since 1975.

Evan Reis is a structural engineer licensed in California and executive director of the U.S. Resiliency Council.

David Unkefer is a senior project management and construction engineer at the FHWA Resource Center, where he provides subject matter expertise for alternative contracting methods, project/schedule management, digital project delivery, and construction automation.

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

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.
For over half a century Stalite Lightweight Aggregate has been used in bridge building. The superior bond and compatibility with cement paste reduces microcracking and enhances durability. Its lower absorption properties help concrete mix easily, which allows it to be pumped over longer distances and to higher elevations. Since concrete mixtures with a range of reduced densities and high strengths can be achieved using Stalite, it is particularly suited for both cast-in-place and precast operations.

Consider adding Stalite Lightweight Aggregate to your concrete.

BUILDING A BRIDGE?

Structural Welded Wire Reinforcement - A Best Kept Secret

Some experts call structural Welded Wire Reinforcement (WWR) the best-kept, time-saving, cost-cutting secret in the concrete reinforcement industry. We can let you in on all the details. We are the Wire Reinforcement Institute—the world’s leading association of manufacturers, professionals, and allied industries engaged in the production and application of WWR.

- Parking Structures
- Paving
- Cast-in-Place
- Tilt-up Panels
- Box Culverts
- Precast

Need a Course to Add to Your Credentials?

Welded Wire Reinforcement Used in Cast-in-Place Concrete Construction

This course demonstrates that by using welded wire reinforcement in cast-in-place projects, contractors can save significantly on time and costs without compromising strength or designers structural intent. Visit our website for more information and to register.

Design Flexibility and Performance with Welded Wire Reinforcement

This overview of welded wire reinforcement in concrete construction explores the benefits and best practices of WWR in creating high-performance structures. Visit our website for more information and to register.
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.

**Focus**
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
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.

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

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.
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 segmental 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.

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. 

History and Growth

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

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

Table 1. Objectives of Resilient and Green Designs

<table>
<thead>
<tr>
<th>Resilient Design</th>
<th>Green Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preserve lives</td>
<td>Use renewable materials</td>
</tr>
<tr>
<td>Produce longer-lasting structures</td>
<td>Use fewer natural resources</td>
</tr>
<tr>
<td>Build stronger communities</td>
<td>Lower energy use</td>
</tr>
<tr>
<td>Faster economic recovery</td>
<td>Produce less waste</td>
</tr>
<tr>
<td>Incur less damage in disaster, therefore producing less debris</td>
<td></td>
</tr>
</tbody>
</table>

Source: U.S. Resiliency Council

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:

\[ \text{Risk} = \text{Probability} \times \text{Vulnerability} \times \text{Consequence} \]

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:

\[ \text{ROI} = \frac{\text{Risk}_{\text{Standard Design}} - \text{Risk}_{\text{Resilient Design}}}{\text{Cost}_{\text{Resilient Design}} - \text{Cost}_{\text{Standard Design}}} \]

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.

**References**


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 FHWA-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.
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.
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.
A dual-shaft pier was used to stabilize the pier segment. 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.
INTRODUCING THE

RB401T-E
STAND-UP REBAR TYING TOOL

The extended frame of the RB401T-E allows you to stand-up and tie rebar for concrete slabs.

The RB401T-E uses the same battery and tie wire as the RB441T and RB611T TwinTiers.

INTERESTED IN A JOBSITE DEMO?
CALL: 1-800-223-4293 X 1031
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
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.

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.
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/ft², 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/ft³) 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 vandalism-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.
For over 50 years Helser has engineered and manufactured precise custom steel forms to meet the unique requirements of their customers. Helser's expertise was utilized in the construction of the Las Vegas monorail. The success of this high profile project was instrumental in Helser forms being specified for the monorail system currently under construction in Sao Paulo Brazil.

Whether your project requires precise architectural detail, structural elements or transportation application,

Helser Industries is on track to get it done right and get it done on time!
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, 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...
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.

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

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
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 yd³. 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 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.

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.
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...
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 yd³. 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.
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. 

Frederick Gottemoeller is the principal of Bridgescape LLC in Alexandria, Va.; Nelson Canjura is Florida bridge business class manager with HDR Inc. in Tampa, Fla.; Jeff Cavallin is principal bridge engineer with Parsons in Minneapolis, Minn.; and Clint Krajnik is Denver Bridge Group leader with RS&H in Denver, Colo.
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, 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. 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.
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.1 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.
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.

References


Daniel J. Baxter is a senior bridge engineer and bridge department manager with Michael Baker International in Minneapolis, Minn., Emily Thomson is a bridge engineer with Michael Baker International in Indianapolis, Ind., and Dr. Francesco M. Russo is vice president and technical director, bridge engineering, with Michael Baker International in Philadelphia, Pa.
Williams Systems Include:
- High tensile steel bars available in seven diameters from 1” (26mm) to 3” (75mm) with guaranteed tensile strengths to 969 kips (4311kN).
- Provided with cold rolled threads over all or a portion of the bar’s length.

Applications:
- Transverse & longitudinal post-tensioning
- Bridge retrofitting
- Prestress block construction
- Seismic restraints
- Many other applications

For More Information Visit: williamsform.com

Segmental Brings Inspiration to Life.
Systems are available to deliver form and function to maximize efficiency in a timely and economic fashion.

Upcoming Events:
October 27-28, 2020 – Virtual Convention
Please Check the ASBI Website Events Page for Details of Virtual Event.

This “How-To Handbook” was developed with the purpose of providing comprehensive coverage of the state-of-the art for construction and inspection practices related to segmental concrete bridges.
The Construction Practices Handbook is a FREE pdf download. This link www.asbi-assoc.org/index.cfm/publications/handbook-download will take you to the registration form to complete the download.

June 7-8, 2021 – 2021 Construction Practices Seminar
Seattle Airport Marriott, SeaTac, WA
Please Check the ASBI Website Events Page for Agenda and Registration.

ASPIRE Fall 2020 | 31
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. 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...
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

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).
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.

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, the most significant change in the revamped specifications was the removal of the prescriptive requirement for a

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.
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. 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/ft² future wearing surface. Details of the three categories of overlays in this system follow.

### 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 1½ 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 1½-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
Other Resources


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.

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.

References


References

PCI Offers New Transportation eLearning Modules

Courses on Design and Fabrication of Precast, Prestressed Concrete Bridge Beams

The PCI eLearning Center is offering a new set of courses that will help experienced bridge designers become more proficient with advanced design methods for precast, prestressed concrete flexural members. There is no cost to enroll in and complete any of these new bridge courses.

The courses are based on the content of AASHTO LRFD and PCI publications. These include several State-of-the-Art and Recommended Practice publications, as well as the PCI Bridge Design Manual. These are available for free to course participants after registering with a valid email. While the courses are designed for an engineer with five or more years of experience, a less experienced engineer will find the content very helpful for understanding concepts and methodologies.

Where applicable, the material is presented as part of a “real world” example of a complete superstructure design so that students can see how actual calculations are completed according to the AASHTO LRFD specifications.

All courses on the PCI eLearning Center are completely FREE. Go to: [http://elearning.pci.org/](http://elearning.pci.org/)

### PCI eLearning Precast, Prestressed Concrete Bridge Girder Series

<table>
<thead>
<tr>
<th>Course</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary Precast, Prestressed Concrete Design</td>
<td>T110</td>
</tr>
<tr>
<td>Materials and Manufacturing of Precast, Prestressed Concrete</td>
<td>T115</td>
</tr>
<tr>
<td>Design Loads and Load Distribution</td>
<td>T120</td>
</tr>
<tr>
<td>Flexure Service</td>
<td>T125</td>
</tr>
<tr>
<td>Flexure Strength</td>
<td>T130</td>
</tr>
<tr>
<td>Prestressed Losses</td>
<td>T135</td>
</tr>
<tr>
<td>Shear</td>
<td>T145</td>
</tr>
<tr>
<td>End Zone Design</td>
<td>T160</td>
</tr>
<tr>
<td>Extending Spans</td>
<td>T310</td>
</tr>
<tr>
<td>Bearing Pads</td>
<td>T450, T455</td>
</tr>
<tr>
<td>In-Service Analysis Load Rating</td>
<td>T710</td>
</tr>
</tbody>
</table>

### Full-Depth Precast Concrete Deck Panels Series

<table>
<thead>
<tr>
<th>Course</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction on Full-Depth Panel Precast Concrete Deck System and Its Advantages</td>
<td>T210</td>
</tr>
<tr>
<td>Design and Detailing of Full-Depth Precast Concrete Deck Panels</td>
<td>T215</td>
</tr>
<tr>
<td>Production and Construction Details of Full-Depth Precast Concrete Deck Panels</td>
<td>T220</td>
</tr>
<tr>
<td>Case Studies and Emerging Developments of Full-Depth Precast Concrete Deck Panels</td>
<td>T225</td>
</tr>
</tbody>
</table>

### Lateral Stability of Precast, Prestressed Concrete Bridge Girders Series

<table>
<thead>
<tr>
<th>Course</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Material and Hanging Girders</td>
<td>T520</td>
</tr>
<tr>
<td>Stability of Transported Girders</td>
<td>T523</td>
</tr>
<tr>
<td>Seated Girders and Stability Issues from Bed to Bridge</td>
<td>T525</td>
</tr>
<tr>
<td>Stability Calculations and Sensitivity Analysis</td>
<td>T527</td>
</tr>
</tbody>
</table>

This material is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange under DTFH61-13-D-00010 Task No. 5010. The U.S. Government assumes no liability for the use of the information. The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers’ names appear in this material only because they are considered essential to the objective of the material. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.
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.”

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. 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.
- Integranlly 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.

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). 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.
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.

### References

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.
PRECAST/PRESTRESSED CONCRETE INSTITUTE (PCI) CERTIFICATION is the industry’s most proven, comprehensive, trusted, and specified certification program.

The PCI Technical Activities Council and Research and Development Council approved a new Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand.

Keep up with all of the industry’s changes by monitoring the PCI Body of Knowledge at pci.org.
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)), and FHWA also incorporated it in the Competitive Highway Bridge Program.

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. 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

<table>
<thead>
<tr>
<th>National bridge count</th>
<th>All Bridges</th>
<th>Locally Owned Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>618,411</td>
<td>307,309</td>
</tr>
<tr>
<td>Good condition</td>
<td>278,507 (45.0%)</td>
<td>141,309 (46.0%)</td>
</tr>
<tr>
<td>Poor condition</td>
<td>44,978 (7.3%)</td>
<td>29,509 (9.6%)</td>
</tr>
<tr>
<td>National bridge deck area (m²)</td>
<td>396,259,573</td>
<td>90,027,336</td>
</tr>
<tr>
<td>Total</td>
<td>173,862,848 (43.9%)</td>
<td>41,823,240 (46.5%)</td>
</tr>
<tr>
<td>Good condition</td>
<td>20,571,497 (5.2%)</td>
<td>6,623,054 (7.4%)</td>
</tr>
<tr>
<td>Poor condition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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®.
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 project bundles and to standardize the process.¹

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 Guidebook² 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).

References


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 project bundles and to standardize the process.¹

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 Guidebook² 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).

References


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 project bundles and to standardize the process.¹

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 Guidebook² 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).

References

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. 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.

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. 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
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. 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. 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. 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.

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 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.)

References


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

Figure 4. No corrosion of the reinforcement was evident in the drilled shafts having significant cracks likely caused by ASR.
The American Association of State Highway and Transportation Officials’ AASHTO LRFD Bridge Design Specifications define “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.

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 of 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.

### References

### Additional Resources
- American Concrete Institute (ACI) Committee 207. 2007. Report on Thermal and Volume Change Effects on Cracking of Mass Concrete (ACI 207.2R-07). Farmington Hills, MI: ACI.

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.

### 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 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.

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.

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/cserving/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.fhwa.dot.gov/AnchoringsToConcreteImp
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.

Add these free PCI Transportation resources to your eBook library. Download at pci.org.
The companies listed on these pages have supported ASPIRE® magazine during 2020. Each offers a high-quality product or service targeted to the bridge industry and is worthy of your consideration. In choosing ASPIRE as the way to communicate with you, they show enormous confidence in us.

These companies share in the significant success achieved by ASPIRE. Advertisers put their money where their mouths are, and they can rightfully be proud of ASPIRE’s success and our ambitious plans for 2021. They enable us to move ahead to better serve our readers.

Just as important, the advertisers create valuable messages for our readers. Their announcements and product information supplement our own content to keep readers current with new ideas.

Whenever an opportunity arises, please contact ASPIRE advertisers, ask them for more information, and thank them for their investment in the bridge community. For an easy way to make a contact, go to www.aspirebridge.org and select the Advertisers tab. Clicking any listing will take you to the advertiser’s home page.

We appreciate our advertisers’ support, and yours, for making ASPIRE the most read and talked about bridge magazine!

<table>
<thead>
<tr>
<th>COMPANY DESCRIPTION</th>
<th>ADDRESS/PHONE #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALLPLAN</strong> is a leading vendor of open BIM solutions for structural and civil engineers; our solutions are used by over 240,000 AEC professionals around the world. As a member of the open BIM initiative, ALLPLAN supports the IFC standard and enables holistic design, construction, and management of bridges and structures.</td>
<td>10 North High Street, Suite 110 West Chester, PA 19380 844-ALLPLAN (844.425.5752)</td>
</tr>
<tr>
<td>America’s Most Preferred Architectural Release Agents Since 1946 Cresset® Chemical has been an innovative leader in precast concrete form release agents and other products for the concrete construction industry. At the core of our competency are superior-looking architectural quality surfaces—but we go beyond the surface to meet the complexity in today’s environmental landscape, providing eco-friendly products to responsibly meet your requirements. Visit Cresset.com or call us at 800-367-2020.</td>
<td>One Cresset Center Box 367 Weston, OH 43569 800.367.2020</td>
</tr>
<tr>
<td>DYWIDAG-Systems International designs, manufactures, supplies, and installs safe and reliable system solutions for post-tensioned and stay cable structures. With our repair and strengthening services, robotics, and automated inspection and monitoring systems, we support your structures’ lifespans.</td>
<td>320 Marmon Drive Bolingbrook, IL 60440 630.739.1100</td>
</tr>
<tr>
<td>e.Construct USA LLC is a structural engineering consulting firm formed in Omaha, Neb., in 2009. We offer a broad range of structural engineering services, including building design, bridge design, and the design and detailing of precast concrete building components. We have completed projects in Nebraska, across the United States, and around the world. We bring together a world class skill set, integrating state-of-the-art technical expertise with cutting edge academic knowledge and an emphasis on quality, innovation, and value.</td>
<td>11823 Arbor Street, Suite 200 Omaha, NE 68144 402.884.9998</td>
</tr>
<tr>
<td>FIGG specializes exclusively in the design and construction engineering of American bridge landmarks.</td>
<td>424 North Callhoun Street Tallahassee, FL 32301 850.224.7400</td>
</tr>
<tr>
<td><strong>Hamilton Form Company</strong> produces custom steel forms and plant production equipment for the prestressed, precast concrete industry.</td>
<td>7009 Midway Road Fort Worth, TX 76118 817.590.2111</td>
</tr>
<tr>
<td>For more than a century, HDR has partnered with clients to shape communities and push the boundaries of what's possible. Our expertise spans 10,000 employees—more than 700 being bridge and structures specialists—in more than 225 locations around the world. From strategy and finance to design and delivery, we help develop innovative, reliable, cost-effective solutions to your infrastructure challenges. HDR is number three among the top 25 bridge design firms according to ENR.</td>
<td>1917 South 67th Street Omaha, NE 68106-2973 402.399.4922</td>
</tr>
<tr>
<td>COMPANY DESCRIPTION</td>
<td>ADDRESS/PHONE #</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Helser Industries</strong> designs and manufactures steel forms for producing precast and prestressed concrete components for numerous commercial applications.</td>
<td>10750 SW Tualatin Rd P.O. Box 1569 Tualatin, OR 97062 503.692.6909</td>
</tr>
<tr>
<td>Lehigh Hanson, Inc., is among the leading producers of cement, aggregates, concrete and asphalt. With plants and distribution terminals strategically located across the United States and Canada, we manufacture a variety of cements, covering a range of ordinary portland cement and EcoCemPLC™ (a portland limestone cement) for traditional uses as well as blended and slag cements; masonry products, custom-colored and TXActive® Photocatalytic cement. For more information, visit us at lehighhanson.com.</td>
<td>300 E John Carpenter Freeway Irving, TX 75062 972.653.5500</td>
</tr>
<tr>
<td>MAX revolutionized the rebar tying industry with the development of the world's first battery powered rebar tying tool in 1993. Since then, MAX has continued improving on its proprietary technology, which led to the development of the TwinTier, a dual wire feeding rebar tying tool. This exclusive technology produces 4000 ties per battery charge, while eliminating wasted wire, for added productivity and cost savings. These features, among others, make the TwinTier the most innovative and efficient rebar tier on the market. Today, MAX manufactures a full line of rebar tiers that can tie between mesh up to #9 x #10 rebar. The latest TwinTier, model RB401T-E, allows users to tie rebar while standing, which is an optimal solution for tying rebar on bridge decks.</td>
<td>205 Express Street Plainview, NY 11803 800.223.4293</td>
</tr>
<tr>
<td>Mi-Jack Products Inc. is recognized as an industry leader and innovator in Travelift® and Translift™ rubber tire gantry crane manufacturing, sales, service, and support.</td>
<td>3111 W. 167th Street Hazel Crest, IL 60429 708.596.5200</td>
</tr>
<tr>
<td>Modjeski and Masters Inc. is one of the world's leading bridge engineering firms, with a reputation for technical excellence and innovation that goes beyond current standards. Established more than 125 years ago, the firm is responsible for the design and maintenance of some of our nation's most recognizable structures. Services include fixed and movable bridge design, inspection and rehabilitation, and all facets of life-cycle maintenance, research, and code development.</td>
<td>100 Sterling Parkway, Suite 302 Mechanicsburg, PA 17050 717.790.9565</td>
</tr>
<tr>
<td>Poseidon Barge Ltd manufactures, sells, and rents portable sectional barges to the heavy highway and marine construction industry. Distribution yards are located in Indiana, Missouri, Florida, Louisiana, Wisconsin, New York, and North Carolina.</td>
<td>725 E. Parr Road Berne, IN 46711 866.992.2743</td>
</tr>
<tr>
<td>STALITE structural lightweight aggregate is a rotary kiln expanded slate lightweight aggregate. STALITE’s light weight, low absorption, and superior particle strength correlate to high performance, high strength, durability, and toughness. STALITE meets all certification requirements in the USA and is especially proud of its European certification. The unique nature of STALITE’s slate raw material combined with our high manufacturing standards results in an extremely high-performance lightweight aggregate.</td>
<td>PO Box 1037 Salisbury, NC 28145 800.898.3772</td>
</tr>
<tr>
<td>Williams Form Engineering Corporation has been providing threaded steel bars and accessories for rock, soil, and concrete anchors, post-tensioning systems, and concrete forming hardware systems in the construction industry for over 95 years. Our rock and soil anchor product line includes our Spin-Lock mechanical rock anchors, polyester resin anchors, multiple corrosion protection anchors, soil nails, strand anchors, Manta Ray soil anchors, Geo-Drill Hollow-Bar anchors, and micropiles. For concrete anchoring, we offer Spin-Lock anchors, undercut anchors, reusable anchors, and cast-in-place anchors. We also have a full line of All-Thread Rebar for tiebacks, micropiles, and post-tensioning.</td>
<td>8165 Graphic Drive Belmont, MI 49306 616.866.0815</td>
</tr>
<tr>
<td>WSP provides a full range of professional services for bridges and structures, from feasibility and planning studies to concept, preliminary and final design, construction management, and asset management services (evaluations, monitoring, inspections, and service life engineering). Experienced in all types of materials, the firm has expertise for cable-supported (cable-stayed and suspension), arch, truss, concrete (precast and segmental), movable, and floating bridges as well as all types of tunnels. For more than a century, WSP (formerly Parsons Brinckerhoff) has contributed to some of the world’s most notable bridges and structures. We strive to bring to our clients’ assets the highest quality, cost-effective designs with cutting edge innovations.</td>
<td>One Penn Plaza New York, NY 10119 212.465.5000</td>
</tr>
</tbody>
</table>
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 issues.
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.

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.

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:
• 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, overweight 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.

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.
Bridge Geometry Manual

FREE PDF (CB-02-20)

The Bridge Geometry Manual has been developed as a resource for bridge engineers and CAD technicians. In nine chapters, the manual presents the basics of roadway geometry and many of the calculations required to define the geometry and associated dimensions of bridges. This manual and course materials are not linked to any software tool. The first five chapters are dedicated to the fundamental tools used to establish bridge geometry and the resulting dimensions of bridges. The vector-based approach to locating the north and east coordinates of a point defined by a horizontal alignment is then used to define the geometry of bridges. This manual includes the bridge geometry developed for straight bridges and curved bridges. The geometry of curved bridges using both straight, chored girders and curved girders is presented.

Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges

FREE PDF (CB-03-20)

The Guide Document for the Design of Curved, Spliced Precast Concrete U-Beam Bridges has been developed as a resource for bridge engineers. In nine chapters, the guide documents the advancement of this bridge technology. This technology, which originated and progressed initially in Colorado over approximately 20 years, has evolved through the collaboration of designers, contractors, and owners. Much of the current technology is in its second or third generation. Agencies and builders have shown interest in replication of this bridge technology in several areas of the United States. However, there are certain areas of practice that have not been quantified. This has made it difficult for owners and the design community to fully embrace the technical solutions needed to design, construct, deliver, and maintain curved, spliced U-beam bridge systems. This document addresses those practices.
This article is part 2 in a four-part series addressing concrete anchoring in the reorganized Section 5 of the American Association of State Highway and Transportation Officials’ AASHTO LRFD Bridge Design Specifications 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). 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. 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. 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. 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, 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, 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 ACI193 for mechanical anchors (torque-controlled wedge anchors, torque-controlled sleeve anchors, concrete screws, and undercut anchors) and AC308 for adhesive anchors, concrete screws, and undercut wedge anchors, torque-controlled sleeve mechanical anchors (torque-controlled sleeve 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 \( \phi \) 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 \( \phi \)-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 it 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 \( \alpha \)-values, are compared to a table of required \( \alpha \)-values, \( \alpha_{req} \). If the test \( \alpha \)-value is below the required \( \alpha \)-value in the table, the category number increases and, consequently, the \( \phi \)-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 (\( \alpha_t \)), short-term temperature exposure (\( \alpha_s \)), durability (freezing/thawing) (\( \alpha_{dur} \)), durability of the anchor system to environmentally aggressive chemicals and crack-width cycling (\( \alpha_{dur} \)), the coefficient of variation of test results (\( \alpha_{cov} \)), regional concrete variations (\( \alpha_{conc} \)), and a reduction if the anchor system is in category 3, the lowest capacity category (\( \alpha_{cat} \)). The last reduction on bond stress is a factor accounting for the reliability tests that were used to determine the anchor category (\( \beta \)). All of these reduction factors are applied to the nominal characteristic tension bond stress (\( t_{k,nom} \)).

### Table 1. Anchor categories for mechanical anchors from ACI 355.2

<table>
<thead>
<tr>
<th>Smallest ratio of characteristic capacities</th>
<th>Anchor category</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0.80 \leq \frac{N_{b,r}}{N_{b,0}} )</td>
<td>1</td>
</tr>
<tr>
<td>( 0.70 \leq \frac{N_{b,r}}{N_{b,0}} \leq 0.80 )</td>
<td>2</td>
</tr>
<tr>
<td>( 0.60 \leq \frac{N_{b,r}}{N_{b,0}} \leq 0.70 )</td>
<td>3</td>
</tr>
<tr>
<td>If ( \frac{N_{b,r}}{N_{b,0}} &lt; 0.60 )</td>
<td>Anchor is unqualified</td>
</tr>
</tbody>
</table>

Note: \( N_r \) = the characteristic tension capacity (5% fractile) in the reliability tests; \( N_{b,0} \) = the characteristic tension capacity (5% fractile) in the reference tests.
to determine the value of the characteristic design tension bond stress (τₖ) 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.

References
5. ACI Committee 318. 2002. Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02). Farmington Hills, MI: ACI.
6. ACI Committee 355. 2019. Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-19) and Commentary. Farmington Hills, MI: ACI.
7. ACI Committee 355. 2019. Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4-19) and Commentary. Farmington Hills, MI: ACI.

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

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' 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.

Reference
THE ULTIMATE BIM SOFTWARE
FOR BRIDGE DESIGN AND
REINFORCEMENT DETAILING

» Integrate 3D and BIM into existing 2D workflows
» Generate high quality construction documents
» Parametric bridge modeling & rebar detailing in one solution
Transforming communities
At HDR, we’re proud to celebrate the success of three award-winning bridges.

hdrinc.com