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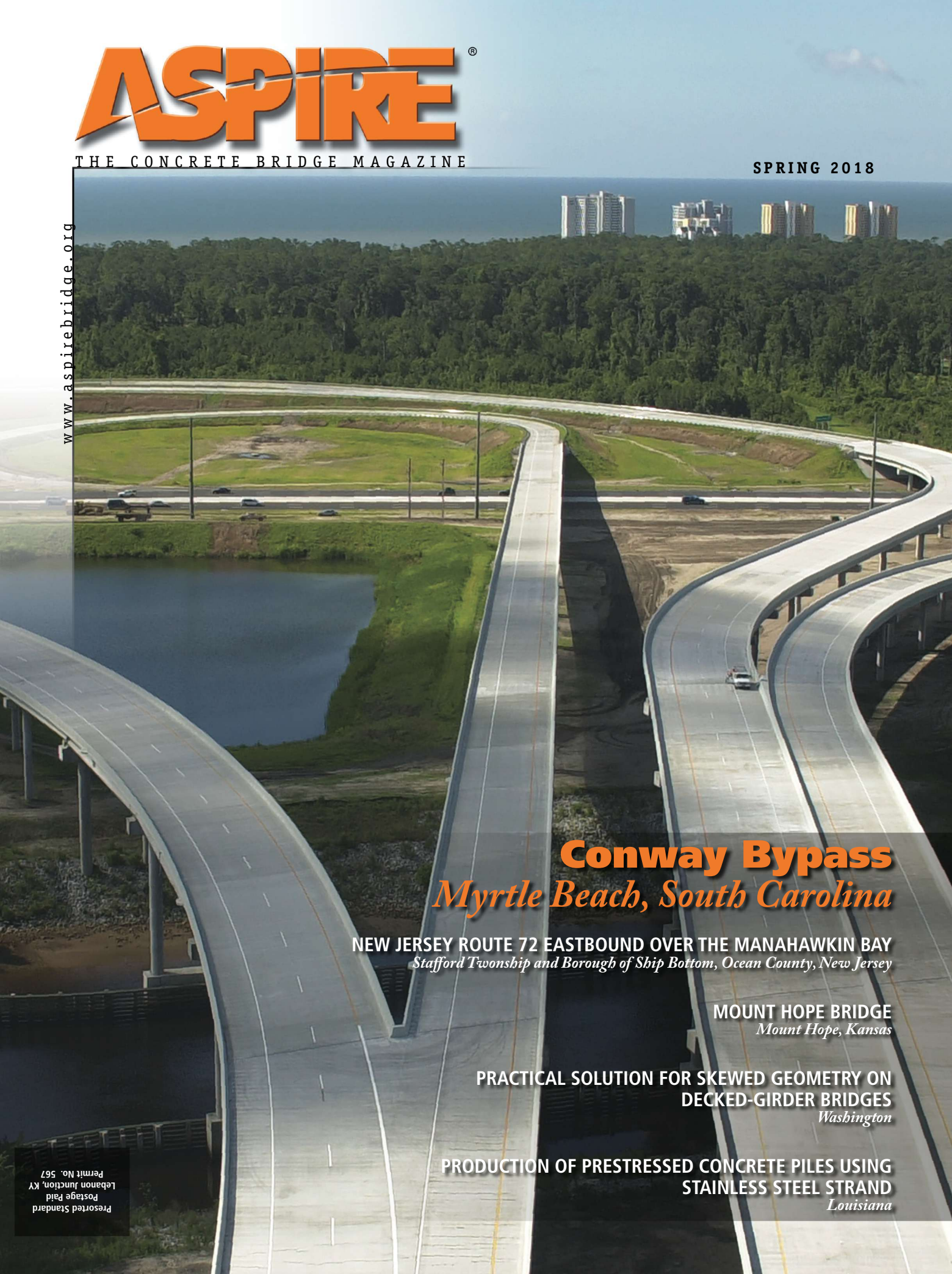

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EDITORIAL

Photo: PCI.

Wisdom and Experience: Striking a Balance

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

A few months ago, my friend Chester Henson passed away. He was a Missouri farm boy, a family man, a civil engineer, and a Vietnam veteran who flew a helicopter during his military service. Occasionally, he would share stories about his time in the military, and I would like to share one of them with you now. Shortly after he was deployed to Vietnam, Chester and his wingman were ordered to fly into a hostile area and pick up a stranded foot patrol. Before they carried out the order, an experienced warrant officer showed Chester a plate that could be added to the underside of the helicopter pilot's seat to provide an additional level of protection during combat. Because the old timer's seat design was unconventional, army mechanics would not make the modification. However, Chester decided to make his seat match the seasoned pilot's seat. This decision proved to be a fateful one. During the mission, his aircraft took on fire, and that plate stopped a bullet.

You may be wondering what this decades-old war story has to do with bridge engineering today. I want to suggest that Chester's choice illustrates the important distinction between wisdom and practical experience, and the value of using both when making decisions.

Since the days of the ancient Greeks, philosophers have classified different types of knowledge, including wisdom and experiential/practical intelligence. The latter type of knowledge has a narrow focus: choosing the means to a given end based on specific facts demonstrated through experience. In contrast, wisdom has a broad scope. The wise person does not neglect experiential knowledge, but his or her thoughts and actions are also informed by insight, common sense, and abstract reasoning. Wisdom may involve looking beyond how to resolve a particular question to explore whether that question is even the right one to ask.

Currently, massive amounts of money and human resources are being spent on engineering protocols, systems development, prototype data collection, high-tech robots, and the latest asset management tools. But I wonder: Are the engineers who conceive of these programs too narrowly focused on precision and repeatability based on data samples collected from bridges built with existing technologies and materials? Is seeking a high degree of accuracy about trends from our past sufficient to successfully advance our newest bridge practices?

Certainly, there is value in gathering data, calculating actuarial trends, and using that knowledge to adjust deterioration models and provide life expectancy curves for existing bridge inventories. However, if we rely exclusively on what we know about past and present experiences, we may squander our stretched resources on options (such as expensive, single-purpose robots) that are not wise solutions for the future.

Now, back to my friend and his army aircraft. Chester had no personal experience with the modified seat that his comrade invented, and there was no accumulation of data to review. However, Chester valued the other pilot's experience and insights, thought the invention made sense, and decided to try it. Not everyone gets to create a lifesaving feature based on the experiences and innovations of others, but, if we catalog our collective experiences, we can leave enough understanding and insight behind to help others act wisely.

We all know that bridges and structures deteriorate. Most challenges can be avoided with robust concrete material selection, and others can be addressed with appropriate design/detailing practices. Let's be sure to teach the next generation of engineers how to be wise enough to move beyond an exclusively experiential focus.

Congratulations to the young engineers from St. Martin University in Lacey, Wash., who won the Big Beam Contest cosponsored by ASPIRE®. Some members of the National Concrete Bridge Council (Alpa Swinger (left), PCA; Randy Cox (right), ASBI; Reid Castrodale (second from left), ESCSI; and William Nickas (second from right), PCI), who are proud sponsors of this student activity, are shown with the contest winners.

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Traylor Bros. served as the subcontractor on the Conway Bypass project in Myrtle Beach, S.C. Photo: Rob Thompson, South Carolina Department of Transportation.

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CONCRETE CALENDAR 2018–2019

For links to websites, email addresses, or telephone numbers for these events, go to www.aspirebridge.org and select the Events tab.

April 9, 2018
ASBI 2018 Grouting Certification Training
J.J. Pickle Research Center Austin, Tex.

April 18–20, 2018
PTI Level 1 & 2 Bonded PT Field Specialist Training and Certification
Baltimore, Md.

April 27–29, 2018
PTI Level 1 & 2 Unbonded PT Inspector Training and Certification
Phoenix, Ariz.

June 11–14, 2018
International Bridge Conference
Gaylord National Resort & Convention Center National Harbor, Md.

June 25–28, 2018
AASHTO Committee on Bridge Structures Meeting
DoubleTree by Hilton
Burlington, Vt.

June 27–29, 2018
DFI Super Pile 2018
www.dfi-superpile.org
New York Marriott Marquis
New York, N.Y.

August 27–29, 2018
2018 NDE/NDT for Structural Materials Technology for Highway and Bridges Joint Conference with the International Symposium on NDT in Civil Engineering
Hyatt Regency New Brunswick
New Brunswick, N.J.

September 16–19, 2018
AREMA 2018 Annual Conference & Exposition
Hilton Chicago
Chicago, Ill.

October 6–12, 2018
fib Congress 2018
Melbourne, Australia

October 10–13, 2018
PCI Committee Days and Membership Conference
Loews Chicago O'Hare Hotel
Rosemont, Ill.

October 14–18, 2018
ACI Fall 2018 Convention and Exposition
Rio All-Suites Hotel and Casino
Las Vegas, Nev.

November 6–7, 2018
ASBI 29th Annual Convention
Loews Chicago O'Hare Hotel
Rosemont, Ill.

January 21–25, 2019
World of Concrete 2019
Las Vegas Convention Center
Las Vegas, Nev.

February 26–March 2, 2019
PCI Convention and National Bridge Conference
Louisville, Ky.

March 24–28, 2019
ACI Spring 2019 Convention
Quebec City Convention Centre and Hilton Quebec Quebec City, QC, Canada

June 2–5, 2019
2nd International Interactive Symposium on Ultra-High-Performance Concrete
Hilton Albany
Albany, N.Y.

October 2–5, 2019
PCI Committee Days and Membership Conference
Loews Chicago O'Hare Hotel
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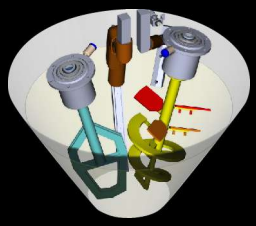

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Rising to the Top

Traylor Bros. used a creative approach to construct the twin 3044-ft-long precast concrete segmental Sailboat Bridge in Grove, Okla. Photo: Oklahoma Department of Transportation.

Traylor Bros.' focus on complicated projects that leverage an extensive array of marine- and land-based equipment keeps clients returning as techniques and delivery methods evolve

by Craig A. Shutt

Since it was founded in 1946, Traylor Bros. Inc. has made a name for itself by building complex bridges over waterways throughout the United States. Aided by its four precasting plants and a host of marine- and land-based equipment, the company based in Evansville, Ind., has established a reputation for taking on complicated, difficult assignments.

"We're a large, somewhat specialized civil construction firm, with complex bridges and infrastructure projects in and over waterways as our forte," says Scott Turnpaugh, a division engineer with the firm's National Heavy Civil Division. That reputation has been enhanced by the company's capabilities and equipment, notes Scott Armstrong, a project manager. "We have a large fleet of marine equipment that makes us uniquely suited to marine work," he says. "We also have a large fleet of cranes that can work on land or water."

Innovative Waterline Work

Traylor's success comes from its innovative approaches as well as specialized equipment. For instance, on the Sailboat Bridge across the Grand Lake O' the Cherokees in Grove, Okla., the Oklahoma Department of Transportation expanded the existing bridge into twin 3044-ft-long precast concrete segmental bridges. To contain costs and accelerate construction in the 90-ft-deep waterway, the foundations of the existing bridge were reused by wire sawing the piers at the waterline and removing the superstructure.

Traylor set up a casting yard near the site for the 41-ft-wide, 7.2-ft-deep segments and also used it to cast concrete tubs that were permanently tied into the tops of the cutoff piers. The tubs were then dewatered so crews could work inside them, below the waterline, to connect the new footings to the existing structure.

"It was a unique approach, and it saved a lot of time due to the depth of the water," explains Skylar Lee, manager in the National Heavy Civil Division and the project manager. "It would have been difficult to build cofferdams or other support systems. We wanted to create permanent elements that ensured we could work in the dry."

Another creative solution was used for the Interstate 45 Galveston Causeway bridge-replacement project in Galveston, Tex. There, the shallow waters of the Intracoastal Canal to Galveston Island were crossed by twin 8592-ft-long structures with three cast-in-place concrete twin-cell segmental main spans. These main spans were constructed using four overhead form-traveler systems for the balanced-cantilever construction. Once the deepest portions were reached, cranes on floating barges were used to finish construction. The remaining 57 spans feature 72-in.-deep prestressed concrete girders.

Procurement Approaches

In recent years, Traylor's creative approaches have involved new delivery methods, including design-build, public-private partnerships (P3), and construction manager at risk (CMAR)—where the construction manager agrees to deliver the project within a guaranteed maximum price. "We're in favor of being part of a P3 team but prefer a teaming structure that includes a separate entity to handle financing," says Armstrong. "We also have done some CMAR projects and continually look for more, as they're fairly similar to design-build projects in the way we participate."

Fifty-seven spans on the Interstate 45 Galveston Causeway bridge feature 72-in.-deep prestressed concrete girders. The frame on the pier cap is part of a system for erecting the girders. Photo: Traylor Bros. Inc.

These new approaches often require more involvement of staff and may cost more, notes Lee. "They create a bigger commitment of resources up front to pursue them, before we learn where the job will go," he says. "But we expect that, as costs to pursue the projects come down, more owners will favor these approaches, which opens more avenues to find funding. But they need to put the risk in the right places."

Traylor served as the subcontractor to design-build manager Fluor on the Conway Bypass project in Myrtle Beach, S.C., the state's first P3 and largest design-build project. This project was part of the state's Partners-in-Progress program designed to accelerate the completion of five significant structures.

Two phases of construction were completed to build 34 concrete bridges over shallow wetland areas. Traylor built its own casting yard and produced more than four thousand 18-in.-thick prestressed concrete flat-slab panels. The company also fabricated more than three thousand seven hundred 18-in.-square prestressed concrete piles at four locations during the project.

"The distance and multiple sites made managing safety and health a difficult task," says Robert DeLouche, project manager. Project management met to discuss safety on a daily basis, creating a proactive stance to stop accidents before they could occur, he adds.

Today, most of the company's projects are delivered through design-build format of some kind, notes Turnpaugh, although the firm also pursues design-bid-build projects. "We like design-build approaches because the earlier we are involved in the process, the more we can help shape the projects through constructability reviews using our technical expertise."

Traylor aims to exercise its unique expertise and abilities when alternative design options are available. "Convincing owners to make changes usually comes down to economics in materials or time," says Turnpaugh. "If we can show an approach provides savings, we'll bring it up. It can be hard to overcome established mindsets, but, as we get more experience around the country, we can apply that knowledge in other states and get an opportunity to advance techniques."

'Convincing owners to make changes usually comes down to economics in materials or time.'

Constructability Reviews

At Traylor, constructability reviews are the driving force for introducing new ideas, notes Lee. "We are always looking at every material to find the best option from a constructability standpoint. What sets us apart is that our people, the estimators and planners who work with designers, have worked closely on designs and have hands-on experience with all the options, so we can anticipate most of the issues that arise and how to meet them."

Typically, he notes, constructability choices come down to two options, whether they involve foundations, substructures, or superstructures.

Traylor served as the subcontractor to design-build manager Fluor on the Conway Bypass project in Myrtle Beach, S.C., the state's first private-public partnership project. Photo: Rob Thompson, South Carolina Department of Transportation.

"Every time, it shakes out that one of two ideas offers the best option, so we work through them to find the [one that is] most effective. In some cases, later decisions make us review earlier choices so that, ultimately, we find the best combination for the entire project, not just for each section."

For example, on the Galveston bridge, Traylor value-engineered several items, including the concrete segment lengths, says Turnpaugh. "We saw an opportunity to optimize the design and create efficiencies by making the segments slightly longer. We could cast them without a problem, and it eliminated a few segments from the total length."

On the Sailboat Bridge, Traylor's team redesigned the type of expansion joint from a rigid one to a steel-finger joint with an elastomeric mortar seal behind the plate connected to the concrete. The new design "created more flexibility and prevented cracking in the concrete," Lee explains.

The ability to perform in-depth constructability reviews depends on the project's schedule, notes DeLouche. "All owners want us to have an opportunity to value-engineer the project to find efficiencies and lower costs," he says. "They almost always offer that chance, but how much can be done depends on the time allotment—and many projects are time-sensitive today." What can be done varies significantly by bridge, owner, and location, he adds. "Soil is different in every state, as is access to the site. Factors vary every time and include desired aesthetics, often based on location, along with longevity and budget."

Traylor's ability to leverage specialized equipment creates a key route to more efficiency. "Equipment capabilities provide a specific constructability 'technique' that goes beyond material or method changes and often make us unique," DeLouche points out. "Each company has its own specialties and expertise, and equipment access is one of ours. When we're involved early in the design process, we can point out these efficiencies to designers. They're often more focused on aesthetics and design issues for the bridge's environment than on efficiencies in constructability."

Speed has become a key issue for all owners, leading Traylor to evaluate a variety of accelerated bridge construction (ABC) methods. "Schedule is always king on projects, especially with P3s that are revenue-generating projects," says Lee. "We always look to minimize overhead and exposure, and ABC techniques help with that. We are very much geared to the faster pace of construction today."

'Schedule is always king on projects, especially with P3s that are revenue-generating projects.'

"We've used a variety of ABC methods," agrees Armstrong. "They don't always produce the most economical approach, but they can provide a shorter construction schedule, which may be the top priority."

Precast Concrete Facilities Aid Projects

The company's own precast concrete facilities, as well as components it purchases from precast concrete producers, often speed up schedules, Armstrong notes. "Precast concrete helps because it creates a parallel track, where the components can be cast while site work is underway. It also removes some of the labor congestion from the site. We often can generate better productivity with our own precast [concrete] factory in that environment."

The company-owned facilities do not drive the firm to default to precast concrete, the project managers agree. "We look at each project with the design team to find the best fit," Turnpaugh says. "Having our own plants gives us more control of the product when precast does turn out to be the best choice." DeLouche agrees. "It depends entirely on the project if our precast plants can help us. We study the situation and what resources are available and if our plants best fill the bill."

Traylor does not use its own products exclusively. "We always cast our own segmental pieces, because those are

The Louisiana Highway LA1 relocation project Phase 1B has a 4-mile-long, high-level bridge featuring prestressed concrete piles, cast-in-place substructures, Type III and BT-78 prestressed concrete girders, precast concrete deck panels, and a cast-in-place concrete deck. Photo: Traylor Bros. Inc.

custom, one-off designs we can produce efficiently," Turnpaugh explains. But standard precast concrete girders and other traditional components often are purchased from local precasters. "The setup costs can be so high that we outsource them to others already producing them efficiently."

In-house and outsourced components combined for the Louisiana Highway LA1 relocation project, in which phase 1B consisted of constructing a 4-mile-long, high-level bridge with connecting ramps and interchanges. The structure consisted of 16-, 24-, and 30-in.-square prestressed concrete pile foundations, cast-in-place substructures, Type III and BT-78 prestressed concrete girders, precast concrete deck panels, and a cast-in-place concrete deck.

The girders were purchased from a local precaster, while Traylor set up a plant 5 miles from the site to produce ready-mix concrete for the cast-in-place concrete. "We always look at the balance between controlling the process versus the risk of outsourcing," explains DeLouche, the project manager. "We look at whether local companies can be more efficient, reliable, and capable of supplying product on time at the needed quantity."

Many federal projects require use of local subcontractors, he notes, and hiring local precast concrete producers helps meet that requirement effortlessly. "We weigh every factor in finding the most efficient approach."

New Techniques

As demands for better, faster, and more economical bridges increase, Traylor evaluates new approaches to concrete design. "Owners want to extend service lives to 100 years in general, and even to 125 years in some cases," says Lee. "We look to additives like silica fume and slag; we do more early tests to determine durability; and we are increasing concrete cover."

Some owners, more-so in the northeastern United States, require stainless steel reinforcement, and the New York Thruway requires galvanized steel. "There definitely is a shift to more corrosion-resistant reinforcement overall," adds Lee. Concrete adds inherent benefits because it resists adverse weather conditions and does not need to be painted, DeLouche notes. "It also can withstand heat and fire very well, which can be a significant factor." DeLouche is also a fan of precast concrete panels for driving surfaces.

'There definitely is a shift to more corrosion-resistant reinforcement overall.'

"We're seeing them used more often, with some states virtually requiring them now," he says. "Others don't like them, possibly due to a past experience, but they have become reliable and popular. I expect their use will grow, as they offer a durable option."

Traylor's History

Traylor Bros. Inc. was founded in 1946 by William F. Traylor, who had experience inspecting a compressed-air tunnel for the City of Evansville, Ind., and worked in the Navy's Pacific Theater Construction Battalion in World War II. His son, Thomas W. Traylor, succeeded him as president, and the company now is led by Thomas' two sons, copresidents Christopher and Michael Traylor.

The firm is based in Evansville, with additional offices in Alexandria, Va., and Long Beach, Calif. It also owns four precast concrete plants, in Tacoma, Wash., Houston, Tex., Littlerock, Calif., and Stockton, Calif. It maintains a fleet of marine-based equipment and a variety of cranes that can be barge-mounted or operated from land.

The privately held firm was ranked 60th in the top design-build firms by *Engineering News Record* (ENR) in 2016, and was ranked 202nd in ENR's 2015 Top 400 Contractors listing, with revenues estimated at $318 million.

Traylor will continue to seek new ideas and present owners and designers with new options. "Our earlier involvement with projects provides the opportunity to introduce new ideas and present those options, and we'll continue to look for them," says DeLouche. "We have a lot of professionals with great expertise, and we will continue to tap into that resource to create more efficiencies."

On the Interstate 45 Galveston Causeway replacement project in Galveston, Tex., Traylor Bros. built three cast-in-place concrete, twin-cell segmental main spans using four overhead form-traveler systems for the balanced-cantilever construction method. Photo: Traylor Bros. Inc.

PERSPECTIVE

Funding of Highway Trust Fund Needs Fixing

by Todd Johnston,
Portland Cement Association

Memorial Causeway Bridge in Florida.
Photo: Portland Cement Association.

As Congress weighs implementation of a $1.5 trillion infrastructure package, supporters of infrastructure spending are pushing for a long-term funding mechanism for the Highway Trust Fund (HTF).

As with many federal programs, the intent of the HTF was good, but its funding is insufficient to maintain the current system of U.S. highways and bridges, let alone build a modern system. In fact, Congress has had to transfer $140 billion into the HTF since 2008 to prevent its insolvency.

The HTF is funded through a number of sources, including a fixed-rate per-gallon excise tax on the sale of gasoline and diesel fuel; a sales tax on heavy trucks, trailers, and tires; and an annual heavy vehicle use tax for vehicles weighing more than 55,000 pounds. The primary source of funding is fuel fees, which have not been increased since 1993. According to the Congressional Budget Office, the HTF is projected to face a more than $100 billion shortfall over the next decade. Because of this shortfall, a wide-ranging coalition of transportation, business, and labor organizations—including the Portland Cement Association (PCA) and the Precast/Prestressed Concrete Institute (PCI)—are urging lawmakers to fix the funding of the HTF as part of an infrastructure package.

Among other reasons, it is imperative that Congress provide funding for the HTF to pay for the thousands of bridges that are needed across the nation. By adding lanes or building new bridges, the total area of bridges in the United States has been growing during the past 10 years at an annual rate of nearly 42 million square feet. Unfortunately, even this level of new bridge construction and expansion has not kept pace with demographic growth. A 2017 analysis by PCA noted several factors that underpin the need for more bridges. By 2040, PCA forecasts:

- An increase in the nation's baseline population of 59 million people (a 17.4% increase)
- Nearly 40 million more licensed drivers
- Nearly 53 million more vehicles on the roads
- An increase in the total number of annual vehicle miles traveled of 600 billion

There are currently more than 610,000 highway bridges in the United States. As population and the number of drivers on the road increase, so will the total number of vehicle miles traveled and the number of bridge crossings. PCA's forecast shows that the number of bridge crossings is expected to increase from 733 billion in 2015 to nearly 867 billion by 2040. The combination of increased crossings and rising vehicle weights will accelerate bridge wear and tear, meaning more existing bridges will become structurally deficient earlier in their lives. Thus, PCA anticipates the need for 140,000 new or replacement bridges by 2040, with at least 70% of these having concrete superstructures.

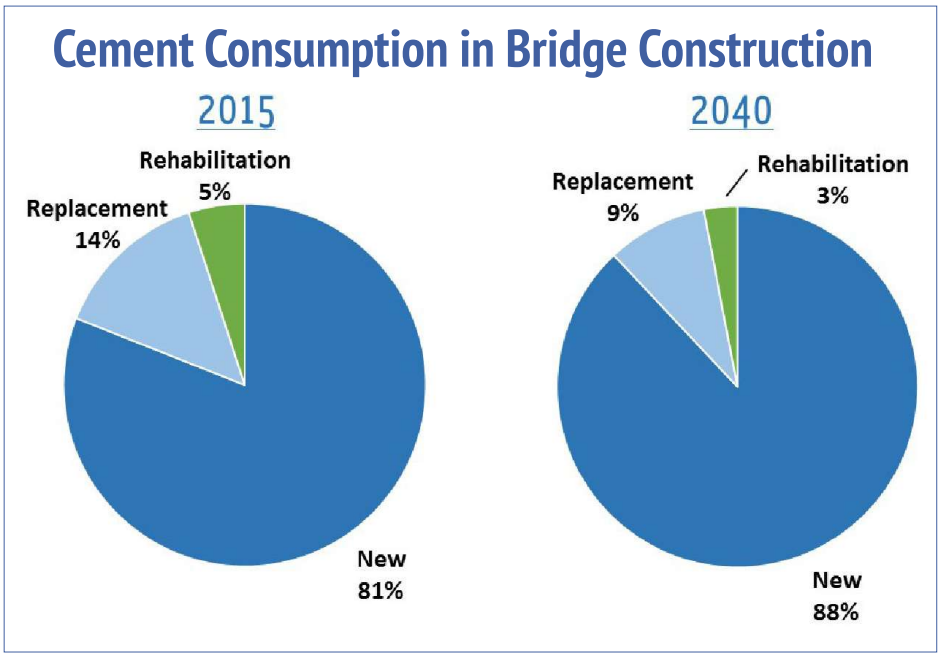
Our nation's bridges are just one of the critical needs of our transportation system. None of the issues will be adequately addressed, however, if the HFT remains insolvent. That is why lawmakers need to take advantage of this opportunity to address the HTF's long-term funding challenges.

Talk of funds, bridges, and highways obscures the fundamental issue in the infrastructure debate—in the final analysis, the issue is about people. A robust, modern transportation system stimulates economic development and raises standards of living. That is good for everyone, including the men and women who work in the cement and concrete industry and the communities where they live.

Cement and concrete product manufacturing, directly and indirectly, employ approximately half a million people, and our collective industries contribute approximately $100 billion to the U.S. economy. The U.S. cement industry has an extensive presence across the country, with more than 90

manufacturing plants in 32 states and distribution facilities in every state.

As part of PCA's message to lawmakers on the need for a robust infrastructure package, we stress the direct economic benefits for the cement workforce and its communities. In terms of the bridge market's importance to the entire U.S. cement industry, the bridge market now accounts for 7.5% of the total United States cement market—up from 3.7% in 2000. In 2015, roughly 81% of bridge cement consumption was attributed to new construction, 14% to bridge replacement, and 5% to bridge rehabilitation. In 2040 PCA projects that 88% will be attributed to new bridges, 9% to bridge replacement, and 3% to bridge rehabilitation. To meet that demand PCA expects cement consumption in the bridge sector to increase by an average of 0.3% annually through 2040.



Todd Johnston is executive vice president of the Portland Cement Association, which represents U.S. cement manufacturers.

EDITOR'S NOTE

The term "structurally deficient," which has been used for many years to characterize the condition of U.S. bridges that are in some state of disrepair, is no longer used in federal regulations, as discussed in the FHWA article appearing on this issue of ASPIRE®.

PROJECT

MOUNT HOPE BRIDGE

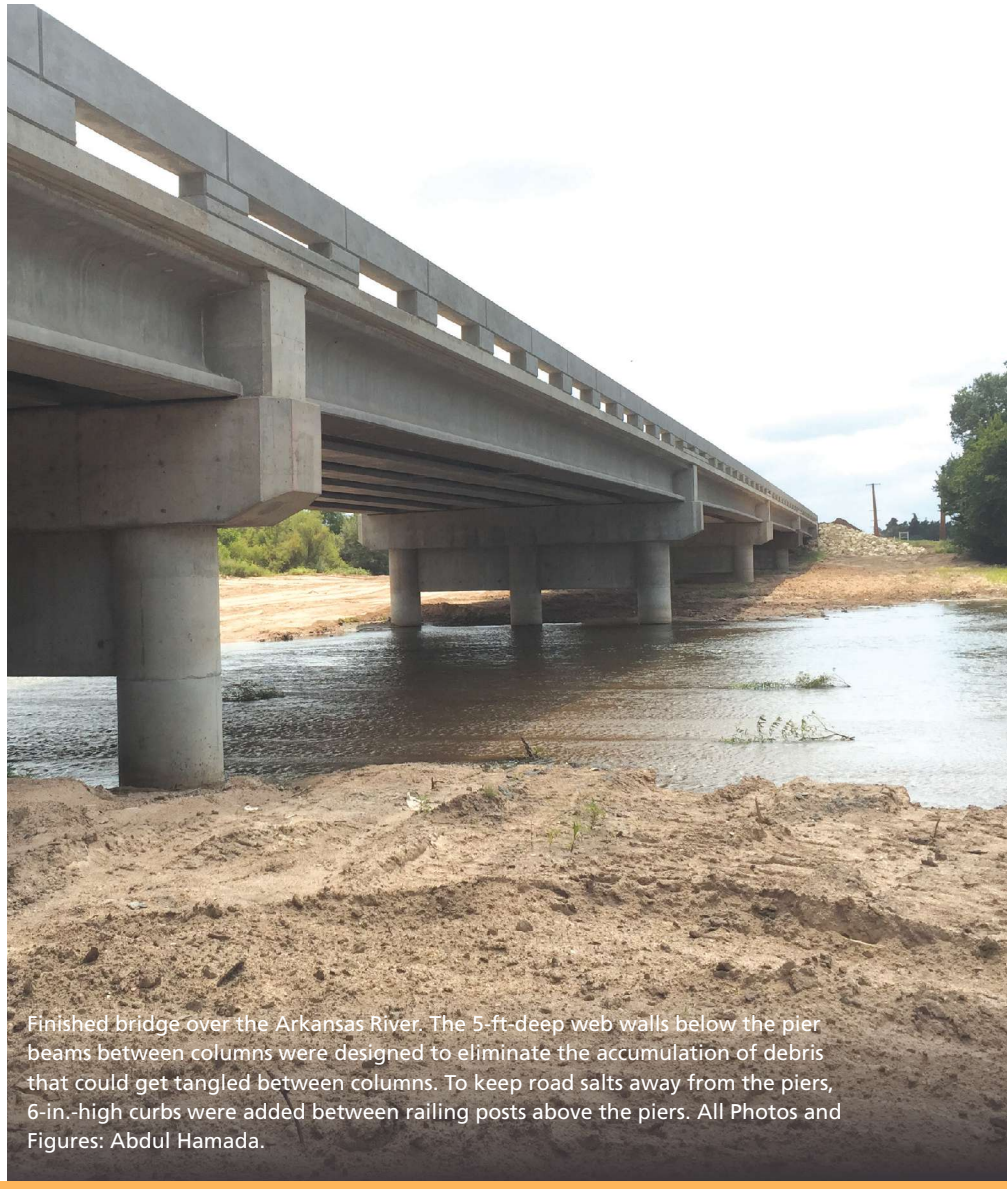
by Abdul Hamada, WSP

The Mount Hope Bridge project is located about 2 miles north of the small rural town of Mount Hope in Sedgwick County, Kans. The bridge spans the Arkansas River and carries 279th Street West, a major collector, and is essential for the local farming community and the traveling public. Every harvest season farmers drive heavy machinery across this bridge, and, after 60 years of use, the previous eight-span, 654-ft-long, and 26-ft-wide structurally deficient bridge had to be replaced to accommodate the traffic demand.

Timeline

Construction of the project started in November 2014 and had an anticipated end date of November 9, 2015. The schedule was accelerated to minimize the closure period of the vital route and the impact of that closure on the farming community. The project timeline was also influenced by the Kansas Department of Wildlife and Parks requirement for construction to stay out of the wetted channel from April 1 to August 31 to protect multiple endangered fish species.

In fact, the project was completed on September 30, 2015, weeks ahead of schedule. The timeline was shortened because Sedgwick County Public Works provided a temporary construction staging area for the contractor and because all environmental and hydraulic permits were acquired before the start of construction. The simplicity of the



Finished bridge over the Arkansas River. The 5-ft-deep web walls below the pier beams between columns were designed to eliminate the accumulation of debris that could get tangled between columns. To keep road salts away from the piers, 6-in.-high curbs were added between railing posts above the piers. All Photos and Figures: Abdul Hamada.

profile

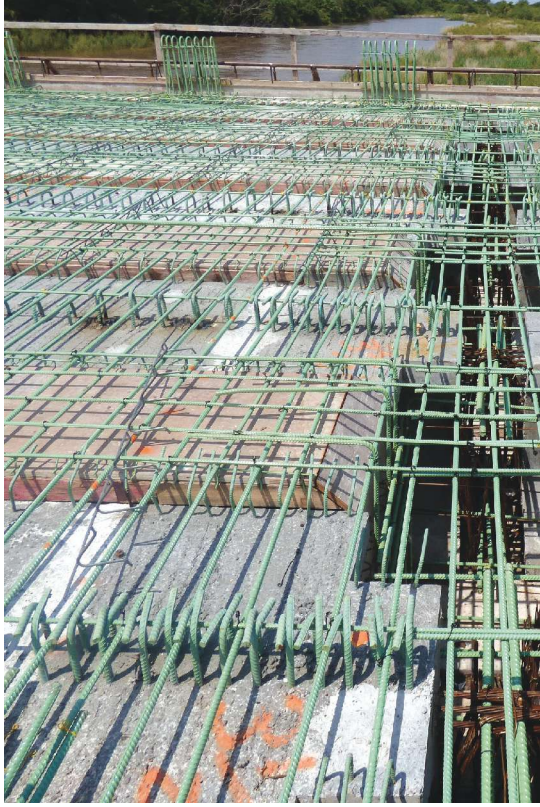
MOUNT HOPE BRIDGE / MOUNT HOPE, KANSAS

BRIDGE DESIGN ENGINEER: WSP, Wichita, Kans.

PRIME CONTRACTOR: Dondlinger Construction, Wichita, Kans.

PRECASTER: Coreslab Structures, Kansas City, Kans.—a PCI-certified producer

NU 1100+25 prestressed concrete girders are in place, and reinforcement is being placed for the abutment. Bent strands extending from girders are used for the connection to the abutment as well as in diaphragms between spans.



All reinforcement in the superstructure was epoxy-coated.

plans and the use of the shallow precast concrete beams were also major factors in completing the project ahead of the tight schedule.

Detour Planning

The project site was too narrow for staged construction, so the project used a signed detour. The official designated signed detour was approximately 22 miles long and used a route that included a bridge at 117th Street North, which was part of another replacement project. That construction had to be completed before work could begin on the Mount Hope Bridge. Coordinating with emergency response teams to ensure coverage for areas north of the bridge, as suggested by the Sedgwick County project manager, was another important step in the detour planning.

Public Engagement

Sedgwick County Public Works conducted several public meetings and published articles in the local newspaper to educate the public about the construction schedule, environmental concerns, detour route, and the construction progress. From the public meeting and discussions, the owner and the transportation-design consultant gained ideas about the scope and importance of the project. The needs of local farmers and the safety of the traveling public became important aspects of the project design. Because the previous bridge could not carry wide farming equipment, the local farmers had to take a long detour. Also, the previous bridge did not have a shoulder, which made it unsafe for travelers who became stranded on the bridge or needed to stop for assistance. In response to these issues, the new design included two 12-ft-wide lanes and two 6-ft-wide shoulders with barriers that comply with current Kansas Department of Transportation design specifications.

Environmental Issues and Construction Challenges

Because the project involved working both over and in the Arkansas River, special permits were required. These were obtained by the owner and the consultant in advance of the start of construction, which allowed the construction schedule to be shortened.

The contractor was obligated to comply with all regulations during construction. A site-specific Stormwater Pollution Prevention Plan was developed to protect and control both potential erosion and the endangered fish species that inhabit

SEDGWICK COUNTY PUBLIC WORKS, OWNER

BRIDGE DESCRIPTION: Replacement of an existing 654-ft-long, 26-ft-wide, 8-span, deteriorated steel beam bridge with a 683-ft-long, 38-ft-wide, 6-span (115-110-110-110-110-115 ft) prestressed concrete beam bridge over the Arkansas River.

STRUCTURAL COMPONENTS: Thirty-six 3 ft 8 5/16-in.-deep prestressed concrete bulb-tee girders spanning 110 or 115 ft; 8½-in.-thick cast-in-place concrete deck; cast-in-place pier caps, and cast-in-place columns and abutments with pile foundations. Epoxy-coated reinforcement was used in the abutments, girders, deck, and railings.

BRIDGE CONSTRUCTION COST: $3,164,200 ($128.40/ft^2)

AWARDS: Kansas American Public Works Association award

the river. As part of this plan, the erosion control measures were inspected every two weeks and after any weather event with more than 0.5 in. of rainfall, and the control measures were repaired or replaced as required.

A temporary river crossing that allowed for the free passage of the various aquatic species in the river was required for the project. The contractor paid special attention to the construction of this crossing to minimize turbulence both during its construction and removal.

Construction of the substructure was completed before April 1, 2015, the start of the critical period in which construction in the active channel was prohibited. To meet the overall construction schedule, the start of construction above the active channel coincided with the period in which construction was prohibited in the active channel.

For greater longevity, the three-column, cast-in-place concrete piers were constructed atop a concrete foundation supported by friction steel piles. Wooden piles had been used in the original 1954 bridge. The number of pier bents in the channel was decreased, and the piers were aligned with the flow of the channel to minimize impact of any potential scour. A 5-ft-deep web wall was added below the pier beam and between columns to eliminate the accumulation of any debris or brush that could get tangled between piers, again to mitigate possible causes for scour.

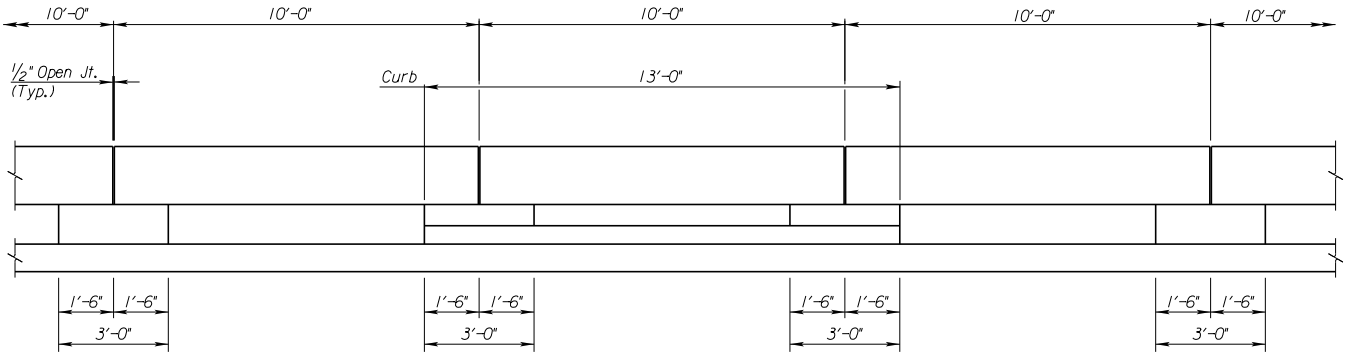
The bridge is in a high-risk Federal Emergency Management Agency (FEMA) flood zone AE, which has a 1% annual chance of flooding— more commonly known as the "100-year floodplain." Bridges in a FEMA zone AE must be designed to prevent any rise to the backwater surface profile. Therefore, the new waterway opening needs to match the existing waterway opening to keep the characteristics of the flow and conveyance of the river unchanged. A design that alters the river's flow and conveyance may lead to flooding downstream or upstream. This hydraulic issue was a challenge in the design, but it was resolved by the careful placement of abutments, piers, and superstructure. The project successfully achieved minimal impact on

Construction Timeline

The actual bridge construction activity start dates were as follows:

August 26, 2014	Bridge letting
October 6, 2014	Begin construction
November 2014	Demolish existing bridge
December 2014	Drive piles; form and place concrete for abutments and piers
March 2015	Place precast concrete girders
April 1 to August 31, 2015	Construction not permitted in wetted channel; superstructure construction continues over channel
April 2015	Cast concrete for intermediate diaphragms; place deck forms and install reinforcement
July 2015	Place cast-in-place concrete deck and install bridge rail
September 30, 2015	Construction complete

Open corral rail with 6-in.-high curb above piers to keep runoff from reaching piers and help prevent corrosion.



PARTIAL CORRAL RAIL ELEVATION
(Along Traffic Face, West Corral Rail shown, East Corral Rail similar)
Showing curb above Pier #2 and Pier #4

the channel below ordinary high water.

The selection of superstructure type was a key decision for this bridge project because it related to the environmental concerns, construction costs, and maintenance costs. Low-profile precast, prestressed concrete bulb-tee girders were selected to maximize the span lengths needed for fewer number of bents in the Arkansas River. These NU1100+25 girders—NU is named after University of Nebraska and is a cross-section type often used in the midwestern states—were designed to span 110 and 115 ft and were 3 ft $8^{5}/_{16}$ in. (1125 mm) deep (30:1 span-to-depth ratio). The NU1100+25 girders had a top flange approximately 4 ft wide and a bottom flange approximately 3 ft 3 in. wide and that contained 0.6-in.-diameter prestressing strands. The span arrangement of the bridge was 110, 115, 115, 115, 115, 110 ft with a total bridge width of 38 ft. Precast, prestressed concrete girders with wide flanges were chosen in part because they would take the least time for construction over the wetted channel, which helped the project deal with the scheduling limitations related to protection of endangered fish species.

Another reason that shallow bulb-tee girders were chosen was to minimize the raising of the vertical profile grade of the road. Keeping the profile low and keeping construction away from a nearby intersection minimized both right-of-way acquisition and approach work. This strategy, in turn, limited the impact of the project on adjacent property owners and reduced the cost of the project significantly.

The precast, prestressed concrete girders were also chosen because of their low maintenance costs. At the time of replacement, the previous bridge's steel beams were severely deteriorated and showed a significant amount of rust. The use of concrete decreased life-cycle costs because concrete requires no paint, does not rust, and exhibits less fatigue than steel. The precast, prestressed concrete girders were cast in an environmentally controlled manufacturing site, which virtually eliminated poor-weather construction situations. By using a system of prestressed concrete girders, cracks are minimized and the durability and longevity of the bridge are increased.

Kansas has harsh winters with snow and ice. To increase the life of the bridge, epoxy-coated reinforcement was used in the superstructure to minimize corrosion in the abutments, girders, deck, and railings that are exposed to road salts during the winter months. The piers can also be exposed to road salts if measures are not taken to protect them. In addition to strip-seal assemblies at the expansion joints, 6-in.-high curbs were added between the posts of the open corral railing above the pier bents, to keep salted water and water runoff from reaching the piers and help prevent corrosion in those vital areas.

Conclusion

Through partnership and close coordination among all the parties involved in the bridge project, all challenges were resolved. The contractor was able to start the project on the Notice to Proceed date; the project was completed ahead of schedule, despite several rainy periods; all the environmental concerns were addressed before or during construction; and the project was open to traffic more than a month ahead of schedule. In addition, the early completion of the project allowed the local community to harvest in the fall of 2015 with minimal interference from bridge construction, and no major complaints about the project were raised during construction.

Abdul Hamada is a project manager with WSP in Wichita, Kans.

NEW JERSEY ROUTE 72—
Eastbound Over Manahawkin Bay Bridge

by Joseph Mumber, David Rue, and Steve Esposito, WSP, and
Pankesh Patel, New Jersey Department of Transportation

Owned and maintained by the New Jersey Department of Transportation (NJDOT), the causeway carrying New Jersey Route 72 over Manahawkin Bay is the only access from the New Jersey mainland to the beach communities of Long Beach Island (LBI), an 18-mile-long coastal barrier island. LBI is home to 20,000 year-round residents in six separate municipalities. During the peak summer tourist season, the population swells to more than 150,000. Therefore, a safe, reliable, and resilient highway connection is essential for residents and visitors, as well as for the local economy.

Aerial view of bridge with all 102 prestressed concrete beams installed and deck installation starting from the east end and extending past the navigation channel. All Photos: WSP and NJDOT.

Resilience Needed

By the early 1990s, many of the fatigue-sensitive details in the existing steel stringer-floorbeam bridge, which was designed in the 1950s, had failed or were failing. NJDOT considered the following alternatives for this critical corridor: total replacement of the bridge; providing dual structures by building a new parallel bridge for one direction and rehabilitating the existing bridge for the other direction; and rehabilitation. To satisfy NJDOT's desire for resiliency, the dual-structure alternative was selected.

The new concrete superstructure is designed to offer distinct advantages over the older design by eliminating the fatigue-prone details. Also, when coupled with the superstructure replacement of the existing bridge, the new, parallel eastbound structure provides operational redundancy in the corridor. If either bridge needs to be closed for any reason (such as hurricane, earthquake, or vessel impact), the other structure will be adequate to carry both directions of traffic.

This approach was validated in 2012, when Superstorm Sandy made landfall near Brigantine, N.J., causing widespread damage to the state's infrastructure. Although the structures on Route 72 were not severely damaged, the storm did cause scoured conditions at several locations, and NJDOT maintenance stabilized the affected structures by installing riprap. The scour design was updated for the project to prepare for hurricane-strength storm-surge conditions suggested in the post-Sandy Federal Emergency Management Agency flood insurance study for the project area. Hydraulic models were updated to include new fathometer survey information that accounts for poststorm conditions. The new bridge was designed to withstand the predicted scour depths without countermeasures. Articulated concrete block mattresses were incorporated to protect the existing bridge's scour-sensitive abutments, and the existing piers were found to be stable for the design storm.

Other Design Features

The new structure was designed to accommodate two lanes of traffic in the eastbound direction, while the existing bridge will carry two lanes westbound once the rehabilitation is completed in 2019. The eastbound structure is 2400 ft long and 52 ft 9.75 in. wide, with six lines of prestressed concrete girders made

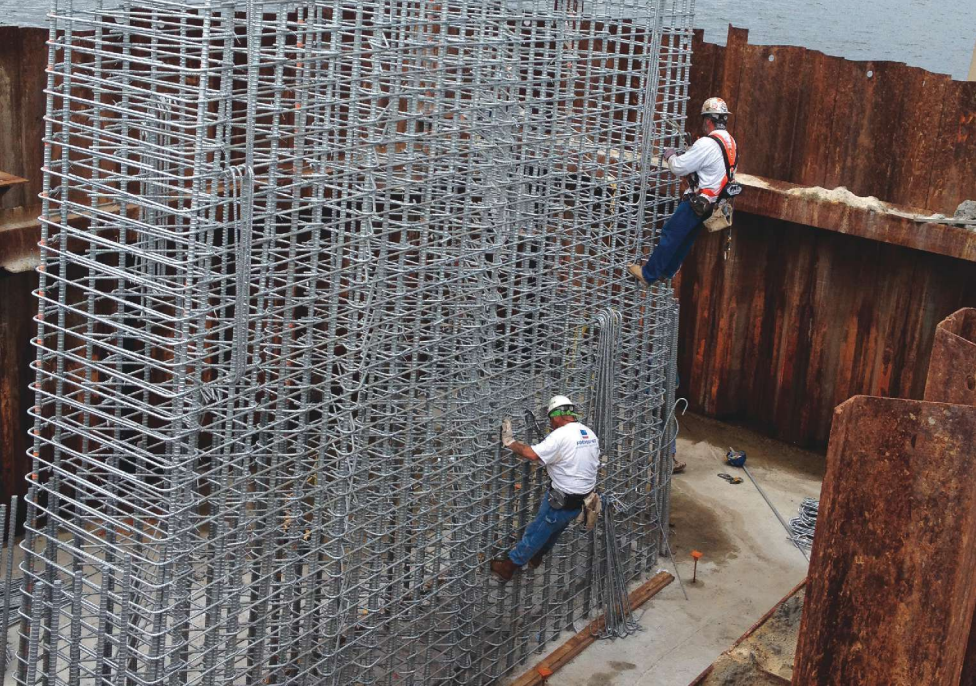
profile

NEW JERSEY ROUTE 72 EASTBOUND OVER THE MANAHAWKIN BAY / STAFFORD TOWNSHIP AND BOROUGH OF SHIP BOTTOM, OCEAN COUNTY, NEW JERSEY

BRIDGE DESIGN ENGINEER: WSP Inc., Lawrenceville, N.J.

PRIME CONTRACTOR: Schiavone Construction Co. LLC, Secaucus, N.J.

PRECASTER: Bayshore Concrete Products, Cape Charles, Va.—a PCI-certified producer



Galvanized reinforcement cages were assembled on barges and lifted into place, extending up and out of the sheetpile cofferdams.

continuous for live load. There are 17 spans that range from 98 ft 8 in. to 147 ft 7 in. from center-to-center of bearings, totaling 102 girders. The concrete girders are among the longest prestressed concrete girders used on any NJDOT project. The final lane configuration on the new bridge includes two 12-ft-wide lanes, a 13-ft-wide inside shoulder, and a 12-ft-wide outside shoulder.

Options considered for the new bridge included both steel and concrete multigirder superstructures with various span lengths. Based on the results of a life-cycle cost estimate for future maintenance costs, NJDOT selected concrete for its durability—an important factor considering the corrosive coastal environment of the bridge location—and its relatively low future painting and maintenance costs as compared to the expenses required for maintaining steel bridges. Furthermore, due to advances in the concrete industry, simply supported precast concrete girders could span the distance needed for the new piers to be set in line with the existing piers, eliminating new obstructions for navigational traffic. Also, NJDOT realized that a concrete bridge made sense because many precast concrete producers in the region have the capability to provide concrete with high compressive strengths and low permeability, and to produce and ship large prestressed concrete beams.

Girder Design

Efficient precast concrete girder sections were selected, in accordance with the Federal Highway Administration's (FHWA's) prestressed concrete economical fabrication (PCEF) initiative, to standardize beams and forms for production. Six XB 79 x 48 PCEF prestressed concrete bulb tees were spaced at 9 ft 3 in. on center for the superstructure. The 79-in.-deep beams used a high-performance concrete mixture with a design compressive strength of 8.5 ksi. The standard 7-in.-thick web was increased to 8 in. to accommodate NJDOT's concrete cover requirements and increase durability, resulting in a total top flange width of 48 in. All mild reinforcement used in the beams was galvanized to match the deck steel and increase corrosion resistance; prestressing steel was plain and not coated. To protect against galvanic corrosion, dielectric insulators were used to avoid contact of dissimilar metals within the beams.

Prestressed concrete beams being erected at Span 15. These 79-in.-deep beams are 150-ft-long and weigh 90 tons. The beams were fabricated in Virginia, shipped by barge to a marina in Camden, N.J., and finally trucked to the project site.

NEW JERSEY DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: New 2400-ft-long bridge over the Intracoastal Waterway, prestressed concrete beam superstructure with cast-in-place deck and piers with galvanized reinforcement

STRUCTURAL COMPONENTS: Twelve 100-ft 4-in.- long, 79-in.-deep prestressed concrete beams; twelve 124-ft-long, 79-in.-deep prestressed concrete beams; seventy-eight 149-ft-long, 79-in.-deep prestressed concrete beams.

BRIDGE CONSTRUCTION COST: $89.8 million (cost of eastbound bridge and approach roadway tie-ins)

AWARD: American Council of Engineering Companies of New Jersey honor award – large project

As required by NJDOT's bridge design practices, the girders were designed for zero tension within the precompressed tensile zones to provide an increased factor of safety against cracking. To minimize the number of deck joints (often a source of chloride attack from deck runoff), the deck was made continuous for live load over all but four piers. At piers where continuity for live load was specified, the strands extended out of the beam ends into cast-in-place concrete diaphragms, and additional longitudinal reinforcement in the deck slab over the piers provided negative moment reinforcement for continuity and structural integrity.

As part of FHWA's "Every Day Counts" initiative, precast concrete piers were evaluated for their potential to shorten the construction schedule. To ensure that economy was achieved, precast concrete piers were included as an alternate bid item to the conventionally constructed concrete hammerhead piers.

Considering Options

One of the primary goals for the project was to attain geometric/aesthetic similarities between the two structures. The existing hammerhead bridge piers consisted of a tapered wall column with a hammerhead cap. The wall columns were tapered in two directions. For the new bridge piers, as recommended by precast concrete manufacturers during design, the pier column segments were designed and detailed to be solid, rather than hollow, and tapered in only one direction to reduce formwork costs and complexities of the pier shapes wherever possible. Solid segments also reduced congestion of reinforcement and eliminated spaces where water might intrude and accumulate inside the piers. Galvanized post-tensioning bars were detailed for the pier segments and were terminated within the footing to eliminate corrosion concerns with post-tensioning near the waterline. After studying several options for precast concrete pier caps, a precast concrete voided shell filled with cast-in-place concrete was incorporated in the bid documents. Precast concrete segment geometry was repeated to simplify fabrication and improve economics. Precast concrete piers and caps were ultimately not selected for construction by the successful bidder, but their inclusion in the bid documents ensured a competitive price and demonstrated that precast concrete pier construction was a viable option.

The span configuration is comprised of two end units with three spans (100, 125, and 150 ft, center-to-center of piers), two interior units with three spans (150 ft each, center-to-center of piers), and one middle unit with five spans (150 ft each, center-to-center of piers, with the center span located over the Intracoastal Waterway), for a total of 17 spans. Making each unit continuous for live load further economized the design and allowed for elimination of 12 deck joints. The largest continuous segment is the five-span unit over the navigation channel, with a total length of 750 ft. Modular deck joints were used to accommodate the large thermal movements and account for creep in the beams. The piers were founded on six 6-ft-diameter drilled shafts that terminate 70 to 85 ft below the bay bottom.

The twin-bridge configuration allows future maintenance of the bridges to be performed offline while maintaining all lanes of traffic on the opposite structure. Although staged-construction requirements typically dictate placing a girder at the middle of a bridge's cross section, the twin-bridge arrangement did not require a center girder, allowing for larger girder spacing and an even number of girders to save costs. Use of modestly sized beams helped limit superstructure dead load on the foundation, allowing a more efficient foundation design and further cost savings. The concrete structure achieved all primary project objectives, including providing redundancy, enhancing safety, and improving traffic operations.

Design for Hazards

Seismic vulnerability was another important factor in designing the new bridge for resiliency. Because the new structure would be the single point of access to and from LBI, its operational classification was deemed "critical"; therefore, ground motions consistent with a design return period of 2500 years were incorporated into the design.

The substructure units were also designed to withstand vessel impacts. A vessel survey was conducted to determine the appropriate design vessel for the bridge. It concluded that the 200-ton barge minimum load per American Association of State Highway and Transportation Officials' specifications governed the design because the predominant ships in the bay are pleasure crafts. The piers and foundations were designed for winds as high as 110 mph and ice as thick as 5 in. drifting in the bay, which is commonly observed to freeze over during the winter.

To protect the fish species that inhabit the environmentally sensitive Manahawkin Bay, the environmental

The east pier at the navigation channel extends more than 55 ft above the water to provide a 100-ft-wide by 55-ft-high navigation clearance for the Intracoastal Waterway.

Featured Lighting

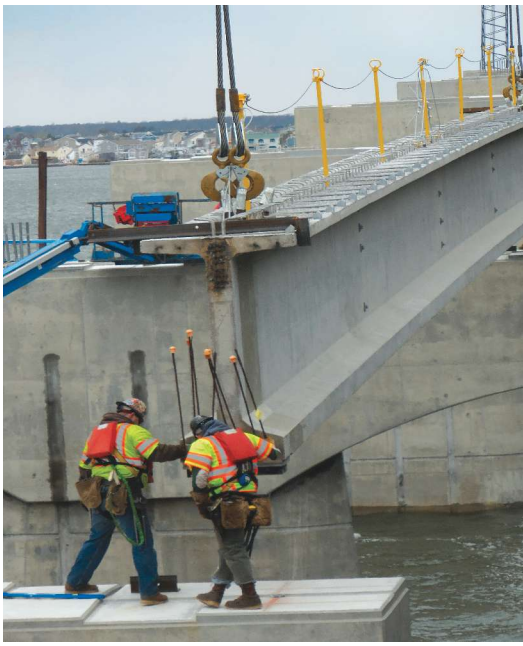
One of the most distinctive features of the existing bridge is that the roadway lighting fixtures are built into the bridge railing, making the view of the bridge at night unique. The bridge is formally named the Dorland J. Henderson Memorial Bridge, after the NJDOT engineer who designed the in-rail lighting system more than 50 years ago. As a tribute to Henderson's contribution to the original design, NJDOT has replicated the railing lighting in the new bridge by attaching linear lighting to the outside of the south parapet of the new bridge and the north parapet of the existing bridge; this lighting is strictly aesthetic.

permits prohibited in-water work from January 1 to June 30 each year, with the caveat that work occurring inside a steel cofferdam would not be considered in-water work. Once the steel cofferdams were installed for the piers, work could proceed unrestricted on the pier foundations.

Construction for this project began in May 2013, and the new bridge over the Intracoastal Waterway opened to traffic on April 22, 2016.

Close coordination between the design team, owner, and precast concrete industry ensured that the bridge details were resilient, efficient, and economical. This partnership with the precast concrete industry facilitated the successful construction of the project, which was completed with minimal modifications proposed by the fabricator, and maintained the desired schedule for opening the bridge to traffic.

Joseph Mumber is vice president, senior technical principal, and structures department manager; David Rue is a senior supervising engineer and senior technical principal; and Steve Esposito is supervising structural engineer and senior technical principal all with WSP in Lawrenceville, N.J. Pankesh Patel is the project manager for the New Jersey Department of Transportation in Trenton, N.J.



One of the 79-in.-deep prestressed concrete beams being erected. Strands extend out of the beam end and are incorporated into the cast-in-place concrete diaphragm for continuity at the pier.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

Since it was built more than 50 years ago, the Dorland J. Henderson Memorial Bridge has been a distinctive bridge, recognized in architectural circles as well as among engineers. It has been noted for its graceful, tapered piers as well as its innovative "string of pearls" lighting. The New Jersey Department of Transportation (NJDOT) is justifiably proud of it. The agency's decision to keep it and build a new similar bridge parallel to it is thus a double win. The original bridge is both preserved and amplified.

The aesthetic value of these bridges begins with their tapered piers. It is amazing how much the basic decision to batter the piers in both directions can improve the appearance of a structure. The reason traces back to people's intuitive impressions of vertical structures. A structure that is wider at the bottom than at the top looks (and is) more stable, and thus seems more satisfying. Nature provides a model: tree trunks are always thicker near their bases than at their tops. (The appearance of retaining walls can be improved the same way, and for the same reason, by simply battering their faces.) A taper can get out of hand if the structure is very tall, but that can be avoided by decreasing the degree of taper. Nature again offers a model: the degree of taper of a redwood trunk is much less than on a live oak, but they are both attractive trees.
The piers borrow another feature from nature: the hammerheads join the pier shafts by means of a curve. Tree branches similarly curve as they join their trunks. It is nature's way of minimizing the higher stresses of a re-entrant corner, a problem engineers also must resolve. The team's development of a precast concrete construction option proves that these features can be applied even with precasting, though the contractor chose not to employ that technique.

Finally, NJDOT's decision to reinstate the string of pearls lighting using modern LED technology must be very heartening to the long-time residents of this recreational area. People come to Long Beach Island to relax and enjoy the attractive natural environment. When we insert something into such environments, there is a heightened responsibility to make sure that the new object adds to, and does not detract from, that environment. The new Manahawkin Bay Bridge meets that standard.

Structural Design Using Stainless Steel Strands

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

This article highlights some of the articles in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* that need special consideration when stainless steel strands are used in the design of pretensioned concrete members. The article numbers and titles referenced here are those of the 8th edition of the specifications.[1] The numbers in parentheses are article numbers (if different) from the 7th edition.[2]

Stainless steel strands being used in the production of prestressed concrete piles for Louisiana Department of Transportation and Development Bayou Thunder Overflow Project (LA 1 bridges near Grand Isle). All Photos: Krista Brown.

5.4.4 Prestressing Steel

Article 5.4.4.1 states that strand shall conform to AASHTO M 203. The AASHTO *Standard Specification for Steel Strand, Uncoated Seven-Wire for Concrete* (AASHTO M 203)[3] provides the required properties for Grades 250 and 270 carbon steel prestressing strands. No similar standard currently exists for stainless steel. A comparison of the properties of carbon steel strand and 2205 stainless steel strand is provided in the following table. Currently, the availability of 2205 stainless steel strand is limited to Grade 250, which has a slightly smaller nominal cross-sectional area than Grade 270. The lower strength of the stainless steel requires more strands compared to a design using Grade 270 strands.

5.4.4.2 Modulus of Elasticity

Article 5.4.4.2 states that the modulus of elasticity of prestressing steel may be taken as 28,500 ksi, if more precise data are not available. As shown in the table, 2205 stainless steel has a lower modulus of elasticity than conventional 1080 strand. Therefore, the lower modulus of elasticity shown in the table would be more appropriate to use when designing with 2205 stainless steel strand. However, it is most accurate to use the value recommended by the manufacturer.

5.5.4.2 Resistance Factors

As shown in the table, 2205 stainless steel strand has considerably less elongation at rupture than conventional 1080 strand. Consequently, flexural members are likely to have less maximum ductility when stainless steel strand is used. To offset this lower maximum elongation, it may be appropriate to use a lower value for the strength resistance factor ϕ in tension-controlled sections when 2205 strand is used. However, specific values for ϕ have not been determined.

	AASHTO M 203	Stainless Steel
Steel type	1080 carbon	2205 stainless
Grade	250 and 270	250
Total elongation	> 3.5%	1.2% to 2.0%
Relaxation: 1000 hours @ 80% GUTS	< 3.5%	< 3.5%
Modulus of elasticity	28,500 ksi*	24,500 ksi*

Note: Data from www.sumidenwire.com/products/stainless-steel-pc-strand.
GUTS = guaranteed ultimate tensile strength.
**Nominal value—actual value may vary with manufacturer's production lot.*

5.6 Design for Flexural and Axial Force Effects – B Regions

Equations in Article 5.6.3.1.1—Components with Bonded Tendons are based on the assumption that the distribution of steel is such that it is reasonable to consider that all of the prestressing force is located at the centroid of the prestressing steel. In addition, an average stress in the strands may be used for calculation of nominal flexural resistance. However, because of the lower ductility of the 2205 stainless steel strand, it may be more appropriate to use a method based on the condition of equilibrium and strain compatibility, with the stress in the extreme row of strands

not exceeding 250 ksi for Grade 250.

5.7 (5.8) Design for Shear and Torsion – B Regions

Alvaro, Kahn, and Kurtis[4] reported that the use of 2205 stainless steel strands in combination with stainless steel 304 wire spiral reinforcement provided shear strength equivalent to that of conventional wire spiral reinforcement when used in prestressed concrete piles. Although the research focused on the spiral reinforcement, there does not seem to be any reason why shear design should be different when 2205 stainless steel strand is used, except to account for its lower tensile strength when calculating the longitudinal reinforcement requirement of Article 5.7.3.5.

5.9.2.2 (5.9.3) Stress Limitations for Prestressing Steel

Table 5.9.2.2-1 limits the stress in low-relaxation strand immediately prior to transfer to 75% of the specified tensile strength f_{pu}. Based on their research with piles, Alvaro, Kahn, and Kurtis[4] recommended that, until further studies are completed, the 2205 stainless steel strand be initially stressed to not greater than 70% of the specified tensile strength f_{pu}. This recommendation was implemented in the project described in the companion article, "Production of Prestressed Concrete Piles Using Stainless Steel Strand," beginning on page 30 of this issue of *ASPIRE*®. Stressing the 2205 stainless steel strand to a lower percentage of the specified tensile strength in combination with the lower tensile strength of the strand results in a larger required area of stainless steel prestressing strand compared to a design using conventional 1080 strand.

5.9.3.3 (5.9.5.3) Approximate Estimate of Time-Dependent Losses

Article 5.9.3.3 includes an equation for long-term prestress loss from creep of concrete, shrinkage of concrete, and relaxation of steel. The values of creep and shrinkage should not change with the use of stainless steel strand. The estimated relaxation loss is taken as 2.4 ksi for conventional low-relaxation strand. Tests have indicated that relaxation losses are similar for both 1080 and 2205 steel strands.[4] However, it is more accurate to use the value recommended by the manufacturer.

5.9.3.4 (5.9.5.4) Refined Estimates of Time-Dependent Losses

Article 5.9.3.4 includes a term for relaxation losses to be taken as 1.2 ksi before the deck is cast and 1.2 ksi after the deck is cast, for a total of 2.4 ksi. Again, it is recommended to use the manufacturer's recommended value.

5.9.4.3 (5.11.4) Development of Pretensioning Strand

Article 5.9.4.3.1 states that the transfer length of pretensioned strand shall be taken as 60 strand diameters. Test results from prestressed concrete piles have indicated that the transfer length of 2205 stainless steel strand was similar to that of 1080 strand and less than 60 strand diameters.[5] Therefore, it seems that 60 strand diameters can be used for stainless steel strands.

Article 5.9.4.3.2 provides an equation for the calculation of development length of pretensioned strand. Measured development lengths of 2205 stainless steel strand were 55% of the lengths calculated using the AASHTO equation.[5] Therefore, the development length with 2205 strand can be conservatively estimated using the equation in Article 5.9.4.3.2.

5.10.1 (5.12.3) Concrete Cover

Article 5.10.1 states that cover for pretensioned prestressing strand shall be the same as for reinforcing steel. Because the specifications do not currently include stainless steel strand, the required concrete cover for 2205 stainless steel strand is the same as that for conventional 1080 strand.

Summary

The availability of stainless steel prestressing strand provides another means to enhance the durability of prestressed concrete. The properties of the stainless steel strand, however, must be considered in the structural design.

References

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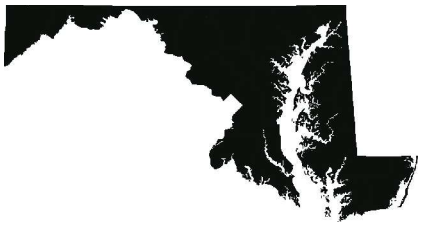
Dr. Henry G. Russell is an engineering consultant and former managing technical editor of ASPIRE.

Packs of stainless steel strand to be used in the production of prestressed concrete piles.

Maryland



by Jeffrey Robert and Justin Mohr, Maryland Department of Transportation

Maryland is located on the East Coast of the United States and shares its borders with four states and the District of Columbia. The state is often referred to as "America in miniature," because of its varied terrain and climates, its role in American history, and the diversity of its residents. Western Maryland is rural and mountainous and experiences heavy snow in the winter. Central Maryland is densely populated, has moderate snowfall in the winter, and experiences extreme heat in the summer. Eastern Maryland has a mix of rural and urban areas, and the Atlantic shoreline is extremely flat. The eastern region experiences minimal snow accumulation but is occasionally affected by hurricanes.

The highway system maintained by the Maryland Department of Transportation State Highway Administration (MDOT SHA) has 2567 bridges, including 511 concrete beam/girder superstructures. In general, the MDOT SHA Office of Structures uses concrete superstructures for bridges over any body of water. The type of beam or girder used at a given location depends on the span length.

Bridge Specifications and Policies

For water crossings spanning less than 55 ft in length, prestressed concrete slab panels are the "go to" bridge type for two reasons. First, this bridge type lends itself to accelerated bridge construction. The superstructures consist of 3- or 4-ft-wide prefabricated, prestressed concrete solid slab elements. Each slab panel must be fabricated using self-consolidating concrete with a required 28-day compressive strength of 8 ksi. Once all the slab panels are set, the slabs are transversely post-tensioned together so the slabs will act in unison. To provide a smooth riding surface, a 5-in.-minimum thickness concrete overlay with synthetic fibers and with either epoxy-coated or polymer-fiber reinforcement is placed. The railing is typically a prefabricated metal railing bolted to the superstructure.

The second reason that the slab-type structure is the preferred bridge option for Maryland's small water crossings is because it can provide a relatively maintenance-free bridge for the life of the structure. MDOT SHA has set the minimum clear cover to the prestressing strands at 3 in., providing extra protection for the one element that could potentially corrode if exposed to chloride-laden water. The structures are also constructed without joints. The elimination of the joints protects the abutments from potential exposure to chloride from roadway deicing salts.

The substructures for these shorter bridges vary based on the site location and conditions. Both precast concrete and cast-in-place concrete elements have been used. Every summer, three or four of these slab-type bridges are constructed in Maryland under a complete road closure and detouring of traffic. The prefabricated elements allow for the complete replacement in fewer than 10 weeks, which means the roadway is open to traffic before schools open in the fall.

For larger water crossings requiring greater than 55-ft span lengths, MDOT SHA uses precast concrete economical fabrication (PCEF) bulb-tee prestressed concrete girders. Like its prestressed concrete slabs, Maryland's PCEF girders are fabricated using self-consolidating concrete with a required 28-day compressive strength of 8 ksi. The use of the PCEF girders is common in many states across the country. Some of the policies and practices that MDOT SHA has adopted regarding these beams are described here.

In response to the concerns raised during years of field inspections about problematic details, MDOT SHA adopted policies to reduce maintenance requirements for the prestressed concrete girders used in bridges. Prestressing strands are not debonded, and the minimum concrete clear cover on the bottom of girders has

Bridge No. 03109 – U.S. Route 40 over Patapsco River. Photo: Maryland Department of Transportation State Highway Administration.

Bridge No. 15033 – Maryland Interstate 195 over Sligo Creek Parkway and Sligo Creek. Photo: Johnson, Mirmiran & Thompson.

been increased from the American Association of State Highway and Transportation Officials' minimum to 3 in. These changes in design practices have slightly increased initial costs; however, MDOT SHA believes that this initially higher expense will be offset by a reduced life-cycle cost.

Another problematic maintenance issue for Maryland has been leaky roadway expansion joints, which contribute to deterioration of bearings, girder ends, and abutment beam seats. To address this issue, Maryland has revised its policies and modified details in the last five years. On a policy level, Maryland has eliminated the expansion joint for bridges in which all spans contributing to expansion have lengths of 70 ft or less. This change essentially makes the structure fixed at all substructure units. MDOT SHA has determined that, for this length, flexibility in the bridge superstructure is sufficient to accommodate expansion or contraction movements, as well as other horizontal movements, without causing duress to the bridge.

When expansion or contraction from lengths of more than 70 ft must be accommodated, a compression-seal joint is used. However, the details have been modified to extend the deck beyond the abutment backwall by 6 in. A grade beam beyond the abutment is built, which is supported on support columns cast on the footer and the back side of the abutment, and the compression-seal joint is set between the grade beam and the extended deck. Any failure of the compression seal at this location will not result in chloride-laden water running onto the bearings or abutment beam seats, which eliminates a long-term maintenance issue. This detail does not require an approach slab.

Bridge Preservation

In recent years, another focus area for Maryland has been bridge preservation. MDOT SHA's inventory of structurally deficient bridges is presently less than 3% of all bridges. As Maryland strives to reduce this inventory, MDOT SHA is keenly aware that bridges built in the 1950s and 1960s will soon need major rehabilitation. If the state waits until major rehabilitation is necessary, financial funding will likely be insufficient to meet the needs. Therefore, MDOT SHA aims to be proactive and perform preventive maintenance and preservation now to extend the life of the current inventory. For example, one program is performing latex-modified concrete bridge deck overlays. Many heavily traveled roads experience accelerated bridge deck deterioration because of the volume of truck traffic and the heavy use of deicing chlorides during the winter. MDOT SHA's typical practice is to remove a minimum of 2 in. of the existing deck. The first inch of removal can be done using mechanical methods such as grinding. Beyond that point, the removal is done with hydroblasting. Performing these deck overlays has extended the life of bridge decks by 15 to 20 years.

Another preservation program focuses on Maryland's historic structures, which provide insight and beauty from the past. Recent efforts on some challenging projects have proven that old concrete structures can be restored, or even upgraded, while maintaining their historic features. Recent successes include the restoration of two open-spandrel reinforced concrete arch bridges. On both projects, the concrete arches were restored while some of the secondary members were removed and replaced. To work on bridges of this type, traffic must be completely removed, and detailed analysis of construction staging and sequencing is needed to maintain balanced-loading conditions.

Conclusion

Maryland, like many states, has a large inventory of concrete bridges to maintain. Through years of observation, MDOT SHA has gained valuable insights about how these bridges perform, and these insights inform how it rehabilitates its bridges and what types of new structures are built. By sharing some of these insights, MDOT SHA hopes that it has helped others in the management of their bridges.

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A prestressed concrete solid slab being installed for the Maryland Route 36 bridge over Georges Creek. Solid slabs are the "go to" bridge type in Maryland for spans less than 55 ft. Photo: Maryland Department of Transportation State Highway Administration.

Bridge No. 01011 – Maryland Route 36 over Elk Lick Run. Photo: Maryland Department of Transportation State Highway Administration.

Innovative Bridge Designs for Rapid Renewal: The ABC Toolkit and Its Implementation

by Finn K. Hubbard, Fickett Structural Solution, and Jamal Elkaissi, Federal Highway Administration

For the past eight years, the second Strategic Highway Research Program (SHRP2) project has been assisting state departments of transportation (DOTs) through an innovative product called the *SHRP2 Report S2-R04-RR-2: Innovative Bridge Designs for Rapid Renewal: ABC Toolkit*. The activities promoting and educating state DOTs about this toolkit have been valuable and well received.

Designed to help states implement accelerated bridge construction (ABC) techniques, the ABC toolkit provides step-by-step design guides, suggested construction specifications, techniques, and recommendations on how a transportation agency might accelerate the replacement of existing bridges. Techniques suggested in the toolkit include prefabricating bridges off site, or, in some cases, sliding bridges in from the side; both of these methods can limit roadway closures to less than one day. The toolkit includes best practices from around the United States and showcases various ABC methods tested by eight "SHRP2 lead adopter" agencies in 2014–2015. During that period, showcases and three peer exchanges were held, with participants from all 50 states and the District of Columbia. The showcases gave the lead adopter states a chance to highlight their bridge projects and lessons learned when applying the ABC toolkit. The peer exchanges offered transportation agencies at the state, federal, and local levels opportunities to share and learn from each other's experiences incorporating ABC into their routine practice by developing standard details, framework charts, cost-estimating spreadsheets, and design and construction specification manuals.

One-Day Training Courses

An important component of the SHRP2 ABC project is a one-day training course, which covers all aspects of ABC, from planning to design, procurement, and construction. Lessons learned are presented from the perspectives of owners, designers, and contractors.

In 2016 and 2017, the training course was held in the following 16 states and U.S. territories: Arkansas, Delaware, Florida, Illinois, Iowa, Louisiana, Michigan, Montana, Nebraska, New Jersey, New Mexico, Pennsylvania, Puerto Rico, South Carolina, South Dakota, and Wisconsin.

A second round of 19 training courses is currently underway. Training courses in this round are confirmed or unconfirmed in the following states: Arizona, California (two sessions), Colorado, Connecticut, Hawaii, Idaho, Indiana, Maine, Maryland, Minnesota, New Hampshire, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, West Virginia, and Wyoming.

In each SHRP2 ABC training course, participants are introduced to the concepts of ABC, with special emphasis on the benefits and advantages of considering ABC. The training course covers prefabricated bridge elements and systems (PBES) along with bridge move-in technologies. Time is spent on the SHRP2 R04 toolkit coverage of the development of the different ABC processes, and special attention is given to ABC methods successfully used in previous projects.

The afternoon session features presentations from two demonstration projects that have implemented the SHRP2 R04 toolkit methods, along with information on the eight state DOT implementation projects supported by SHRP2. Lessons learned from these projects are presented, including feedback from the state DOTs about ABC experiences.

The final part of the training course covers procurement issues, costs and savings considerations, and contractor perspectives about ABC. The class finishes with a "tour" of state ABC projects. These projects are gathered from the 42 states that attended the three peer-to-peer exchanges hosted in 2015. The wide range of ABC topics stimulates excellent discussion and questions from class participants.

Lessons Learned During the Training Sessions

Each host state for a one-day training course is invited to present ABC-related activities that the state has completed or is in the process of implementing. These ABC experiences vary from minor work involving PBES to the installation of a bridge system made completely from prefabricated elements and installed in a week or less. The following is a synthesis of the information obtained during the state training sessions:

- Most states have tried one form or another of ABC.
- Some states have institutionalized ABC programs into their practices.
- States are working to implement ABC on a more regular basis.
- In urban states, congestion is a major factor that drives the adoption of ABC.
- In rural states, detour length is an important factor in considering ABC.
- States have great interest in how to implement ABC and are very interested in other states' experiences.
- States want to know what criteria should be used when evaluating a project for the possible use of ABC.
- States want to know the real costs and real savings of ABC.
- States are looking for successful ways to gain contractor buy-in by communicating the shared benefits of using ABC.
- States want to determine how policy changes, creation of standards, plan development, and time commitments affect the level of effort (cost) involved

in a state ABC program.

- States want advice about how to sell ABC to upper management and policy makers. They realize that the whole team needs to be on board for ABC to be successful.
- States like hearing about the "pitfalls" in past ABC projects and want to discuss how best to avoid these issues.
- Generally, states implementing ABC have had good experiences with ABC and its learning curve.
- Costs of using ABC continue to be a challenge. Bid prices for ABC bridge projects are approximately 20% higher than those for traditionally constructed bridges. However, comparisons of total costs of ABC versus traditional construction (including items such as project management, traffic control, user costs, and service life) show that ABC projects can be economically competitive. In states that have completed several ABC projects, unit bid prices have fallen to the point that some bid prices on ABC precast concrete elements are now lower than cast-in-place options.
- In all the projects reviewed in this effort, the ABC projects have a lower total cost to society than traditionally built projects once user costs are factored in. This finding suggests that a commitment to ABC in the short run will result in cost savings for both the state DOT and the users in the long-run.

Summary

ABC is no longer a new concept and is becoming an accepted practice among state DOTs with and without SHRP2 implementation support. Lessons learned from demonstration projects and shared experiences from peer-to-peer exchanges have minimized the risks of ABC projects for the owners, designers, and contractors who execute them. Recent and ongoing state training sessions clearly explain to significant groups of agency staff members and contractors the "why and how" of ABC for bridge projects, thereby providing a better understanding at all levels of the benefits of using an ABC approach in projects.

As ABC methods and understanding mature, all parties involved in the process will become better informed about the costs and benefits of building bridges with an accelerated approach. The PBES that are presented in the ABC Toolkit are good examples of how the bridge-building industry can reduce user delays and improve the quality and safety of bridge projects.

For more information, presentations, documents, and resources, please visit the American Association of State Highway and Transportation Officials' SHRP2 site (http://shrp2.transportation.org/Pages/Bridge-Designs-for-Rapid-Renewal.aspx) and the Federal Highway Administration's GOSHRP2 site (https://www.fhwa.dot.gov/goshrp2). For other inquiries, email Jamal Elkaissi of the Federal Highway Administration at: Jamal.Elkaissi@dot.gov.

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EDITOR'S NOTE

The editors of ASPIRE® *appreciate the continued efforts of FHWA and AASHTO to encourage widespread use of PBES.*

Strategic Highway Research Program accelerated bridge construction training class in South Dakota. Photo: Pam Hutton, SHRP2 Implementation Manager.

Practical Solution for Skewed Geometry on Decked-Girder Bridges

by Susan M. Kovich and Jerome J. Nicholls, Nicholls Kovich Engineering PLLC

Decked-girder bridges with precast, prestressed concrete girders are used extensively throughout Washington state, particularly for local agencies with low-volume roadways. Decked girders are plant-fabricated and transported by truck to a bridge site for side-by-side placement. The deck, or driving surface of the bridge, is the top flange of the girder and is typically at least 6 in. thick. Decked girders can be fabricated in various cross sections, but the most common type in the Northwest is the decked bulb-tee girder. These sections are versatile, with overall depths ranging from 35 to 65 in. and top flange widths ranging from 4 to 8 ft. These bulb tees have the capability to span up to 160 ft.

One challenge of decked-girder construction involves a geometric issue with skewed bridge alignments. This issue can be overcome with some forethought and planning during the design phase.

Advantages to Decked Girder Construction

There are many advantages to decked-girder construction. First, decked systems are cost-effective. Both design and construction costs are lower when compared to the costs of cast-in-place deck construction. Second, construction time is reduced when erecting decked girders because the deck is fully precast. Typically, a single-span prestressed concrete superstructure can be shipped, erected, and grouted within one week. Finally, a decked-girder bridge, when properly designed and constructed, provides for easy construction and durability, good structural performance, and low maintenance for the life of the bridge.

Each bridge site should be evaluated for feasibility of this system. Not all sites are suitable for decked girders. For example, bridges with high traffic volumes or superelevation transitions are better accommodated by cast-in-place decks. Additionally, the engineer must consider access to the site and a source for the precast, prestressed concrete girders.

Consideration of Girder Camber

For precast, prestressed concrete girders, it is imperative to predict the estimated girder camber during the design phase. Camber is the upward deflection of the girder due to effective prestressing force and dead load. Although determining camber is not an exact science, camber prediction methods have a history of reasonable accuracy. Camber can be predicted using published formulas or, girder design software, or a girder manufacturer can be consulted. Camber does change over time, so camber at the time of girder setting is of particular importance.

It is advantageous to design the vertical profile of the roadway to fit the camber of the girder. If this method is not possible at a particular bridge site, the girder flanges can be thickened at the ends to result in a flat grade even when the girder is cambered.

To design the vertical profile of the roadway to fit the camber of the girder, the girder end slopes can be determined by using the following equation for a parabolic curve:

$$G = \frac{4C}{12L}$$

where

G = tangent slope at girder ends
C = net girder camber (in.) at the time of girder setting
L = span length (ft)
$2G$ = change in slope over span length of girder

For example, a 100-ft span girder with a camber of 4.5 in. has 1.5% slope at each girder end, resulting in a 3% change in grade over the girder span. To align the roadway profile grade with girder camber, the engineer would need to ensure that the vertical curve length extends the entire length of the skewed bridge, from beginning to end, including the skewed corners. The overall grade change of the vertical curve would need to be greater than 3%.

Skewed decked bulb-tee girders erected for the Hatley Bridge, Whitman County, Wash. Photo: Whitman County Public Works Department.

Skewed Decked Girders

Due to roadway or stream alignment, a bridge may need to be skewed at the ends. A geometric anomaly in the deck, known as the "sawtooth" effect, can result if the skew angle is not properly accounted for in the beam seat elevations. Let's look more deeply at this issue and visualize what can occur.

Each prestressed concrete girder in the bridge will have camber, or upward deflection. Should the girder have skewed ends, the acute corner of the girder end will be lower on the camber curve than the obtuse corner. Now, imagine setting an adjacent girder if the abutment elevations were level. Due to camber, the adjacent girder corner would not have the same

elevation as the previous girder. Because each adjacent girder in the deck would not align vertically with the previous one, a "sawtooth" effect would be created across the full bridge deck.

A practical solution[1] to this issue caused by skew involves correcting the abutment seat elevations to account for camber, along with considering the longitudinal slope and cross slope. Should the girder ends be perpendicular with no skew, the effect of camber would simply be zero. The following example will show the corrections to make along the abutments. Ideally, a correction for each girder seat should be made and used to construct the abutments to the proper elevations. The equations can be used for various skews, profile grades, and cross slopes. The engineer will need to carefully consider the units of the input and the algebraic sign associated with each quantity.

Example Calculation

The following equation calculates abutment elevations that account for equal skew angles at each abutment, a constant longitudinal grade, camber, and a constant cross slope, to provide for proper vertical alignment between flanges of adjacent girders at ends after setting:

> Abutment elevation = Roadway elevation at the centerline of the bridge at the centerline of bearing ± Correction for longitudinal slope ± Correction for camber ± Correction for cross slope – depth of girder – thickness of bearing pad

Given:

L	=	100 ft	span length
L_{abut}	=	38 ft	abutment length as measured along skew
θ	=	30°	skew angle (clockwise positive)
$Elev_1$	=	502 ft	elevation at centerline of bearings at abutment 1 at centerline of roadway (point B)
$Elev_2$	=	503 ft	elevation at centerline of bearings at abutment 2 at centerline of roadway (point E)
Cross slope	=	1.00%	cross slope of roadway (left to right)
H	=	41 in.	depth of girder
	=	3.417 ft	
t	=	0.75 in.	thickness of bearing pad
	=	0.0625 ft	
C	=	4.5 in.	girder camber at time of girder setting

Calculation:

Elevation correction for constant longitudinal roadway slope

$$\text{Longitudinal slope} = \frac{(Elev_2 - Elev_1)}{L} = \frac{(503-502)}{100} = +1.00\%$$

Constant longitudinal roadway slope

$$\text{Correction for longitudinal slope} = \text{Longitudinal slope}\frac{(L_{abut})}{2}\sin\theta$$

$$= 0.010\frac{(38)}{2}\sin(30^\circ) = 0.095 \text{ ft}$$

Elevation correction for camber

$$G = \frac{4C}{12L}$$

where

G = tangent slope at girder ends (L must be in ft and C in in.)

$$G = \frac{4C}{12L} = \frac{4(4.5)}{12(100)} = 0.0150 = 1.50\%$$

Effect on slope at girder ends due to camber:

$$\text{Correction for camber} = G\frac{(L_{abut})}{2}\sin\theta$$

$$= 0.0150\frac{(38)}{2}\sin(30) = 0.143 \text{ ft}$$

Elevation correction for constant cross slope

$$\text{Correction for cross slope} = \text{Cross slope}\frac{(L_{abut})}{2}\cos\theta$$

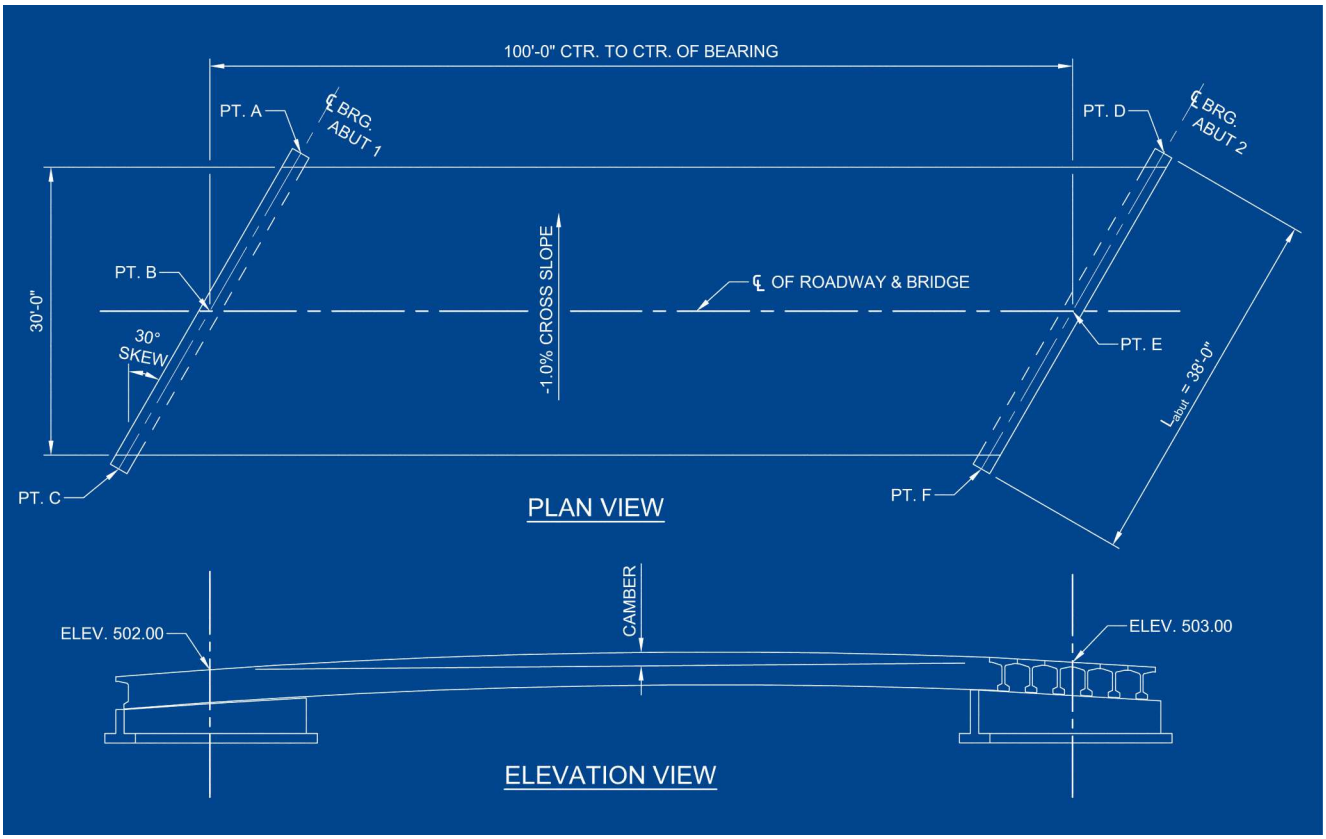
$$= 0.010\frac{(38)}{2}\cos(30) = 0.165 \text{ ft}$$

The same approach can be applied to determine individual seat elevations for each decked bulb tee, and to account for a crowned roadway or for different skew angles and grades at each end of a span. A correction for camber would not be needed if the girder flanges had variable thickness due to a straight grade. However, ensuring that the H value was correct to account for thickened girder depth at centerline of bearing would be needed. A variable top flange thickness is often used on straight or flat grades to avoid a "bump" due to girder camber.

Summary of Results (ft)

	Abutment 1 (at CL Bearings)			Abutment 2 (at CL Bearings)		
	Point A	Point B	Point C	Point D	Point E	Point F
Roadway elevation at centerline of bearings at abutment at centerline of roadway	502	502	502	503	503	503
Correction for longitudinal slope	+0.095	0	–0.095	+0.095	0	–0.095
Correction for camber	+0.143	0	–0.143	–0.143	0	+0.143
Correction for cross slope	–0.165	0	+0.165	–0.165	0	+0.165
Depth of girder[a]	–3.417	–3.417	–3.417	–3.417	–3.417	–3.417
Thickness of bearing pad[a]	–0.062	–0.062	–0.062	–0.062	–0.062	–0.062
Top of abutment elevation[b]	**498.59**	**498.52**	**498.45**	**499.31**	**499.52**	**499.73**

[a]Signs have been changed to reflect subtraction in formula.
[b]Rounded to the nearest 0.01 ft as typical for most bridge construction.
Note: Points are identified in plan view of figure that follows. CL = centerline.



Plan and elevation views of typical decked bulb-tee girder bridge. Note: Points for design example are labeled in plan view. Figure: Nicholls Kovich Engineering, PLLC.

Finished deck of skewed decked bulb-tee girders for the Old Blewett No. 1 Bridge, Chelan County, Wash. Photo: Chelan County Public Works Department.

Conclusion

This practical procedure will provide for a span in which the top flange edges of adjacent decked girders align within reasonable tolerances. Many decked-girder projects have used this practical procedure with great success, including the Old Blewett No. 1 Bridge over Peshastin Creek in Chelan County, Wash.

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Production of Prestressed Concrete Piles Using Stainless Steel Strand

by Dr. Krista Brown

Although stainless steel strand is not a new technology, it has rarely been used for precast, prestressed concrete components in transportation structures. There are rumors and misconceptions about special requirements and equipment needed for its incorporation into the prestressed concrete fabrication process. This article focuses on the production process of full-size prestressed concrete piles using stainless steel strand. The article "Structural Design Using Stainless Steel Strands" in this issue of *ASPIRE*® addresses designing prestressed concrete components using stainless steel strand.

Background

According to Mark Bucci, bridge design manager at the Louisiana Department of Transportation and Development (LaDOTD), the use of noncarbon steel strand in the precast, prestressed concrete piles on one of three bridges on the Bayou Thunder Overflow Project is an effort to increase the service life of the structure from 50 to 100 years. Corrosion-resistant strand (stainless steel or carbon fiber reinforced polymer) was specified for the forty-two 24-in.-square, 78-ft-long prestressed concrete piles on one of the three bridges of the project. Low-permeability concrete was used in these piles to limit saltwater and chloride intrusion and new detailing for the pile tip and head was also incorporated. The cost of the piles with the stainless steel strands and other detailing measures to increase service life was more than 200% higher than that of piles using conventional carbon steel strands. The result was a $590,000 increase to the cost of the project.

Gulf Coast Pre-Stress (GCP) in Pass Christian, Miss., bid the project based on the stainless steel option and was awarded the contract to produce the piles. GCP then began the journey to fabricate the first prestressed concrete piles using stainless steel strand to be used in an LaDOTD structure.

Materials

For the project, LaDOTD specified that the 7-wire, ½-in.-diameter stainless steel strand meet the chemical requirements of ASTM A276 and the mechanical and dimensional requirements of ASTM A416. Stainless steel alloy 2205 meets these requirements. In addition to the material testing certificates provided by the strand supplier, LaDOTD performed its own tests on strand samples that GCP took from the strand packs for this project.

Compared with its carbon steel counterpart, 2205 stainless steel strand has a lower tensile strength and a lower elastic modulus, as shown in the table below. The stainless steel strands were also stressed to a lower fraction of the tensile strength (70% instead of 75%) as designed by LaDOTD, so the force in each strand was reduced. Therefore, to achieve the same level of precompression in the piles, twenty-eight ½-in.-diameter stainless steel strands were required instead of the 24 carbon steel strands typically used in a 24-in.-square pile. Another reason to increase the number of strands by four was to keep the strand pattern symmetrical. It should be noted that the LaDOTD design for the piles was based on a 240 ksi ultimate strength for the stainless steel strands, which was lower than the 250 ksi for the strands that were used. To obtain the LaDOTD specified prestressing force, the strand was stressed to a fraction slightly less than 70% of the tensile strength.

Comparison of Material Properties for Types of Strands

Strand Material	Minimum Tensile Strength f_{pu}, ksi	Elastic Modulus E, ksi
2205 Stainless Steel Grade 250[a]	250	25,500
1080 Carbon Steel Grade 270[b]	270	28,600

[a]Reference: Sumiden Wire mill certificate.
[b]Data from: www.sumidenwire.com/products/pc-strand

Strand was not the only item in the concrete piles that was stainless steel. LaDOTD specified that the W4.5 wire spirals be Type 304 or 316 annealed stainless steel. The tie wire, the strand used for lift loops, and the reinforcing bar template that GCP uses to ensure strand placement in the middle of the long piles, were also required to be stainless steel.

In 2016, LaDOTD introduced performance-based concrete specifications[1] that included low-permeability concrete mixtures. GCP had already received approval for a 6-ksi concrete mixture with a minimum surface resistivity of 22 kohm-cm at 28 days. The concrete mixture did not require any modifications because of the stainless steel strand.

Long Lead Times for Materials

Stainless steel strand is not a stock item, especially when domestically produced strand is required, as on this project. Currently, suppliers only produce the strand when a sufficient number of orders have been placed to warrant production. Sumiden Wire was willing to guarantee delivery within six months for the ½-in.-diameter stainless steel strand, which is produced in its Dickson, Tenn., facility. Lead times for the stainless wire for the spirals and preformed tie wire were six and two weeks, respectively.

Production

In November 2017, GCP cast the 78-ft-long, 24-in.-square prestressed concrete piles. In the typical production cycle, four piles were cast in each of two adjacent 420-ft-long casting beds, for a total of eight piles. The use of the stainless steel strand did not require GCP to change

The 24-in.-square, 78-ft-long concrete piles prestressed with stainless steel strand were bunked at the lifting points while work was performed for the corrosion-resistant detail at the ends. All Photos: Krista Brown.

its normal procedures for the following:

- Storage and handling of stainless steel strand and wire for spirals.
- Forming of spirals from stainless steel wire, which is a semiautomated process.
- Cleaning and maintenance of strand chucks at the live and dead ends of the strand. The chucks were the same as used with conventional strand.
- Tensioning and de-tensioning, including calculation of strand elongations.

Quality control tasks were also not altered for fabrication using stainless steel strand. As with other LaDOTD precast concrete projects produced at the GCP facility, Volkert Inc. performed inspection duties under contract for LaDOTD.

The following items, although not directly attributable to the use of stainless steel strand, were notable differences from typical pile production at GCP:

- The 28-strand pattern was not typical for a 24-in.-square pile produced at its plant, and GCP did not want to modify the thick stressing plates at the dead and live ends. Inside the beds, GCP had sufficient room to install a steel rendering plate at each end to redirect the ½-in.-diameter stainless steel strand into the required pattern. Because this plate was not cast into the pile, it was not required to be stainless steel.
- Because all embedded steel items needed to be stainless steel, the reinforcing bars used to make templates to hold the strand in place in the middle of the pile also needed to be stainless steel. The longer lead time for stainless steel bar was almost overlooked.
- Workers reported that, as compared with carbon steel strand, more oxygen was needed in the gas mixture for the flame-cutting process during de-tensioning.
- The new pile end detail for the 100-year service life required the strands to be cut 2 in. below the pile head and tip. This led GCP to create a 2-in.-deep recess using a customized wood header

A custom header to separate the piles in the casting bed was fashioned to form the 2-in.-deep recess for strand. This formwork was challenging to make and remove.

Stainless steel preformed wire ties were used to tie the spirals to the strand. Workers reported that the stainless steel ties required more effort to tie than their carbon steel counterpart.

Gulf Coast Pre-Stress typically uses a template made from reinforcing bars to keep strands in position in the middle of long piles. For this project, the template had to be stainless steel.

No modifications to the tensioning procedure were necessary for the stainless steel strand.

The normal de-tensioning procedure was used, but workers reported that more oxygen was needed in the gas mixture to flame-cut the stainless steel strand than carbon steel strand.

The Louisiana Department of Transportation and Development (LaDOTD) required a new corrosion-resistant detail for both ends of the piles to attain a 100-year service life. The detail required that the stainless steel strands be recessed 2 in. at each end and the recess be filled with cementitious grout.

(bulkhead). The complicated shape was needed so that the strand could be saw-cut at the base of the recess. Constructing the wood form took extra hours, and removing it and cutting the strands flush were labor intensive endeavors. Afterward, the recess was formed and grouted.

- After the initial tensioning of each stainless steel strand to 3 kips, the strands were carefully examined for any notches before the tensioning process continued to the required 26 kips.
- The stainless steel preformed tie wire required more effort, and therefore more time, than the comparable carbon steel tie wire when tying the spirals to the strand, according to Dusty Carver, GCP superintendent.

Controlling Material Costs During Production

Material costs were a special concern during production because of the use of stainless steel. Stainless steel is more expensive than carbon steel, and, more importantly, the long lead times for orders of stainless steel materials meant that a shortage of any of the stainless steel items could have severe consequences for the schedule. Care was therefore taken to ensure that the quantities of stainless steel strand and spiral wire ordered were sufficient to allow for the possible remake of a pile. Also, strand used for the lift loops for the initial casting of piles needed to be cut from the virgin strand packs. Thereafter, the leftover strand at the dead and live ends of the beds could be used for the lift loops.

Specific material-handling and inventory-control procedures were adopted for the precious stainless steel preformed tie wires. According to Ben Spruill, vice president at GCP, these measures were so successful that they may become standard practices at the plant for other items.

Summary

The production process for precast concrete piles prestressed with stainless steel strand was not markedly different from that using conventional carbon steel strand. "We thought it would be more problematic," said Spruill. "Most things were regular SOP [standard operating procedure], but a lot more attention" was placed on this project. Long lead times for the stainless steel materials, especially the strand, were the greatest challenge.

Acknowledgments

The author acknowledges the cooperation, assistance, and hospitality of the staff, especially Andrew Levens, Dusty Carver, and Ben Spruill, at Gulf Coast Pre-Stress, Pass Christian, Miss. Steve Koch, Sumiden Wire, and Mark Bucci, LaDOTD, provided information for this article.

Reference

1. Louisiana Department of Transportation and Development (LaDOTD). 2016. *Louisiana Standard Specifications for Roads and Bridges*, 2016 ed. Baton Rouge, LA: LaDOTD.

EDITOR'S NOTE

See concrete connections on p. 44 for links to resources for designing using stainless steel strand.

Changing Bridge Terminology of the Federal-aid Highway Program

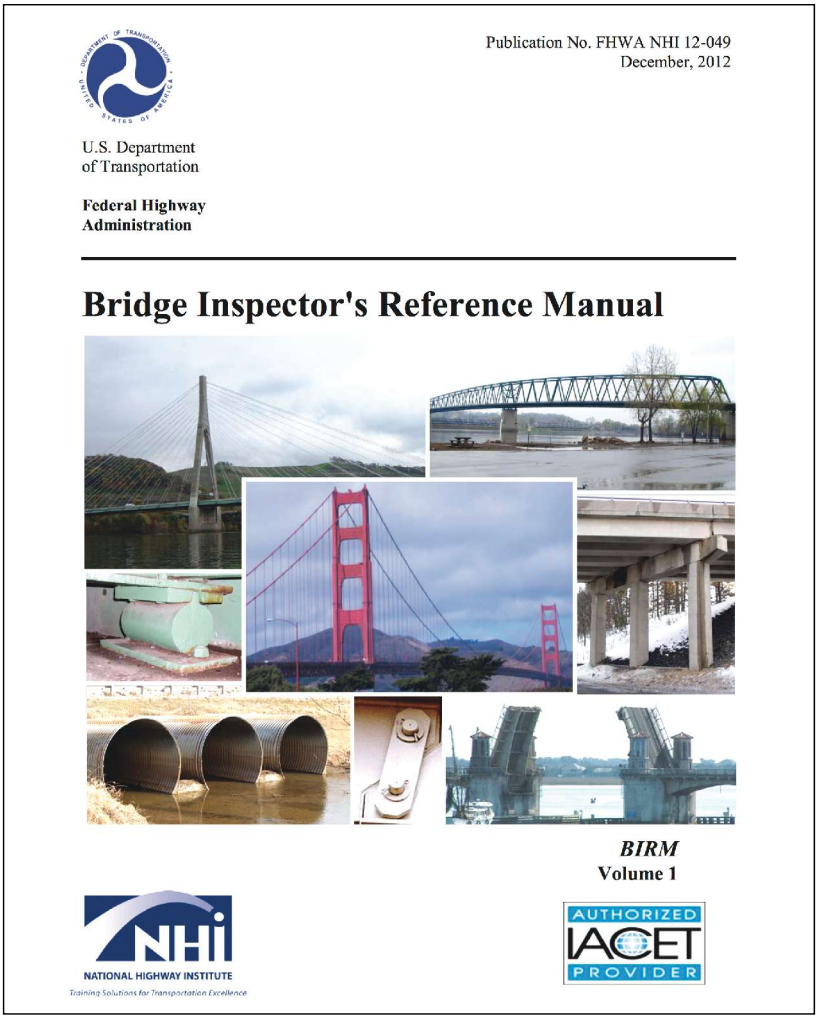
by Dr. Joseph L. Hartmann

The collapse of a span of the Interstate 5 Skagit River Bridge after being struck by an overheight load on May 23, 2013, resulted in a National Transportation Safety Board (NTSB) highway accident investigation. On site the next day, I helped the NTSB chairman prepare for a press conference on the incident and found myself once again explaining the language of the Federal-aid Highway Program, what the language meant, and, just as important, what it did not mean.

If you are a bridge engineer, you are likely to be familiar with the language of the program and, hopefully, understand its purpose and how to use it. To help the chairman prepare for the unavoidable questions that are always asked after a bridge incident, I skipped the formal definitions and associated each of the bridge-specific terms with a characteristic of the bridge or program.

- *Structurally Deficient* (SD) refers to the condition of the bridge.
- *Functionally Obsolete* (FO) refers to the roadway geometry on the bridge.
- *Sufficiency Rating* (SR) refers to funding the bridge is eligible for.
- *Fracture Critical* (FC) refers to how a bridge is inspected.

After explaining each association with the chairman, I was very deliberate and careful to include a qualifier. This term (SD, FO, SR, or FC) does not mean a bridge is unsafe: open bridges are safe, and unsafe bridges are closed. That last part might seem like an oversimplification to detail-oriented engineers, who would rather hear something like, "Open bridges are safe for all legal and unrestricted loads as long as vehicle operators self-enforce any bridge load-posting limits or similar operating restrictions," but that statement just does not roll off the tongue as easily. Once the chairman was prepared, I left, thinking once again that a change in language was long past due.



Publication No. FHWA NHI 12-049
December, 2012

U.S. Department of Transportation

Federal Highway Administration

Bridge Inspector's Reference Manual

BIRM
Volume 1

NATIONAL HIGHWAY INSTITUTE
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In late 2013, I interviewed for the position I currently hold at the Federal Highway Administration (FHWA) as director of the Office of Bridges and Structures. During those interviews, I spoke of the need to change or eliminate federally instituted but sometimes confusing, unclear, misleading, and even alarming terms from the language of bridge engineers. Although this language has served the bridge community well for decades, I recognized that the common usage of these terms differ significantly from the technical definitions, and therefore they do not translate well outside the discipline. In early 2014, I was fortunate to be selected to serve as director and be given the authority to change the terminology.

Revising the language would not have been possible without the enactment of the Moving Ahead for Progress in the 21st Century Act (MAP-21) in 2012. MAP-21 reduced the number of core programs that fund the Federal-aid Highway Program from 17 to 4. In doing so, the need to determine the status of a bridge (SD, FO, or not deficient) or its SR to establish funding eligibility ended. Soon after MAP-21 became law, I started speaking within the FHWA about the possibility of making changes, and, in 2014, I raised the topic externally at the meeting of American Association of State Highway and Transportation Officials' (AASHTO's) Committee on Bridges and Structures (CBS), formerly known as SCOBS (Subcommittee on Bridges and Structures).

What was a SD bridge?

Before MAP-21, a highway bridge could have one of three status classifications: not deficient, FO, or SD. Bridges and bridge-sized

culverts were classified SD if the condition was poor or worse (a condition rating of 4 or less for any component of the structure), or if they had an appraisal rating of 2 or less for structural evaluation or waterway adequacy, which are used to evaluate the level of service provided by a bridge compared to a bridge built to modern standards. Under the performance-based funding programs established by MAP-21 and its associated regulations, SD has been redefined, using the same criteria mentioned above, as **Poor** in a Good/Fair/Poor condition classification system, and, as a result, the SD term is no longer needed within the Federal-aid Highway Program.

What was an FO bridge?

An FO bridge or bridge-sized culvert was one that primarily did not meet current geometric design standards, such as lane width or number of lanes, relative to the current traffic volume carried by the bridge. An FO determination indicated an appraisal rating of 3 or less for deck geometry, underclearances, or approach roadway alignment, or an appraisal rating of 3 for structural evaluation or waterway adequacy of a bridge. Although the measure was well intentioned, the industry constructs FO bridges every year. These structures are typically built in urban settings where the lane and deck geometries must match what is on the servicing highway and both the highway and bridge are laterally or vertically constrained by other assets or natural features. In those situations, only the bridge, and not the highway, was classified as FO. Because the programmatic need to determine a FO classification is now obsolete and the classification serves no other constructive purpose, FO is no longer needed within the Federal-aid Highway Program.

What was the SR?

A bridge's SR (on a scale from 0 to 100) was determined by evaluating three components that relied on a total of 19 inventory and inspection items reported to the National Bridge Inventory:

- structural adequacy and safety;
- serviceability and functional obsolescence; and
- essentiality for public use.

Bridges with a SD or FO status and a SR of 80.0 or less but 50.0 or more were eligible for replacement or rehabilitation with federal funding, whereas those with a SR of 80.0 or less but more than 50.0 were eligible for rehabilitation with federal funding. As noted, because the programs that relied on a SR to determine eligibility have been eliminated, SR is now a legacy term that is no longer needed within the Federal-aid Highway Program.

What is an FC bridge?

An FC bridge contains at least one fracture-critical member (a steel member in tension, or with a tension element whose failure would probably cause a portion of or the entire bridge to collapse). Once constructed, FC bridges are subject to more rigorous inspection procedures than non-FC bridges. This term will be with us a little while longer. However, FHWA is pursuing an update to the National Bridge Inspection Standards (NBIS) regulation and intends to replace this term with language that is more illustrative of the notion, yet less alarming to the public.

In short, SD, FO, and SR are no longer used within the Federal-aid Highway Program, and FC is likely to be phased out during the ongoing update to the NBIS. Overall bridge condition is now classified using a scale of Good, Fair, or Poor. This is a transformational change, and FHWA recognizes that state departments of transportation (DOTs), AASHTO, and others still use the former terminology. Although it may take years to retire the outmoded terminology, FHWA has taken the lead to initiate that transition.

To reiterate, the terms SD, FO, SR, and FC do not directly reflect the safety of a bridge. Decades of success have proven that the National Bridge Inspection Program, as implemented by state DOTs through appropriate inspection and load rating and, where necessary, posting or restriction, is effective at ensuring that open bridges are safe and unsafe bridges are closed. I encourage you to join FHWA in embracing this change of language and helping institutionalize it throughout our bridge community.

DEVELOPING A GREATER FEEL FOR STRUCTURAL ENGINEERING

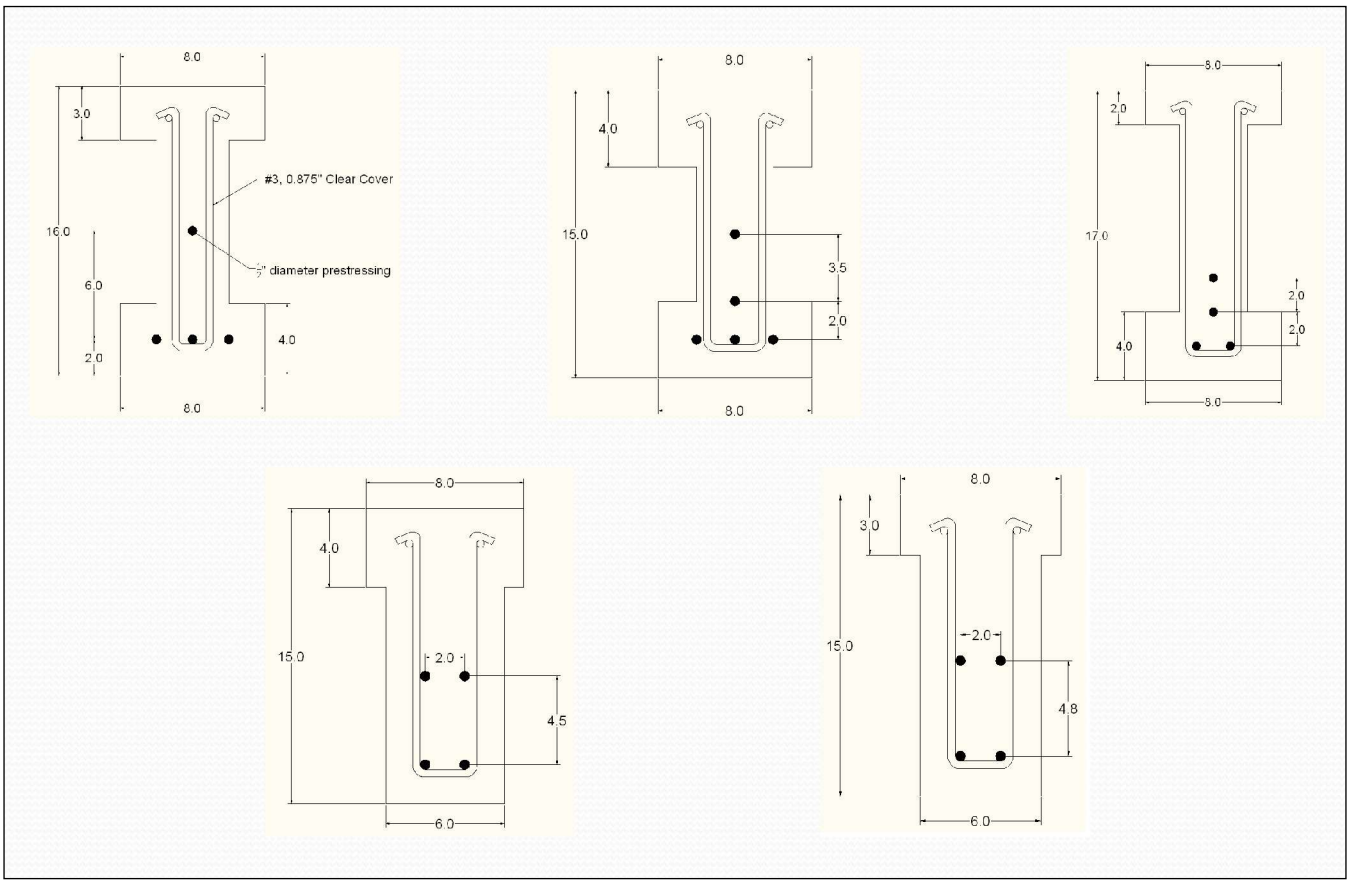
A faculty approach to augmenting structural engineering students' understanding of prestressed concrete member behavior using parametric analysis

by Dr. John J. Myers, Missouri University of Science and Technology

Just before the holiday season, Dr. Reid Castrodale, the managing technical editor of *ASPIRE*®, approached me with a wonderful opportunity to share my "professor's perspective" on educating our current students and future bridge engineers. This would be a chance to share what I have learned in nearly a decade of practical design experience in industry and, more recently, nearly two decades of experience as a professor and educator at Missouri University of Science and Technology (Missouri S&T), which is one of the oldest civil engineering programs in the nation (2020 will be the 150th anniversary of the start of the civil engineering program and founding of our institution). So, naturally, I immediately said, "Yes!" The next thought that crossed my mind was, "What could I possibly share with the *ASPIRE* audience that would perhaps help other educators in our field influence structural engineering students in their educational development?"

'What could I possibly share with the *ASPIRE* audience that would perhaps help other educators in our field influence structural engineering students in their educational development?'

Sample project with cross sections and tendon layouts to be varied to evaluate effects on structural behavior. All Figures: Dr. John J. Myers.



Changing Dynamics in Academia

Before introducing one of my pedagogical approaches to foster an improved understanding of prestressed concrete member behavior, it is important to reflect on the changing dynamics in academia. Nearly two decades ago, when I came to the Rolla, Mo., campus as a young faculty member, one of the first expressions I heard was "the Rolla way." This phrase was shorthand for the long-standing approach we took to educating our engineering students. Being a new faculty member at the time, much like a young college student in his or her first class, I had to question, "What is the Rolla way?" Soon enough, I came to understand that it meant providing not only traditional textbook theory but also a high level of practical and hands-on activities that were integrated within the curriculum experience to produce a more "street-ready" engineer who would be prepared to function at a high level in industry as a design or field engineer.

'...providing not only traditional textbook theory but also a high level of practical and hands-on activitites...to produce a more "street-ready" engineer'

Since I joined the faculty, Missouri S&T, like many other institutions of higher learning, has faced both financial constraints and changes in the depth of the engineering curriculum. For example, in my two decades as an educator, state resources directed toward higher learning have dwindled. When I started at Missouri S&T, the state contributed approximately two-thirds of the education costs for a student at our institution; today, the state contribution is about one-third. During this same period, engineering enrollment has almost doubled, which has greatly increased the student-to-faculty ratio. Furthermore, during my tenure, the engineering programs have been streamlined to reduce the required credit hours for a bachelor of science (BS) degree from 141 to 128, both to decrease student time to graduation and to align degree requirements with those of peer institutions.

These changes at my institution reflect national trends. To adjust, Missouri S&T and many comparable institutions have been forced to cut engineering program costs by reducing the number of laboratories and hands-on activities that historically have allowed our students to be more practice-ready upon graduation. Consequently, educators today must be more creative in how we educate our students and take advantage of advances in technology. One bright spot in recent decades has been the emergence of numerous opportunities to provide supplemental experiential and service learning outside of the classroom experience, such as our own Prestressed/Precast Concrete Institute (PCI) Big Beam Competition, the American Society of Civil Engineers Concrete Canoe and Steel Bridge competitions, the American Concrete Institute's student competitions, Engineers Without Borders, and many other activities that engage students in engineering.

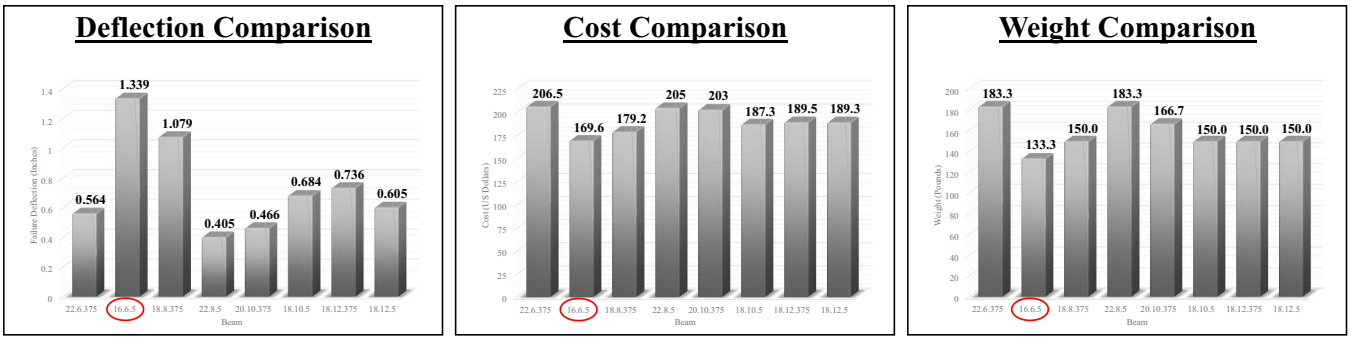
Extending Experiential Learning to the Classroom

Given the budgetary challenges, the reductions in program credit hours, and expanding class sizes, what can educators do to help today's students develop a greater feel for structural engineering member behavior? What are our options when opportunities for physical, hands-on laboratory exercises are limited by the associated costs? Certainly, internships and co-ops can help in this regard. Additionally, activities such as student design competitions and service-learning activities can meet this need to some degree. However, not all students join a design or service team, and even those who participate may not find experiential learning activities that are relevant to their area of study.

Using the PCI Big Beam Competition as a Parametric Learning Tool

In 2003, I began my long-standing engagement as a faculty adviser to the Missouri S&T team participating in the PCI Big Beam Competition (https://www.pci.org/PCI/Education/Student_Education/Student_Competitions/PCI/Education/Student_Competitions.aspx?hkey=6de3c1e2-4fb8-4d16-a4af-bf2032614c2d). For those readers who are unfamiliar with this event, each student team must work with a PCI Producer Member to fabricate a precast/prestressed concrete beam that is tested in a laboratory. Students must design a prestressed concrete component within certain specified requirements and then predict aspects of structural behavior and efficiency, including capacity and serviceability. This event has been the perfect activity for students to apply what they have learned in a typical prestressed concrete design class to a practical application outside of the classroom environment. However, it is not feasible for every engineering student at an institution to compete. Enrollment in prestressed concrete design classes can approach 50 students, which would mean having multiple teams in the Competition, and it would be extremely challenging to solicit sufficient plant sponsorships for that many teams and to pursue member fabrication at the level required in the contest. Also, some prestressed concrete design courses are taught at times that do not coincide with the competition.

Given the limits on the number of students who can compete, my approach, which I am pleased to share with the *ASPIRE* audience, has been to encourage those students who have the greatest interest to participate in the PCI Big Beam Competition and then use the competition's objectives as a framework to offer all students in my prestressed concrete design course the opportunity to undertake a semester-long parametric project. This project helps students improve their practical awareness of prestressed concrete structural behavior by understanding the effect of modifying a design consideration variable and the resulting impact on structural behavior. Through the use of computing capability and software such as Mathcad® or Excel®, students can develop sophisticated spreadsheets to examine everything from allowable fiber stresses to section flexural capacity, shear capacity, and serviceability behavior. With material unit costs, they can examine how changes in structural design affect



Prioritized optimization criteria: comparison of deflection, cost, and weight at failure [measure of section ductility] for various designs.

cost and member efficiency.

In this project, students are first required to develop their parametric matrix by selecting their variables for investigation, which may include member cross section, tendon size, type, and layout; inclusion of mild steel and shear reinforcement; concrete unit weight; and compressive strength. Through their process of study, they must verify which member configurations satisfy all code requirements in terms of transfer and service stresses, strength, and serviceability, and, at this point, they often narrow their extensive matrix to a few members for final consideration. Finally, students examine which sections are most efficient and cost-effective and recommend a final design for fabrication.

Conclusion

The aim of this semester-long endeavor is to combine classroom theory and design aspects studied throughout the semester into a final course project that is geared to help students develop a greater feel for structural behavior through parametric analysis. They develop analysis and design spreadsheets throughout the semester through various assignments and then apply them to the parametric study. This pedagogical approach takes advantage of today's computing capabilities without requiring access to special facilities or laboratories. As a result, the project has improved operational efficiency and offers an alternative approach to traditional hands-on laboratory activities that may have been eliminated in today's engineering curriculums.

Bridge Deck Overhang Construction:

A Precast Concrete Solution

by Sean P. Clifton, Magnusson Klemencic Associates, and Dr. Oguzhan Bayrak, University of Texas at Austin

An experimental investigation was conducted at the Ferguson Structural Engineering Laboratory at the University of Texas at Austin to evaluate conventional bridge deck overhang construction practice and develop a simpler, precast concrete solution. This article provides a summary of the precast concrete bridge deck overhang system developed by the authors.[1,2] (For another precast concrete overhang construction method, see the Concrete Bridge Technology article "Precast Concrete Overhang Panels for Safer and Faster Bridge Deck Construction" in the Fall 2017 issue of *ASPIRE*®.)

Context

The overhang construction method discussed in this article has been developed and tested as part of the master's research of the primary author, supervised by the second author. The authors do not know if the concept, or its variants, have been implemented in practice. Implementation of the concept will likely result in further refinements. It is the hope of the authors that dissemination of this concept will help its consideration by the industry.

Advantages and Disadvantages

To illustrate the potential benefits of a precast concrete deck overhang system, the advantages and disadvantages of the precast concrete solution and the conventional cast-in-place deck approach that is supported by overhang brackets are outlined. The conventional, overhang bracket system referred to in this article is the system of bridge deck overhang brackets and embedded hangers, as shown in Fig. 1, that support the deck forms, screed rail, and walkway. The proposed system involving a precast concrete deck overhang solution, also shown in Fig. 1, is described in detail in this article. The precast concrete deck overhang solution presented herein serves as stay-in-place formwork and is part of the deck overhang for structural purposes.

Advantages of current overhang construction technique:

- Contractor flexibility: The bracket system allows for last-minute changes at the bridge site to the overhang design, and the casting profile can be adjusted as needed to fit the specified profile.
- Current practice: The system is in use today and has been for decades.

Disadvantages of current overhang construction technique:

- Time: Installation and disassembly of overhang brackets are time-consuming. The time required to adjust the brackets and to construct the form overhang at the bridge site is significant.
- Cost and safety: The system demands significant resources for formwork, crane time, and possibly a form-stripping buggy. Brackets and non-reusable embedded hangers are costly, and the labor costs of installation, forming, and disassembly are also substantial. In cases where a bridge is constructed over traffic, safety is an issue.
- Reduced stiffness: Overhang brackets and formwork can undergo noticeable deflections during placement of deck concrete that may lead to an uneven finished surface, especially if the overhang brackets slip as they engage to support the deck concrete.
- Screed rail movement during concrete placement: The authors of the paper are aware of cases in which the screed rail that supports the bridge paver moved due to overhang bracket slip.

Advantages of precast concrete deck overhang system:

- Cost: The new construction technique will likely lead to a more efficient, and ultimately cheaper, construction process and result in a more economical bridge. A similar economy was achieved when the use of partial-depth precast concrete stay-in-place deck panels was first implemented.
- Stiffness: Because the precast concrete overhang is a very stiff element and will not deflect significantly during the finishing process, it will lead to a smooth riding surface. Bracket slip problems are eliminated.
- Time: Eliminating the need for assembly and disassembly of overhang brackets and wooden formwork greatly reduces the onsite time required to construct the bridge deck and eliminates safety concerns when working over traffic.

Disadvantages of precast concrete deck overhang system:

- New concept: As with any new procedure in construction, the refinement and optimization of the process will involve a learning curve.
- Planning time: Because a portion of the overhang may be constructed at the fabrication yard, certain characteristics of the bridge geometry must be determined with enough lead time to be applied in the fabrication yard.

Overview of Proposed Procedure

Figure 2 shows the recommended steps of the precast concrete solution from girder fabrication to the completed bridge. The procedure is:

1. During the casting of the fascia girder, add supplementary reinforcement (L-shaped bar shown in Fig. 2) for the precast concrete overhang during the casting of the fascia girder.
2. After prestress transfer and prior to girder erection, move girders and form a 4-in.-thick concrete overhang on the fascia girders.

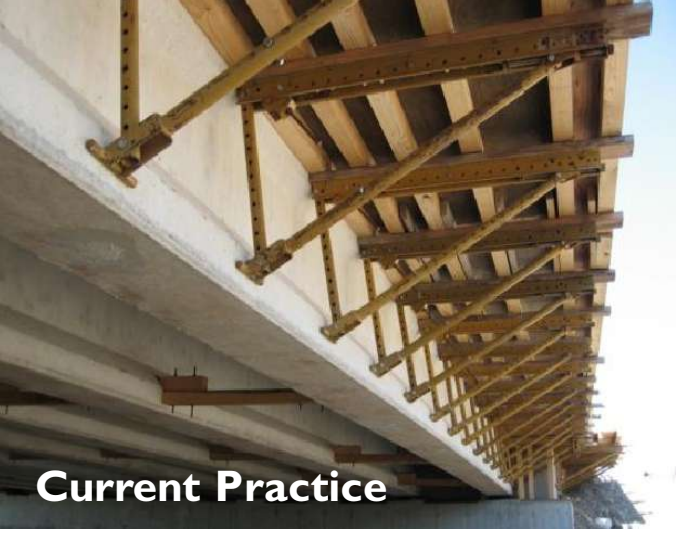


Figure 1. The current deck overhang bracket system and the proposed precast concrete overhang system.. All Figures and Photos: Sean P. Clifton.

3. Cast a 4-in.-thick concrete overhang on the fascia girders. The precast concrete overhang is an eccentric load that creates stability challenges in lifting, transportation, and erection; however, methods exist to address these challenges.
4. Install the work platform.
5. Install the screed rail.
6. Install side forms and the forming system for other bays of the bridge.
7. Place cast-in-place concrete deck.
8. Construct bridge rail.

Load Testing

To verify the strength and stiffness of the precast concrete overhang, two sets of directly comparable tests were performed on a 70-in.-deep I-beam specimen (Tx70) fabricated in the laboratory. To balance the load applied to the precast concrete overhang, standard overhang brackets were attached to the inside of the fascia girder and loaded simultaneously with the precast concrete overhang. Figure 3 shows the test setup. On the precast concrete overhang, two 3 x 3 x ¾ in. plates placed 6 in. from the overhang edge and 36 in. apart were used as loading points.

In both tests, the precast concrete overhang cracked under a vertical load of approximately 6300 lb per load point (a total of 12,600 lb on the precast concrete overhang). The overhang cracked at the location where the 4-in.-thick overhang meets the top flange of the girder, which is 21 in. from the overhang edge. While the precast concrete overhang was shown to be very robust, cracking in the overhang is undesirable during construction, and the cracking load is therefore the design limit state. Cracking is important because the stiffness of the precast concrete overhang lessens after the formation of flexural cracks. Using conservative load estimates for typical construction loads, a design margin factor of approximately 2 was determined to prevent cracking and should be used to prevent cracking of the precast concrete overhang during construction.

Loading the test girder on both the precast concrete overhang and the overhang

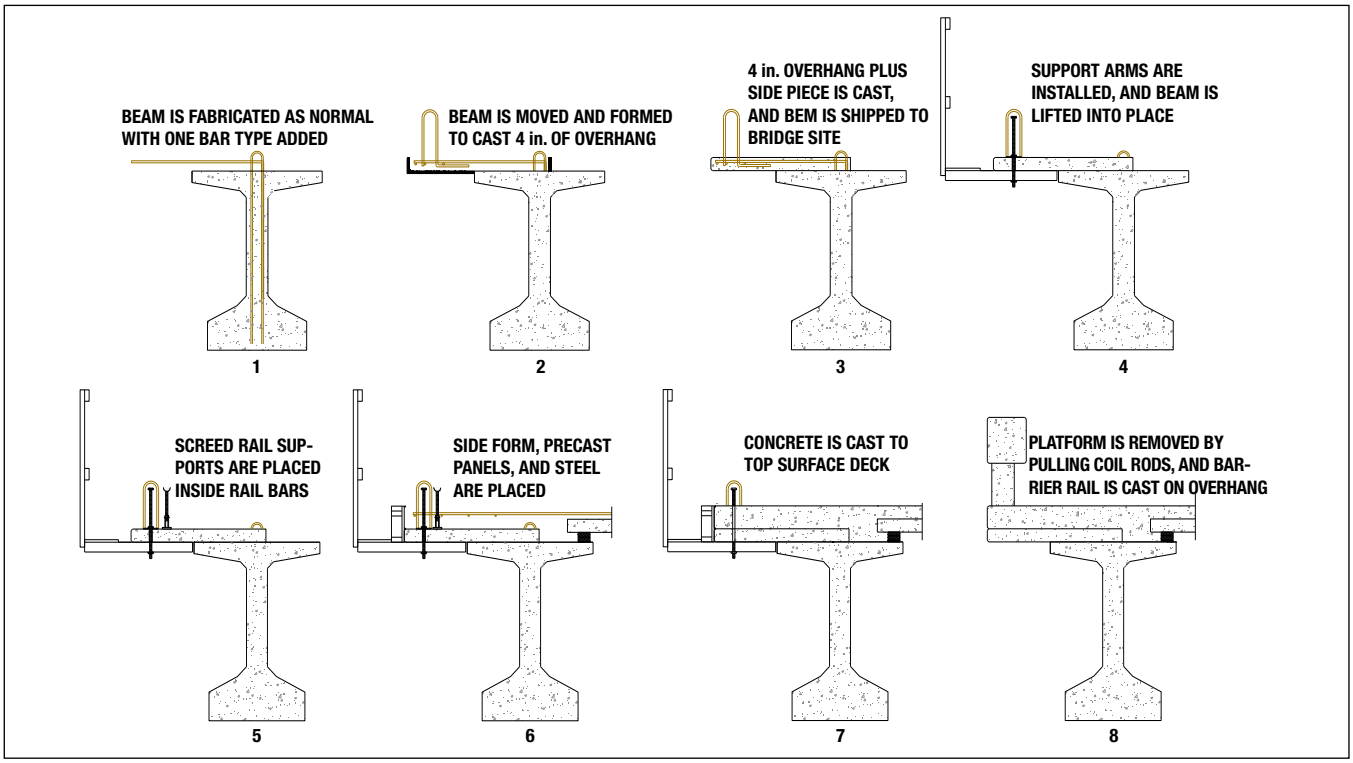


Figure 2. Steps in constructing the precast deck overhang and the remainder of the bridge.

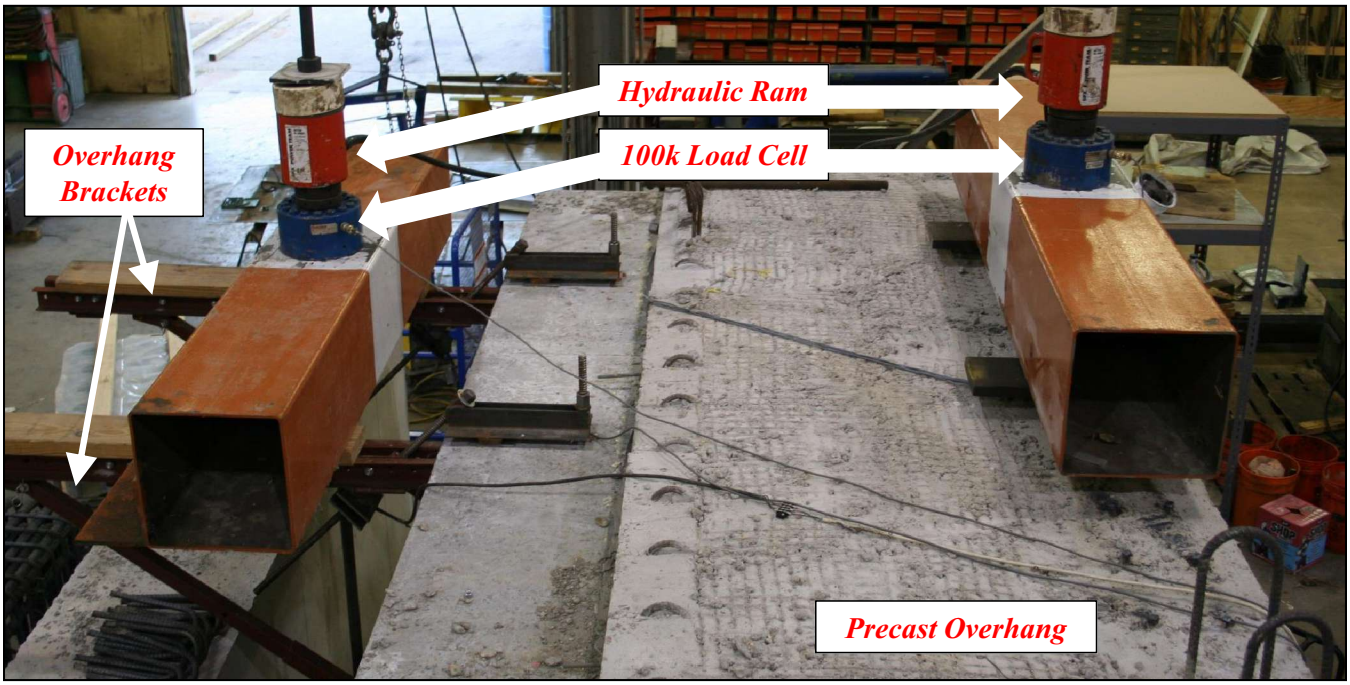


Figure 3. Setup for testing

brackets allowed for a direct comparison of the stiffness of the two systems. String potentiometers were used to measure deflections directly beneath the load points on each side of the girder.

Figure 4 illustrates the significant difference in stiffness of the precast concrete overhang compared to the overhang bracket system. The deflection of the bracket system at the load point is more than five times the deflection of the precast concrete overhang. The overhang brackets tested were also significantly stiffer than other, previously tested brackets.[1] Hence, for the specimens tested in this study, it can be concluded that, on average, the precast concrete overhang was at least five times stiffer than the tested bracket system.

Summary

A precast concrete deck overhang system was developed during the course of this study[1,2]. Its feasibility was investigated by building a full-scale mock-up in the laboratory and load testing the specimen. The system was presented to a few precast concrete producers and several general contractors. While some concerns and recommendations were expressed by some of the contractors, most favorably received the concept of a new precast concrete deck overhang alternative.

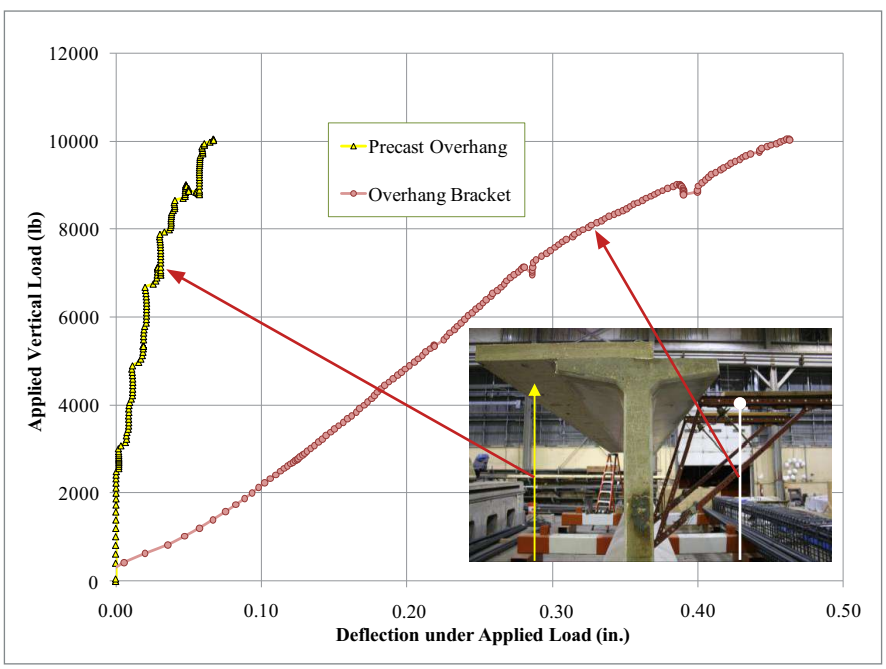


Figure 4. Load versus deflection comparison of the two deck overhang systems.[2] The yellow arrow in the photo corresponds to the location where the precast overhang deflections were measured. The white line in the photo corresponds to the location where the overhang bracket deflections were measured.

Acknowledgments

The authors greatly appreciate financial support from the Texas Department of Transportation (TxDOT) that made this study possible. The support of TxDOT's project monitoring committee, John Holt, Amy (Eskridge) Smith, and Randy Cox, TxDOT's Bridge Division Director at the time, is also very much appreciated. The contents of this article reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views of TxDOT.

References

1. Clifton, Sean P. 2008. "Bridge Deck Overhang Construction." Master of science thesis. University of Texas at Austin.
2. Clifton, Sean P. and O. Bayrak. 2008. *Bridge Deck Overhang Construction*. Technical Report IAC 88-5DD1A003-2. Austin, TX: Texas Department of Transportation.

Sean P. Clifton is a senior associate with Magnusson Klemencic Associates in Seattle, Wash., and Dr. Oguzhan Bayrak is a Distinguished Teaching Professor at the University of Texas at Austin.

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CONCRETE CONNECTIONS

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

IN THIS ISSUE

http://leavcom.com/2000n/law_112600.htm
This is a link to a news release about the use of 18 inch square prestressed concrete piles on the Conway Bypass, which is mentioned in the article featuring Traylor Bros. on page 6.

http://www.cityofgroveok.gov/community/page/sailboat-bridge-album
This is a link to a website showcasing photos of Sailboat Bridge after completion. Sailboat Bridge was constructed by Traylor Bros, the contractor featured in the article on page 6.

https://www.fhwa.dot.gov/goshrp2/Solutions/All/R04/Innovative_Bridge_Designs_for_Rapid_Renewal
This is a link to a second Strategic Highway Research Program (SHRP2) webpage that contains additional links to webinars, videos, and the toolkit mentioned in the Concrete Bridge Technology article on page 24.

http://shrp2.transportation.org/Pages/Bridge-Designs-for-Rapid-Renewal.aspx
This is a link to an American Association of State Highway and Transportation Officials (AASHTO) webpage that has detailed information on SHRP2 and links to slides of the one-day training course, standard drawings and specifications, states' accelerated bridge construction (ABC) reports, and other resources for information on ABC. SHRP2 is the subject of the Concrete Bridge Technology article on page 24.

http://www.mapaprecast.org/index.cfm/precast-bridge/PCEF-Docs
This is a link to precast concrete economic fabrication (PCEF) standards and bulb-tee drawings on the Mid-Atlantic Precast Association website. PCEF is mentioned in the article for the featured state, Maryland, on page 22.

http://www.aspirebridge.com/additionalresources/index.shtml
This is a link to a page on the *ASPIRE*® website that has a crosswalk between the 7th and 8th editions for Section 5 of the *AASHTO LRFD Bridge Design Specifications*. The contents of Section 5.9 in the recently published 8th edition are the subject of the LRFD article on page 48.

https://bookstore.transportation.org/item_details.aspx?id=3731
This is a link to the AASHTO webpage that has a free, downloadable crosswalk between the 7th and 8th editions for Section 5 of the *AASHTO LRFD Bridge Design Specifications*. The crosswalk is labeled as Appendix E5. The contents of Section 5.9 in the recently published 8th edition are the subject of the LRFD article on page 48.

https://www.pci.org/PCI/Education/Student_Education/Student_Competitions/PCI/Education/Student_Competitions.aspx?hkey=6de3c1e2-4fb8-4d16-a4af-bf2032614c2d
This is a link to the rules for this year's PCI Big Beam Competition as well as videos and reports from previous winners. The contest is mentioned in the Professor's Perspective article on page 36.

http://g92018.eos-intl.net/eLibSQL14_G92018_Documents/11-34.pdf
This is a direct link to the 2015 Georgia Department of Transportation research report "Corrosion-Free Precast Prestressed Concrete Piles Made with Stainless Steel Reinforcement: Construction, Test and Evaluation." Aspects of prestressed concrete design and pile production using stainless steel strand are discussed in articles on pages 20 and 21.

http://www.concretebridgeviews.com/i74/Article3.php
This is a direct link to "Stainless Steel Prestressing Strand for Durable Bridge Piles," an article in *Concrete Bridge Views Newsletter* that summarizes research on properties of stainless steel strand and the testing of prestressed concrete piles. Aspects of prestressed concrete design and pile production using stainless steel strand are discussed in articles on pages 20 and 30.

https://www.pci.org/PCI_Docs/Publications/PCI%20Journal/2017/May-June/Transfer%20and%20development%20length%20of%20high-strength%20duplex%20stainless%20steel%20strand.pdf
This is a link to "Transfer and Development Length of High-Strength Duplex Stainless Steel Strand in Prestressed Concrete Piles," an article that appeared in the May–June 2017 issue of *PCI Journal*. The designing of structures using stainless steel strand is the topic of an article on page 30.

http://www.state.nj.us/transportation/commuter/roads/rte72manahawkinbaybridges/photos18.shtm
This is a link to the New Jersey Department of Transportation's website with photos of the construction and rehabilitation of the twin structures of the Manahawkin Bay Bridge. The bridge is the focus of a Project article on page 16.

http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp12-69_fr_guidelines.pdf
This is a link to the *Guidelines for Design and Construction of Decked Precast, Prestressed Concrete Girder Bridges*, which is the final report for NCHRP Project 12-69 discussed in the article on page 26.

OTHER INFORMATION

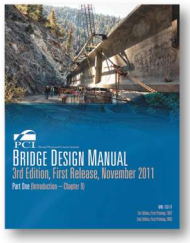
http://elearning.pci.org
This is a link to the PCI eLearning Center website, which provides access to online courses that satisfy the continuing education requirements of engineers in all 50 states. The topics are varied and include not only design and manufacture of precast concrete structures and components but also high-performance materials, resiliency, and case studies.

https://www.fhwa.dot.gov/bridge/concrete/hif15016.pdf
This is a direct link to the FHWA publication *Post-Tensioned Box Girder Design Manual.*

Carriage Pavillion Bridge at Union Station, Kansas City, MO
photo: Burns & McDonnell

PCI Precast/Prestressed Concrete Institute

PCI's Transportation ePubs are compatible with a variety of devices including PCs, Macs, iPads, and e-readers. Download free ePub resources at www.pci.org



PCI Bridge Design Manual 3rd Edition, Second Release, August 2014

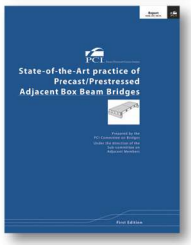
This up-to-date reference complies with the fifth edition of the *AASHTO LRFD Bridge Design Specifications* through the 2011 interim revisions and is a must-have for everyone who contributes to the transportation industry. This edition includes a new chapter on sustainability and a completely rewritten chapter on bearings that explains the new method B simplified approach. Eleven LRFD up-to-date examples illustrate the various new alternative code provisions, including prestress losses, shear design, and transformed sections.

www.pci.org/MNL-133-11

The PCI State-of-the-Art Report on
Full-Depth Precast Concrete Bridge Deck Panels

The *PCI State-of-the-Art Report on Full-Depth Precast Concrete Bridge Deck Panels* (SOA-01-1911) is a report and guide for selecting, designing, detailing, and constructing precast concrete full-depth deck panels for bridge construction. This report is relevant for new bridge construction or bridge-deck replacement.

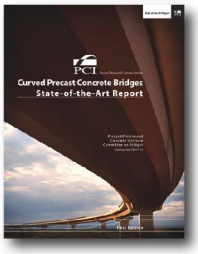
www.pci.org/SOA-01-1911



The PCI State-of-the-Practice Report of
Precast/Prestressed Adjacent Box Beam Bridges

Adjacent box beam bridges are widely used in new bridge construction and have many advantages over other bridge types in speed and ease of construction, aesthetics, span-to-depth ratio, and cost. Although early construction practices may have led to serviceability issues, improved practices have made the box girder bridge a viable, cost-effective structural system. A discussion on current practice, historical issues, lessons learned, and improved performance of box girder bridges is provided.

www.pci.org/SOP-02-2011



The PCI State-of-the-Art Report on
The Curved Precast Concrete Bridges

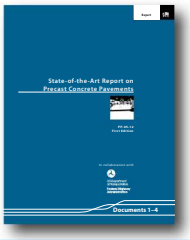
This report details the application of curved precast concrete bridge design, fabrication, construction techniques, and considerations through the study of twelve related projects and constitutes a state-of-the-art report on this topic. The document was written and intended to provide bridge owners, designers, fabricators, and engineers an up-to-date reference in developing precast concrete bridge solutions for curved geometric situations.

www.pci.org/CB-01-12

The PCI State-of-the-Art Report on
Seismic Design of Precast Concrete Bridges

Seismic design of precast concrete bridges begins with a global analysis of the response of the structure to earthquake loadings and a detailed evaluation of connections between precast elements of the superstructure and substructure. Because modeling techniques have not yet been implemented for jointed details, the focus of this report is on procedures for the evaluation of system response and the detailing of connections for emulative behavior.

www.pci.org/SD-01-13



The PCI State-of-the-Art Report on
Precast Concrete Pavements

This report is the combination of four documents on the use of precast concrete pavement systems (PCPS) and constitutes a state-of-the-art report. The documents were developed through a cooperative agreement between PCI and the Federal Highway Administration and cover the following: Applications for Precast Concrete Pavements, Design and Maintenance, Manufacture of Precast Concrete Pavement Panels, and Construction of Precast Concrete Pavements.

www.pci.org/PP-05-12

A simple log-in to the PCI website is all that is needed to download these free resources.

* ePubs are fully searchable with hot links to references, enabling direct access to the internet.

Supplementary Cementitious Materials: Fly Ash

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

Supplementary cementitious materials (SCMs) used in concrete generally consist of fly ash, slag cement, silica fume, and pozzolans. These materials are used separately or in various combinations with portland cement or blended cements to enhance the properties of the fresh and hardened concrete. They are also used as a component in blended cements. This article is part of a series - that provides brief descriptions of each material and resources for more information.

Fly Ash

Fly ash is the most widely used SCM in concrete. Fly ashes are divided into two classes according to AASHTO M 295: Class F fly ash has pozzolanic properties; Class C fly ash has some cementitious properties in addition to pozzolanic properties. Some fly ashes meet both Class F and Class C criteria.

The use of fly ash in concrete reduces water demand, increases cohesiveness, reduces permeability, reduces segregation, and improves finishability of the fresh concrete. The use of fly ash as a cement replacement reduces the heat of hydration, thereby reducing peak temperatures and the potential for thermal cracking.

Fly ash improves the properties of hardened concrete through its pozzolanic reaction. This results in concrete with a lower permeability, higher resistivity, increased resistance to alkali-silica reactivity, and increased long-term compressive strength.

According to a 2012 survey by the American Coal Ash Association, all state department of transportation specifications permit the use of fly ash. Twelve states, however, specify only one type of fly ash, Class F. Most state specifications have an upper limit on the amount of fly ash that may be included in the concrete. The upper limit is usually in the range of 15% to 30% of the total cementitious materials, with some as low as 10% or as high as 35%. Some states require the use of a high percentage of fly ash to control alkali-aggregate reactivity.

Additional Information

1. AASHTO (American Association of State Highway and Transportation Officials). 2015. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. AASHTO M 295-11. Washington, DC: AASHTO.
2. ACI (American Concrete Institute) Committee 232. 2003. *Use of Fly Ash in Concrete (ACI 232.2R-03)*. Farmington Hills, MI: ACI.
3. American Coal Ash Association, https://www.acaa-usa.org/.
4. Kosmatka, S. H., and M. L. Wilson. 2016. *Design and Control of Concrete Mixtures.* Engineering Bulletin 001. Skokie, IL: Portland Cement Association.
5. Russell, H. G. 2013. *NCHRP Synthesis of Highway Practice 441: High Performance Concrete Specifications and Practices for Bridges*. Washington, DC: Transportation Research Board.

Dr. Henry G. Russell is an engineering consultant and former managing technical editor of ASPIRE®.

AASHTO LRFD Bridge Design Specifications: Benefits of a Reorganized Article on Prestressing

by Dr. Oguzhan Bayrak, University of Texas at Austin

The first edition of American Association of State Highway and Transportation Officials' (AASHTO's) *AASHTO LRFD Bridge Design Specifications* were published in 1994. As is generally the case with standards and specifications, the AASHTO LRFD specifications then went through an "organic growth" period for about a quarter century before they were reorganized to address growing concerns expressed by various states about the logical flow of information. This type of evolution is to be expected because the knowledge creation, accumulation, vetting, and acceptance process is highly nonlinear. The article by R. Kent Montgomery, Shri Bhide, and Gregg Freeby published in the Winter 2017 issue of *ASPIRE*® discusses the reorganization of Section 5 in the 8th edition of the AASHTO LRFD specifications. This article focuses on the topic of prestressing and the reorganization of Article 5.9.

Article 5.9 covers the design of prestressed concrete elements. In this sense, the focus of Article 5.9 did not change from the 7th to the 8th edition of the AASHTO LRFD specifications.[1,2] However, the 8th edition introduces significant differences in the content and organization of this article. Article 5.9 of the 8th edition does a much better job delineating pretensioning and post-tensioning requirements. Detailing requirements from Article 5.10 of the 7th edition of the AASHTO LRFD specifications were moved to logical places in Article 5.9. In this way, these requirements are no longer mixed with those that apply to ordinary reinforcement in Article 5.10. The principal stress check for the webs of flexural elements is now required for all concrete bridge types except for pretensioned concrete beams made with concrete with a design compressive strength less than 10 ksi – this exception was made because past experiences of the states showed that cracking in the webs of such elements has not been an issue.

An overall comparison of Articles 5.9 and 5.10 in the 7th and 8th editions clearly shows that the information flows in a more logical way in the new edition. However, some of these changes will take a little getting used to, especially for experienced designers who are accustomed to looking for certain provisions of the AASHTO LRFD specifications in certain places. Nevertheless, once you use the new specifications a few times, I am confident you will find the new organization intuitive.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2014. *AASHTO LRFD Bridge Design Specifications*, 7th ed. Washington, DC: AASHTO.
2. AASHTO. 2017. *AASHTO LRFD Bridge Design Specifications*, 8th ed. Washington, DC: AASHTO.

Article	Title	Description
5.9.1	General Design Considerations	Section properties, crack control requirements, buckling, and harped or draped tendons.
5.9.2	Stress Limitations	Stresses due to imposed deformations, stress limits for prestressing steel, initial and long-term stress limits for concrete in compression or in tension, and principal tensile stress limits for webs.
5.9.3	Prestress Losses	Losses that apply to pretensioned and post-tensioned elements are covered separately. Furthermore, approximate and refined methods for determining time-dependent losses are treated in depth.
5.9.4	Details for Pretensioning	Provisions for detailing, including spacing of pretensioning strands, debonding limits, and anchorage zone detailing.
5.9.5	Details for Post-Tensioning	Provisions for minimum tendon and duct spacing and considerations for horizontally curved tendons, duct supports, tendon or duct couplers, design of anchorage zones, and all other details that are pertinent to post-tensioning technology.

Note: Adapted from C5.9.2.3.3-2 in *AASHTO LRFD Bridge Design Specifications*, 8th ed.