ASPIRE®

THE CONCRETE BRIDGE MAGAZINE

WINTER 2019

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Interstate 91 Brattleboro Bridge
Brattleboro, Vermont

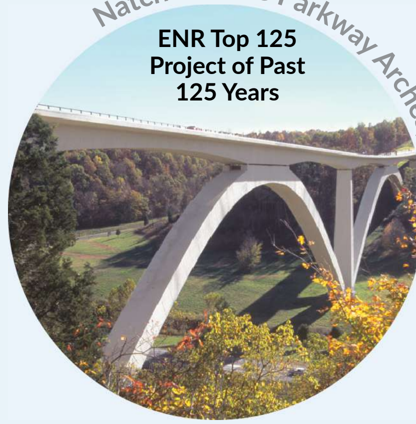
INTERSTATE 78 BRIDGE UNDERCLEARANCE PROJECT
Berks County, Pennsylvania

U.S. ROUTE 206 BRIDGES OVER STONY BROOK
Princeton, New Jersey

Presorted Standard
Postage Paid
Lebanon Junction, KY
Permit No. 567

I-275 Bob Graham Sunshine Skyway Bridge, Florida

Natchez Trace Parkway Arches, Tennessee



Penobscot Narrows Bridge & Observatory, Maine

New I-35W Bridge, Minnesota

US 191 over the Colorado River, Utah

Sarah Mildred Long Bridge, Maine/New Hampshire

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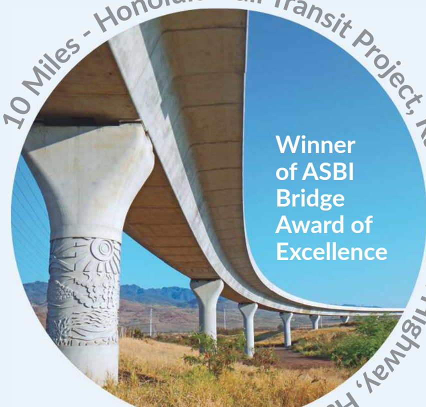
10 Miles - Honolulu Rail Transit Project, Kamehameha Highway, Hawaii



I-4 Crosstown Connector, Florida

I-91 Brattleboro Bridge Replacement, Vermont

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Photo: Alfred Benesch & Company.

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EDITORIAL

Photo: PCI.

Building on Traditions

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

In my editorial for the Fall 2018 issue of *ASPIRE*®, I briefly discussed a few potential technology changes that may affect concrete bridge construction in the next decade. New structural concrete and reinforcing materials are likely to lead to code changes to accommodate those advancements. My request was that we ensure that any changes are improvements. In this editorial, I am continuing this vital conversation about what constitutes improvement by focusing on what can we learn from the past.

I recently had an opportunity to reflect on the past and the value of traditions when I went to my 35th college class reunion at The Citadel in Charleston, S.C. It was interesting to see classmates and participate in the events at my alma mater for the weekend. My uncle George was also there. As a graduate of the class of 1968, he was celebrating his 50th reunion, and he and his classmates received special recognition as presidential guests. These honorees had a particularly grand time marching and mimicking cadet life of their past. As Uncle George always tells me, strong traditions and past success in every field of practice are keys to future successes.

During the reunion, the Department of Civil Engineering (CE) dedicated a classroom to one of my uncle's classmates, and one of my CE professors, Captain (now Colonel) Thomas Dion, who was retiring. For more than 40 years, Colonel Dion imparted his unique Charlestonian style of teaching in courses on drafting, surveying, hydraulics, and land development. In his classrooms, numerous freshman and sophomore CE students were simultaneously amused by his colloquial statements ("You are spinning your wheels!") and inspired by his calls to develop a passion for one's selected career.

Dion's encouragement of professional passion reflects a value of The Citadel as a whole. In addition to offering formal classroom studies similar to those found at many other learning institutions, The Citadel provides a distinctively rigorous, disciplined experience shaped by the institution's steadfast traditions and rules. The result is an environment that pushes your limits and builds an aptitude to expand your mind.

One notable Citadel tradition is that the regimental commander of the senior class always writes a letter to the incoming freshmen concerning the upcoming four-year college experiences they will face and grow from. Frederick J. Whittle closed his letter to my class of 1983 with the following exhortation: "Accept its [college's] challenges with a steadfast determination. Follow in the path of those who have come before you, and knowledge, integrity, patriotism, and self-reliance will be yours." This concept of following in the path of others is front and center each May in The Citadel's "Long Gray Line" parade during commencement week. The Long Gray Line refers to the men and women who have graduated from the South Carolina Corps of Cadets; in the parade, the graduating class becomes part of the line and transfers command to the incoming seniors.

As I watched campus life during my reunion, it was obvious to me that the community of new faculty and cadets is fully capable of reinventing the student experience and delivering solutions that will draw strength from the college's traditional foundation and continue to drive leadership. As I reflect on the future of the bridge construction industry, I likewise feel confident that the traditions underlying our engineering principles will be upheld in the future by new leaders.

On page 37 in this issue of *ASPIRE*, you will find an article that I have written, which includes some interesting data on the last 40 years of concrete bridges in the United States. I encourage you to stay in touch with this publication as our team seeks to showcase your concrete bridge engineering accomplishments. I hope your endeavors will create an even greater "gray line" impact in the decades to come.

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The Interstate 91 Brattleboro Bridge in Brattleboro, Vt., received a 2018 CRSI HONORS Design and Construction Award. Photo: © Adam Cohen 2017, Figg Engineering Group.

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

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Dr. Henry Russell is an engineering consultant who has been involved with the applications of concrete in bridges for over 35 years. He has published many papers on the applications of high-performance concrete.

Dr. Jill K. Walsh joined Saint Martin's University in Lacey, Wash., as an assistant professor in 2015. She was previously a senior bridge engineer with T.Y. Lin International.

CONCRETE CALENDAR 2019

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

January 13–17, 2019
Transportation Research Board 98th Annual Meeting
Walter E. Washington Convention Center
Washington, D.C.

January 18, 2019
Deadline for submitting abstracts for the 2019 International Accelerated Bridge Construction Conference
To be held December 12–13, 2019
Miami, Fla.

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

January 24, 2019
Deadline for submitting abstracts for the 2019 PCI Committee Days and National Bridge Conference
To be held September 25–28, 2019
Loews Chicago O'Hare Hotel
Rosemont, Ill.

February 26–March 2, 2019
PCI Convention with The Precast Show
Kentucky International Convention Center
Louisville, Ky.

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

April 8, 2019
ASBI Grouting Certification Training Course
J.J Pickle Research Campus
Austin, Tex.

April 8–10, 2019
DBIA Design-Build for Transportation Conference
Duke Energy Convention Center
Cincinnati, Ohio

May 5–8, 2019
PTI 2019 Convention & Expo
Hyatt Regency Seattle
Seattle, Wash.

May 27–29, 2019
fib Symposium 2019
Krakow, Poland

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

June 10–13, 2019
International Bridge Conference
Gaylord National Resort and Convention Center
National Harbor, Md.

June 24–27, 2019
AASHTO Committee on Bridges and Structures Annual Meeting
Renaissance Montgomery Hotel at the Convention Center
Montgomery, Ala.

July 22–25, 2019
BEI–2019 (Bridge Engineering Institute Conference)
Hyatt Regency Waikiki
Honolulu, Hawaii

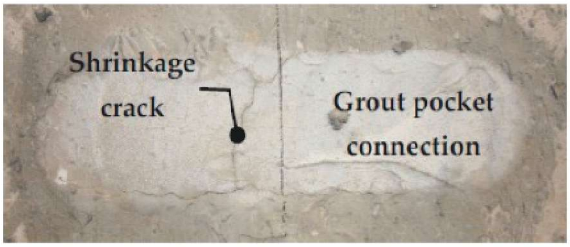
August 4–7, 2019
AASHTO Committee on Materials and Pavements Annual Meeting
Four Seasons Hotel Baltimore
Baltimore, Md.

September 4–6, 2019
Western Bridge Engineers' Seminar
The Boise Centre
Boise, Idaho

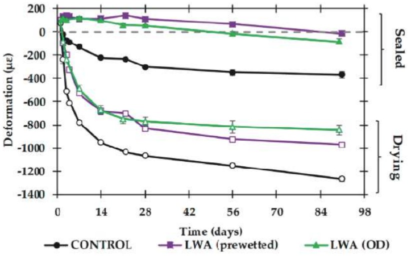
September 25–28, 2019
PCI Committee Days and National Bridge Conference
Loews Chicago O'Hare Hotel
Rosemont, Ill.

October 20–24, 2019
ACI Fall 2019 Conference
Duke Energy Convention Center & Hyatt Regency Cincinnati
Cincinnati, Ohio

November 4–6, 2019
ASBI 31st Annual Convention and Committee Meetings
Disney's Contemporary Resort and Grand Floridian Resort
Lake Buena Vista, Fla.



Commonly observed shrinkage cracking on top of the deck at the grout pocket



Long-term autogenous and drying deformations for the grouts with and without IC per ASTM C157

Internal Curing for Grouted ABC Connections

The use of accelerated bridge construction (ABC) has been growing across the U.S. to reduce the impact of construction on the public and improve safety for construction workers. One approach is to use prefabricated bridge elements (PBE), allowing construction of bridge components off site to shorten project impacts on the public. This requires connections between the precast elements that will provide the necessary durability for long-service life.

Research conducted at the Federal Highway Administration's Turner Fairbank Highway Research Center has demonstrated that many conventional "non-shrink" grouts have undesirable levels of shrinkage and may not provide durable connections. The researchers have demonstrated that using lightweight fine aggregate to provide internal curing (IC) within grouts has improved the performance of the grouts by reducing both autogenous and drying shrinkage.

The most recent paper from this research is "Cracking, Bond, and Durability Performance of Internally Cured Cementitious Grouts for Prefabricated Bridge Element Connections" by De la Varga, et al. (Figures above are from this paper.) The paper has been published in the journal Sustainability and can be downloaded using this link: https://www.mdpi.com/2071-1050/10/11/3881. The paper uses the dual ring test, formation factor concepts, and microstructural analysis to evaluate improvements in cracking, bond, and durability performance. Results show that, while IC grouts did not alter bond performance, they improved cracking and durability properties, confirming that using IC in cementitious grouts is an effective strategy to increase the durability and thus sustainability of bridge structures. The paper also provides a lengthy list of other references on the topic.

CRSI Reinforces Its Services and Programs

Concrete Reinforcing Steel Institute

The Concrete Reinforcing Steel Institute develops standards, technical publications, and design aids with emphasis on industry certifications, education programs, and support for members and others in the steel-reinforced concrete industry.

by Craig A. Shutt

After a brief time away, Dr. Danielle Kleinhans returned to the Concrete Reinforcing Steel Institute (CRSI) in November 2017 as president and chief executive officer (CEO). Having previously worked at the organization for five years beginning in 2011, she understood the organization. Since returning, she has worked with staff to bolster and upgrade technical and engineering services for members as well as the engineers, designers, consultants, owners, and others who work with its members.

"I saw it [the job of president/CEO] as an opportunity to step into a leadership role in the industry and use my technical background and familiarity with the group to advance its mission," she says. "It felt like coming home. I'm very excited about how we can expand our programs, especially in educational areas."

Expanding Certification

One of CRSI's key initiatives for advancing educational efforts comes through its certification programs for members' products. "We've beefed up our approach by creating national standards for the certification processes," Kleinhans explains.

The association has long offered certification for members' epoxy-coating plants and recently began offering certification for fabricators of epoxy-coated reinforcement. In 2018, CRSI added certification for fabricators of stainless steel reinforcement.

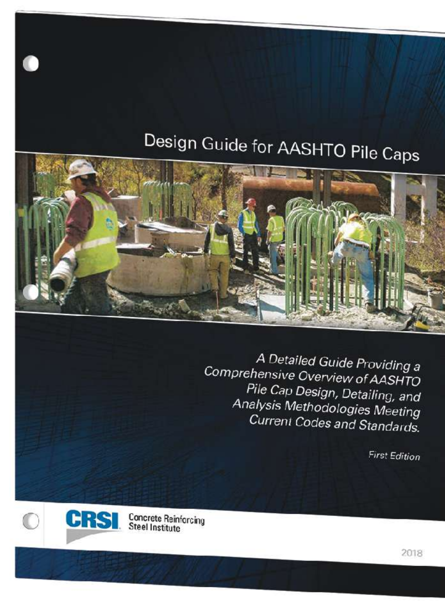
"There is interest in stainless steel reinforcement from DOTs [departments of transportation], which makes it more visible to all owners," Kleinhans says. The stainless steel certification standard varies from epoxy-coating standards in several ways, she notes. The stainless steel standard focuses on avoiding contamination from carbon steel in the fabrication process, whereas epoxy-coating standards focus on handling procedures to avoid damage to the protective coating.

The certification programs help specifiers ensure they receive a high-quality product regardless of their choice. "Everyone wants answers as to which reinforcing steel is best for their project," Kleinhans says. "I know it's frustrating to hear that it [the best choice] depends on the application, but that's the reality. We want to ensure specifiers understand what the products can do so they can invest for the most cost-effective impact. The goal for all of our certification programs is the same: to produce a quality product that meets specific needs."

'Everyone wants answers as to which reinforcing steel is best for their project.'

Publications

CRSI produces a variety of publications associated with its research efforts and publishes updates on a regular basis.



Manuals produced by the Concrete Reinforcing Steel Institute (CRSI) offer technical information of interest to professionals in the industry. Photo: CRSI.

The most recent title, *Design Guide for AASHTO Pile Caps,* offers details on the analysis, design, and detailing of reinforced concrete pile caps in accordance with the 2014 edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*. (See the article on this new publication in the Fall 2018 issue of *ASPIRE*®.)

"Some of our publications are geared to member needs, but others focus on what engineers need to know," Kleinhans says. "We are constantly looking for

Prefabricated reinforcing cage for bridge column in seismic region with very heavy reinforcement. The Concrete Reinforcing Steel Institute's certification standards for epoxy-coating plants, fabricators of epoxy-coated bars, and fabricators of stainless steel reinforcement help ensure quality products. Photo: Dimension Fabricators Inc.

feedback on our programs, from both members and owners, especially about what we're missing, so we can meet their needs better." She points out that some member publications also would be of interest to individuals in the engineering community. "They might find it interesting to see what it takes to turn their engineering drawings into field drawings."

The array of titles that may be of interest to bridge designers includes the *Manual of Standard Practice, High-Strength Reinforcing Bars,* and *Corrosion Resistant Steel Reinforcement: Summary of Test Methods.*

One of Kleinhans's favorite manuals is *Vintage Steel Reinforcement in Concrete Structures,* which presents information and photos of types, styles, and material properties of steel reinforcing bars and mesh used throughout history. "It's fascinating to look back at what has been used in the past, and the manual aids forensic engineers in determining the age and type of construction used on a bridge that is being inspected or evaluated for repair or replacement."

Apps and e-Learning

CRSI's education efforts expanded in 2018 with the introduction of its first application for smart phones. The association's pocket-sized guide for reinforcing bar sizes and diameters was digitized so it can be referenced at the job site.

"We're starting our app program with baby steps," Kleinhans explains. "We want to make our resources more useful and dynamic." Its technology plan includes apps that offer calculations on amounts of reinforcement and similar aids. "We're looking at the basics of what we can provide to get us started."

Another CRSI service is Rebar U (www.rebar-u.org), an e-learning web portal. Launched in January 2017, Rebar U serves as a home for CRSI's growing collection of publicly available e-learning courses and webinars for continuing education and professional development. Several self-paced courses are free to all visitors, while on-demand and live webinars are free for corporate members. The live webinars typically run bimonthly.

CRSI HONORS Bridges

CRSI's efforts also involve its design awards program, which for 40 years has recognized innovative reinforced concrete structures throughout North America. In 2013, the program was revised as the CRSI HONORS Design and Construction Awards. It singles out concrete projects that are distinctive not just for their design or achievement but also for the specific ways that reinforced concrete was used to improve the appearance, sustainability, and durability of the structure.

The winning entries, which are selected biannually and include various building types and bridges, are promoted by the CRSI via university lectures, regional seminars, and other means. "Our goal is to find projects that can inspire prospective clientele as well as students and young professionals seeking to become tomorrow's design and construction leaders," Kleinhans explains.

Two bridges received awards in 2018. The first award winner was the Interstate 90 Dresbach Bridge over the Mississippi River near La Crosse, Wisc., which consists of twin 2593-ft-long structures. Each features a four-span, 1667-ft-long, cast-in-place, post-tensioned, segmental box-girder design built from above by the balanced-cantilever method over the main channel. A six-span, 926-ft-long precast, pretensioned concrete beam unit spans over the east channel. This approach provided uninterrupted commercial and recreational use of the river during construction—a key requirement for the owner, the Minnesota Department of Transportation.

The bridge, which features dual 508-ft-long main spans, was constructed by Ames Construction in Burnsville, Minn., with FIGG in Denver, Colo., as the designer for the main span. The judges said the bridge is "a great example of innovation, durability, and context-sensitive design." (For more on this project, see the article in the Summer 2016 issue of *ASPIRE*.)

The second bridge to be honored was the Interstate 91 Brattleboro Bridge in Brattleboro, Vt., owned by the Vermont Agency of Transportation. The bridge, also built using the balanced-cantilever method with form travelers, is a 1036-ft-long, three-span segmental, cast-in-place concrete box-girder structure. The design-build team led by PCL Civil Constructors Inc. in Raleigh, N.C., as the prime contractor and included FIGG in Exton, Pa., as the engineer of record; and Sebago Technics in South Portland, Me., as roadway/general civil engineer. Judges noted that the bridge's 515-ft-long main span provides "durability and structural features for over 150-year design life—beating the owner's 100-year design-life requirement." (For more on this bridge, see the article in the Winter 2018 issue of *ASPIRE*.)

Sustainability Aids

CRSI has completed an environmental product declaration (EPD) for reinforcing bar. Life-cycle assessment (LCA) has become a standardized way of quantifying the environmental impact of a product or system. The EPD, which is created from an LCA, includes information on the environmental impact of raw material acquisition; energy use and efficiency; content of materials and chemical substances; emissions to air, soil, and water; and waste generation.

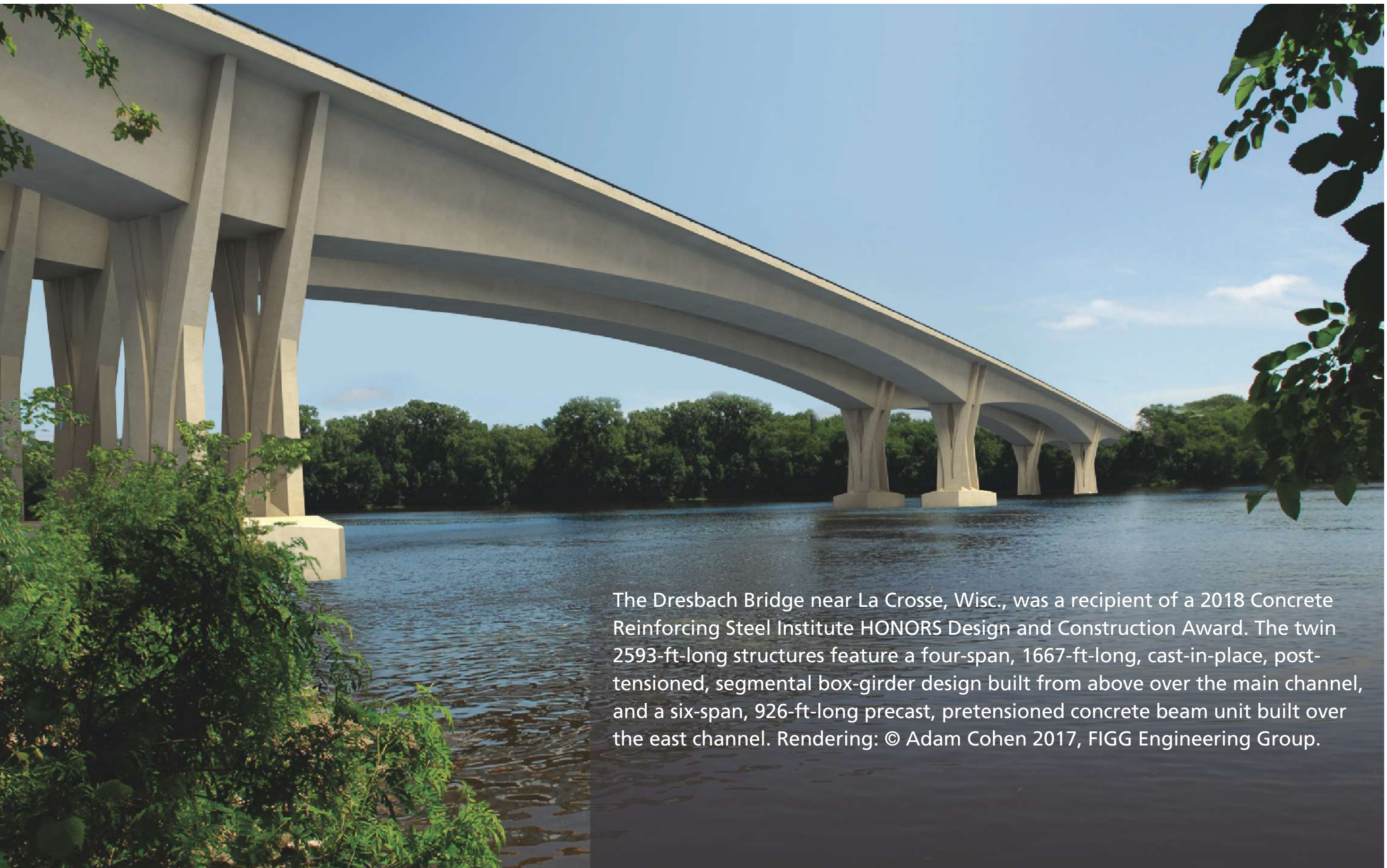
Reinforcing bar, Kleinhans stresses, is a very sustainable product and helps meet "green" goals. "About 97% of all reinforcing bar is made from recycled steel and scrap products," she says. "Because we have such a sustainable product, we want to stay on top of all sustainability documentation and ensure that specifiers are aware of the benefits of using concrete with reinforcing steel."

Advocacy, Alliances, and Interest Groups

CRSI is also involved in helping craft federal policy through its one-person Washington, D.C., office and its Rebar Political Action Committee (PAC). Launched in 2014, the PAC allows CRSI to support congressional leadership that advocates for the industry's goals in such areas as transportation funding and resilient construction. "It serves as a tool to help us partner with others in the political arena," Kleinhans says.

CRSI members also serve on an internal CRSI Government Affairs Committee, which monitors legislation and regulations at the state and federal levels and advocates for the industry. Through this committee, CRSI has issued position communications, letters of support, and opposition statements.

CRSI also works closely with the North American Concrete Alliance, an organization representing various associations involved in the concrete



The Dresbach Bridge near La Crosse, Wisc., was a recipient of a 2018 Concrete Reinforcing Steel Institute HONORS Design and Construction Award. The twin 2593-ft-long structures feature a four-span, 1667-ft-long, cast-in-place, post-tensioned, segmental box-girder design built from above over the main channel, and a six-span, 926-ft-long precast, pretensioned concrete beam unit built over the east channel. Rendering: © Adam Cohen 2017, FIGG Engineering Group.

The Interstate 91 Brattleboro Bridge in Brattleboro, Vt., received a 2018 Concrete Reinforcing Steel Institute HONORS Design and Construction Award. The 1036-ft-long, three-span segmental, cast-in-place concrete box-girder structure features a 515-ft-long main span that was designed for a 150-year service life. Photo: © Adam Cohen 2017, Figg Engineering Group.

industry with the goal of promoting reinforced concrete construction at the federal level, and the Alliance for Concrete Codes and Standards, which coordinates industry positions on provisions and proposed changes under consideration by national codes and standards writing organizations.

"We are trying to encourage more spending on infrastructure, which is sorely needed to replace outdated structures," Kleinhans says. Many legislators want to improve infrastructure, she notes, but there is little consensus on funding sources and how much investment is needed. "We'll continue our efforts to educate legislators and keep them aware of the growing need."

CRSI also operates two interest groups that focus on specific aspects of the industry. The Epoxy Interest Group was formed in 2008 to promote and market fusion-bonded epoxy-coated steel reinforcing bars. The group operates as "an institute within the institute," Kleinhans says, with its own managing director, steering committee, dues, budget, and website (www.epoxyinterestgroup.org).

The Independent Fabricators Interest Group was established in 2010 to strengthen the business operations and competitiveness of independent fabricators. It operates within CRSI and offers an opportunity for qualified CRSI members to discuss business issues and trends.

Planning for the Future

In addition to providing resources and educational materials for today's engineers and industry professionals, CRSI is looking to nurture future generations of engineers and improve their understanding of reinforcing steel. The CRSI Education and Research Foundation is a nonprofit educational foundation that funds and administers graduate and undergraduate scholarships for architectural and engineering students as well as scholarships and training programs at vocational and technical schools for estimating or detailing reinforcing steel. The CRSI Foundation also works with CRSI's Research and Development Committee to provide support for worthy research projects that advance the reinforced concrete industry. The foundation is currently funding approximately $150,000 in research programs and offers up to $30,000 per year in scholarships.

"Our goal is to support students studying subjects that include reinforced concrete," says Kleinhans. "Our members have challenges in finding new employees, and we want to create initiatives that can inform students about the products and alert them to industry opportunities they may be unaware of, so they can have satisfying careers and our members can fill positions."

'Our goal is to support students studying subjects that include reinforced concrete.'

Efforts to encourage younger CRSI members are being aided by the group's "Next Generation Engagement Initiative," which was introduced at CRSI's annual conference in October 2018 in Chicago, Ill. CRSI encouraged its member companies to bring employees who had previously never attended the conference so they could see the programs. CRSI is soliciting feedback from these attendees to find out what they liked and how they think the programs could be improved. "It provides a chance to bring in new blood, new perspectives, that can ensure we are best targeting our audiences' needs today," Kleinhans says.

These and other programs will keep CRSI aligned with industry needs. "These new programs will aid the industry in many ways and provide better understanding about our products and their potential."

95 Years of Service to the Industry

The Concrete Reinforcing Steel Institute, one of the oldest trade associations in the United States, was founded in 1924 as a technical institute and standards-developing organization devoted to establishing standards and offering resources about steel-reinforced concrete construction.

Each year, approximately 8 million tons of reinforcing steel are efficiently manufactured using scrap steel. It is estimated that the industry affects more than 75,000 people in steel transportation and placement in North America.

CRSI members represent more than 80% of U.S. manufacturers, fabricators, material suppliers, and placers of steel reinforcing bar and related products. Industry professionals involved in research, design, and construction also are members. CRSI members employ approximately 15,000 people in steel production and rebar fabrication at more than 600 locations in 49 states.

Based in Schaumburg, Ill., CRSI operates regional offices in the Northeast (Williamstown, N.J.), Midwest (Rochester Hills, Mich.), Southeast (Tega Cay, S.C.), Greater Southwest (location to be announced), and West (Fairfield, Calif.).

Engaging Communities in Bridge Projects

Effective strategies for community engagement are evolving and can determine the success of a project

by Richard R. Dion, Bridge Museum

When embarking on a bridge project, owners, designers, and contractors alike should be aware of the role that local communities will play in determining whether the project succeeds. When government agencies and companies effectively engage the public, community members will understand issues related to structural requirements and have a voice in discussions about aesthetic choices, funding, and the project's impact on the locality. Encouraging public engagement also demonstrates that those involved in the project will act transparently and will be held accountable for their actions. In the digital age, sharing information is relatively simple, but genuine communication requires creative effort and an openness to dialogue.

Public Engagement by Government Agencies

From the most mundane off- and on-ramps to signature megaprojects, bridges connect localities, regions, and countries. However, many citizens underestimate the roles that bridges play in our society and take transportation infrastructure for granted until there is a problem or a controversy, at which point they want to know what is happening, why it is happening, and who is responsible. Government agencies must also be prepared for questions regarding how taxpayer dollars are spent. Clearly, bridge owners and government agencies therefore need effective communication strategies to help the public understand the many factors involved in building and maintaining safe bridges.

Because infrastructure projects are largely funded by tax monies, government agencies must ensure that the process is transparent to the public, and costs are monitored and contained. If bridge owners or communities want to build a signature structure that is not only functional but also beautiful, they will need to make a business case for any added costs for aesthetics. The decision-making policies and procedures of any bid process should be made public, and the benefits and risks of investments must be clearly communicated to citizens. On any project, government officials must also share information about the schedule, possible traffic delays, and other issues that need public input, such as where a bridge may be built and its potential impact on local communities. Otherwise, community relationships can become strained and cooperation is lost.

Websites and social media are convenient tools that government officials can use for communicating with the public. Many local authorities have YouTube channels and Facebook pages. Unfortunately, many posts about projects are not particularly engaging. It is important to keep in mind that the job of communicating to the public

The 35th Street Pedestrian Bridge in Chicago, Ill., unites the Bronzeville neighborhood with the Lake Michigan lakefront. The signature bridge is an asset to the community. The bridge is featured in the Fall 2018 issue of *ASPIRE*®. Photo: Dave Burk Photography.

To engage the community, the design-build team of the Interstate 91 Brattleboro Bridge led trail talks, visited local schools to present lessons on engineering and bridge construction, and included a Vermont-like stone finish to enhance the design. See the Winter 2018 issue of *ASPIRE* for more details. Photo: © Adam Cohen 2017, Figg Engineering Group.

is not over once an update is posted. Instead, those who post information must be open to feedback and ongoing dialogue.

In the rare instance that a bridge fails or must be taken out of service because of an accident or other situation, public agencies will take the lead in the response to the disaster, its investigation, and recovery efforts. At such times, these agencies must have a crisis management strategy already in place to ensure that the problems are not compounded by a lack of planning or poor communication.

While investigations are underway and remedies are being developed, agency representatives must update communications with users and communities constantly and consistently in terms that are understandable to the layperson. In tense situations, engineers may find it particularly difficult to effectively communicate technical information to the public; however, at such times, community members may be especially receptive to what an empathetic and well-spoken engineer can teach them about key aspects of infrastructure. In the long run, informing the public during a crisis could lead to a new culture of maintenance and greater public appreciation of infrastructure.

Public Engagment by Companies

Although the design of a bridge for use by drivers, bikers, and pedestrians is important, other aspects of the project—including alternative routes during construction, disruptions to businesses, lane closures, and environmental impacts—are also crucial and need to be given due consideration by designers and contractors. In the United Kingdom, a voluntary program known as the Considerate Constructors Scheme has developed a *Code of Considerate Practice* that commits companies and construction sites to care about appearance, respect the community, protect the environment, secure everyone's safety, and value their workforce.[1] As suggested by the tenets of this code, companies need to demonstrate by their actions that they are good neighbors to others in the community.

Companies can benefit from transparently and frequently consulting with local communities in the time leading up to a bid proposal. Informal market research or more structured discussions with community leaders could help the company not only build relationships but also transform information into knowledge that can be reflected in the bid proposal, showing that the company has gone the extra mile to engage the public.

Once a project begins, ongoing education of the public fosters a good relationship between the contractor and the community. In major projects, visitor centers featuring project photos and three-dimensional models are relatively commonplace. However, in the digital age, companies and their stakeholder professionals can also use other tools to engage the public and demonstrate the scope and scale of a bridge project. Virtual reality, augmented reality (the overlay of a virtual object on real-world objects), and the use of drones can provide that experience.

Companies may also invest in outreach to schools and colleges in the community surrounding the project. Efforts could include hosting field trips to the project site, having company representatives make classroom visits, or offering curriculum ideas that promote STEAM (science, technology, engineering, art/architecture, and mathematics) disciplines. Internships for college-level engineering and architecture students can also help to build community partnerships.

When considering public engagement strategies, companies must consider that a bridge project may deliver a service for millions of people and for generations to come. A project's success is arguably a company's greatest asset in business development elsewhere. A poorly executed job could be disastrous for a company. Instead of a culture of "design, deliver, defend," companies should strive for a "dialogue, design, deliver" culture, in which employees, shareholders, and communities will all reap the benefits.

Conclusion

When problems occur during a bridge project, they can spread quickly through traditional and social media. Local authorities may be bombarded by community members protesting decisions or complaining about the project's impact. Fortunately, strong community relationships and a culture of dialogue can help prevent problems during the project and head-off longer term issues. For this reason, it is crucial that government agencies and companies take the views of local communities into careful consideration.

Reference

1. Considerate Constructors Scheme. *Code of Considerate Practice*. https://www.ccscheme.org.uk/ccs-ltd/code-of-considerate-practice-2. Accessed October 23, 2018.

EDITOR'S NOTE

The St. Croix River Crossing bridge, featured in the Fall 2018 issue of **ASPIRE*****, is a great example of a several-decades-long process of community involvement.***

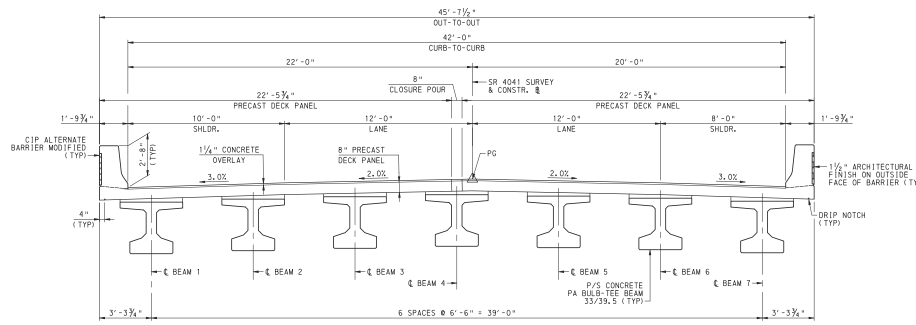
PROJECT

Interstate 78 Bridge Undercleareance Project

by Brian Brawand, Alfred Benesch & Company

The Pennsylvania Department of Transportation (PennDOT) District 5 recently replaced six overhead bridges located consecutively along an 8-mile stretch of Interstate 78 (I-78) in western Berks County, Pa. This project, which spanned the 2016 and 2017 construction seasons, used accelerated bridge construction (ABC) techniques and featured the first implementation of full-height precast concrete cantilever abutments for PennDOT. The bridges were replaced to increase the minimum vertical clearance over I-78 from approximately 14 ft to 16 ft 6 in. and accommodate the future widening of I-78. As part of the project, approach roadways and ramps were reconstructed to accommodate the roadway profile and width modifications.

All six replacement bridges are single-span precast, prestressed concrete bulb-tee beam bridges that include aesthetic features such as an architectural finish and color scheme. Most of the substructures consist of full-height cantilever abutments supported on spread footings (one structure is supported on pile foundations). The use of ABC techniques under roadway closures reduced the average construction duration for each structure from one year to 45 calendar days. ABC techniques used on the project included time-based bidding techniques and prefabricated bridge elements, such as precast concrete footings, stem pieces, pedestals, back walls, full-depth deck panels, approach slabs, sleeper slabs, and moment slabs. The table provides an overview for each of the six replacement bridges, highlighting the span lengths, widths, skews, number of precast concrete pieces, and number of calendar days for construction and noting if the bridge is located at an interchange.



State Route 4041 bridge cross section. Figure: Alfred Benesch & Company.

Time-Based Bidding

After considering available options, the project team elected to apply an *A + Bx* time-based bidding approach for

Overview of the Six Berks County, Pa., Interstate 78 Replacement Bridges

State Route No.	Span Length, ft	Deck Width, ft	Skew, degrees	Located at Interchange?	No. of Precast Concrete Pieces	No. of Calendar Days for Construction
183	121	53	17	Yes	126	40
419	133	50	30	Yes	146	58
4011	111	58	15	Yes	88	40
4041	115	46	0	Yes	86	44
4043	103	32	0	No	54	37
4045	104	32	0	No	40	40

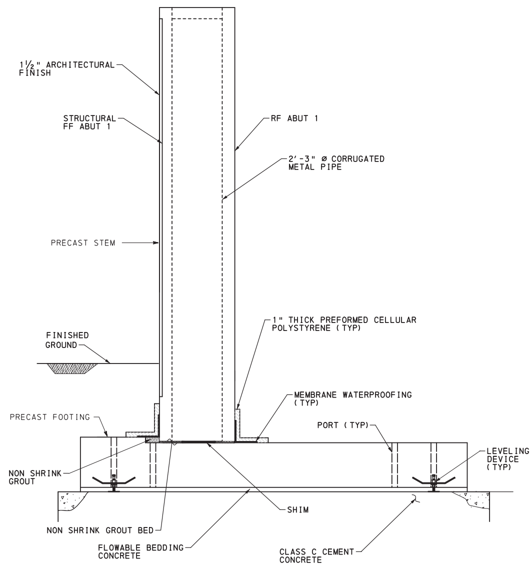
profile

INTERSTATE 78 BRIDGE UNDERCLEARANCE PROJECT / BERKS COUNTY, PENNSYLVANIA

BRIDGE DESIGN ENGINEERS: Alfred Benesch & Company, Allentown, Pa. (engineer of record [EOR] for two bridges); Johnson Mirmiran & Thompson, Allentown, Pa. (EOR for two bridges); Erdman Anthony, Mechanicsburg, Pa. (EOR for one bridge); AECOM, Conshohocken, Pa. (EOR for one bridge)

PRIME CONTRACTOR: HRI Inc., State College, Pa.

PRECASTER: PennStress, Roaring Spring, Pa.—a PCI-certified producer



Typical section of State Route 183 precast concrete stem piece at abutment. The 2-ft 3-in.-diameter corrugated metal pipe was used in stem pieces of two bridges to keep the piece weight within the 50-ton limit. Figure: Alfred Benesch & Company.

this project. The *A* component was the dollar amount proposed by the bidder for construction of a structure. The *Bx* component was the number of days for roadway closure proposed by the bidder multiplied by a road-user liquidated damages (RULD) value calculated by the project team for a given location. The RULD value was based on the average daily traffic at each structure and the associated detour length. There were six separate *A* + *Bx* bidding items as part of the project, one for each bridge. The time-based bidding approach placed significant value on the time component of the bid and helped determine the sequential order in which the bridges would be constructed.

Prefabricated Elements

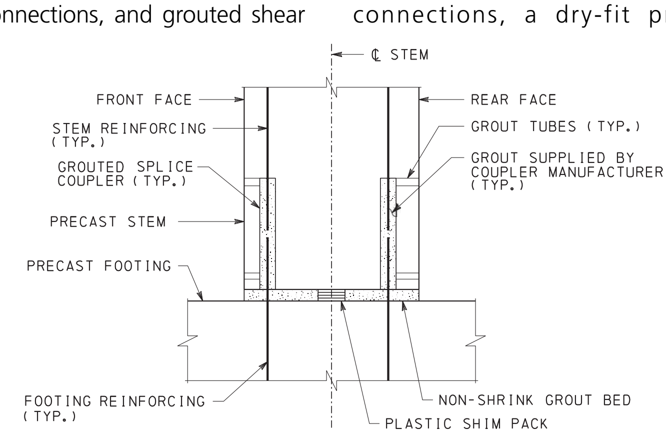
The project used more than 500 prefabricated bridge elements. The precast concrete footing and stem components were the largest prefabricated bridge elements in the project. The precast concrete footing pieces were up to 2 ft 9 in. thick, 18 ft 6 in. long, and 14 ft 6 in. wide. The precast concrete stem components were up to 3 ft 6 in. thick, 30 ft tall, and 12 ft wide. The weight of all precast concrete pieces was limited to 50 tons. On two of the bridges, corrugated metal pipes were used to form voids within the stem pieces to reduce the piece weight and meet the 50-ton requirement. After erection, concrete was used to fill the voids. Some of the prefabricated element connections or concepts for the substructure included overlapping or staggering of the precast concrete stem and footing joints, grouted splice couplers for the precast concrete footing to stem connections, and grouted shear keys between adjacent precast concrete footing and stem pieces.

The full-depth precast concrete deck panel pieces were typically 8 in. thick and less than 14 ft wide to facilitate shipping. The six bridges had significantly different bridge widths; therefore, some bridges used precast concrete deck panel components that extended across the full bridge width while others used two or three precast concrete deck panel components to extend across the full bridge width.

Blockouts in the deck panels, protruding bars from the bulb-tee beams, and ultra-high-performance concrete (UHPC) in the beam pockets were used for the panel-to-beam connections; additionally, longitudinal closure pours with UHPC, transverse joints with shear keys, and longitudinal post-tensioning of the precast concrete deck panels were also used in the construction of the superstructure.

Dry-Fit Procedure

Fabrication of the prefabricated concrete bridge elements required tight tolerances to avoid fit-up issues on site. Given the accelerated nature of the project and minimal tolerances permitted by some of the prefabricated bridge element connections, a dry-fit procedure



Grouted splice-coupler connection detail between precast concrete footing and precast concrete stem. Figure: Alfred Benesch & Company and Johnson, Mirmiran & Thompson.

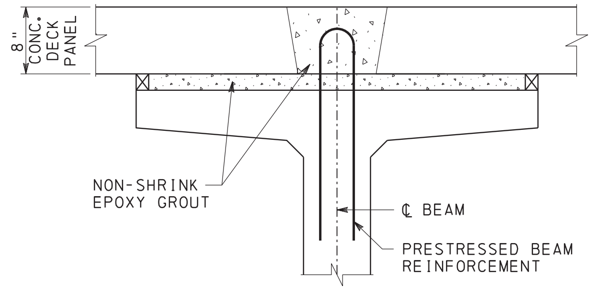
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION DISTRICT 5, OWNER

BRIDGE DESCRIPTIONS: Six single-span precast, prestressed concrete bulb-tee beam bridges that used prefabricated concrete bridge elements for both the substructure and superstructure, including full-height cantilever abutments typically supported on spread footings

STRUCTURAL COMPONENTS: 104 precast concrete footing components, 182 precast concrete stem components, 41 precast, prestressed concrete bulb-tee beams, and 122 precast concrete full-depth deck panel components with bonded post-tensioning tendons

BRIDGE CONSTRUCTION COST: $44.5 million (project cost)

AWARD: 2018 American Society of Highway Engineers East Penn Section Project of the Year (over $20 million in construction costs)



Precast concrete deck panel–to–beam connection detail. Figure: Alfred Benesch & Company and Johnson, Mirmiran & Thompson.

completed at the fabricator's storage yard was required for the project. These connections included the grouted splice-coupler connections between the precast concrete footing and stem pieces and the connection between the precast concrete beams and deck panels.

The substructure dry fit was completed by initially placing all of the precast concrete footing pieces for one abutment in place. Each precast concrete stem piece was moved to a sand bed staging area where it was rotated into a vertical position. The precast concrete stem piece was then lifted, brought to the footing area, and lowered into place over the splice couplers to ensure proper fit. The stem piece was removed, and each additional stem piece was subsequently checked for fit. The superstructure dry fit was completed by initially placing all, or a portion of, the precast concrete bulb-tee beams for a structure into place. Precast concrete deck panel pieces were lifted and placed onto the beams to ensure proper fit of deck panel beam pockets and bars protruding from the beams.

Demolition and Construction

Demolition of the existing three-span bridges' end spans and abutments was completed during normal work hours. Demolition of the center span over I-78 was completed at night while the roadway below was protected with timber mats. Traffic on I-78 was maintained, depending on the specific bridge location, with use of a ramp around the construction or a detour route. Piers adjacent to the I-78 shoulders were removed with the use of protective shielding.

The major construction activities required for substructure construction included the following:

Precast concrete footings:

- Placement of subfoundation concrete
- Placement of shims to proper elevation
- Erection of precast concrete footing pieces
- Placement of flowable concrete underneath footing
- Placement of grout in transverse joints between adjacent footing pieces

State Route 183 precast concrete footing being erected on site. Photo: Alfred Benesch & Company.

Precast concrete stems:

- Placement of shims to proper elevation
- Placement of grout on top of footing
- Erection of precast concrete stem pieces
- Installation of temporary bracing
- Injection of grout into splice couplers
- Placement of grout in transverse joints between adjacent stem pieces

State Route 183 precast concrete stem and footing undergoing fit-up procedure at precast concrete plant. Photo: Alfred Benesch & Company.

Erection at the State Route 4045 bridge of the precast concrete stem piece. Note the stone-like architectural finish. Photo: Alfred Benesch & Company.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

Overpass bridges on freeways have a very limited time to make an aesthetic impression because their "audience" is typically traveling at 55 to 75 miles per hour. From the point at which the bridge is close enough for its components to be discerned (no more than 1500 ft away) to the point at which the bridge is so close that travelers are looking through and beyond it (perhaps 300 ft away), just 10 to 12 seconds elapse. Only the largest elements can be seen from the traveler's perspective. Therefore, making a memorable impression requires visual simplicity.

When overpass bridges are closely spaced, similarity is also very important. While moving at 70 miles per hour, travelers see the six bridges of the Interstate 78 (I-78) Underclearance Project at a rate of about one every 1 minute and 10 seconds. Imagine the aesthetic effect if the bridges' appearances were all different!

The I-78 bridges make their visual impression with only four significant elements:

- The brown concrete bulb tees
- The rough gray form-liner "stone" of the abutment wing walls
- The smooth, gray horizontal band of concrete at the tops of the wing walls, which follows the roadway slab across the bulb tees and visually ties the whole bridge together
- The same gray rough "stone" on the parapet face

At a more detailed level, the designers took the trouble to make sure that the form-liner stone actually looks like a real stone wall. Each stone is stained a slightly different color, which provides visual texture. Plus, at the corners, the same stones and mortar lines appear on each wall face. As a final effective detail, the deepening of the horizontal band at each beam seat nicely frames the bulb tees. For travelers on I-78, these visually simple, elegantly detailed new bridges must represent a significant visual improvement on their three-span predecessors.

Precast concrete beams and deck panels were erected at night, and I-78 traffic was maintained, depending on the specific bridge location, with the use of a ramp around the construction or temporary 15-minute closures of I-78.

The major construction activities required for precast concrete deck panel construction included the following:

- Erection of the precast concrete full-depth deck panels
- Placement UHPC in the transverse joints
- Tensioning and grouting of longitudinal post-tensioning
- Placement of UHPC in the composite reinforcement blockouts, haunches, post-tensioning anchor blockouts, and longitudinal closure pours

Major construction activities to complete construction of a typical bridge included precast concrete sleeper slab and approach slab construction, cast-in-place concrete parapet construction, deck milling, and placement of the latex-modified concrete overlay.

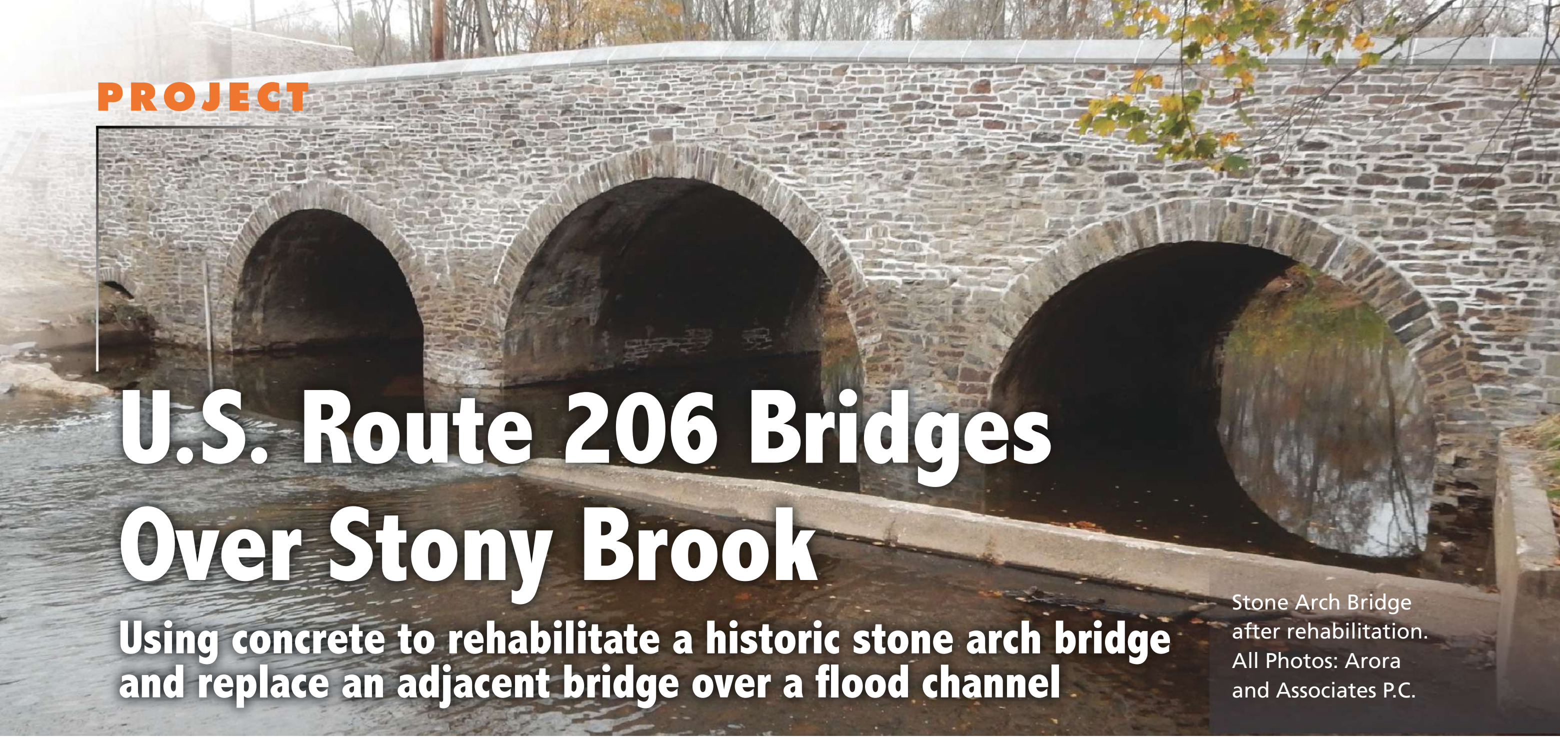
Conclusion

The I-78 Bridge Underclearance Project was a successful PennDOT District 5 ABC project, featuring the first implementation of precast concrete full-height cantilever abutments for PennDOT. The project replaced six bridges over two construction seasons with an average construction duration of 45 calendar days per bridge. The use of prefabricated concrete bridge elements and a time-based bidding technique were both critical aspects of this PennDOT District 5 ABC project.

Brian Brawand is a project manager in the Structural Group of the Allentown, Pa., office of Alfred Benesch & Company.

At the State Route 183 bridge, ultra-high-performance concrete is placed to fill the beam-to-deck panel connections. Photo: Alfred Benesch & Company.

Elevation view of the State Route 4045 constructed bridge. Exposed concrete surfaces have been stained to enhance the appearance of formed-stone surfaces. Photo: Alfred Benesch & Company.



U.S. Route 206 Bridges Over Stony Brook

Using concrete to rehabilitate a historic stone arch bridge and replace an adjacent bridge over a flood channel

Stone Arch Bridge after rehabilitation. All Photos: Arora and Associates P.C.

by David Hutchinson and Khairul Alam, Arora and Associates P.C., and Pankesh Patel, New Jersey Department of Transportation

Built in 1792, the Stone Arch Bridge over Stony Brook in Princeton, N.J., is the oldest still-in-use bridge owned by the state. The triple-arch stone bridge was built by local masons using stone from nearby quarries and currently carries U.S. Route 206 vehicular traffic in Mercer County. In 2016, after serving the public for more than two centuries, the historic bridge was nearing the end of its service life and was unsuitable to support traffic loadings in the 21st century. A rehabilitation project using cast-in-place concrete within the fill of the arches effectively strengthened and added durability to the structure, while preserving the beauty of the original bridge.

Partial collapse of the stone parapet and spandrel wall of the Stone Arch Bridge. The ruin wall of Worth's Mill is on the right. The Flood Channel Bridge is just beyond the ruin wall.

Emergency Repairs

On February 22, 2016, the parapet and spandrel wall above the north arch on the upstream side of the structure partially collapsed, forcing closure of this section of Route 206. The failed area was stabilized, and an in-depth inspection of the bridge was performed, which revealed more areas that needed repair. The partial collapse was a sign that the bridge needed attention to address the underlying causes of the failure. The roadway was reopened to traffic on March 7, 2016. However, heavy truck traffic across the bridge was prohibited, and the failed area and extensive leaning and bulging of the spandrel walls and parapets on the upstream face remained.

The emergency repair, including the installation of temporary concrete barriers to protect the collapsed area and other nonstable parapet areas, allowed for the continued use of the bridge while the project to retrofit the structure for strength, safety, and durability was undertaken.

Historical Considerations

The historic nature of the bridge and adjacent structures was an important factor in the rehabilitation project. The crossing where the Stone Arch Bridge stands was part of the early 18th-century King's Highway and an important crossing during the Revolutionary War. The original timber bridge, which dated to 1738, when the area was settled by Quakers, was damaged for strategic reasons in the Battle of Princeton. The Stone Arch Bridge was

profile

U.S. ROUTE 206 BRIDGES OVER STONY BROOK / PRINCETON, NEW JERSEY

BRIDGE DESIGN ENGINEER: Arora and Associates P.C., Lawrenceville, N.J.

PRIME CONTRACTOR: South State Inc., Bridgeton, N.J.

PRECASTER: Precast Systems Inc., Allentown, N.J.—a PCI-certified producer built as a replacement for the first structure a decade after the end of the Revolutionary War. It originally had a cart-way width of 18 ft but was widened to 32 ft around 1916.

Next to the Stone Arch Bridge on the southern approach is the Route 206 Bridge over the Stony Brook Flood Channel (Flood Channel Bridge). Built in 1892, the original Flood Channel Bridge was a a three-span bridge, which was later widened along with the Stone Arch Bridge. The Flood Channel Bridge was an important feature of the King's Highway historic district; however, at the time that the Stone Arch Bridge partially collapsed, the Flood Channel Bridge was in poor condition and in need of replacement. Therefore, the decision was made to replace the Flood Channel Bridge while the Stone Arch Bridge was rehabilitated. Undertaking both projects at the same time would accelerate construction and limit the duration of the Route 206 detour.

Another important aspect of the project was the treatment of the ruins of the Worth's Mill southern wall, which stands next to both the Stone Arch and Flood Channel Bridges. This ruin wall, which predates the Stone Arch Bridge, was determined to be in poor condition and in need of repair and stabilization. To ensure the stability of the wall during construction, electronic monitoring of the structure for vibration, displacement, and tilting was conducted.

Project authorization by the Historic Sites Council was required under the New Jersey Register of Historic Places Act. The project received approval with 18 mitigating conditions—such as recording the structures to the Historic American Engineering Record (HAER) standards, archaeological monitoring, construction of a minimum of two test panels for approval by stakeholders, and a long-term stabilization plan for the Worth's Mill ruin wall—which were incorporated into the project.

Excavation above the arches was accomplished by hand labor and small equipment.

Design Concepts and Construction Methods

The rehabilitation of the Stone Arch Bridge involved removing the fill above the arches; rebuilding out-of-plumb walls with the same stone and a lime-based, historically appropriate mortar; and constructing reinforced concrete saddles and walls within the roadway fill to strengthen the arches. The replacement fill of the roadway above the arches was constructed with lightweight concrete to eliminate water infiltration. A reinforced concrete core was used for the parapets for crash worthiness and was faced with existing stone. The concrete core for the parapets extends up from the cast-in-place spandrels walls. The parapet maintains the existing draping pattern across the bridge but is raised to meet the American Association of State Highway and Transportation Officials (AASHTO) Test Level 4 crash rating.

Although the existing stone arch was not designed to be composite with the new saddle, some composite action is anticipated because the top of the stone arch has an irregular shape due to the original coursed stone construction. The saddle and spandrel walls are reinforced and are the structural system that takes the vertical and horizontal loads. The top of the existing stone arch was cleaned of all dirt and loose material. The original design called for the remaining fill above the arch to be filled with a lower strength lightweight flowable fill, but the contractor decided to use Class A lightweight concrete throughout the fill because it did not want to form out the spandrel walls. Because it was designed to current loads, the bridge is no longer posted.

The Flood Channel Bridge was replaced by a single-span, prestressed concrete adjacent-box-beam bridge with a total bridge length of 150 ft. The location of the north abutment was moved to

Construction of concrete saddles to strengthen the arches of the Stone Arch Bridge.

NEW JERSEY DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTIONS: Stone Arch Bridge: Rehabilitated three-span stone arch bridge (originally built in 1792) spanning Stony Brook with a 26 ft 6 in. center span and 20 ft 9 in. flanking spans; Flood Channel Bridge: Single-span, 65-ft-long structure constructed from adjacent prestressed concrete box beams

STRUCTURAL COMPONENTS: Stone Arch Bridge: Reinforced concrete saddle; Flood Channel Bridge: 27-in.-deep AASHTO Type BI-48 prestressed concrete box beams

PROJECT CONSTRUCTION COST: $7.4 million

AWARDS: Professional Engineers Society of Mercer County Project of the Year; American Council of Engineering Companies NJ Honor Award; American Society of Highway Engineers Southern NJ—Honor Award; New Jersey Historic Preservation Award avoid demolition and excavation near the Worth's Mill wall. The abutments were faced with a similar ashlar stone to blend in with the environment and connect the history of the two bridges and the ruin wall of Worth's Mill.

An accelerated 120-day construction schedule was set to complete the bridges and approach work; during this time, archaeological monitoring was conducted and documented. Collaboration among all stakeholders during design and construction was the key to the success of the project. Local and agency stakeholders included the New Jersey Historic Preservation Office and the Princeton Historic Preservation Committee, both of which contributed to specific design elements and were involved with the project from inception to completion.

For the Stone Arch Bridge rehabilitation, certain aspects of the 68-ft long and 33-ft 9-in.-wide structure needed to be changed. For example the parapets, which were only 10 in. high at the bridge ends, had to be raised. To address this issue, an alternative approach to the safety needs of the public was required to achieve stakeholder consensus. Other substandard features, including substandard shoulder width and superelevation, received design exceptions because correcting these features would have had significant financial, historical, and environmental impacts.

Benefits of Concrete

Cast-in-place concrete is a flexible and adaptive construction material that allows for field changes while maintaining the desired structural strength. There are many unknowns when removing the fill above an arch in a structure as old as the Stone Arch Bridge. As-built plans for the bridge did not exist, and methods to determine the fill depth and material (such as ground penetration radar and pavement corings) can be inconclusive. The use of cast-in-place concrete allowed for quick adjustments to the reinforced concrete saddles and spandrel walls based on the actual field conditions after excavation. Much of the concrete that had been placed during the 1916 widening of the bridge was incorporated into the 2016 rehabilitation to avoid further impact on masonry areas that did not need be reconstructed. Epoxy-coated reinforcing steel was used in the concrete saddle and spandrel walls to provide additional corrosion protection. The flexibility of cast-in-place concrete also proved beneficial for construction of the reinforced concrete collars, which were placed in the waterway to protect the footings against scour and doubled as a support for the framing system designed to temporarily support the arches during construction.

Placing lightweight concrete for fill above arches. Note the epoxy-coated reinforcement for concrete core for the parapets.

For the Flood Channel Bridge, adjacent prestressed concrete box beams with P-3 concrete were used to construct a single-span, 65-ft-long structure. Class P-3 concrete has a compressive strength of 7 ksi and is typically used for prestressed concrete members. High-performance concrete was used for the deck, parapet, suspended backwall, and sleeper slabs on the project. The shallow 27 in. depth of the box beams helped maximize the hydraulic opening. Removal of two piers within the channel allowed the new north abutment to be located in front of the existing abutment, portions of which remained in place to avoid demolition and excavation close to the ruin wall. The precast, prestressed concrete box beams were quickly installed and, without the need for deck formwork, allowed the contractor to quickly traverse the new bridge and access both sides of the arch bridge to remove the fill and place concrete.

Conclusion

Rehabilitation techniques were developed to strengthen a historic stone arch bridge with structural concrete within the fill area of the structure and to leave the existing masonry in place by rebuilding out-of-plumb sections and repointing other masonry. Reinforced concrete saddling of the arches was designed for modern loading. Additionally, reinforced concrete spandrel walls were placed within the fill to resist horizontal loads and were extended into the parapets, which may not have met current crash-worthiness requirements. In a rehabilitation project like the Stone Arch Bridge, coordination with stakeholders throughout the design and construction stages was a key to the success of the project. When proper respect is paid to the environmental and historical aspects of a project, durable and beautiful structures that preserve valuable history can be delivered to the satisfaction of the owner and all stakeholders.

David Hutchinson is vice president, highway engineering, and Khairul Alam is vice president, structural engineering, both for Arora and Associates P.C. in Lawrenceville, N.J. Pankesh Patel is project manager for the New Jersey Department of Transportation in Trenton, N.J.

The new prestressed concrete box-beam Flood Channel Bridge. Worth's Mill ruin wall is on the left.

Downstream view of the rehabilitated Stone Arch Bridge and new Flood Channel Bridge.

HAMILTON FORM CREATES FUNCTION

12 CASE STUDY

SELF-STRESSING NEXT BEAM FORM

> **"Hamilton Form was invaluable in helping us with our first NEXT Beam project. From form design to shipping, installation and even developing a stressing and de-tensioning sequence, their expertise is second to none. "**
>
> ***Joe Carrara***
> ***General Manager***
> ***J.P. Carrara & Sons, Inc.***

The Project:

Originally built in the 1930s, the Eliot Road Overpass in Kittery, Maine was replaced by a single span, precast/prestressed concrete bridge using the New England Extreme Tee or NEXT Beam. J.P Carrara & Sons in Middlebury, Vermont supplied the beams for the project, cast in forms fabricated by Hamilton Form Company.

The Solution:

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The Result:

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The 10,000 cars that use the Elliot Road Overpass every day benefit from a new, safer bridge built with NEXT Beams provided by J.P. Carrara & Sons.

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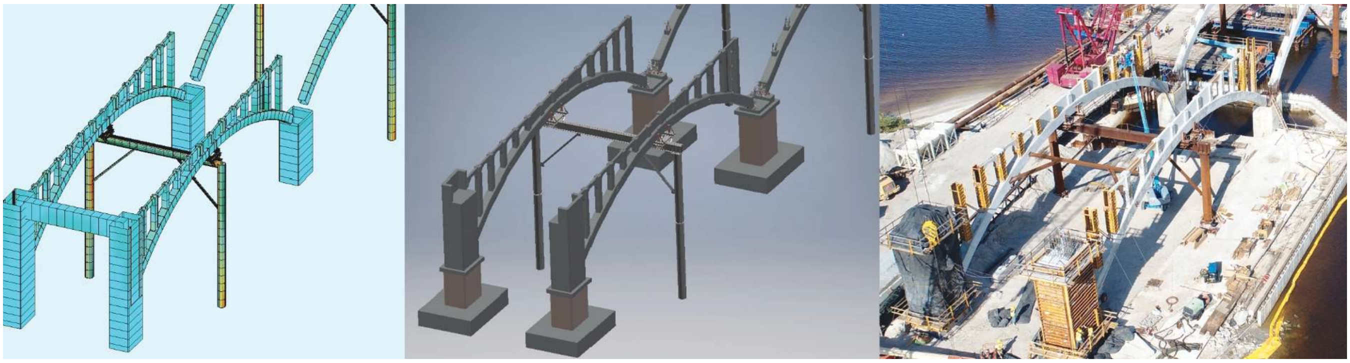
BrIM Redefined

by Ivan Liu and Jerry Pfuntner, FINLEY Engineering Group



Bridge integration modeling (BrIM) workflow can provide an integrated solution for managing data for design, construction, and asset management from analysis to production to reality. Figures: FINLEY Engineering Group. Photo: Johnson Bros. Corporation.

Bridge information modeling continues to steadily develop as a tool that blends three-dimensional (3-D) visualization capabilities with database storage of information. In the development of complex projects, FINLEY has redefined bridge information modeling as bridge *integration* modeling (BrIM). This approach takes the next logical step in the use of 3-D visualization and advanced engineering software to integrate bridge information databases into the planning, design, construction, maintenance, and inspection processes. BrIM can be used to improve efficiency, consistency, and quality throughout the entire life cycle of a bridge, from the first planning stages to asset management of the completed structure.

In this article, the Veterans Memorial Bridge in Daytona Beach, Fla., and Wekiva Parkway Section 6 in Sorrento, Fla., are provided as examples for FINLEY's application of BrIM on complex bridge projects.

Phases of the BrIM Workflow

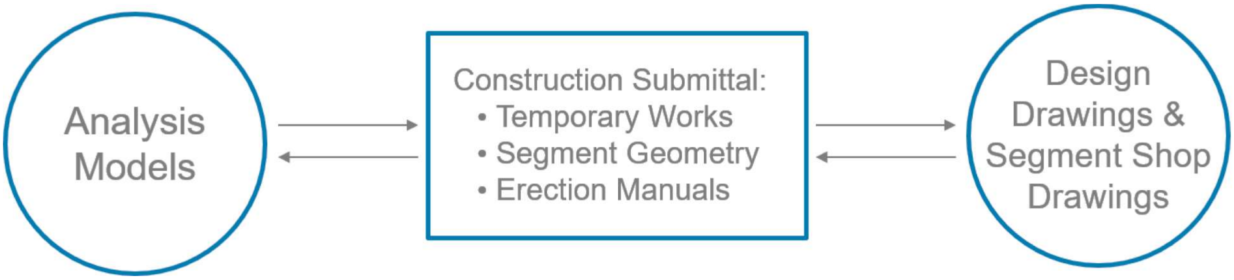
Traditionally, the workflow for a project involves the analysis of the bridge, the design of bridge components and temporary works, and the production of construction drawings. Within those three phases, engineers transfer bridge data, such as roadway geometry, concrete geometry, post-tensioning layouts, and member sizes, into the analysis model, then again into temporary works models, and once again into computer-aided design/drafting (CAD) models.

Before the introduction of modern engineering software to integrate bridge data among separate models, that process of data transfer was time consuming and cumbersome, and there was a risk with each transfer that the data might be input incorrectly or inconsistently. The ideal scenario is to use software to import and export the bridge data among models to minimize repeated efforts by the engineer.

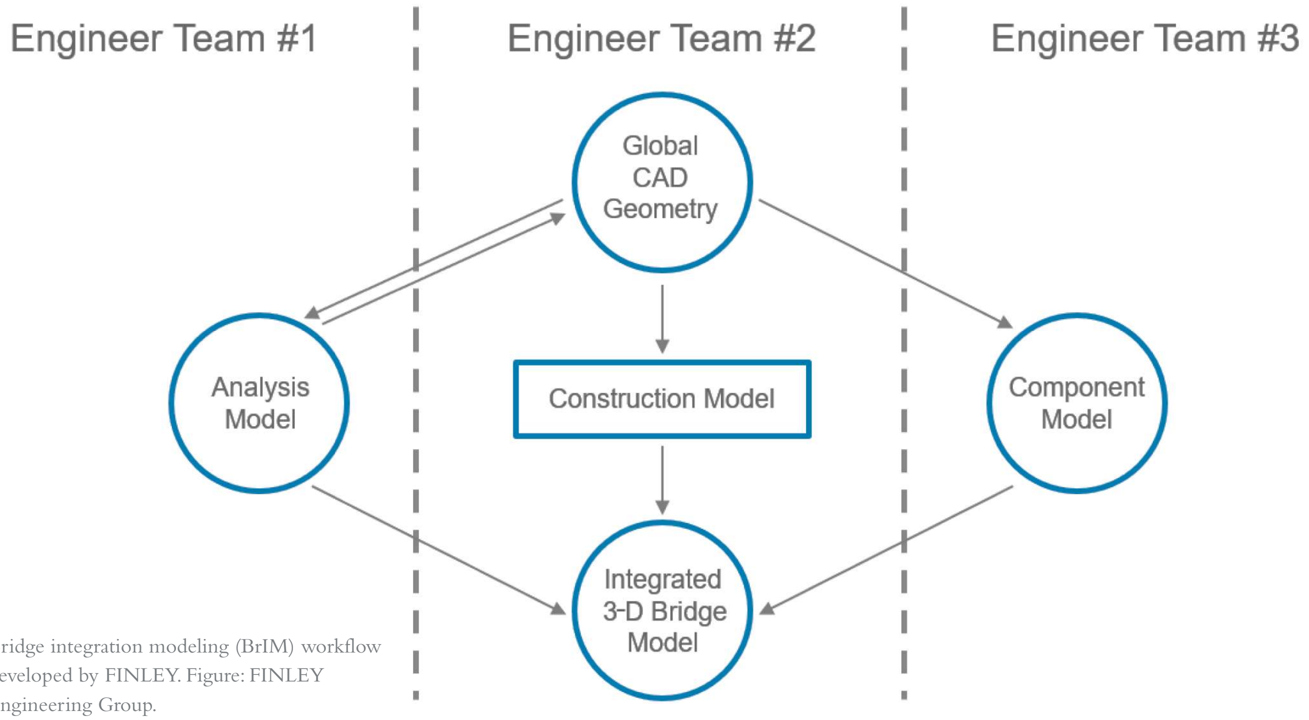
The BrIM workflow is a culmination of FINLEY's efforts to combine its project workflow experience with modern engineering software containing integration capabilities. The following three phases for BrIM workflow have been developed:

1. Input of global CAD geometry;
2. Development of the analysis, construction, and component models; and
3. Generation of the integrated 3-D bridge model.

Phase 1, the foundation of this workflow, is the AutoCAD engine used within the analysis software SOFiSTiK, which FINLEY uses for complex bridge design. The ability to create the geometry of the analysis model through an AutoCAD engine allows the BrIM workflow to begin with a single 3-D geometry model that centralizes the bridge data used by the analysis, visualization, and CAD software. A single centralized and integrated geometry model, or global CAD geometry,



Traditional workflow for bridge design and construction with repetitive effort and risk of errors. Figure: FINLEY Engineering Group.



Bridge integration modeling (BrIM) workflow developed by FINLEY. Figure: FINLEY Engineering Group.

allows for bridge data to be input only once with model referencing; the result is a simplified procedure for any future modifications.

In the second phase of the BrIM workflow, software is used to efficiently output global CAD geometry data from the first phase to generate the analysis, construction, and component models. These three models are needed for the engineering analysis, the design/detailing of temporary work items for construction, and the development of 3-D visualization models for design/shop drawing production, respectively.

In phase 3 of the BrIM workflow, all elements from phases 1 and 2 are assembled within a single integrated 3-D bridge model. For example, the integrated 3-D model might align the existing geometry coordinates of the global CAD geometry from phase 1 with temporary work items and the 3-D component models from phase 2. This third-phase model is used to integrate all bridge visualization, create construction manual drawings, detect conflicts, and identify various construction support items for the bridge project. A significant advantage of the BrIM workflow is that it does not require additional efforts to recreate modeling elements for phase 3.

The Veterans Memorial Bridge

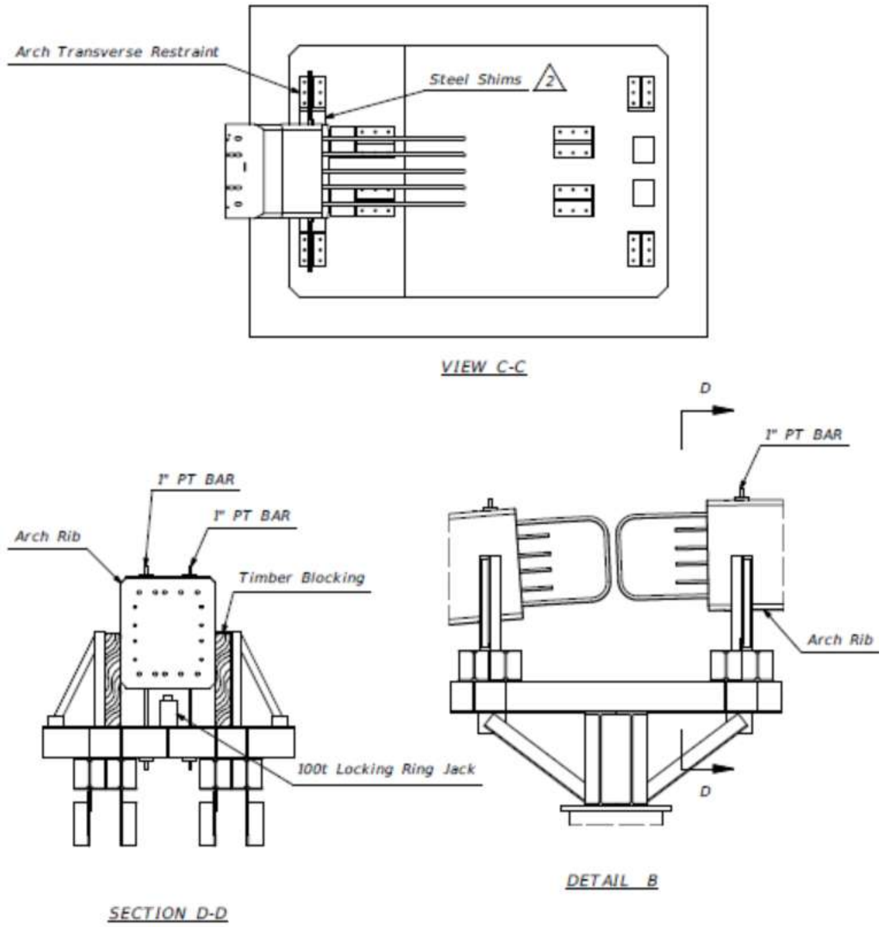
The Veterans Memorial Bridge in Daytona Beach, Fla., is composed of seven spans of a precast concrete arch substructure with spandrel columns and an edge beam that supports transverse precast concrete T-beams beneath a reinforced concrete deck. As part of FINLEY's construction engineering efforts, two types of falsework towers were used at each spandrel arch span. Design and detailing of the falsework towers for the erection of the precast concrete arch ribs benefitted greatly from the BrIM workflow process. The falsework framing geometry was sized and created as required within the analysis model and exported to the construction model, where the framing geometry was used directly to detail the steel member sections for the falsework drawings. As changes were made within the analysis model, the construction model was automatically updated as well.

The advantages of the BrIM workflow were also apparent in the integrated 3-D bridge model used for the construction manual. All updates to the falsework towers in the integrated bridge model were also shown in every drawing sheet of the construction manual, significantly reducing errors and CAD-production effort. Using the construction models with the bridge visualization, the fabrication understanding of the temporary falsework towers was simplified with 3-D isometric views; also, the falsework drawings were similar to the physical product produced.

Integrated three-dimensional bridge model in software with temporary construction supports shown. Figure: FINLEY Engineering Group.

Wekiva Parkway Section 6

Section 6 of the Wekiva Parkway in Sorrento, Fla., consists of a trio of three-span cast-in-place (CIP) segmental bridges built using cantilever construction with form travelers. For each bridge, there are two cantilevers containing 10 pairs of 16-ft-long CIP segments with



Using bridge integration modeling (BrIM) workflow, drawings were produced for the construction manual of the Veterans Memorial Bridge, such as these falsework and connection details for the precast concrete arch segments. Figure: FINLEY Engineering Group.

a twin-column integral pier table. The segmental bridges are post-tensioned using a combination of external draped and internal unbonded tendons.

For the Wekiva Parkway project, shop drawings were required for all CIP segments. FINLEY used the component models created from the BrIM workflow to generate parametric shop drawings that would update with every approved modification required by the contractor. The initial stages for the parametric setup required significant effort, but the payoff was an efficient shop drawing process in which the time required for minor to average shop drawing revisions was reduced from hours to just minutes. The contractor also used these 3-D component models on the project to assist in reinforcement placement for the pier table.


The integrated three-dimensional bridge model (inset) and the actual construction of the precast concrete arch substructure with spandrel columns on the Veterans Memorial Bridge. Figure and Photo: FINLEY Engineering Group.


For the Wekiva Parkway pier table, three-dimensional component models were used to facilitate reinforcement placement. Photo: FINLEY Engineering Group.

Asset Management

Beyond design and construction, BrIM also has applications in asset management. During construction, details of the entire construction history, such as temporary blockouts and lifting holes, can be stored within the BrIM model for future reference. Furthermore, field changes and repairs can also be recorded along with supporting documentation such as photographs, descriptions of repair procedures, and material catalog cuts. Bridge inspections can also be annotated directly within the BrIM model.

Future developments of BrIM could include the incorporation of as-built geometry and load ratings into models. This visualization of design, construction, and inspection creates a powerful tool to help owners proactively address future maintenance issues and assess repair products and repair details.

Conclusion

FINLEY has applied BrIM to multiple projects with great success. Efficiency and quality production are substantial benefits of using the BrIM workflow in place of past methodologies. The ability of engineers to work simultaneously on multiple facets of a project and the increased consistency among models reduces design hours and opportunities for error. Complex projects such as the Veterans Memorial Bridge and Wekiva Parkway clearly demonstrate that BrIM is no longer a future prospect—it is an asset today.

Ivan Liu is a bridge engineer and Jerry Pfuntner is principal and regional bridge engineer with FINLEY Engineering Group in Tallahassee, Fla.

Calculations for Handling and Shipping Precast Concrete Deck Panels

by Dr. Krista Brown

A common misconception is that increasing the amount of reinforcement in concrete will prevent cracking. Not so! When the stress in concrete reaches its tensile strength, cracking results. Reinforcement will control the width and distribution of cracks, but it does not prevent cracking.

Precast concrete deck panels may be more susceptible to cracking during handling and transportation stages, when strengths are typically lower and support points fewer, than in service. Cracking is a risk as panels are stripped from forms, transported to the storage yard, loaded onto a truck, shipped, and installed.

Precasters of building components, especially wall panels, have successfully designed panels with specific pick-point locations to avoid cracking during handling and transportation. This article presents simple calculations and measures to help designers, owners, precasters, and contractors ensure that precast concrete deck panels do not experience unacceptable cracking during handling and transportation. Cracking that may occur due to drying shrinkage, thermal factors, and other causes will not be addressed.

Methodology

Section 8.3 of the *PCI Design Handbook: Precast and Prestressed Concrete*[1] provides a procedure and examples for determining stresses in flat panels during handling and transportation. With this procedure, which includes the effects of openings and other changes in cross-section geometry, tensile stresses in a precast concrete deck panel are calculated using basic mechanics of materials and compared to the allowable tensile stress. The notation of the *PCI Design Handbook* is used in this article. Because only tensile stresses are calculated, all stresses will be shown as positive. Stresses are also shown in psi units rather than ksi used in bridge design.

The allowable tensile stress, $f_{allowable}$, is a criterion for no-discernible cracking that is used in the building industry.[1] It is determined by applying a factor of safety of 1.5 to the concrete modulus of rupture, which is a function of compressive strength.

$$f_{allowable} = \frac{7.5\sqrt{f'_c}}{1.5} = 5\sqrt{f'_c}$$

where

f'_c = concrete compressive strength at the time of handling or transportation, psi

Note $5\sqrt{f'_c}$ is equivalent to $0.158\sqrt{f'_c}$ with both f'_c and $f_{allowable}$ in ksi.

The tensile stress in the concrete section, f_t, is calculated by

$$f_t = \frac{M}{S}$$

where

M = moment at the concrete section with a PCI-recommended load multiplier applied for handling or transportation, kip-in.

S = section modulus, in.^{3}

Table 8.3.1 in the *PCI Design Handbook* lists recommended load multipliers to account for forces caused by form suction and impact during handling and transportation. These multipliers are applied to the weight of the panel and are based on typical experience of precast concrete producers. The multipliers may be modified based on specific conditions and the experience or preferences of precasters or owners.

Because the multipliers and concrete strengths vary with each stage of handling and transportation, tensile stress and allowable tensile stress must be determined for each stage. The following examples demonstrate calculations for precast concrete deck panels at two stages—stripping from forms and shipping.

Example of Calculations for a Rectangular Deck Panel

Assume a 10 ft by 32 ft by 8¾ in. precast concrete panel with no openings, internal ducts, or other irregularities in the cross section.

Given

Normalweight concrete at 150 lb/ft^3

f'_{ci} = 4000 psi at stripping from forms

f'_c = 5000 psi at shipping

The panel will be handled with a four-point pick at locations shown in *PCI Design Handbook* Fig. 8.3.2, which equalizes positive and negative moments.

Calculate the allowable tensile stress at stripping:

$$f_{allowable} = 5\sqrt{4000} = 316 \text{ psi}$$

Calculate the maximum tensile stress in the panel's longitudinal direction using the equation from Fig. 8.3.2 of the *PCI Design Handbook* that assumes uniform loading.

a = 10 ft

b = 32 ft

t = 8.75 in.

$$w = \left(\frac{8.75}{12}\right)(150) = 109.4 \text{ lb/ft}^2$$

$$M = 0.214wab^2 = 0.0214(109.4)(10)(32^2)$$
$$= 23{,}973 \text{ lb-ft}$$

For a rectangular cross section:

$$S = \frac{at^2}{6} = (10)(12)\left(\frac{8.75^2}{6}\right) = 1531 \text{ in.}^3$$

At stripping from forms, apply a 1.3 multiplier for suction to determine tensile stress.

$$f_t = \frac{M}{S} = \frac{1.3(23{,}973)(12)}{1531} = 244 \text{ psi} \le 316 \text{ psi}$$

Allowable stress is not exceeded when stripping from forms. **OK**

In this example, the design concrete strength at shipping is higher than for stripping from forms, but the PCI-recommended load multiplier, 1.5, is also higher. It is assumed that the panel is supported by dunnage placed at the same locations as the pick points.

Repeat the procedure using f'_c = 5000 psi and a 1.5 load multiplier:

$$f_{allowable} = 5\sqrt{5000} = 354 \text{ psi}$$

$$f_t = \frac{M}{S} = \frac{(1.5)(23{,}973)(12)}{1531} = 282 \text{ psi} \le 354 \text{ psi}$$

Allowable stress is not exceeded during shipping. **OK**

Stresses in the panel should be checked in both directions. However, in this example, the tensile stress in the panel's transverse direction is not checked and does not govern due to the panel's dimensions. Lifter capacities and moment and shear capacities of the panel should also be checked.

Deck Panel with Full-Depth Pockets

Next, consider the same deck panel, except that it has a series of five 6 in. by 24 in. full-depth pockets for a connection that will later be grouted. For the purposes of this example, the pockets are at or near the lifting points, but this is not recommended in practice since this is the location of maximum moment. Because of the pockets, the effective cross section will have a reduced width. The slight reduction in the weight of the panel will be neglected.

$$S = \frac{at^2}{6} = \left[10 - 5\left(\frac{6}{12}\right)\right](12)\left(\frac{8.75^2}{6}\right) = 1148 \text{ in.}^3$$

At stripping from forms:

$$f_t = \frac{M}{S} = \frac{1.3(23{,}973)(12)}{1148} = 326 \text{ psi} > 316 \text{ psi}$$

Allowable tensile stress is exceeded. **No good.**

At shipping:

$$f_t = \frac{M}{S} = \frac{1.5(23{,}973)(12)}{1148} = 376 \text{ psi} > 354 \text{ psi}$$

Allowable tensile stress is exceeded. **No good.**

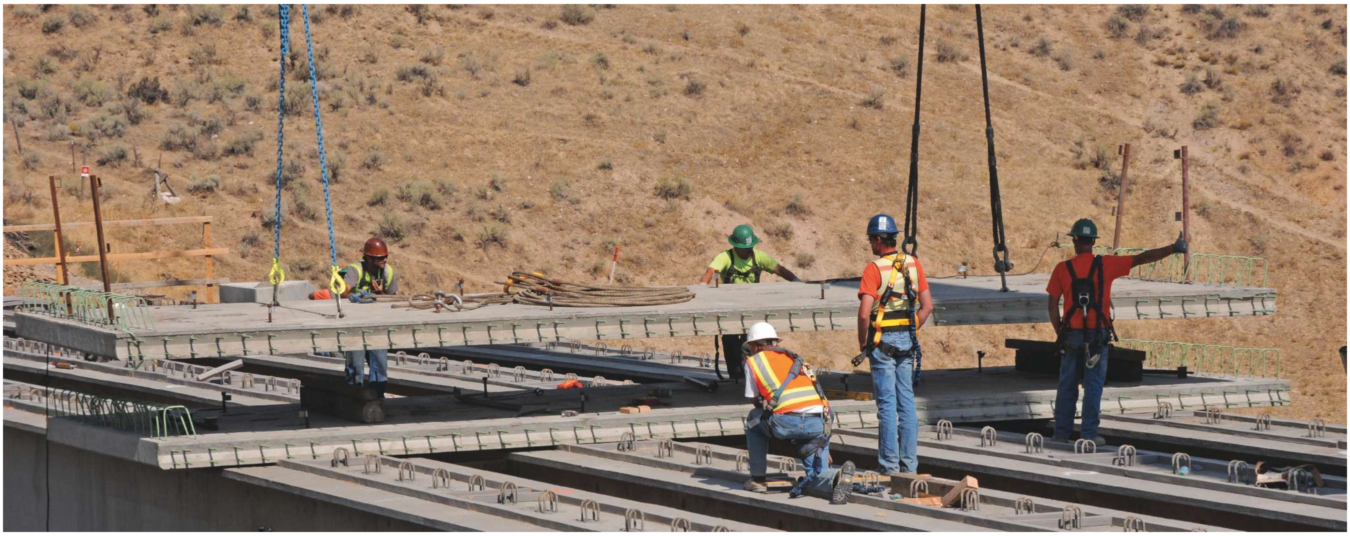
In this case, because the calculated and allowable tensile stresses are close, increasing the concrete compressive strengths may be an acceptable way of raising the allowable stresses. Using values of f'_{ci} = 4300 psi at stripping and f'_c = 5700 psi at shipping results in allowable tensile stresses of 328 and 377 psi, respectively, which are greater than the computed stresses and therefore satisfy PCI recommendations.

Another option to bring the computed tensile stresses within the allowable tensile stresses might be to increase the thickness of the panel. Increasing the thickness from 8¾ in. to 9¼ in. would reduce the stresses to 308 psi at stripping and 356 psi at shipping. However, the 5.7% increase in panel weight and the ½-in. increase in panel thickness may not be desirable.

A third option, which is especially useful when there is greater disparity between the computed tensile stress and the allowable stress, is to use prestressing. In the previous example with the five blockouts, placing a total of six ½-in.-diameter strands initially tensioned to 31 kip at midheight of the panel cross section, allowing for a 10% prestress loss and assuming the blockouts are at a location where the pretensioning force is fully transferred, would add compressive stress in the reduced cross section:

$$f_{prestress} = -\frac{(6)(1-0.1)(31)(1000)}{\left[10 - \left(5\left(\frac{6}{12}\right)\right)\right](12)(8.75)}$$
$$= -213 \text{ psi (compression)}$$

Superimposing the effect of the prestressing force on the stress caused by the weight of the panel, the net stress at



Full-depth deck panel being installed using a four-point pick. Photo: Precast/Prestressed Concrete Institute.

stripping from forms is now:

$$f_t = 326 - 213 = 113 \text{ psi (tension)} \leq 316 \text{ psi}$$

Allowable tensile stress is not exceeded when stripping from forms. OK.

The net stress at shipping is now:

$$f_t = 376 - 213 = 163 \text{ psi (tension)} \leq 354 \text{ psi}$$

Allowable tensile stress is not exceeded for shipping. OK.

Therefore, prestressing the panel reduces the excessive tensile stress and brings the stresses within the allowable stress limits.

Another option would be to use an eight-point pick. For long panels, this may

Table 8.3.1. Equivalent static load multipliers to account for stripping and dynamic forces[a,b]

Product type	Finish	
	Exposed aggregate with retarder	**Smooth form (release agent only)**
Flat, with removable side forms, no false joints or reveals	1.2	1.3
Flat, with false joints and/or reveals	1.3	1.4
Fluted, with proper draft[c]	1.4	1.6
Sculptured and other conditions	1.5	1.7
Yard handling[d] and erection[b]		
All products	1.2	1.2
Transportation[d]		
All products	1.5	1.5

Notes:

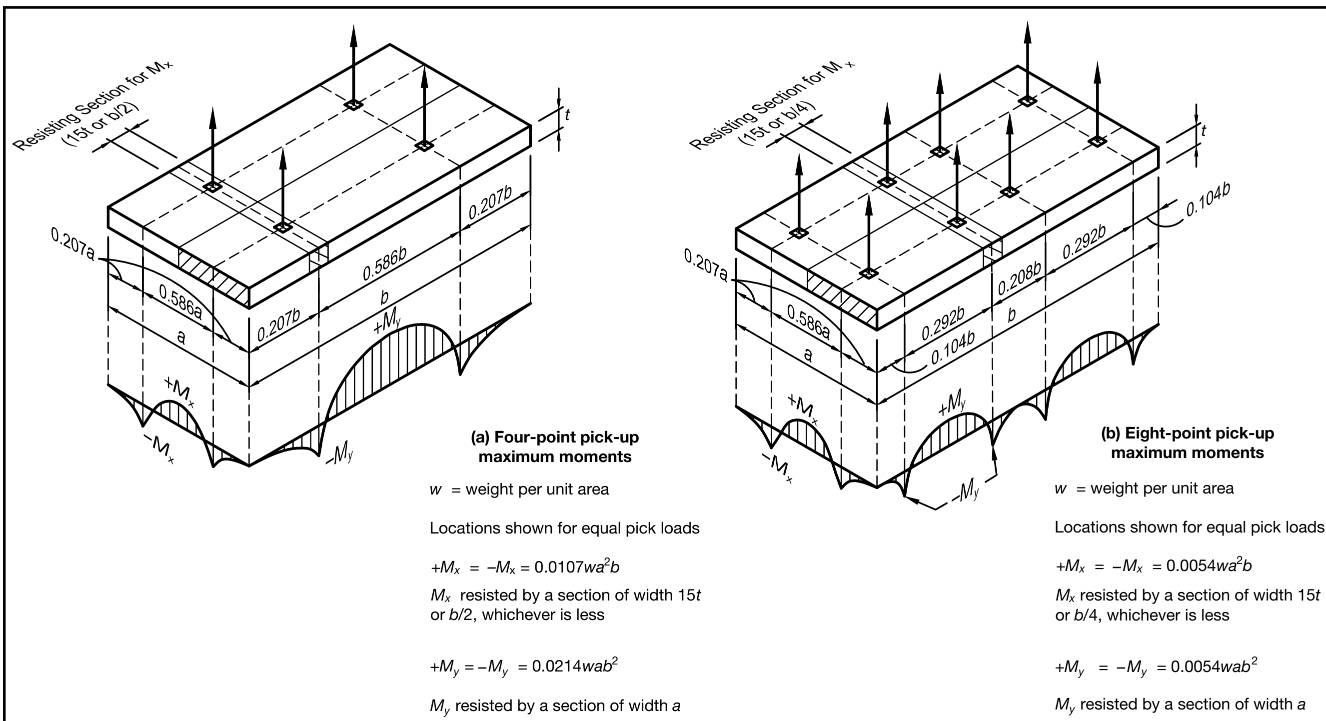
[a] These factors are used in flexural design of panels and are not to be applied to required safety factors on lifting devices. At stripping, suction between product and form introduces forces, which are treated here by introducing a multiplier on product weight. It would be more accurate to establish these multipliers based on the actual contact area and a suction factor independent of product weight.

[b] May be higher under certain circumstances.

[c] For example, tees, channels, and fluted panels.

[d] Certain unfavorable conditions in road surface, equipment, etc. may require use of higher values.

Source: Table 8.3.1 from the eighth edition *PCI Design Handbook: Precast and Prestressed Concrete*.



Moments developed in panels stripped flat. Source: Figure 8.3.2 from the eighth edition *PCI Design Handbook: Precast and Prestressed Concrete*.

be necessary. Equations for calculating stresses for an eight-point pick are found in the *PCI Design Handbook*. Other options are to change the location of pick points and to use rockers during shipping, which are also discussed in the *PCI Design Handbook*.

Resources

Precasters, contractors, engineers, and owners of precast concrete deck panels can perform a few calculations and take steps to prevent undesirable cracking during handling and shipping. This article has presented the options of increasing concrete strengths, thickening the panels, prestressing, and adding more pick points. The examples in this article checked tensile stresses in the panel's longitudinal direction and for only two cases. Stresses in the transverse direction, lifter capacities, effects of rigging angles, and shear and moment capacities of the panel should also be checked.

In addition to the *PCI Design Handbook*, guidance on handling and shipping of precast concrete deck panels is available in references 2–7.

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A Winning Combination:

PCI Big Beam Competition and ASCE *Civil Engineering Body of Knowledge* Outcomes

by Dr. Jill Walsh, St. Martin's University

A bachelor of science degree in civil engineering is the typical educational pathway to a career in bridge engineering. In the latest draft of the third edition of *Civil Engineering Body of Knowledge*, the American Society of Civil Engineers (ASCE) defines the Civil Engineering Body of Knowledge as a "set of knowledge, skills and attitudes necessary for entry into practice of civil engineering at professional level."[1] For the *Civil Engineering Body of Knowledge*, ASCE describes 21 outcomes, grouped in four categories (see **Table 1**).

The typical civil engineering program is designed to introduce students to multiple branches of civil engineering. As a result, the typical bridge engineer has taken at least one course in environmental, transportation, structures, geotechnical, hydraulics, and surveying. The foundational and engineering fundamentals categories typically consume the first two years of an undergraduate degree. The breadth of engineering (the technical category) is introduced through upper-level requirements in the second two years.

Comprehension of the breadth of civil engineering is of course important, but engineering students are left with little time in their fully packed schedules for exposure to professional and technical topics specific to bridge engineering. Students must take specialty topics, such as prestressed concrete, in their discipline of choice as electives. In smaller academic programs, specialty topics may be offered only every other year, further limiting choices for students. Therefore, students wanting to prepare for a career in bridge engineering are left to seek other pathways for gaining discipline-specific knowledge.

The *Civil Engineering Body of Knowledge* outlines pathways to attain civil engineering competence at the professional level. **Table 2** shows that students and early-career engineers are expected to supplement formal education with mentored experience and self-development. Industry competitions such as the PCI Big Beam Competition are one way to incorporate both the mentored experience and self-development pathways to provide students with professional education in a specialty topic such as prestressed concrete.

PCI Big Beam Competition

In the PCI Big Beam Competition, student teams work with PCI producer members to design, build, and test a 17-ft-long precast, prestressed concrete beam. The producer member provides materials, construction assistance, and guidance, as well as beam transportation to the testing facility. Saint Martin's University has participated in Big Beam for three years with PCI producer member Concrete Technology Corporation (CTC) as their sponsor.

Saint Martin's University currently offers a prestressed concrete design course every other academic year. This means that some students haven't even had exposure to prestressed concrete before participating in the competition. CTC design engineer Austin Maue travels to the university campus to give the students a "crash course" in prestressed concrete. He arranges plant tours for the students, provides feedback on their designs, schedules construction days with them, and is on site during their beam construction.

Competition participation has been a student-led endeavor, independent of any

Table 1. Selected *Civil Engineering Body of Knowledge* Outcomes

Category	Outcomes (partial list)
1. Foundational	Math, science, humanities
2. Engineering fundamentals	Materials, engineering mechanics, experimental, critical thinking
3. Technical	Project management, breadth in civil engineering, design, technical depth
4. Professional	Communication, teamwork, lifelong learning, professional attitudes and responsibilities

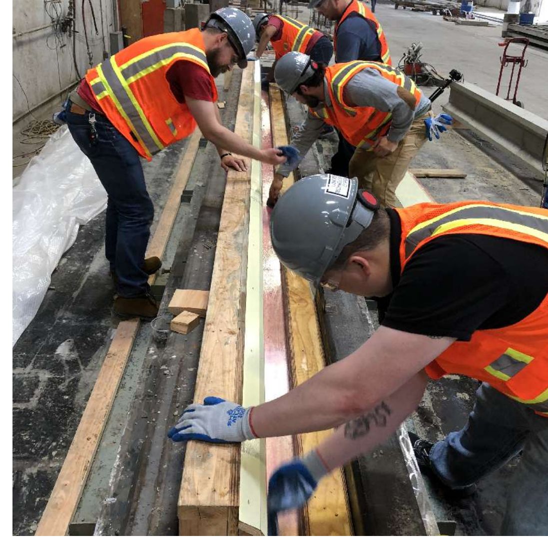
Source: Based on Appendix F of the 3rd edition of *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer.*

Table 2. *Civil Engineering Body of Knowledge* Typical Pathways for Outcome Achievement

Pathway	Description
Undergraduate education	Undergraduate education leading to a bachelor's degree in civil engineering or a closely related engineering discipline, generally from a four-year ABET/EAC-accredited program
Postgraduate education	Postgraduate education equivalent to or leading to a master's degree in civil engineering or a closely related engineering discipline, generally equivalent to one year of full-time study
Mentored experience	Early-career experience under the mentorship of a civil engineer practicing at the professional level, which progresses in both complexity and level of responsibility
Self-developed	Individual self-development through formal or informal activities and personal observation and reflection

Note: ABET = Accreditation Board for Engineering and Technology; EAC = Engineering Accreditation Commission.
Source: Based on the 3rd edition of *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer.*

St. Martin University's 2017 PCI Big Beam Competition team prior to testing at the University of Washington structural engineering laboratory. Photo: Dr. Jill Walsh.



St. Martin University's 2018 PCI Big Beam Competition team during beam construction. Photo: Jarad Roschi.

course requirements, and accomplishes many of the *Civil Engineering Body of Knowledge* outcomes. Students learn about team work by working together to accomplish competition requirements. They learn about project management by completing design activities to meet construction days that align with the fabricator's schedule. The teams sharpen their technical communication skills by producing a professional report, which includes team predictions and results (see **Tables 3** and **4**). After testing, assumptions for the initial predictions are reexamined and revised predictions are computed. The report includes calculations (math), written discussion on the structural design and the concrete mixture (design), and team member statements on what they have learned (lifelong learning).

Importance of Mentoring

When I was 16, I thought I knew everything. When I graduated with a PhD in structural engineering, I realized just how little I knew. I was fortunate to be hired at T.Y. Lin International and learn from some of the most brilliant bridge engineers in the business. While my education provided a good foundation, it was while working in industry that I truly learned that being a bridge engineer would require a lifelong commitment to continuing education—for both my own advancement and that of the next generation of bridge engineers.

Knowledge transfer is vital in the engineering profession and benefits the mentor as well as the apprentice. Just as mentoring is a knowledge pathway for students and young professionals, it is also a pathway for continued professional development for the practicing engineer. As professionals building knowledge daily, we may too easily forget how far we've come and where we started. Working with students is rewarding. They have fresh perspectives, unburdened by the veteran engineer's "should not" experiences and expectations about cost prohibitions, and they are eager to learn and grateful for the professional's time.

Experience can humble you, change your perspective, broaden your horizons, and open your eyes to new ideas. I hope to present my students with opportunities to learn for themselves about the values of questioning, observing, listening, and pushing oneself to continuously improve and learn. I am proud of the students for their self-directed motivation and revel in seeing how their perspectives are changed by their participation in the PCI Big Beam Competition.

Table 3. Initial Predictions and Test Results

	Prediction	Results	Error Analysis
Ultimate load, kip	34.61	34.88	0.79%
Deflection at ultimate load, in.	6.17	5.44	11.89%
Cracking load, kip	26.37	24.44	7.30%
Total	—	—	19.99%

Table: Jarad Roschi.

Table 4. Post-test Predictions with Hypothesized Corrections and Test Results

	Prediction	Results	Error Analysis
Ultimate load, kip	34.61	34.88	0.79%
Deflection at ultimate load, in.	5.33	5.44	0.06%
Cracking load, kip	24.46	24.44	2.00%
Total	—	—	2.85%

Table: Jarad Roschi.

Acknowledgments

The guidance and mentorship of Austin Maue, P.E., design engineer at Concrete Technology Corporation in Tacoma, Wash., have been instrumental in the Big Beam accomplishments of St. Martin's University teams [winning national titles in 2017 and 2018]. The author wishes to thank Concrete Technology Corporation for its generous donation of time, materials, and beam transportation, and Professor John Stanton and the University of Washington for hosting and testing Saint Martin's competition entries.

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Concrete Bridge Deck Service-Life Prediction Tools

by Reggie Holt, Federal Highway Administration

Many of our nation's bridges have aging decks, and bridge owners are struggling to keep these decks in satisfactory condition. Bridge decks directly support vehicular and truck traffic and have large surface areas that are exposed to the environment, which makes them among the most difficult bridge components to maintain. Bridge owners are constantly searching for ways to build and maintain long-lasting decks. The research project described in this article used the National Bridge Inventory (NBI) database to study concrete bridge deck performance and develop probabilistic service-life prediction tools which may assist owners in maintaining their concrete bridge decks.

Nationwide Concrete Bridge Deck Performance Inventory

The NBI database includes data on every highway bridge on public roads in the United States (615,002 bridges in the 2017 edition). After filtering this massive database, researchers found 150,136 suitable concrete bridge deck service-life data strings between the years of 1992 and 2014.

There are 116 data fields for each bridge in the NBI. The researchers identified 21 parameters and computed four others that offer useful service-life data. These 25 parameters were compiled for each of the 150,136 service-life data strings to develop a database that the researchers titled the Nationwide Concrete Highway Bridge Deck Performance Inventory (NCBDPI). **Table 1** lists 18 parameters; 14 that came from the NBI and are included in the NCBDPI, and the four others were computed from NBI data.

Time-in-Condition Rating

The bridge deck condition rating (CR), NBI item 58, provides a numerical assessment of the bridge deck's condition on a scale from 0 (failed condition) to 9 (excellent condition). This assessment is typically made by visual inspections in which inspectors use indicators such as cracking, spalling, leaching, delamination, and full or partial-depth failures to assign a CR. The researchers identified a string of unchanged condition rating assessments occurring over multiple years as a time-in-condition rating (TICR). Therefore, TICR is defined as the duration of time in years that a CR remains constant before it decreases, indicating further deterioration. Sample CRs for three hypothetical concrete bridge decks for the period from 1992 to 2014 are shown in the figure on the opposite page. A TICR can be visually identified in the figure as any plateau in the data string.

The ideal service-life TICR data string falls completely within the time boundaries of the research period (1992–2014) and shows no anomalies such as gaps or sudden drops and rebounds in the CR value. A significant proportion of TICR data (approximately two-thirds of the CR from the NCBDPI database) is "censored," meaning that the plateau forming the TICR is only partially observable. A key attribute of this research was the proper treatment of censored data. Examples of censored and uncensored TICR strings for the three hypothetical bridge decks are shown in the figure. Discarding censored data or treating them as uncensored data would introduce significant bias. In contrast, the approach used by the researchers resulted in a more robust and accurate analysis.

Table 1. Nationwide Concrete Highway Bridge Deck Performance Inventory (NCBDPI) Parameters and Data Sources

NCBDPI Parameter	Data Source or Corresponding National Bridge Inventory Location
County (parish) code	Item 3
Structure number	Item 8
Maintenance responsibility	Item 21
Functional classification of inventory route	Item 26
Lanes on structure	Item 28
Structural material/design	Item 43a
Type of design and/or construction	Item 43b
Deck condition rating (CR)	Item 58
Designated inspection frequency	Item 91
Deck structure type	Item 107
Type of wearing surface	Item 108a
Type of membrane	Item 108b
Deck protection	Item 108c
Average daily truck traffic (ADTT)	Item 109
Deck area	Item 49 × item 51
Climatic region	Assigned using the IECC
Distance to seawater	Calculated based on coastline and bridge location items 16 and 17
Bridge age	Based on items 27 and 106

Note: IECC, *International Energy Conservation Code*. Table: Federal Highway Administration.

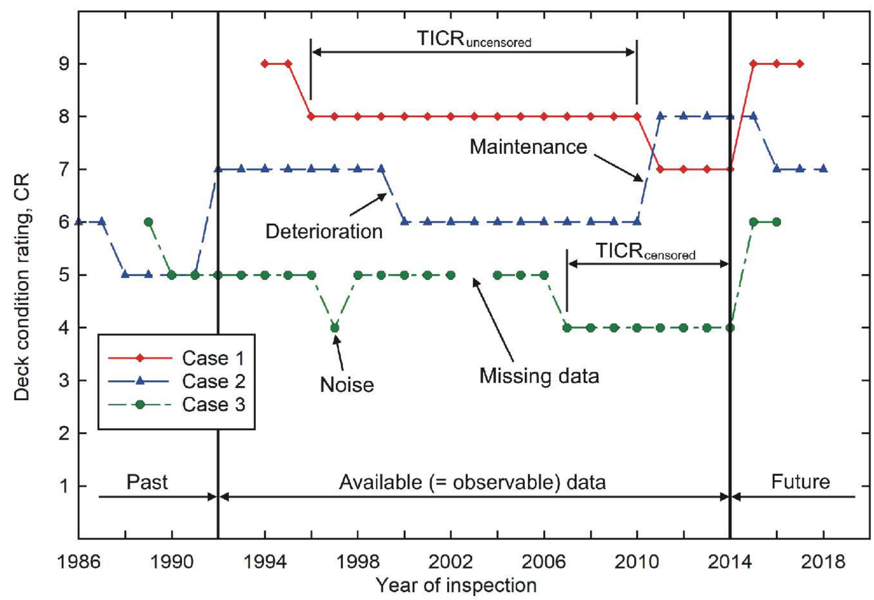
Bridge Deck Survival Analysis

Survival analysis is routinely used in other industries to analyze data in which the time until an "event of interest," such as death, divorce, or failure of a mechanical part, occurs. In this research, the "event of interest" is a drop in the CR. In this study, a Bayesian survival analysis was used to compute the probability that the CR of a bridge deck with specific characteristics remains unchanged. The analysis results were used to generate survival curves for varying parameters. These survival curves provide practical data in an illustrative graph. The research found that varying the parameters of climatic region, average daily truck traffic (ADTT), maintenance responsibility, and structure type generated the most noticeable changes in TICR survival. An example of hypothetical concrete bridge deck survival curves is shown in a figure on this page. This curve was generated

Example of a concrete bridge deck in poor condition. Photo: Dr. Thomas Schumacher.

assuming the following parameters:

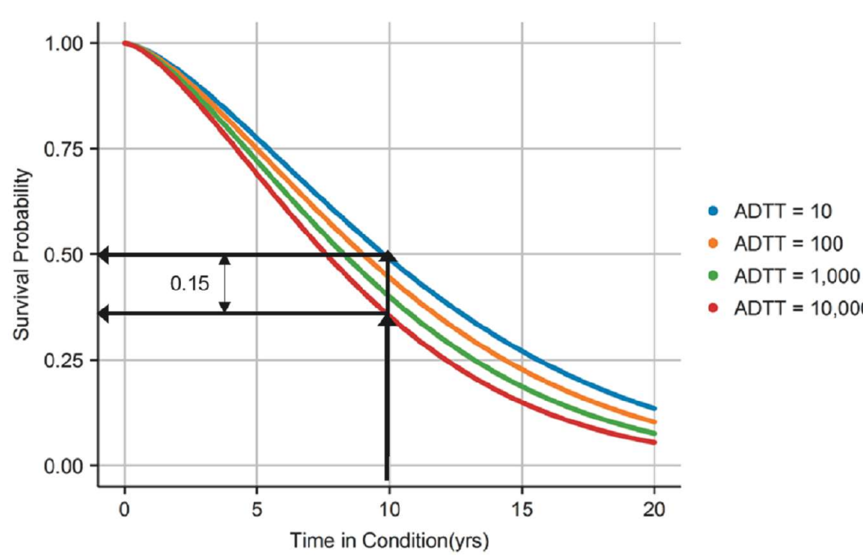
- CR = 7
- Climatic region = cold
- Deck protection = none
- Deck type = concrete: cast-in-place
- Distance from seawater > 3 km
- Functional class = urban
- Maintenance responsibility = state highway agency
- Superstructure type = steel: simple-span



Condition ratings (CR) for three hypothetical concrete bridge decks and the determination of time-in-condition rating (TICR). Figure: Federal Highway Administration.

This figure shows the probability that this bridge deck will stay at a CR = 7 (that is, survive) for varying ADTT levels. The curve shows a clear trend: As ADTT increases, the likelihood that the CR for this bridge deck will stay at 7 decreases. Survival curves can be used to answer important questions such as, "What is the change in probability that a bridge deck will stay at CR = 7 with TICR = 10 years if the ADTT increases from 10 to 10,000?" The curve for this bridge deck shows that it has an approximate survival probability of 50% with an ADTT of 10, compared with a survival probability of approximately 35% with an ADTT of 10,000.

The results of this research study are found in a TechBrief titled "Performance of Concrete Highway Bridge Decks using Nationwide Condition Data," which will be available from the Federal Highway Administration (FHWA).[1] The information included in this article and the posted TechBrief are a result of the FHWA-funded research by Ghonima et al. An internal final report is available online.[2]



Survival curves for a hypothetical bridge deck for varying average daily truck traffic (ADTT) levels. Figure: Federal Highway Administration.

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SIGNIFICANTLY IMPROVE CONCRETE DURABILITY AND SERVICE LIFE BY USING A 100-YEAR-OLD TECHNOLOGY

by Ken Harmon, Stalite and Chair of the Structural Committee of the Expanded Shale, Clay and Slate Institute

Owners and designers of many new structures are specifying a design life of 100 years or more to ensure durability and sustainability. Tourney Consulting Group LLC (TCG) in Kalamazoo, Mich., recently conducted a study[1] for the Expanded Shale, Clay and Slate Institute (ESCSI) to determine the effects of lightweight coarse and fine aggregates—100-year-old technology—on the transport properties and other durability-related properties of concrete.

Ten expanded shale, clay, and slate lightweight coarse aggregates from across the United States were used in "sand lightweight" concrete mixtures that were compared to a normalweight concrete control mixture with respect to transport properties. Transport properties of concrete are measurements of the ability of ions and fluids to move through the material.

In addition, one mixture with normalweight coarse aggregate and lightweight fine aggregate (an "inverted" mixture); one mixture with lightweight coarse and lightweight fine aggregates ("all-lightweight" concrete); and one mixture with normalweight aggregate with a partial replacement of normalweight sand by lightweight fine aggregate (an "internally cured" mixture) were also evaluated for transport properties.

All mixtures used 658 lb/yd^3 of Type I portland cement. No supplementary cementitious materials were used. **Table 1** lists the 14 concrete mixtures tested and their properties. The transport properties from the TCG tests were used in several service-life prediction software models, including STADIUM® and Life-365™, and analysis according to *fib Bulletin 34: Model Code for Service Life Design*. A bridge deck subjected to deicing salts in Detroit, Mich., was modeled using the two software programs.

The results for the analysis using STADIUM showed that the concrete bridge deck's service life would be increased in comparison to the normalweight concrete control mixture as follows:

- By approximately 22% when using the "sand lightweight" mixtures

Table 1. Concrete Mixture Proportions and Properties[1]

Mixture description	LW1			LW2							ALW	LWF	IC	C
Lafarge Alpena Type I cement, lb/yd^3	658	658	658	658	658	658	658	658	658	658	658	658	658	658
Aggregate Resource Midway Pit NW FA, lb/yd^3 (SSD)	1360	1342	1320	1119	1119	1074	1568	1346	990	1465	—	—	846	1294
Bay Aggregates Cedarville Pit NW limestone CA No. 67, lb/yd^3 (SSD)	450	350	150	—	—	—	—	—	—	—	—	1800	1800	1800
LW CA, lb/yd^3 (SSD)	500	650	862	1215	1209	1209	862	1038	1273	875	1115	—	—	—
LW FA, lb/yd^3 (SSD) Total water, lb/yd^3	250	250	244	243	243	243	242	243	243	246	243	243	243	243
Designed air, %	6.5	6.5	6.0	7.0	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Designed plastic density, lb/ft^3	120.5	120.4	118.9	119.7	119.5	117.8	123.3	121.7	117.2	120.1	108.7	130.9	142.6	148
Water-cement ratio	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Admixtures														
BASF Master Air AE100, oz/cwt	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.4	0.5
BASF Glenium 7500, oz/cwt	3.2	3.6	3.7	3.9	4.3	3.9	5.2	5.8	3.5	5.0	4.3	5.3	5.0	4.4
Physical properties														
Slump, in.	4.00	5.00	3.50	3.00	8.75	5.00	2.75	5.25	3.00	4.00	3.00	5.00	7.50	4.00
As-tested air, % (volumetric)	6.75	8.00	7.50	7.25	6.50	6.50	7.00	6.25	6.25	7.00	6.25	6.00	7.00	7.10
Plastic density, lb/ft^3 (concrete)	120.5	123.0	118.8	119.1	122.6	122.2	125.7	123.5	121.4	120.7	109.8	133.3	141.6	146.2
Oven-dry density, lb/ft^3 (concrete)	111.9	113.8	108.9	109.2	109.8	108.2	115.7	114.0	109.1	114.1	95.6	130.1	137.2	142.1
Equilibrium air dry density, lb/ft^3 (concrete)	118.6	119.9	115.4	117.3	117.7	115.9	122.3	120.7	117.1	120.3	104.8	136.5	142.9	147.3
No. of days to reach equilibrium (average 2)	112	84	84	140	140	140	112	112	112	56	140	84	84	67
Compressive strength	Average			Average										
1-day strength, psi (3 each)	2870			3370							2700	3500	3570	3310
28-day strength, psi (3 each)	5650			6540							6160	7120	6760	5470
90-day strength, psi (3 each)	6260			7240							7140	8040	7743	5950

Note: For compressive strength tests, three cylinders were tested for each mixture at each age and the average compressive strength is reported.
For LW1 mixtures, the compressive strength value shown is the average of the average values for the three mixtures of this type.
For LW2 mixtures, the compressive strength value shown is the average of the average values for the seven mixtures of this type.
ALW = one "all-lightweight" mixture with LW CA and FA; C = one control mixture with NW CA and FA; CA = coarse aggregate; FA = fine aggregate; IC = one "internally cured" mixture with NW CA, NW FA, and some LW FA; LW = lightweight; LWF = one "inverted" mixture with NW CA and LW FA; LW1 = three "sand lightweight" mixtures with LW CA, some NW CA, and NW FA; LW2 = seven "sand lightweight" mixtures with LW CA and NW FA; NW = natural, normalweight; SSD = saturated surface dry.

- By approximately 88% when using the "inverted" mixture
- By approximately 35% when using the "all-lightweight" mixture
- By approximately 32% when using the "internally cured" mixture

While these results are encouraging, other studies[2–5] have shown greater improvements in properties related to durability and service life for different types of lightweight and internally cured concrete mixtures. Such results would indicate even greater increases in predicted service life than are presented in the findings of the TCG study.

Increased service life of structural lightweight concrete is due to several factors. Water absorbed within the lightweight aggregate pores does not influence the plastic concrete's water–cementitious materials ratio, but it does maintain moisture equilibrium (internal curing) during the early stages of drying, thus delaying drying-shrinkage and reducing drying shrinkage cracks while improving the cement hydration efficiency. Also, lightweight aggregate particles have more surface area than normalweight aggregates and are actually pozzolanic, providing a significantly superior contact zone. Elastic similarity of the lightweight aggregate and the surrounding cementitious matrix allows for reduced microcracking at the matrix-lightweight aggregate interface and developing a concrete that is less pervious.

The results of the Life-365 analysis showed comparable performance between the sand lightweight mixtures and the control mixture. As with the STADIUM analysis, significant increases in projected service life were shown with the lightweight fines (up to three times when lightweight fine aggregate replaced normalweight sand, that is, the "inverted" mixture).

The service-life predictions discussed are estimates for uncracked concrete. As part of the testing program, TCG also evaluated the cracking potential of an internally cured concrete mixture. Compared to the normalweight control mixture, the internally cured mixture was shown to delay restrained shrinkage cracking and increase compressive strength, both of which would be expected to increase service life. In this case, TCG's findings agree with studies by others[2–5] that also found that lightweight concrete has a reduced potential for cracking compared to normalweight control concrete mixtures, providing further benefit for increasing the service life of concrete structures beyond the factors considered in the Life-365 and STADIUM analyses.

For more information on the tests performed by TCG to determine the transport and durability properties of concrete, as well as the assumptions and inputs used for the service-life analyses, see the full report, *Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling*, dated August 23, 2018, which can be downloaded from www.escsi.org.

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Determining In-Place Concrete Compressive Strength

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

There are numerous situations in bridge construction where it is necessary to determine the in-place compressive strength of the concrete. These include removal of formwork, application of post-tensioning, transfer of force from pretensioned strands, termination of cold weather protection, and opening a bridge to traffic. Failure to achieve the specified compressive strength using the standard-cured cylindrical specimens is an unplanned situation that occasionally occurs. This article is part of a series of articles that provide brief descriptions of methods to determine the in-place compressive strength and resources for more information. A more detailed description of these and other methods is provided in *In-Place Methods to Estimate Concrete Strength (ACI 228.1R-03)*.[1]

Field-Cured Cylinders

In this method, standard concrete cylinders are left at the job site for curing in, as nearly as practicable, the same manner as the concrete in the structure.[2] In practice, this usually means placing the concrete cylinders on or near the member or under the sheet-curing material, if used. This method may be used for cast-in-place concrete as well as precast concrete. For cast-in-place concrete, it is the simplest method; however, at best, the cylinders only represent the concrete near the surface of the member. For precast heat-cured concrete, the cylinders are generally placed under an insulated cover and receive curing more similar to that of the member.

Concrete Cores

This method is usually used when the standard-cured cylinders fail to achieve the specified compressive strength and no more cylinders are available for later age tests. It is the most direct method to determine the compressive strength of concrete in a structure because the test is made on the actual concrete that has been subjected to the in-place curing environment. Nevertheless, the core locations must be carefully selected because all parts of the member may not have been subjected to the same curing conditions. The core locations must avoid reinforcement, other embedments, and highly stressed areas.

The strength measured on the cores must also be carefully evaluated. For example,

It [the concrete core technique] is the most direct method to determine the compressive strength of concrete in a structure because the test is made on the actual concrete that has been subjected to the in-place curing environment.

according to the American Concrete Institute's (ACI's) *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*,[3] concrete in an area represented by core tests shall be considered structurally adequate if the average strength of three cores is equal to at least 85% of the specified strength and if no single core strength is less than 75% of the specified strength. No similar provision is included in the American Association of State Highway and Transportation Officials (AASHTO) specifications,[4] although individual project specifications may address it.

Match Curing

Match curing is a system for curing standard concrete cylinders—usually 4 × 8 in.—at the same temperature as that measured in a concrete member.[5,6] Commercial systems include a temperature sensor in the member, a controller, special insulated cylinder molds with built-in heating systems, and a temperature sensor in the mold. The controller is used to control the heating systems so that the temperature in the cylinder matches the temperatures measured in the member. The system may also include a means to record and read the member temperatures and the cylinder temperatures. Noncommercial systems have also been used with this technique. Some precast concrete plants have used heated cabinets for this purpose rather than individual molds.

The method is particularly useful for determining the concrete compressive strength at early ages in the fabrication of precast concrete members or for determining the compressive strength of concrete at a critical section in a member. The location of the temperature sensor in the member is particularly important because temperatures can vary throughout a member and temperature influences the rate of strength gain.

The [match-curing] method is particularly useful for determining the concrete compressive strength at early ages in the fabrication of precast concrete members or for determining the compressive strength of concrete at a critical section in a member.

Because the match-curing system only provides heat to the cylinders and cannot cool them, the temperature of the cylinders may exceed that of the member if the temperature of the member decreases at a faster rate than that of the cylinders. If this happens, the cylinder strengths may not entirely represent the in-place concrete strength.

Sensors at the Black Ankle Valley Bridge were also used to monitor test cylinders for curing compliance and verification of strengths. Photo: John Gnaedinger, Con-Cure LLC.

Maturity Method

The maturity method involves laboratory tests to determine a strength-maturity relationship for the specific concrete mix that will be used in the structure.[7] The strength-maturity relationship is a mathematical expression that is used to convert the concrete temperature history to a maturity index. The in-place concrete temperature is then measured continuously and the in-place concrete maturity index is calculated from the data. The in-place compressive strength is then estimated from the maturity index and the strength-maturity relationship.

The maturity method involves laboratory tests to determine a strength-maturity relationship for the specific concrete mix that will be used in the structure.

Several commercial products are available to monitor and record the concrete temperature as a function of time. They include embedded digital devices that store the data and can be accessed remotely for downloading the data in real time. Some devices will calculate the maturity index. This method is the most complex method described in this series of articles, but it has been successfully used on many projects to expedite construction.

References

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Other Resources

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2. ACI Committee 306. 2016. *Guide to Cold Weather Concreting (ACI 306R-16)*. Farmington Hills, MI: ACI.

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THE LONG GRAY LINE

Reflections on concrete bridge progress

by William Nickas

In 1948, the history of prestressed concrete bridges in the United States began when a Belgian professor named Gustave Magnel oversaw the design, prefabrication, and testing of 160-ft-long girders used to construct the first prestressed concrete girder bridge in the U.S., the Walnut Lane Memorial Bridge in Philadelphia, Pa. As I noted in my editorial for this issue of *ASPIRE*®, we can learn much about possible future improvements for the industry by reflecting on past achievements. As members of the bridge engineering community, we are part of a "long gray line" that connects what we do today, and what we want to do tomorrow, with the accomplishments of those who came before us.

Industry Progress

There are many ways to review the progression of our industry over the last seven decades. PCI issued a chronicle of the first 25 years compiled by industry pioneers titled *Reflections on the Beginnings of Prestressed Concrete in America*.[1] The American Society of Civil Engineers (ASCE) and other organizations periodically evaluate of the health of our infrastructure. These "report cards" help educate us and our communities about the need for infrastructure investments and the revenue streams to pay for them (such as tolls or gas taxes). (For the ASCE report card, see www.asce.org/infrastructure.)

This article takes a different look at benchmarks of our industry's progress. The Federal Highway Administration's (FHWA's) National Bridge Inventory (NBI) (see www.fhwa.dot.gov/bridge/nbi.cfm) is the source of the data used for comparisons. A bridge in the NBI database is classified by the material of its superstructure and the year it was built. So to start, let's use the period 1977 to 2006 as the base period for an analysis of recent trends. During the 30-year period, NBI data indicate that 476,417 bridges were built and 25 of 52 states (for our discussion, "states" will be taken to include the District of Columbia, and Puerto Rico) used some type of concrete (reinforced or prestressed) superstructure for at least 65% of the bridges built during the period. In contrast, during the most recent decade for which data are available, the period between 2007 and 2016, 123,158 bridges were built, 31 states met the 65% benchmark, and 35 states increased their use of concrete superstructure types. The states hitting the 65% benchmark in the 2007–2016 decade are colored in dark grey in **Table 1** and **Figure 1**. As shown in the light-gray portions of the table, an additional seven regions are above 50% concrete utilization. Overall, the market share for all types of concrete superstructures has increased from 68.7% in the base period to 71.6% in the last decade (an increase of 2.9%).

When examining the historical data, we gain further insight by looking at the types of crossings and the functional needs for the structures. In the base years of this study, shorter-span bridges (openings of 20 to 40 ft) were generally reinforced concrete whereas the long spans were typically constructed of prestressed concrete or steel. To better understand the progress of the prestressed concrete industry and its future growth potential, let's consider only steel and prestressed concrete bridges, which generally represent the longer spans. **Table 2** and **Figure 2** focus on these longer-span bridges by comparing the number of steel and prestressed (pretensioned or post-tensioned) concrete bridges built: 175,180 in the base period and 48,095 in the most recent decade. The table also presents the percentage of prestressed girder bridges based on the total number of these two bridge superstructure materials for each period. Between 2007 and 2016, 32 states built more than 50% of their longer-span bridges with prestressed concrete (those shown in dark gray or light gray) and 21 regions had an increase in use of prestressed concrete of over 5% in the last decade. This represents a 5.8% increase in prestressed concrete use in the last decade compared to the previous three decades.

Looking Forward

The data reviewed in this article demonstrate the notable growth of the concrete bridge industry in recent years—and that's good news. However, a few questions remain about the growth potential of prestressed concrete. For example, 13 of the 52 regions still select steel over prestressed concrete 65% of the time. Why do these jurisdictions prefer steel? Is there capacity to deliver concrete bridges in those areas? Understanding what is driving trends will help us expand the growth we have recently experienced.

We need to choose benchmarks that help us move forward and improve. How shall we put other future priorities and technological innovations into historical context so we can effectively identify progress? For example, we know that new shallow concrete beam shapes can be used where span-to-depth ratios were previously seen as a de facto steel solution. We also can anticipate that accelerated bridge construction deliveries will need solutions that are constructible from off-the-shelf components, and prestressed concrete answers this need. Perhaps there are lessons to be learned from the long gray line of our seven decades as an industry that can help us toward this goal.

Reference

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EDITOR'S NOTE

The data presented in this article were collected from the FHWA NBI portal in July 2018. The author thanks Hank Bonstedt for his diligence in the tedious task of analyzing the decades of data. Bonstedt presented a review of concrete bridges in the Spring 2017 issue of ASPIRE*.*

Table 1. Comparison of All Types of Bridges and Concrete Bridges, 1977–2016

	States	30–Year Base Period, 1977–2006			Recent 10–Year Period, 2007–2016				
		All Types	Concrete	Concrete %	All Types	Concrete	Concrete %	Concrete % Change	
1	South Carolina	3811	3181	83.47%	666	634	95.20%	11.73%	South Carolina
2	Arizona	4072	3641	89.42%	904	859	95.02%	5.61%	Arizona
3	Mississippi	8897	8042	90.39%	1835	1732	94.39%	4.00%	Mississippi
4	Minnesota	7028	5720	81.39%	1774	1662	93.69%	12.30%	Minnesota
5	California	8307	7429	89.43%	1880	1736	92.34%	2.91%	California
6	Tennessee	10128	9134	90.19%	1584	1414	89.27%	–0.92%	Tennessee
7	Georgia	7186	5492	76.43%	1126	984	87.39%	10.96%	Georgia
8	Texas	23708	19590	82.63%	7901	6859	86.81%	4.18%	Texas
9	Nevada	1065	911	85.54%	282	242	85.82%	0.28%	Nevada
10	Louisiana	5614	4490	79.98%	1377	1170	84.97%	4.99%	Louisiana
11	Puerto Rico	990	908	91.72%	204	173	84.80%	–6.91%	Puerto Rico
12	New Mexico	1639	1286	78.46%	359	304	84.68%	6.22%	New Mexico
13	Alabama	6865	5527	80.51%	962	813	84.51%	4.00%	Alabama
14	Wisconsin	7906	6269	79.29%	1814	1530	84.34%	5.05%	Wisconsin
15	South Dakota	2077	1684	81.08%	469	395	84.22%	3.14%	South Dakota
16	Florida	6114	5159	84.38%	1968	1647	83.69%	–0.69%	Florida
17	Oregon	3077	2565	83.36%	620	501	80.81%	–2.55%	Oregon
18	Washington	3128	2616	83.63%	825	651	78.91%	–4.72%	Washington
19	North Dakota	1929	1498	77.66%	438	341	77.85%	0.20%	North Dakota
20	Colorado	4837	2999	62.00%	746	570	76.41%	14.41%	Colorado
21	North Carolina	8064	4187	51.92%	2543	1854	72.91%	20.98%	North Carolina
22	Hawaii	258	212	82.17%	32	23	71.88%	–10.30%	Hawaii
23	Illinois	15010	11709	78.01%	3210	2279	71.00%	–7.01%	Illinois
24	Kentucky	5715	4676	81.82%	1347	953	70.75%	–11.07%	Kentucky
25	Utah	1483	967	65.21%	540	382	70.74%	5.54%	Utah
26	Iowa	10798	7306	67.66%	2445	1712	70.02%	2.36%	Iowa
27	Pennsylvania	8560	5519	64.47%	4417	3074	69.59%	5.12%	Pennsylvania
28	Indiana	11446	7299	63.77%	2847	1949	68.46%	4.69%	Indiana
29	Kansas	9758	6168	63.21%	1983	1322	66.67%	3.46%	Kansas
30	Montana	2002	1235	61.69%	677	450	66.47%	4.78%	Montana
31	Ohio	14700	8578	58.35%	3918	2569	65.57%	7.22%	Ohio
32	Idaho	1782	1234	69.25%	508	325	63.98%	–5.27%	Idaho
33	Delaware	450	198	44.00%	112	70	62.50%	18.50%	Delaware
34	Nebraska	8050	4561	56.66%	1552	966	62.24%	5.58%	Nebraska
35	Michigan	5198	3262	62.75%	1500	933	62.20%	–0.55%	Michigan
36	Missouri	12464	6095	48.90%	3824	2269	59.34%	10.43%	Missouri
37	Oklahoma	9190	5866	63.83%	3040	1681	55.30%	–8.53%	Oklahoma
38	Virginia	5589	2763	49.44%	1418	775	54.65%	5.22%	Virginia
39	West Virginia	3887	2076	53.41%	793	395	49.81%	–3.60%	West Virginia
40	Arkansas	6075	3275	53.91%	1268	631	49.76%	–4.15%	Arkansas
41	Connecticut	2076	959	46.19%	339	165	48.67%	2.48%	Connecticut
42	Rhode Island	323	141	43.65%	104	49	47.12%	3.46%	Rhode Island
43	New York	8416	3038	36.10%	2197	1008	45.88%	9.78%	New York
44	Maryland	2698	663	24.57%	491	213	43.38%	18.81%	Maryland
45	Vermont	987	389	39.41%	389	166	42.67%	3.26%	Vermont
46	New Hampshire	1225	348	28.41%	396	161	40.66%	12.25%	New Hampshire
47	Massachusetts	1945	817	42.01%	506	198	39.13%	–2.87%	Massachusetts
48	New Jersey	2702	1292	47.82%	824	309	37.50%	–10.32%	New Jersey
49	Wyoming	1190	397	33.36%	223	78	34.98%	1.62%	Wyoming
50	Maine	924	274	29.65%	309	105	33.98%	4.33%	Maine
51	Alaska	948	309	32.59%	253	81	32.02%	–0.58%	Alaska
52	District of Columbia	132	40	30.30%	49	8	16.33%	–13.98%	District of Columbia
	Overall	282,423	193,994	68.69%	71,788	51,370	71.56%	2.87%	

≥5% improvement in concrete consumption in the last decade.

2016 National Bridge Inventory data downloaded in July 2018.

Figure 1

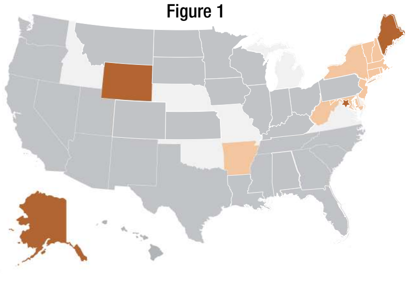


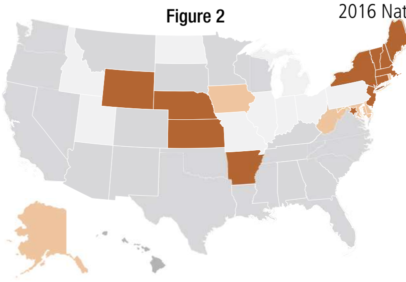
Table 2. Comparison of Steel and Prestressed Concrete Bridges, 1977-2016

	States	30-Year Base Period, 1977-2006			Recent 10-Year Period, 2007-2016				
		Steel	Prestressed Concrete (PS)	Prestressed Concrete % of Steel & PS	Steel	Prestressed Concrete	Prestressed Concrete % of Steel & PS	Prestressed Concrete % Change	
1	South Carolina	581	1460	71.53%	28	512	94.81%	23.28%	South Carolina*
2	Arizona	404	1327	76.66%	44	358	89.05%	12.39%	Arizona*
3	Minnesota	833	1720	67.37%	85	643	88.32%	20.95%	Minnesota*
4	Mississippi	515	2999	85.34%	85	602	87.63%	2.28%	Mississippi
5	California	714	3187	81.70%	137	859	86.24%	4.55%	California
6	Georgia	1572	1849	54.05%	128	627	83.05%	29.00%	Georgia*
7	Texas	3668	9004	71.05%	990	4539	82.09%	11.04%	Texas
8	Tennessee	938	3511	78.92%	158	718	81.96%	3.05%	Tennessee
9	Puerto Rico	82	600	87.98%	30	126	80.77%	–7.21%	Puerto Rico
10	Oregon	316	2237	87.62%	107	434	80.22%	–7.40%	Oregon
11	Florida	661	3302	83.32%	273	1081	79.84%	–3.48%	Florida
12	Nevada	142	284	66.67%	40	134	77.01%	10.34%	Nevada
13	New Mexico	320	613	65.70%	52	165	76.04%	10.33%	New Mexico*
14	Wisconsin	1320	2574	66.10%	250	734	74.59%	8.49%	Wisconsin*
15	Washington	404	1949	82.83%	160	467	74.48%	–8.35%	Washington
16	North Carolina	3688	2998	44.84%	588	1643	73.64%	28.80%	North Carolina*
17	Colorado	1703	1785	51.18%	156	383	71.06%	19.88%	Colorado*
18	South Dakota	326	776	70.42%	68	156	69.64%	–0.77%	South Dakota
19	Alabama	926	1419	60.51%	127	273	68.25%	7.74%	Alabama
20	Louisiana	768	811	51.36%	124	266	68.21%	16.84%	Louisiana
21	Montana	532	1049	66.35%	170	361	67.98%	1.63%	Montana
22	Kentucky	923	3990	81.21%	365	710	66.05%	–15.17%	Kentucky
23	Hawaii	34	137	80.12%	7	13	65.00%	–15.12%	Hawaii
24	Pennsylvania	2844	4102	59.06%	1262	2316	64.73%	5.67%	Pennsylvania*
25	Illinois	3239	7996	71.17%	910	1542	62.89%	–8.28%	Illinois
26	Utah	462	594	56.25%	152	231	60.31%	4.06%	Utah
27	Indiana	3250	4519	58.17%	822	1222	59.78%	1.62%	Indiana
28	Michigan	1544	2663	63.30%	478	704	59.56%	–3.74%	Michigan
29	Idaho	363	781	68.27%	152	216	58.70%	–9.57%	Idaho
30	North Dakota	343	898	72.36%	87	100	53.48%	–18.89%	North Dakota
31	Ohio	5952	5704	48.94%	1307	1412	51.93%	2.99%	Ohio
32	Missouri	6286	3135	33.28%	1498	1516	50.30%	17.02%	Missouri*
33	Iowa	2604	2934	52.98%	603	548	47.61%	–5.37%	Iowa
34	Delaware	223	122	35.36%	27	23	46.00%	10.64%	Delaware*
35	West Virginia	1712	1869	52.19%	391	322	45.16%	–7.03%	West Virginia
36	Oklahoma	3249	3211	49.71%	1347	1017	43.02%	–6.69%	Oklahoma
37	Rhode Island	170	83	32.81%	53	34	39.08%	6.27%	Rhode Island
38	Alaska	411	295	41.78%	125	80	39.02%	–2.76%	Alaska
39	Maryland	1857	236	11.28%	252	151	37.47%	26.19%	Maryland*
40	New York	4892	2017	29.19%	1116	590	34.58%	5.39%	New York*
41	Virginia	2773	786	22.08%	616	292	32.16%	10.07%	Virginia*
42	Massachusetts	1066	654	38.02%	282	133	32.05%	–5.98%	Massachusetts
43	Connecticut	1066	561	34.48%	163	76	31.80%	–2.68%	Connecticut
44	New Jersey	1186	882	42.65%	494	203	29.12%	–13.53%	New Jersey
45	Vermont	546	84	13.33%	202	77	27.60%	14.27%	Vermont
46	Nebraska	3292	1101	25.06%	558	210	27.34%	2.28%	Nebraska
47	Kansas	3463	824	19.22%	643	204	24.09%	4.86%	Kansas
48	Maine	577	123	17.57%	183	58	24.07%	6.49%	Maine
49	New Hampshire	784	119	13.18%	213	44	17.12%	3.94%	New Hampshire
50	District of Columbia	91	13	12.50%	41	5	10.87%	–1.63%	District of Columbia
51	Wyoming	743	135	15.38%	137	16	10.46%	–4.92%	Wyoming
52	Arkansas	2689	111	3.96%	621	42	6.33%	2.37%	Arkansas
	Overall	79,047	96,133	54.88%	18,907	29,188	60.69%	5.81%	

≥5% improvement in concrete consumption in the last decade.

*Indicates ≥5% improvement in concrete consumption in the last decade as indicated in Table 1.

Figure 2



2016 National Bridge Inventory data downloaded in July 2018.

Migrating Corrosion Inhibitors: A Positive Invasion Against Corrosion

by Julie Holmquist, Cortec Corporation

Corrosion is a serious enemy of reinforced concrete bridges, especially those exposed to deicing salts or salt-water spray. As bridges age, the high pH environment of new concrete—which initially protects steel reinforcement from corrosion—declines through carbonation. When moisture, oxygen, and chlorides seep into the concrete pores, they foster an environment for the reinforcement to rust. The pressure of the rusting reinforcement causes the concrete to crack and spall. The damaged concrete allows corrosive elements greater access to the reinforcement, accelerating the corrosion cycle and damaging the bridge. Accelerated corrosion and damage are a serious concern because bridges are complex and expensive structures to design, build, and replace.

Migrating Corrosion Inhibitor Technology

While it is not possible to fully stop corrosion, there are many strategies to slow corrosion and extend service life. Among these are migrating corrosion inhibitors, which have been in use for more than 30 years. These products, including some that are patented, come in a variety of delivery methods, giving flexibility for use in the construction, repair, or maintenance of new or existing bridge structures.

Migrating corrosion inhibitors are based on salts of amine alcohols or amine carboxylates. They have the ability to work their way through concrete pores to reach the surface of the

Migrating corrosion inhibitor powders were used to protect post-tensioning strands on the St. Croix Crossing Bridge between Minnesota and Wisconsin. During this multi-year project, tendon grouting was sometimes delayed by cold weather. Photo: Minnesota Department of Transportation.

A 100% silane sealer containing migrating corrosion inhibitors was applied to the deck of the Francis Scott Key Bridge in Baltimore, Md., as part of routine maintenance in 2008. The manufacturer recommends another application this year. Photo: Cortec Corporation.

Table 1. *ASTM C1582 Physical Property Results for Migrating Corrosion Inhibiting Admixture A*[2]

	Control	Migrating Inhibitor A	Relative to Control	ASTM C1582 Requirement	Result
Setting time, minutes					
Initial set	312	431	+119	≤ ±210	OK
Final set	404	524	+120	≤ ±210	OK
Compressive strength, psi					
3-day	3290	3647	111%	≥ 80%	OK
7-day	4070	4377	108%	≥ 80%	OK
28-day	5143	5330	104%	≥ 80%	OK
6-month	6077	6650	109%	≥ 80%	OK
1-year	6463	6877	106%	≥ 80%	OK
Flexural strength, psi					
3-day	585	591	101%	≥ 80%	OK
7-day	661	691	105%	≥ 80%	OK
28-day	757	797	105%	≥ 80%	OK
Shrinkage, %					
Length change	–0.025	–0.021	+0.004 84%	≤ 0.010 ≤ 135%	OK
Durability, RDF					
Freeze/thaw durability	99.1	98.8	99.7%	RDF ≥ 80%	OK

Table 2. *ASTM C1582 Corrosion Results for Migrating Corrosion Inhibiting Admixture B*[3]

	Control	Migrating Inhibitor B	Relative to Control	ASTM C1582 Requirement	Result
Mean integrated current, C	155	29	n/a	≤ 50 C when control is 150 C	OK
Mean area corroded, in.^{2}	8.93	2.36	0.26	≤ ⅓ of control	OK
Mean chloride content, ppm*	2861†	2898	101%	≥ Critical chloride content	OK

*Based on control average at 50 coulombs plus 1 standard deviation.

†Critical chloride content

reinforcement and form a protective molecular layer on it. This layer interferes with the natural corrosion reaction that takes place when oxygen, moisture, and chlorides are in contact with steel. As a result, corrosion is delayed or reduced once started.

Uses in New Construction

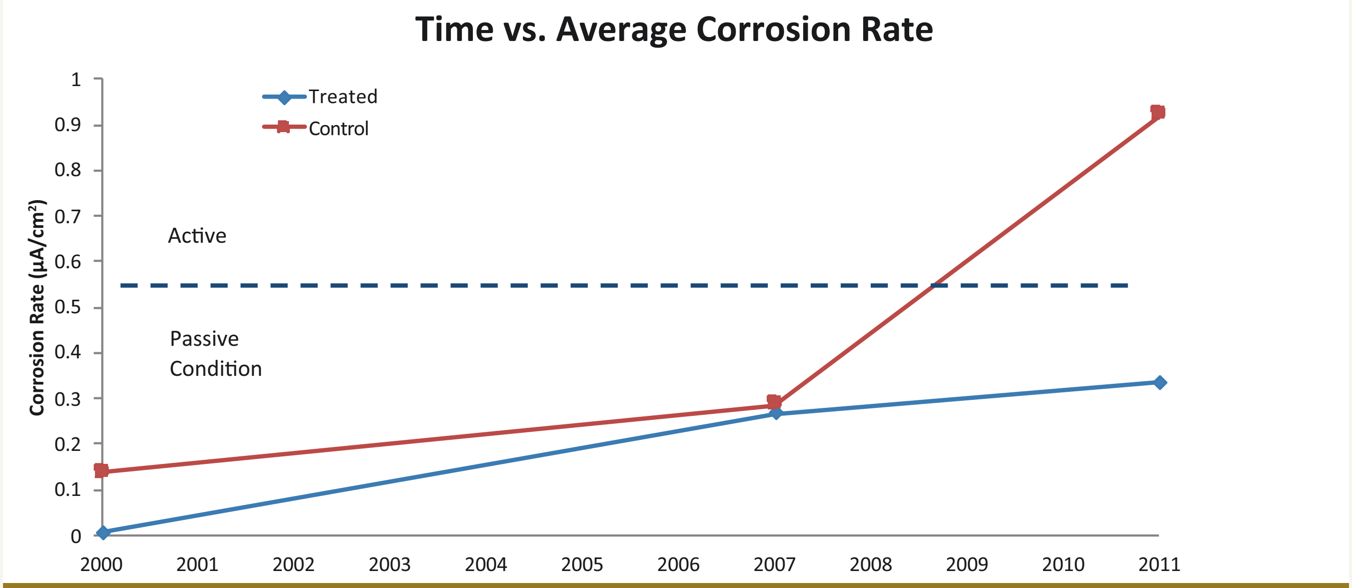
Migrating corrosion inhibitor admixtures can be mixed directly into the concrete mixture. Some meet ASTM C1582[1] physical property standards for set time, compressive strength, flexural strength, shrinkage, and freeze/thaw durability (see **Tables 1** and **2**).[2,3] They may also meet ASTM C1582 requirements for corrosion reduction in a chloride environment.

Unlike calcium nitrite, which has a high tendency to leach into water, several migrating corrosion inhibitor admixtures have been UL certified to meet NSF/ANSI Standard 61[4] for use in potable-water structures. In some cases, migrating corrosion inhibitors can be added to shotcrete and repair mortars.

For post-tensioned bridges, a low-pressure air hose can be used to blow migrating corrosion inhibitor powder through post-tensioning ducts to protect post-tensioning cables before grouting, as was done on the St. Croix Crossing Bridge over the Mississipi River between Wisconsin and Minnesota when cold weather delayed tendon grouting (see the Fall 2018 issue of *ASPIRE* for an article on the project). With this method, the ducts are capped, and the low-toxicity corrosion inhibitor vaporizes and disperses throughout the void space, forming a protective molecular layer on the post-tensioning strands. Little or no surface preparation is required before the powder is applied, and the powder does not need to be flushed out before grouting.

Uses for Repair and Maintenance

Migrating corrosion inhibiting admixtures can also be used in repair applications to discourage further corrosion where corrosion damage has already occurred, as was done on the Randolph Avenue Bridge in St. Paul, Minn., where winters are harsh and deicing salts are regularly used. By 1986, the bridge, which was built in 1963, was in need of an overlay repair. The westbound lanes had more damage than the eastbound lanes and were overlaid slightly thicker (0.31 in. deeper on average), using a concrete mixture with a migrating corrosion inhibitor admixture. To serve as a control, the eastbound lanes were overlaid with the same concrete mixture but no inhibitor. Corrosion rates in the treated side remained lower, while corrosion rates in the eastbound control lanes spiked into the active range between the 2007 and 2011 readings.[5]



Randolph Avenue Bridge corrosion rates. Figure: Cortec Corporation.

Surface-applied migrating corrosion inhibitors can be applied to existing structures during repair or maintenance. These inhibitors enter concrete pores first as a liquid by capillary action and then by vapor diffusion, with the advantage of protecting reinforcement that has already been embedded under the surface. In "pure" inhibitor form (no water repellant), the inhibitor can migrate up to 3 in. deep to slow deterioration of reinforcement that may have started to rust beneath the concrete surface. It can also be combined with 40% or 100% silane sealers to discourage water and contaminant intrusion at the surface and provide inhibitor protection beneath.

Conclusion

Migrating corrosion inhibitors offer several innovative and easy-to-apply strategies for fighting corrosion on bridges. They have the advantages of being useful on new and existing structures and being highly compatible with concrete mixtures. Additionally, they are good candidates for use near waterways due to their low toxicity and NSF/ ANSI 61 Standard certifications for use in potable-water structures.

Migrating corrosion inhibitors were tested in an overlay repair on the Randolph Avenue Bridge in St. Paul, Minn. Photo: Cortec Corporation.

While migrating corrosion inhibitors are minimally invasive to the concrete structure as a whole, they are a positive force to "invade" concrete for the purpose of reducing corrosion on new and existing bridges.

References

1. ASTM International. 2017. *Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete*. ASTM C1582/ C1582M-11(2017)e1. West Conshohocken, PA: ASTM International.

2. Ade, K., et al. 2016. "Admixture to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete (ASTM C1582)." Prepared for Cortec Corporation by Tourney Consulting Group, Kalamazoo, MI, April 14, 2016.

3. Ade, K., et al. 2016. "2005 NS Admixture to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete (ASTM C1582)." Prepared for Cortec Corporation by Tourney Consulting Group, Kalamazoo, MI, May 27, 2016.

4. NSF International. 2016. *Drinking Water System Components–Health Effects*. NSF/ANSI 61. Ann Arbor, MI: NSF International.

5. Meyer, J. 2017. "Organic Corrosion Inhibitors—New Build and Existing Structures Performance." Paper presented at the Brian Cherry International Concrete Symposium, Australian Corrosion Association, Melbourne, Australia.

Julie Holmquist is content writer at Cortec Corporation in St. Paul, Minn.

2019 Call for Papers

2019 PCI Committee Days

September 25 – 28, 2019
Loews O'Hare, Rosemont, IL

PCI is accepting abstracts for technical papers to be presented at the 2019 PCI Committee Days, September 25–28, 2019, at the Loews O'Hare in Rosemont, Ill.

The Call for Papers offers an opportunity to exchange ideas and information on precast/prestressed concrete design, fabrication, and construction. Abstracts submitted must be relevant to the precast/prestressed concrete industry.

Abstracts and papers will be peer reviewed, and accepted papers will be published in the proceedings. The authors of accepted abstracts will be notified via email on or about February 15, 2019.

Submit abstracts here: **https://www.softconf.com/i/pci2019**

Abstracts are due January 24, 2019.

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For more information, go to the Call for Papers page on the PCI website:
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For questions regarding submissions on buildings or materials, contact: Roger J. Becker, P.E., S.E. (rbecker@pci.org).

For questions regarding submissions on bridges or transportation, contact: William Nickas, P.E. (wnickas@pci.org).

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

www.rebar-u.org
This is a link to the Concrete Reinforcing Steel Institute (CRSI) website with self-paced, informational or continuing education courses on various aspects of steel reinforced concrete. CRSI is featured in the Focus article on page 6.

https://www.ccscheme.org.uk/ccs-ltd/what-is-the-ccs2
This is a link to the website for Considerate Contractors Scheme, a nonprofit organization in the United Kingdom that strives to improve the image of the construction industry by having companies practice good-neighbor policies. Good relationships between companies and communities are emphasized in the Perspective article on page 10.

https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=76
This is a link to a Pennsylvania Department of Transportation website and information on the Interstate 78 Underclearance project. The six concrete bridges of the project are featured in a Project article on page 12.

https://vimeo.com/243907218
This is a link to a time-lapse video of the replacement of one of the bridges that was part of the Interstate 78 Underclearance project, which is featured in a Project article on page 12.

https://www.youtube.com/watch?v=-UeUQwYvsWA
This is a link to a video of construction activities or the Stone Arch Bridge over Stony Brook in Princeton, N.J. The rehabilitation of the historic bridge and construction of a new bridge over an adjacent flood channel are featured in a Project article on page 16.

https://www.news-journalonline.com/news/20180130/1st-of-its-kind-in-florida-daytonas-orange-avenue-bridge-takes-shape
This is a link to a newspaper article and photos of the Veterans Memorial Bridge in Daytona Beach, Fla. Bridge integration modeling was used for the workflow and to create three-dimensional documents for the design and construction of the structure. This new workflow technique is the topic of a Concrete Bridge Technology article on page 20.

http://www.pcine.org/index.cfm/resources/bridge/Bridge_Deck_Panels
This is a link to the website of the PCI Northeast chapter, which has extensive information on precast concrete bridge deck panels. The handling and transportation of precast concrete deck panels is the subject of a Concrete Bridge Technology article on page 24.

http://elearning.pci.org
This is a link to the PCI eLearning website, which contains continuing education courses on various precast/prestressed concrete topics, including *Course T220: Production and Construction Details of Full-Depth Precast Concrete Deck Panels.* The handling and transportation of precast concrete deck panels is the subject of a Concrete Bridge Technology article on page 24.

https://igamemom.com/build-pencil-da-vinci-bridge-stem-challenge
This is a link to a website that has instructions on how to build a Da Vinci bridge using pencils and rubber bands, a good activity for children. Providing educational activities to children in the STEAM (science, technology, engineering, art/architecture, and mathematics) areas is mentioned in the Professor's Perspective article on page 28.

https://www.pci.org/PCI/Education/Student_Competitions.aspx
This is a direct link to the website containing rules of the 2019 PCI Engineering Student Design (Big Beam) Competition. Also on the website are the winning videos and reports from previous competitions. The competition is mentioned in the Professor's Perspective article on page 28.

https://www.escsi.org/wp-content/uploads/2018/12/16059-LW-Aggregate-Transport-Property-August-23-2018.pdf
This is a direct link to *Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling.* This report is the subject of the Safety and Serviceability article on increasing durability and service life of bridges on page 32.

OTHER INFORMATION

https://store.transportation.org/Item/PublicationDetail?ID=4134
This is a link to a website where the recently published American Association of State Highway and Transportation Officials' (AASHTO's) *LRFD Guide Specifications for Accelerated Bridge Construction,* 1st edition, can be purchased. These specifications cover both design and construction and address items not covered in the *AASHTO LRFD Bridge Design Specifications* and *AASHTO LRFD Bridge Construction Specifications*.

http://www.trb.org/main/blurbs/178161.aspx
This is link to download *End-Region Behavior and Shear Strength of Pretensioned Concrete Girders Employing 0.7-in. Diameter Strands* by the Center for Transportation Research at the University of Texas at Austin. This recent report documents a research project on end-region serviceability and shear strength of Texas pretensioned concrete bulb-tee girders with 0.7-in.-diameter strands.

https://abc-utc.fiu.edu/events/webinar-archives
This is a link to the website for the Accelerated Bridge Construction University Transportation Center at Florida International University. The website has webinars such as *ABC Methods for Delaware's All-Precast Bridge 1-438.* The bridge was constructed with just a 31-day closure.

AASHTO LRFD Bridge Design Specifications: Stability of Pretensioned Concrete Girders

by Dr. Oguzhan Bayrak, University of Texas at Austin

Over the past 10 to 15 years, the design and fabrication of prestressed concrete girders have benefited from the availability of high-performance materials, new technologies, and advanced methods for structural design. More specifically, the advent of concrete materials technology, widespread availability of high-performance/high-strength concrete, the development and popularization of self-consolidating concrete, and the introduction of 0.6-in.-diameter strands with the potential for 300-ksi and 0.7-in.-diameter strands have created new opportunities within the prestressed concrete industry. Coupled with these advances in materials, the industry has moved forward to accept more sophisticated methods of design that allow for better optimization by removing unnecessary levels of design conservatism. As a result of these advancements, many states have developed better-optimized prestressed concrete bridge girders. In at least three states—Washington, Nebraska, and Florida—record-breaking spans have been designed and constructed.

With girder lengths in excess of 200 ft, the stability of slender pretensioned concrete girders has recently become a serious concern, which necessitates additional considerations in bridge design, fabrication, handling, transportation, erection, and construction. To address this concern, the Washington State Department of Transportation (WSDOT) has been requiring designers to evaluate stability of girders during both handling and transportation. (For more on the WSDOT views on this issue, see "Designing Precast, Prestressed Concrete Bridge Girders for Lateral Stability: An Owner's Perspective" in the Winter 2018 issue of *ASPIRE*®.) Additionally, on the national level, the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures took on this issue by adopting revisions to several articles in the *AASHTO LRFD Bridge Design Specifications* 8th edition at the committee's June 2018 meeting in Burlington, Vt.

First, Article 5.5.4.3 and its commentary have been revised to highlight the importance of considering girder stability. The specifications have been revised as follows: "Buckling and stability of precast members during handling, transportation, and erection shall be investigated." Commentary for this article provides the necessary background, stating that "Stability during handling, transportation, and erection can govern the design of precast, prestressed girders. Precast members should be designed such that safe storage, handling, and erection can be accomplished by the contractor. This consideration does not make the designer responsible for the contractor's means and methods for construction, as discussed in 2.5.3."

Second, Article 5.9.4.5 has been developed and added to the specifications. This article addresses the use of temporary top strands. This specification states, "Temporary top strands may be used to control tensile stresses in precast, prestressed girders during handling and transportation. These strands may be pretensioned or post-tensioned prior to lifting the girder from the casting bed or post-tensioned prior to transportation of the girder. Detensioning of temporary strands shall be shown in the construction sequence and typically occurs after the girders are securely braced and before construction of intermediate concrete diaphragms, if applicable." Additional useful details about providing, tensioning, and detensioning temporary strands are also presented. Further, the effects of temporary strands on camber calculations and prestress losses are also acknowledged.

The commentary for the article provides a detailed discussion about how the use of temporary top strands improves the stability of girders by

Erecting a long-span pretensioned concrete girders. Photo: Concrete Technology Corporation.

altering stresses and reducing initial camber and camber growth. The beneficial effects of moving the lifting points away from the girder ends are also discussed.

Third, the commentary for Article 5.12.3.2.1 has also been revised to read: "*AASHTO LRFD Bridge Construction Specifications* places the responsibility on the Contractor to provide adequate devices and methods for the safe storage, handling, erection, and temporary bracing of precast members. However, these preservice conditions may govern and should be considered in the design, as discussed in 2.5.3." The last sentence in this commentary is provided to draw the attention of all responsible parties—the designer, the beam fabricator, and the contractor—to the fact that better-optimized girders require careful consideration from their conception to their use in service.

The three important revisions summarized previously are intended to draw our attention to consequences using the better-optimized girders and higher-performance materials of the 21st century to economically construct longer-span bridges, which allow the prestressed concrete industry to compete for new span ranges. However, with that stated, and as I say in my classes frequently, we do not get something for nothing in structural engineering. Better-optimized sections and higher-performance materials require better engineering and additional care during beam fabrication, storage, and transportation. Furthermore, girder erection, bracing (temporary or permanent), and superstructure construction all require considerations that were either less significant or not significant at all in the recent past. Advancing the state of practice in precast concrete bridge construction requires close coordination among all interested/responsible parties. In my view, the assignment of a particular responsibility, such as girder stability considerations, to a particular party carries a secondary level of importance. What is most important is that girder stability gets considered in the process of design, fabrication, handling, storage, transportation, erection, and construction.

As we aspire to move the profession forward, we must do so with care. The revisions to the AASHTO LRFD specifications discussed in this column are all aimed at accomplishing this goal. Additionally, Seguirant and colleagues[1] provide a useful example illustrating stability considerations. PCI has published a detailed procedure for evaluating the lateral stability of a girder during production, storage, transportation, erection, and construction.[2] PCI is also developing eLearning modules on lateral stability and a spreadsheet that implements the procedures in reference 2.

References

1. Seguirant, S.J., R. Brice, and B. Khaleghi. 2009. "Design Optimization for Fabrication of Pretensioned Concrete Bridge Girders: An Example Problem." *PCI Journal* 54(4): 73-111.
2. Precast/Prestressed Concrete Institute (PCI). 2016. *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*. Publication CB-02-16-E. Chicago, IL: PCI.


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