# STEEL BRIDGES 2013

There's always a solution in steel.

**www.steelbridges.org**

Item NSBA-012

# Welcome to Steel Bridges 2013!

This publication contains all bridge related information collected from Modern Steel Construction magazine in 2013. These articles have been combined into one organized document for our readership to access quickly and easily. Within this publication, readers will find information about Steel Centurions, aesthetics, and rapid replacement among many other interesting topics. Readers may also download any and all of these articles (free of charge) in electronic format by visiting **www.modernsteel.org**.

The National Steel Bridge Alliance is dedicated to advancing the state-of-the-art of steel bridge design and construction. We are a unified industry organization of businesses and agencies interested in the development, promotion, and construction of cost-effective steel bridges and we look forward to working with all of you in 2014.

Sincerely,

Bill McEleney

NSBA Managing Director
National Steel Bridge Alliance

## Table of Contents



## Advertisers



**National Steel Bridge Alliance (A division of American Institute of Steel Construction)**
**One East Wacker Drive, Suite 700, Chicago, IL 60601 • 312.670.2400 • www.steelbridges.org**

# A Bridge in Building's Clothing

BY TIMOTHY COSTELLO, P.E., AND MARK RAULLI, P.E.

**A community college conceives a creative crossing to connect its campus.**

**THERE ARE A FEW WAYS** to get over a gorge.

One idea is to build a bridge. Another might be to build a building.

Onondaga Community College decided to do both—but in one structure—and is in the process of completing an $18.9 million, 45,000-sq.-ft "bridge building" across the foliage-filled Furnace Brook Gorge, a 60-ft-deep fissure that divides its campus in Syracuse, N.Y. The gorge was, in fact, previously spanned by a bridge, but one that was open to wind, rain and snow. The new building will provide a protected crossing over the gorge—particularly enticing during the area's harsh winters. In addition, the two-story structure makes use of otherwise unusable land. And by avoiding underground rerouting of elements such as sewer lines and electrical conduits, which would have been required with the original proposed building location, it was achievable within the college's original budget.

The building is actually an addition to the school's Ferrante Hall and is also attached to the Gordon Student Center, uniting the east and west campuses and connecting the campus spine on the south with public, staff and student parking to the north. Conceived as a teaching facility offering outreach to community organizations in need of performance venues, the new building encourages an integrative approach to music by providing facilities for the entire music school, including administration, production, teaching, research and support spaces. The building also shares the Gordon Student Center's loading dock and other support functions.

Inside the addition, called Ferrante Hall Academic II, are a 150-seat music recital hall, a music resource center, a 2,500-sq.-ft instrumental/choral rehearsal room, a 1,200-sq.-ft percussion dedicated rehearsal room, 20 practice rooms of various sizes, 16 faculty teaching offices and eight classrooms. The recital hall can accommodate up to a 50-piece orchestra with a 40-member chorus.

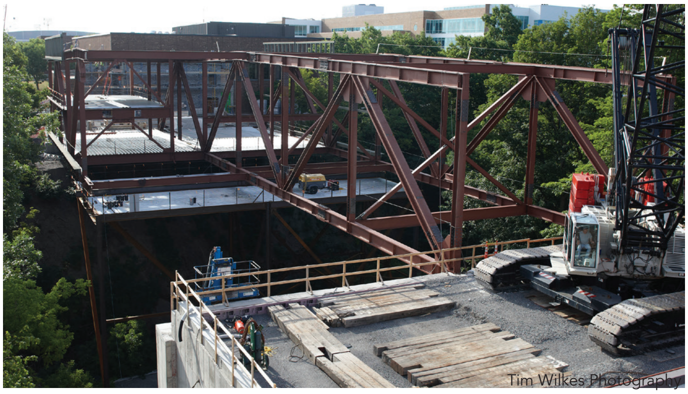
Because limited excavation was needed to bury elements such as electrical conduits and sewer lines, and because the building taps into existing parking, loading, utility infrastructure and site work, construction costs and environmental disruption were considerably reduced, freeing up resources to attack the project's numerous engineering challenges. These included a constricted work area, uneven loading, deflection and rock fragmentation.


Ferrante Hall Academic II, which opens in May, adds 45,000 sq. ft of building space to the Onondaga Community College campus.

Installation of two of the 200-ft-long trusses for the new building.


The new "bridge building" uses 860 tons of structural steel in all.

The final truss is installed.


**Timothy Costello** is an associate vice president with Cannon Design and can be reached at **tcostello@cannondesign.com**. **Mark Raulli** is an engineer and estimator with Raulli & Sons, Inc., and can be reached at **mark@raulliandsons.com**.

## Over the Gorge

Use of bridge construction materials and techniques was essential in achieving the architectural vision, given the structure's double life as a bridge and a building. Three two-story, 200-ft trusses support the building and its range of interior room types, and bridge bearings are used to transfer loads to the building's foundations (called pot bearings, there were six total, one under each end of each truss). On either side of the truss are link buildings (60 ft to 80 ft in length) that attach the addition to the existing structures on either side of the gorge. The new building uses a total of 860 tons of structural steel.

To withstand structural forces, the 30-ft-high trusses incorporate some of the largest rolled steel elements available (up to W14x665). With limited working room on either side, the construction team built a temporary single-support steel tower in the middle of the gorge, allowing the trusses to be erected in two halves and spliced in the middle; the largest half-truss was 70 tons. This piecewise approach facilitated field assembly of the trusses to occur in a smaller area and enabled the use of a smaller crane. When unexpected rock fragmentation was discovered on one side of the gorge during excavation, drilled mini-piles and rock anchors were installed by a specialty contractor to supplement the foundation's original 7-ft-diameter caissons.

## A Balanced Recital

The recital hall posed a major structural challenge, due to its configuration in comparison to the rest of the building. Because it was a two-story space on one side of the building and the other side of the building was composed of two one-story layers, the load on the structure was unbalanced. While the north truss supported the weight of the roof and two lower levels, the south truss only supported a roof and one lower level, and the center truss supported a two-story space on one side and two one-story spaces on the other.

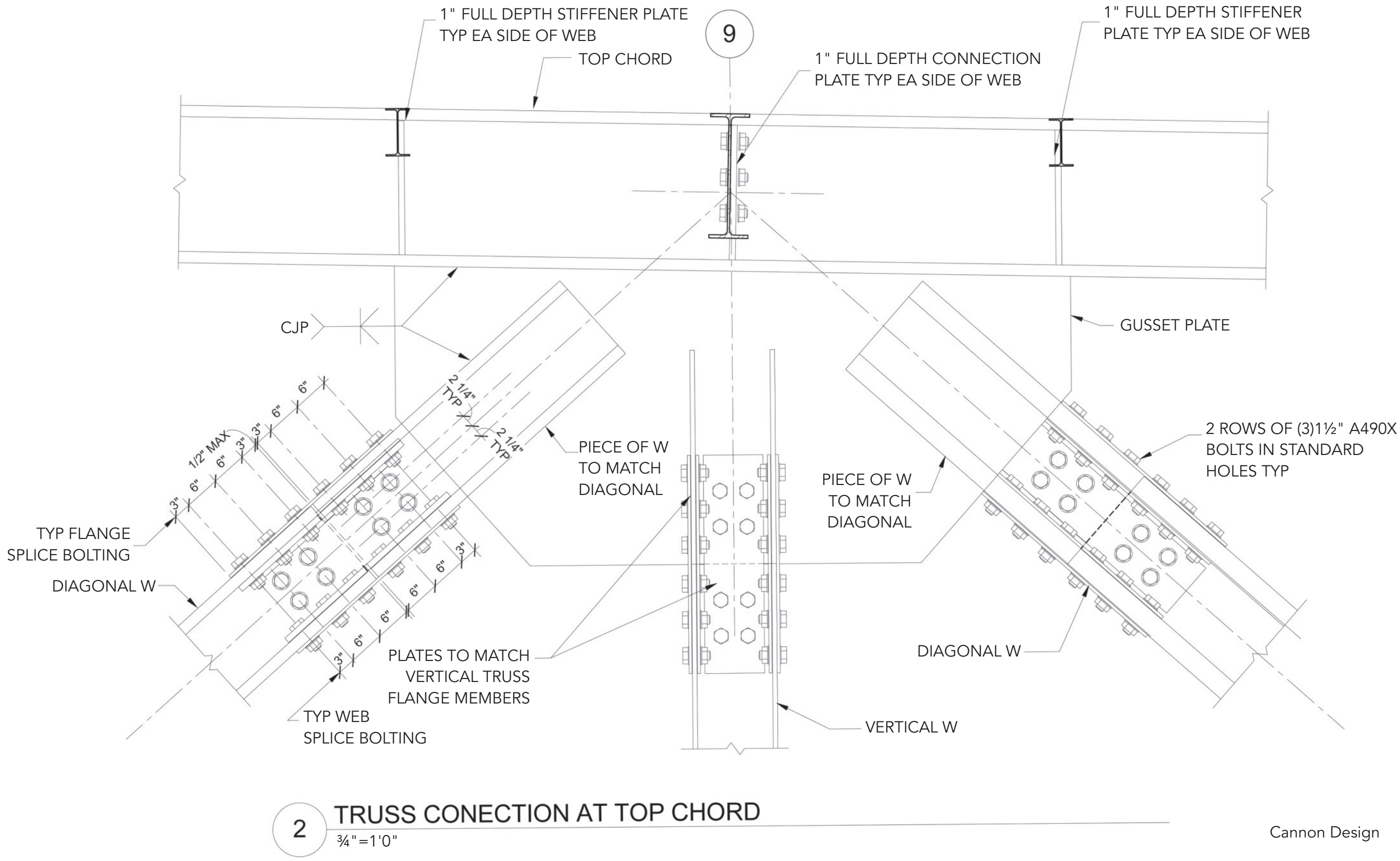
If trusses were loaded after placement of curtainwall or exposed concrete floors, the deflection of the trusses could cause windows to pop out and the concrete to crack excessively. Construction was sequenced to take as much deflection out of the trusses as possible prior to placing deflection-sensitive materials. The team considered two options: preloading the trusses to neutralize deflections and sequentially unloading them as the building was completed, or installing non-deflection-critical items first to help deflect the trusses. A combination of the two was eventually chosen. As many materials as possible were installed prior to the curtain wall; once it was determined that enough deflection had occurred in the truss, the curtain wall was installed.



▲ Lift and installation of truss 1.

◄ The construction team built a temporary single-support steel tower in the middle of the gorge, allowing the trusses to be erected in two halves and spliced in the middle.

▼ A top truss cord gusset connection.




Cannon Design

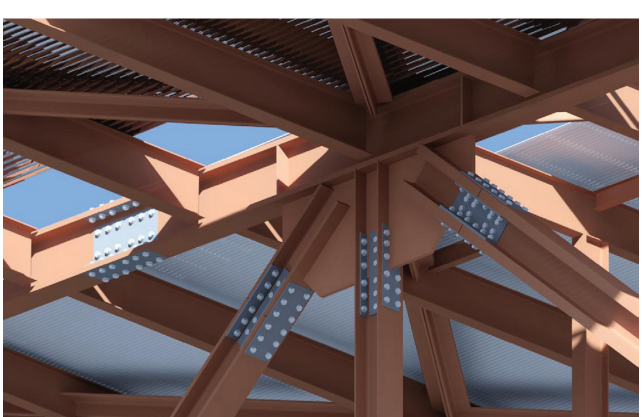
A detail of a top truss chord connection.

## Bolt Dilemma

Besides the unique construction area and balance issues, bolting also posed a challenge. During steel fabrication, the team learned that the 1½-in. A490 bolts specified in the design had a tendency to fail if they were installed by turning the head end of the bolt rather than the nut end. In the building's design, however, the bolts were an architectural feature specifically designed to be installed in one direction—via rotation of the bolt head. And because the bolts were so large, they couldn't be installed any other way. (Due to manufacturing techniques used for the large bolts, a special lubricant was needed to achieve the required torque for them, as the friction would have been too great otherwise.)

When the new bridge building opens in May, Onondaga Community College students, faculty and visitors will have a new path across Furnace Creek Gorge, as well as a new music building surrounded on all sides—including below—by natural beauty. ■

A truss connection as a Revit model...



Cannon Design

... and as-built.

Cannon Design


**Owner**
Onondaga Community College, Syracuse, N.Y.

**Architect and Structural Engineer**
Cannon Design, Grand Island, N.Y.

**General Contractor**
Hueber-Breuer Construction Company, Inc., Syracuse

**Construction Manager**
C&S Companies, Syracuse

**Steel Team**

**Fabricator and Erector**
Raulli & Sons, Inc., Syracuse, N.Y. (AISC Member/AISC Certified Fabricator and Erector)

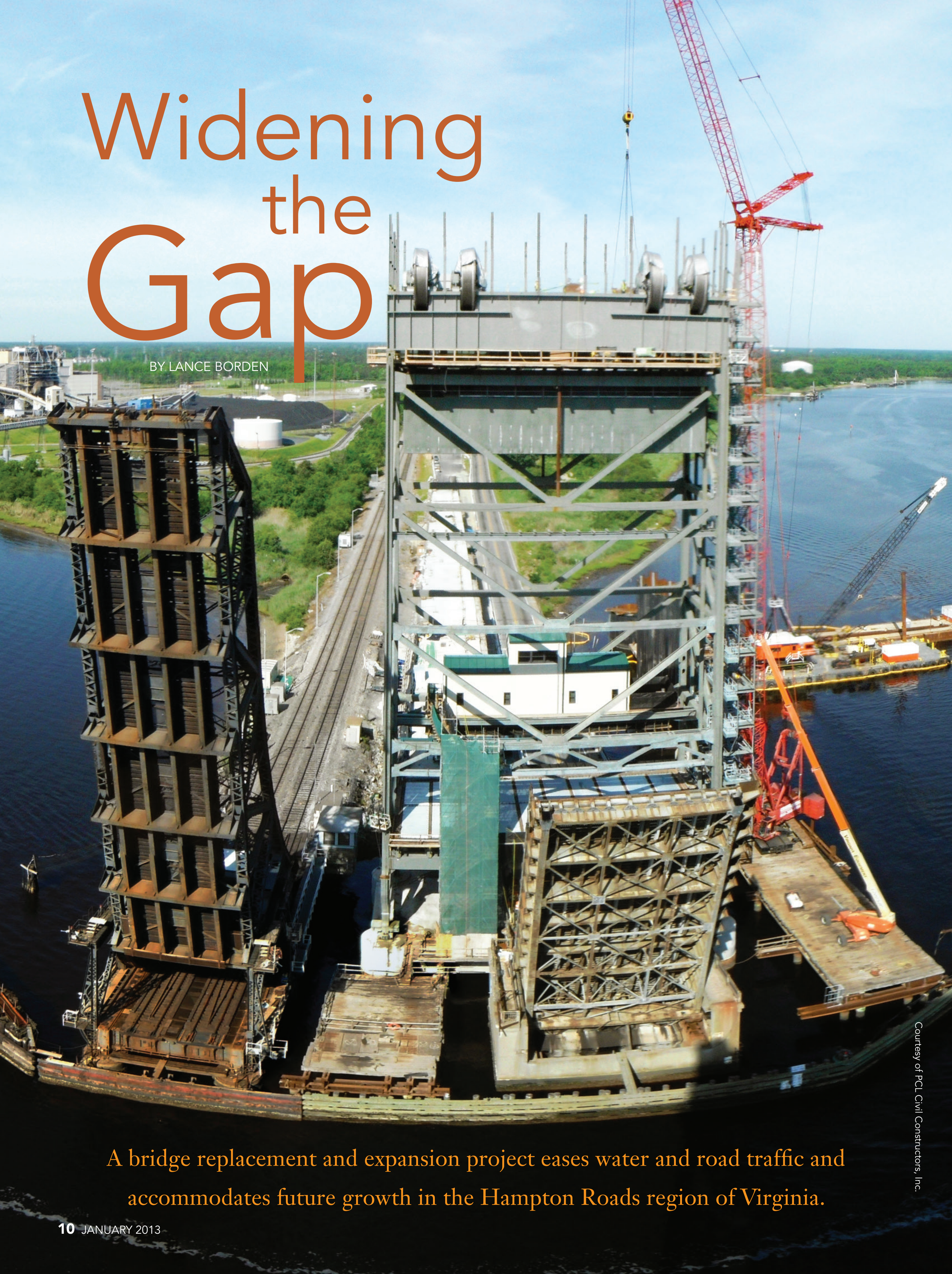
**Detailer**
JCM and Associates, Ltd., Frankford, Ontario, Canada (AISC Member)

▲ The building sits above a 60-ft-deep fissure.

▼ Lift and installation of truss 2.

# Widening the Gap

BY LANCE BORDEN



Courtesy of PCL Civil Constructors, Inc.

A bridge replacement and expansion project eases water and road traffic and accommodates future growth in the Hampton Roads region of Virginia.

Courtesy of Modjeski and Masters

**ONE OF THE WORLD'S** largest natural harbors and home to 1.7 million people, the Hampton Roads area in southeastern Virginia, is known for its year-round ice-free waterways, high concentration of military bases and shipyards, and miles of waterfront property.

The Henry G. Gilmerton Bridge is one of five critical bridges connecting the region and carries approximately one million travelers every month. In the late 1990s, nearly 70 years after the bridge was originally constructed, the City of Chesapeake recognized the need to replace the aging span to accommodate future growth in an area becoming increasingly congested both on the land and in the water.

The original bascule span's 11-ft clearance required a large number of bridge lifts, making it the most frequently opened bridge in Hampton Roads at 7,500 openings per year. It also carries Military Highway over the Elizabeth River and thus needed to assist with expanding the highway to help facilitate the area's increasing motor traffic.

As such, the City of Chesapeake embarked on a $134 million replacement project. Early plans called for building a new bridge on a separate alignment, then later demolishing the original bascule span. However, it was determined that any alternate alignment would further impact already tight navigational tolerances at the site. The city turned to bridge engineering firm Modjeski and Masters for the complex design assignment—one that required the new bridge to be built on the exact same alignment. Doing so, however, would potentially create a significant disruption of traffic. Military Highway is a critical artery in the Hampton Roads region, carrying more than 35,000 motorists every day, and any lengthy

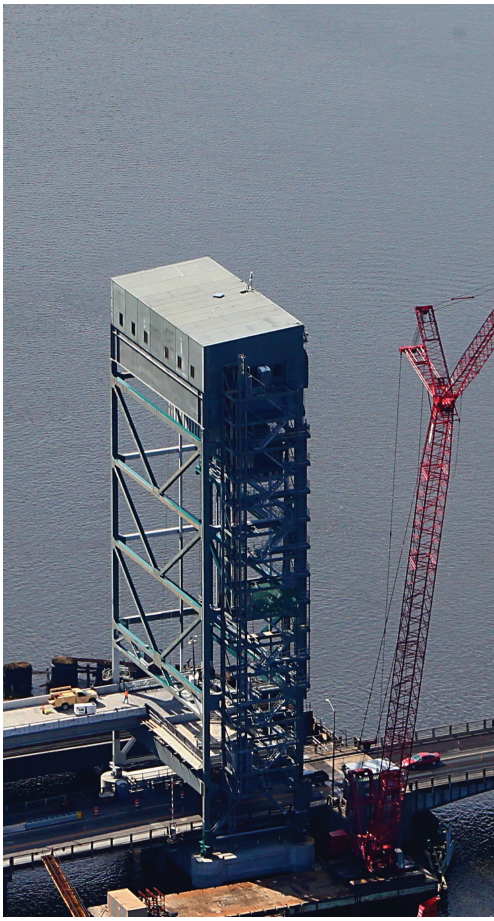
◄ The new bridge's two main lift towers, 207 ft tall, were erected directly over live traffic.

▲ Only 25 ft separate the Gilmerton Bridge from an adjacent railroad bridge.

**Lance Borden** is a senior associate and design project manager with Modjeski and Masters. You can reach him at **lvborden@modjeski.com**.

The Gilmerton Bridge and railroad bridge, before construction.

Courtesy of the Virginia Department of Transportation



disruption to traffic could significantly impact travel and commerce.

## Above and Below

The design team thus came up with a plan that involved building the bridge above and below the existing structure, with the original bridge remaining functional until the float-in of the new span. The new bridge was originally proposed as a bascule span, but was later designed as a vertical lift bridge to accommodate the necessary increase in bridge length and width.

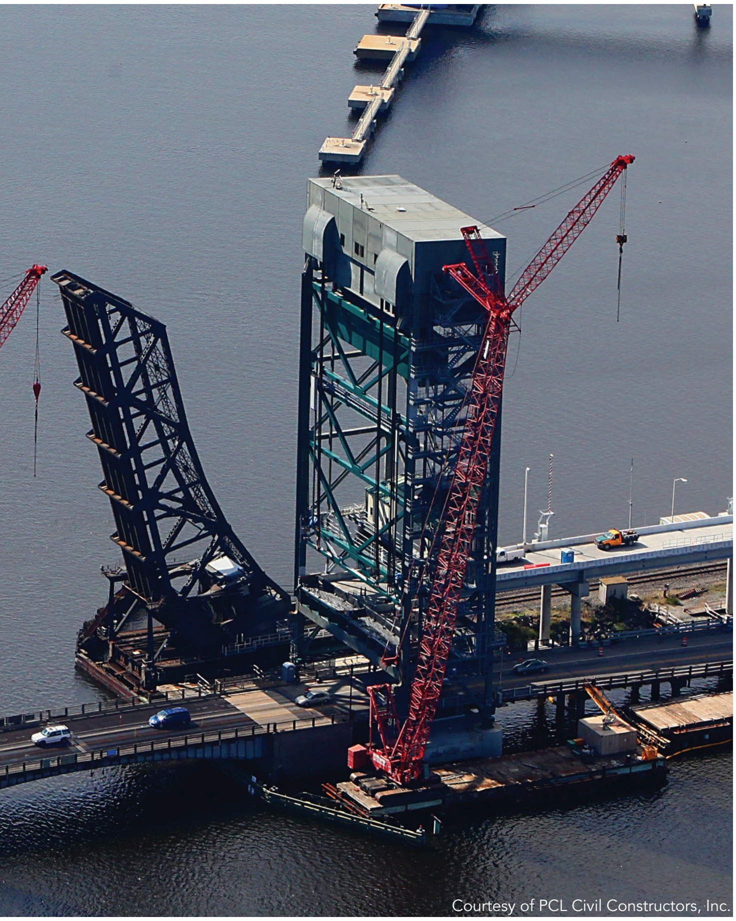
Construction of the new bridge began in late 2009, following completion of final design, and it is scheduled to be completed in 2014. As one of the challenges with the replacement project was minimizing impact on the traveling public, construction was not only coordinated around morning and evening rush hours but also around peak summer travel when both marine and motorist traffic are heavy.

With construction underway, the teams faced several challenges, starting with the proximity of a nearby railroad bridge. The railroad bridge, which is owned by Norfolk Southern, is a primary route for the coal industry and is heavily used. With only 25 ft between the Gilmerton Bridge and the railroad bridge—coupled with the necessity to create wider foundations for the new bridge—setting the foundations, constructing the substructure and demolishing the original bridge would need to be done in a way that did not disrupt the railroad bridge or its foundations. The team used seismic instruments to monitor and identify potential settlement impacts to the railroad bridge foundations during installation of the new drilled shafts. Fortunately, it was determined that the vibrations from a typical freight train passage were greater than those produced from the installation of the shafts.

Laying the foundations also presented a challenge for the construction and design teams. The Gilmerton Bridge is located in the Great Dismal Swamp, a marshy area on the coastal plains region with less than desirable soil conditions. To effectively support the new lift span, a total of eight 12-ft-diameter drilled shafts were needed. The drilled shaft foundations were designed to reach 120 ft below ground level, a feat that would require special equipment and a team of industry experts. The contractor, PCL Civil Constructors, used a specially made massive oscillator to drill the foundations, and the project features some of the largest drilled shafts ever constructed using the oscillating method.

Above ground, 207-ft-tall steel main span lift towers were erected directly over live traffic. The towers span from 38 ft from center of front column to center of rear column and are 89 ft center to center, transversely, to match the lift span. The tower columns and horizontal braces are box shaped, with I-shaped diagonal bracing members. The new steel towers exceed the required 135 ft of vertical clearance for the 250-ft long and 85-ft wide lift span, which ended up being one of the widest lift spans ever designed. Due to the exceptional bridge width, four 15-ft-diameter sheaves, each carrying twelve 2¼-in.-diameter wire ropes, were required on each tower to support the load of the lift span and counterweights—twice as many as typically necessary.

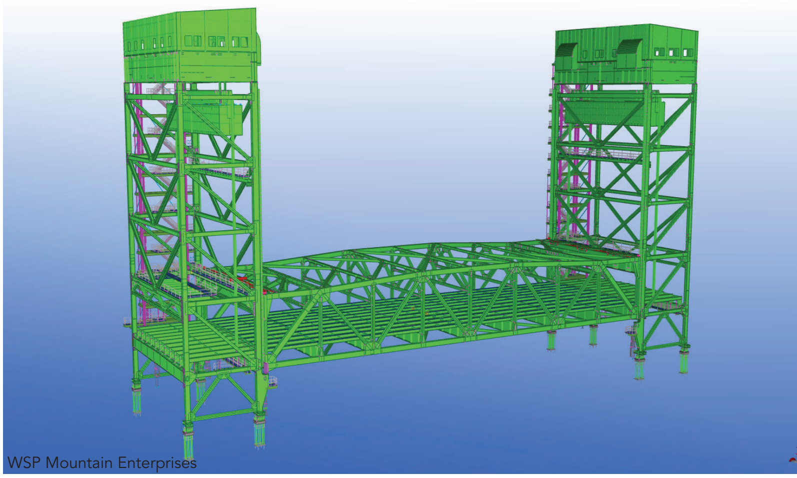
The front and rear tower columns incorporate jacking brackets that allow the tower, with the full weight of the lift span and counterweight, to be jacked and shimmed should there be any differential settlement of the drilled shafts. Finger shims will



Courtesy of PCL Civil Constructors, Inc.

◄ The new lift span has a vertical clearance of more than 35 ft in the closed position, compared to the original bridge's 11-ft clearance.

▼ A 3D Tekla Structures model of the bridge.



WSP Mountain Enterprises

be placed under the tower bearings to bring the tower back to vertical and at the correct elevation.

It is typical on a vertical lift bridge for the bottom panel of the tower to be designed as a portal frame, because bracing cannot be used in order for the roadway to pass through the tower. On the Gilmerton Bridge the bottom panel is located where the existing bridge passes through the tower and the second panel is located where the new bridge roadway passes through the tower. Therefore, the two bottom panels of the tower are designed as portal frames. To relieve the moments in the tower columns that are realized by wind loading, the front and rear transverse floor beams were designed with full moment connections. In addition, the anchor bolts are post-tensioned in order to provide a fixed support at the base.

Wind loads control many of the bracing members in the towers. An aerodynamic study of the main span was performed during the design phase, which revealed that some of the tower bracing members may be susceptible to wind-induced vibrations. To solve this problem the flat plates that would normally make up the flanges of the I-shaped members were replaced with channels in order to increase their out-of-plane stiffness.

The bridge itself also needed to be designed and built in a way that would accommodate increased traffic and expansion of Military Highway. Again, proximity to the adjacent railroad bridge created challenges. A hard bend in the river south of the bridge eliminated the possibility of expanding in that direction, so Norfolk Southern's willingness to yield some of its right-of-way was the only way the wider bridge could be constructed. Ultimately, the new bridge is designed to carry six travel lanes, while the existing bridge carries four. Both outside lanes will be striped, allowing them to operate as shoulders before the necessary expansion.

The float-in of the lift span is scheduled to take place early this year, and the project is expected to finish later in the year. The new six-lane bridge is 1,908 ft long and 85 ft wide, with the lift bridge portion measuring 335 ft long. The final lift bridge will use a total of 5,000 tons of structural steel and 650 tons of miscellaneous steel. The new lift span has a vertical clearance of more than 35 ft in the closed position, compared to the original bridge's 11-ft clearance. Increased clearance will lead to fewer annual lifts, easing the strains placed on this movable bridge and facilitating maritime traffic flow by allowing more vessels to pass without additional bridge openings. It is predicted that the new bridge will see 40% fewer openings each year, easing traffic and marine congestion alike. ■

**Owner**
Virginia Department of Transportation

**Structural Engineer**
Modjeski and Masters, Mechanicsburg, Pa.

**General Contractor and Erector**
PCL Civil Constructors, Inc., Chesapeake, Va.

**Steel Team**

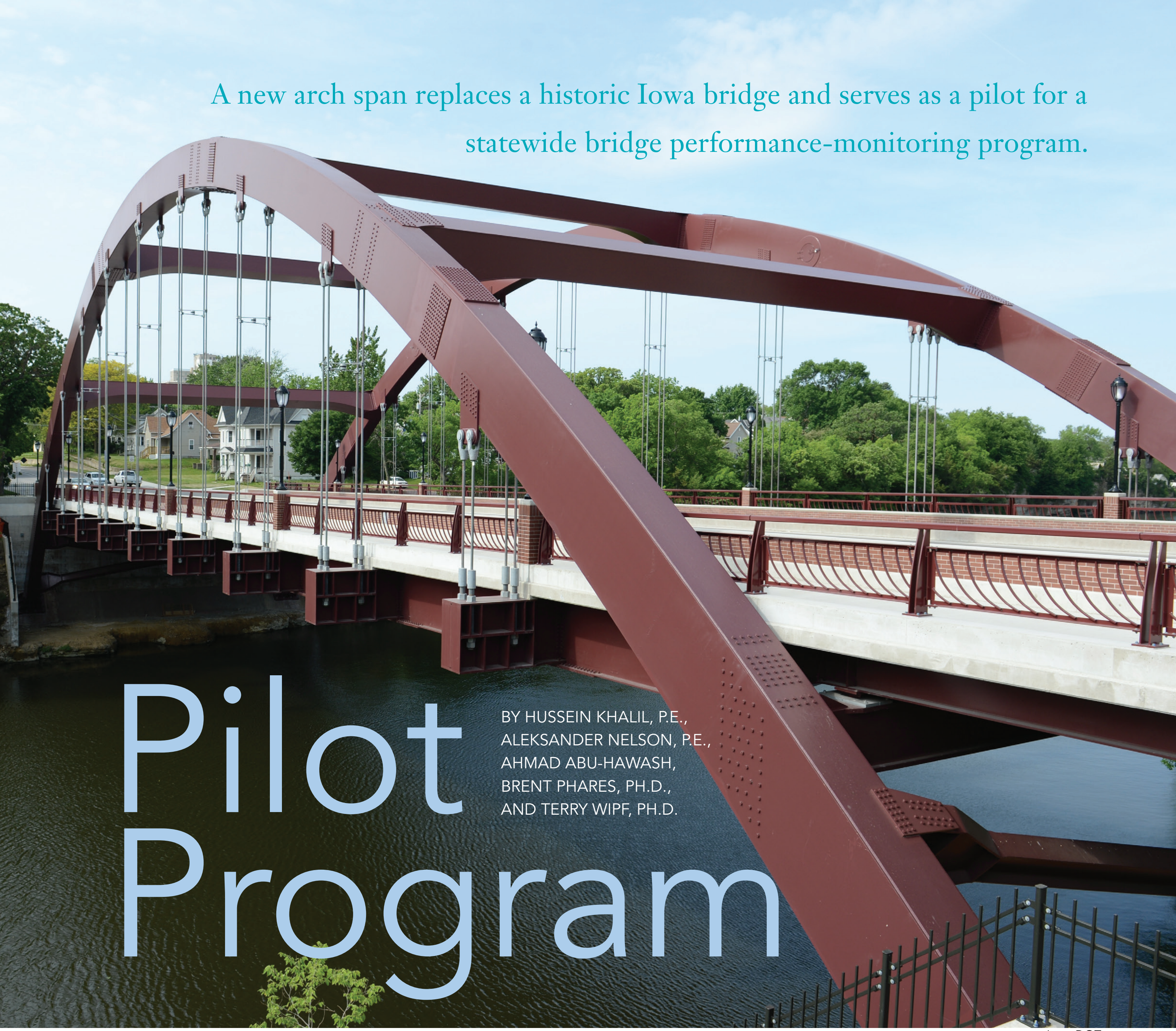
**Fabricator**
Banker Steel Co., LLC, Lynchburg, Va. (AISC Member/ AISC Certified Fabricator/NSBA Member)

**Detailer**
WSP Mountain Enterprises, Inc., Sharpsburg, Md., (AISC Member)

A new arch span replaces a historic Iowa bridge and serves as a pilot for a statewide bridge performance-monitoring program.

# Pilot Program

BY HUSSEIN KHALIL, P.E., ALEKSANDER NELSON, P.E., AHMAD ABU-HAWASH, BRENT PHARES, PH.D., AND TERRY WIPF, PH.D.



Iowa DOT

**REPLACEMENT DECISIONS AREN'T ALWAYS EASY—** especially when the structure in question is listed on the National Register of Historic Places.

In the case of the Iowa Falls Bridge, which crosses the Iowa River on U.S. Highway 65 in Iowa Falls, Iowa, it had to happen. The bridge, a 235-ft-long reinforced concrete open spandrel deck arch structure (with a 24-ft-wide roadway and 5-ft-wide sidewalks on each side), was built in 1928 and was considered a local landmark. The existing bridge had undergone rehabilitation on seven different occasions, including major ones in 1976 and 2000. However, by 2007, the bridge had become structurally deficient and the costs of repairs and strengthening were deemed high enough to warrant replacing it rather than rehabilitating it yet again.

Under a contract with the Iowa Department of Transportation (Iowa DOT), HDR Engineering, Inc., performed a study of feasible replacement options and demolition concepts as well as final design services for the new span. (In addition, and under a separate contract, Iowa State University instituted a field test program to focus on the structural performance evaluation of several critical components during construction of the new bridge for correlation with expected design performance. See the sidebar for more.)

Iowa Falls prides itself as a scenic town with the Iowa River at the center of its beauty, and is committed to historical preservation; any replacement option that did not fit the desired aesthetics and community expectations would have faced strong opposition. Through a brainstorming session between Iowa DOT and HDR, it was decided that replacement options would be limited to girder and arch type bridges. Four different bridge alternatives were considered and evaluated for cost, timeline for construction, aesthetic value, constructability and impact on the community. The bridge options evaluated were: a prestressed concrete girder, a haunched steel girder, a concrete deck arch and a partial through steel arch.

In an effort to engage the community and solicit opinions on the type of bridge to replace the existing arch bridge, the Iowa DOT held a public information meeting to showcase each of the options considered. The attendees favored the partial through steel arch bridge, and this ended up being the chosen design.

## Tight Quarters

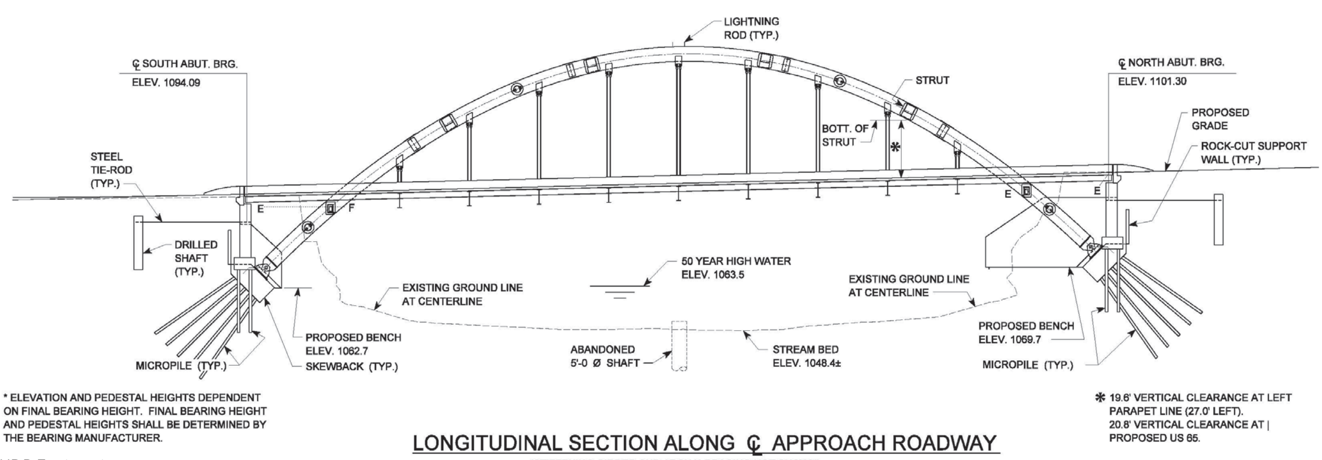
The new bridge is approximately 30 ft wider than the existing bridge, and with intersecting city streets just off each end, Saint Matthew's Episcopal Church on the northwest corner and private property owners on both the southeast and northeast corners, available room for the proposed span was a precious commodity. With the arch foundations required to be set approximately 30 ft below grade, coupled with the need to maintain access to the east side of the church, vertical cuts in the rock were required to allow room for the footings and yet leave sufficient space for access. In addition, retaining walls were constructed to preserve and stabilize the ground adjacent to the church and nearby properties.

The partial through steel arch is 67 ft, 10-in. wide between the centers of the two arch ribs and 276 ft long between the bearing pins. The structure supports a 63-ft, 8-in. bridge deck consisting of a 5-ft, 2-in. wide sidewalk, 11-ft,10-in.-wide multi-use trail and a 42-ft-wide clear roadway. For design and aesthetic reasons, a height factor of 0.25 was used for the parabolic curve of the arch ribs. The arch ribs are braced by four struts above the bridge deck, two framed-in floor beams and one set of cross bracing below the bridge deck at each end of the bridge.

The bridge deck is supported on a steel stringer and floor beam system. Nine of the floor beams are hung from the arch rib while the two end floor beams are framed directly into the arch ribs. The interior stringers connect to the interior floor beams with simple shear clip angle connections and run continuous over the top of the end floor beams. The exterior stringers are stiffening girders designed to distribute vehicular loads from the deck to multiple hanger cables, as well as minimize local live load deflections.

◀ The Iowa Falls Bridge replaces a reinforced concrete open spandrel deck arch structure.

▼ A drawing of the longitudinal section of the new partial thru steel arch bridge.




HDR Engineering

**Hussein Khalil** is a vice president and the construction services section manager for the Transportation Group in HDR's Omaha office.

**Aleksander Nelson** is a senior project manager for the Transportation Group in HDR's Omaha office.

**Ahmad Abu-Hawash** is the chief structural engineer with the Iowa Department of Transportation.

**Brent Phares** is associate director for Bridges and Structures at the Center for Transportation Research and Education at Iowa State University.

**Terry Wipf** serves as the interim chair for the Civil, Construction and Environmental Engineering Department at Iowa State University.


The four bridge alternatives that were considered. Clockwise from upper-left: a prestressed concrete girder, a haunched steel girder, a partial through steel arch (the selected design) and a concrete deck arch.

The stiffening girders were designed in tandem with the hangers from both a functional and a theoretical standpoint. The arch ribs are protected from vehicular traffic by a traffic separation barrier, either a sidewalk or a multiuse trail, and finally by a steel handrail on a raised concrete parapet. To allow ease of maintenance and in case of damage to the hanger cables, the cables were sized to allow for full roadway traffic with any one of the four cables in a set removed or damaged.

The stiffening girder design was governed by the effects of the live load causing differential elongations in the hanger cables as the load moves over the bridge deck. A baseline analysis was performed on a conventional girder bridge on rigid supports, and the hanger cable connections were modeled as rigid supports in the vertical direction. The results from this analysis were used in the design of the end spans where the stiffening girder passes over the rigid end floor beam. However, for the locations where the interior floor beams are supported by the hanger cables, a second model was created to include the effects of the cable elongation under load and the distributing effects of the stiffening girder. The moment demand on the stiffening girder generated by the live load was approximately five times higher than the baseline analysis due to the effects of hanger cable elongation.

## Geometric Issues

The design of the arch rib had a few added complications due to the geometry of the bridge. There were situations in the bridge where conventional design practices used to minimize out-of-plane loads could not be followed. One case is the wind bracing between the arch ribs. In many arch bridges the bracing system is trussed to limit weak axis bending as a result of wind loads perpendicular to the arch rib. However, due to the bridge's width-to-span ratio, a trussed bracing system was deemed inefficient and impractical. Therefore, four struts were provided between the arch ribs to allow them to share the lateral loads, but the resistance to those loads would be in the weak axis bending of the arch ribs. This resulted in an arch rib with with minor tension in the corners at service load. This complicated the requirements for testing on the arch rib as it became a fracture-critical component.

Another area where the large bridge width-to-span ratio caused the design to diverge from conventional thinking was with the end floor beams that frame directly into the arch rib. A shorter bridge span allows for a smaller arch rib, but a larger bridge width requires a larger end floor beam, and thus a larger end floor beam connection. The result was that the end floor beam needed to be both as narrow and shallow as possible and yet still impart significant out-of-plane bending forces into the arch rib.

To minimize the size of the end floor beam as well as provide it with increased toughness and fatigue resistance, it was designed to be made of A709 Grade HPS50W. While the design limits of HPS steel are similar to those of standard

## Healthy Bridges

As part of designing, building and maintaining the bridge infrastructure in Iowa, the Iowa DOT has in recent years focused efforts on investigating the use of new high-performance materials, new design concepts and construction methods, and various new maintenance methods. These progressive efforts are intended to increase the life span of bridges in meeting the DOT's objective of building and maintaining safe, cost-effective structures. Bridge testing and monitoring has been beneficial in helping with these efforts, as well as providing important information to evaluate the structural performance and safety of bridges.

The Iowa DOT testing and monitoring program, in coordination with the Bridge Engineering Center (BEC) at Iowa State University, collects performance data to compare against design-based structural parameters to determine if the structural response is appropriate. The data may also be used to "calibrate" an analytical model that may be used to provide a more detailed structural assessment (e.g., a load rating to determine safe bridge capacity). Diagnostic testing has also been used to help identify deterioration or damage, or to assess the integrity of an implemented repair or strengthening method.

In cases where the Iowa DOT has investigated the use of innovative materials (e.g., high-performance steel, ultra-high-performance concrete and fiber-reinforced polymers) and design/construction methods, they have used testing as part of a program for evaluating the bridge performance. The most challenging research program has been related to developing structural health monitoring (SHM) to determine the real-time structural and continuous condition of a bridge. An example of such work that has been ongoing for several years aimed to develop a SHM system to identify crack development in fatigue-prone areas of structural steel bridges. The next step in the evolution of bridge monitoring for the Iowa DOT is to implement monitoring systems that not only assess targeted structural performance parameters, but that can also be applicable to assessing general conditions (both structural and nonstructural) using multiple sensors and sensor types.

With respect to the Iowa Falls Bridge project, the goal was to implement a multi-sensor continuous SHM system. This pilot monitoring system was developed for general performance evaluation (structural, environmental, etc.) so that it can be easily adapted to other bridge types and other monitoring needs (the system has been functioning successfully and plans are currently underway for implementing it on a second bridge). It allows easy access to real-time data and provides the data in a format that allows for immediate implementation by the Iowa DOT.

The general attributes of the sensor system are as follows:

**Environmental**

- Wind speed and direction
- Bridge deck potential icing conditions

**Structural**

- Corrosion potential on one micropile foundation
- Corrosion potential in substructure element at one bridge end expansion joint and at tie-back rod connecting abutment to drilled shaft
- Corrosion of bridge deck
- Moisture in arch rib
- Relative movement between south and north abutments
- Behavior of concrete anchors for rock cut support wall
- Arch Forces (strain gages)
    - At mid-span
    - Just above base at south end
    - Type B floorbeam
    - Each flange splice location
    - At outer support plate of the hinge bearing at south end
    - Rotation (tilt) at hinge bearing on south end
- Hanger forces and floor beam connection (cable type strain gage and/or accelerometers)
    - Hanger exceeds threshold stress (or hanger breaks); send alert
    - Stiffening girder fatigue at transition
- Collect data for offline office use in updating bridge superstructure rating (i.e., live load demand) and for detection of heavy loads

**Vehicle Classification System and other Communication**

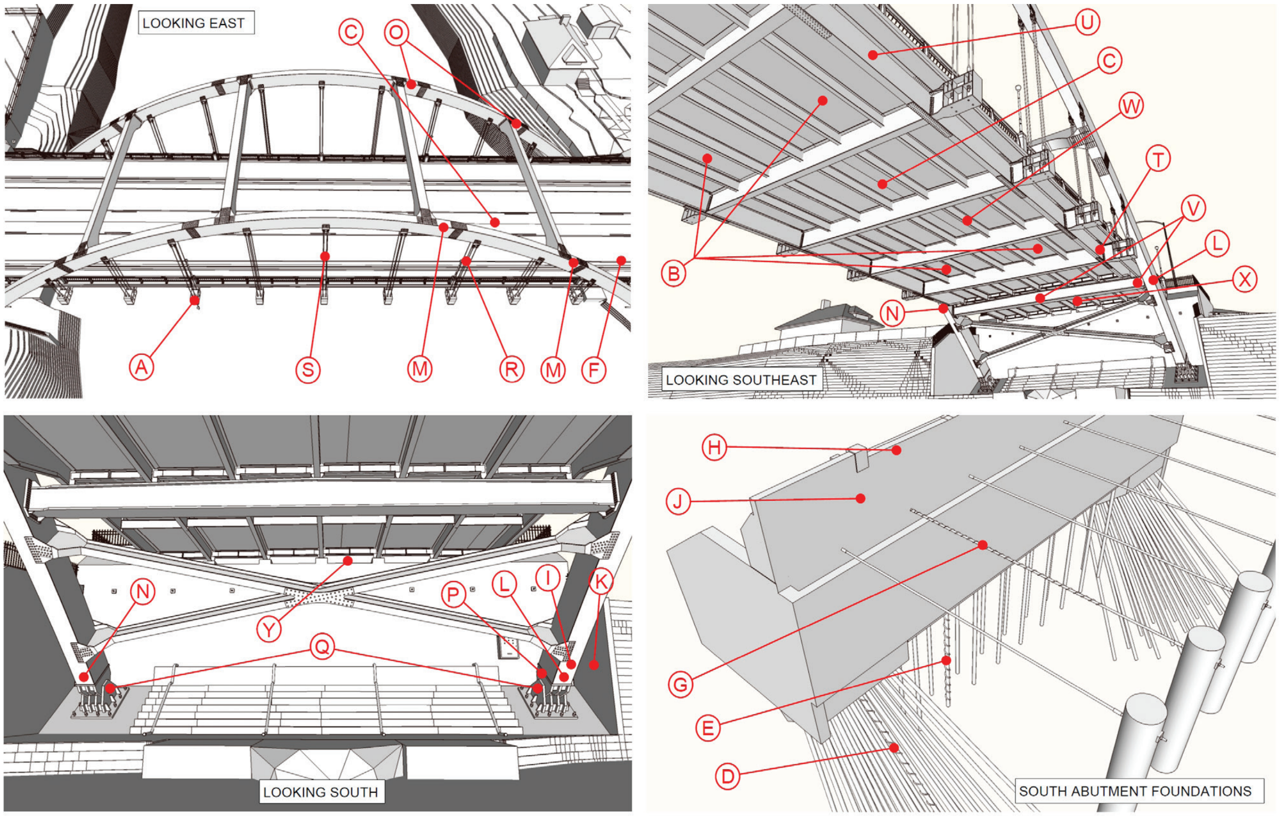
- Vehicle geometry/volume, alert for delays, etc.
- Web-based "dashboard"

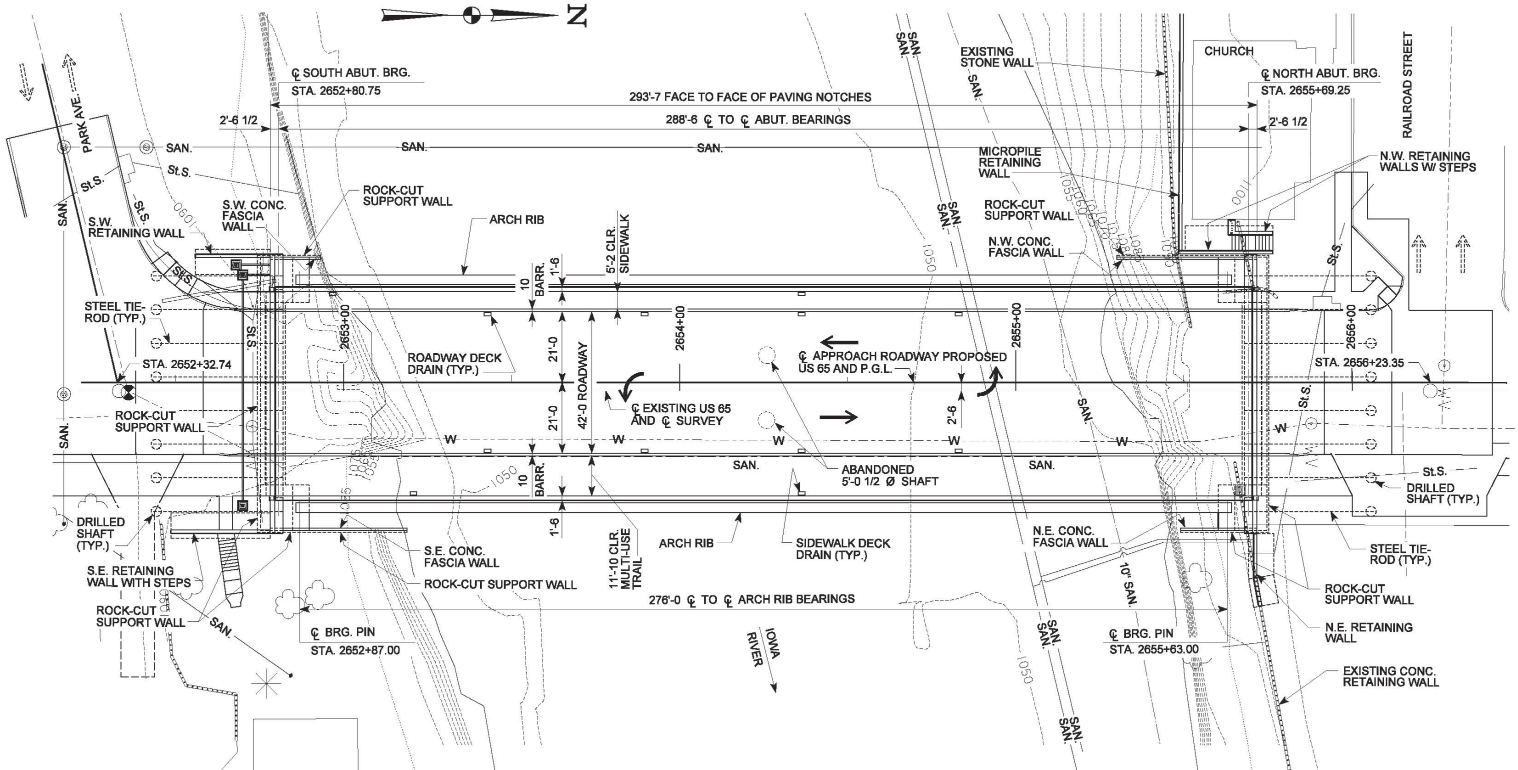
Custom software was developed for this SHM system deployment and was made to be generic enough such that transfer to other applications is seamless. One critical component is the proprietary damage detection algorithm developed at the BEC. This algorithm is included in the software such that the entire system provides operational data, environmental data and a real-time check of conditions.

One critical product developed for this project was a web-based "dashboard" (i.e., real-time reporting for operational center management). There is one primary web page containing web links designed for each appropriate DOT office to use the SHM field data. The format of the data is based upon structural performance parameters (e.g., live load distribution, member live load forces, vehicle position on the bridge, etc.), which can be used directly in updating the rating. The format of the data is also based upon critical inspection performance indicators (e.g,. corrosion growth and moisture accumulation), as well as structural response indicators, such as stress, that might exceed acceptable thresholds.

Locations of the health monitoring instrumentation for the Iowa Falls Bridge.

Iowa DOT

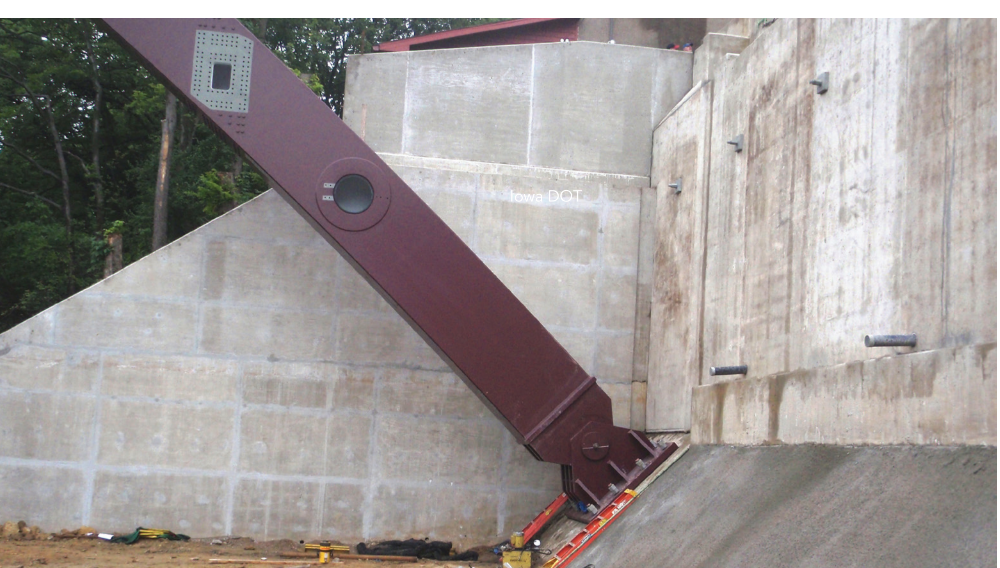





HDR Engineering

SITUATION PLAN

Iowa DOT



HDR Engineering

A stuation plan of the bridge.

Aerial rendering of the project. Available room on either bank was a precious commodity.

weathering steel, it inherently has higher fatigue and fracture resistance. Initially, the potential for higher yield strengths of the HPS steel were also considered. However, to limit deflections, a higher moment of inertia and a lower yield strength were deemed the better option for this situation.

Another design challenge was deciding on the type of bearing used to support the arch ribs. Often, with longer spans, the reduced "k" value for the "kL/r" ratio obtained by use of a fixed bearing will more than offset the additional steel required to resist the higher moments developed at the arch skewback due to the fixity of the bearing. After much iterative analysis, it was determined the overall weight of structural steel for the bridge would not be significantly impacted by the choice of bearing. However, the pinned bearing connection removes the primary moment from the footing, resulting in a smaller required footing. This benefit, in conjunction with the aforementioned tight

A pinned bearing constructed in place.


Iowa DOT

HDR Engineering

▲ Demolition of the existing concrete bridge.

➤ Erection of the new steel bridge.

geometrics, was the ultimate reason for choosing a pinned bearing connection.

### Construction

The contractor, Cramer and Associates, Inc., of Grimes, Iowa, accessed the bridge site from the city boat ramp identified early in the concept stage as a possible means of access. Cramer used the ramp to float barges onto the river to aid in the demolition of the existing bridge and the construction of the replacement bridge. On top of these barges were mounted cranes and aerial lifts to grant the ability to access the water line of the rock walls as well as assist in the erection of the arch.

Cramer first constructed the micropile retaining wall on the south side of the historic church. This wall's purpose was more than just replacing a crumbling wall impacted by the bridge construction; it was also needed to stabilize the foundation of the historical church to limit the risk from vibrations during demolition of the existing bridge. Following this construction, they proceeded with the demolition of the arch. Conventional methods were used for the removal of the existing deck and columns. The concrete from the deck removal was then used to line the channel underneath the bridge, as it was Cramer's intent to drop the arch pieces onto the rubble pad built under the bridge. The arches were jackhammered at a strategic location near the end, thus allowing them to fall under their own weight onto the earthen pad constructed underneath the existing bridge. The construction team then proceeded to perform the excavation for the abutment and construct the rock walls around the abutments. Concurrently with the excavation and abutment construction, Cramer constructed the falsework supports to aid in the erection of the steel arch and the deck framing.

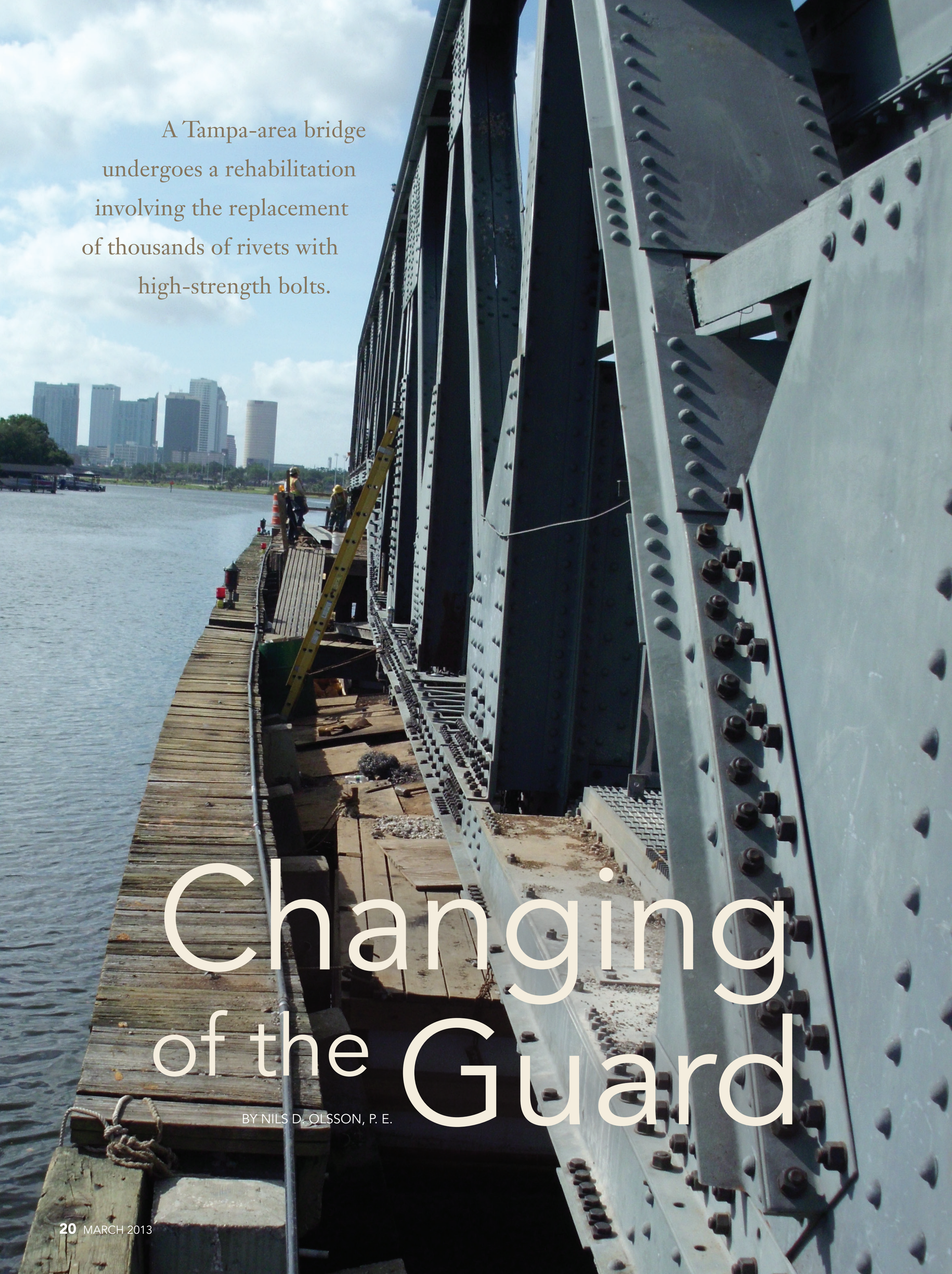
The steel erection began with the placement of the south bearings. Using falsework towers in the river, the first two segments of the arch were erected from both sides of the river. The falsework towers were designed to allow the segments of the arch to be adjusted vertically to facilitate the setting of the crown section. After both arch ribs were erected along with the end floor beams, lower cross bracing and the cross struts, the contractor started erecting the floor system. The floor system was erected in a panel-by-panel method from south to north. The new bridge used 835 tons of structural steel in all.

The Iowa DOT met its goals by replacing an existing functionally obsolete and structurally deficient bridge with an economical solution that met the community expectations. Cramer was allotted 190 contract days to complete construction. It opened the bridge to traffic on November 18, 2010, and was therefore eligible for the "No Excuse Bonus" of $250,000 for completing construction within the required timeframe. ■

**Owner**
Iowa Department of Transportation

**Structural Engineer**
HDR Engineering, Inc., Omaha, Neb.

**General Contractor**
Cramer and Associates, Inc., Grimes, Iowa



A Tampa-area bridge undergoes a rehabilitation involving the replacement of thousands of rivets with high-strength bolts.

# Changing of the Guard

BY NILS D. OLSSON, P. E.

Parsons Brinckerhoff

**THE RIVET IS A SYMBOL** of a bygone steel construction era.

But there is a significant family of existing steel structures in America that are still held together with rivets—such as the Empire State Building and the Golden Gate Bridge.

Another one, though not as well-known as those two icons, is the Columbus Drive Bridge, which spans the south-flowing Hillsborough River in Tampa, Fla., and opened to traffic in 1927. The city of Tampa was first developed on the east side of the river, but with the influx of new residents following World War I, developers were anxious to expand into the area west of the river, so bridges were built to foster this westward expansion; the Columbus Drive Bridge (then known as the Michigan Avenue Bridge) was one of these. Early in its life, the bridge was opened an average of 10 times per day; today the openings mostly occur on weekends at the rate of three or four times per week.

The original configuration was for two lanes of automobile traffic, one track in the middle for streetcars and sidewalks on both sides. The heavily counterbalanced, 57-ft, 10¾-in. back span rotated about its pivot point in a counterclockwise direction when opening, and the 106-ft, 6-in main span responds in the counterclockwise direction to accommodate the skewed river channel. The west approach consisted of seven concrete spans, and the east side was composed of four concrete spans. Eventually, due to the decline of the streetcar, the streetcar tracks were removed and paved over to accommodate more automobile traffic, and the number of traffic lanes was increased from two to four (two in each direction).

After more than eight decades of service, the bridge had earned

▲ The rehabilitated swing span, in place.

▼ Rivet replacement taking place on an H-pile shoring platform.

Nils Olsson

◄ Originally opened in 1927, the Columbus Drive Bridge in Tampa was held together with 30,000 rivets.

▼ A mixture of rivets and bolts.

Nils Olsson

**Nils D. Olsson** is the bridge engineer with Hillsborough County (Fla.) Public Works Department and can be reached at **olssonn@hillsboroughcounty.org**.


Nils Olsson

Some of the new A325 high-strength bolts, which replaced a significant portion of the original rivets.


Nils Olsson

The bridge incorporates 128 tons of new steel.

an upgrade; the rehbilitation began last year and concluded early this year. The scope of the project included replacement of 110 tons of corroded structural elements, such as gusset plates for the trusses and angles for the many built-up sections, with 128 tons of new steel. As a consequence, nearly half of the bridge's original rivets would also be replaced with A-325 high-strength bolts.

The swing spans of the bridge consist of 740 tons of structural steel, including two side trusses, 43 ft apart, each tied together with transverse floor beams located at all 10 nodes of the trusses' nine panels, which are spaced 17 ft, 2 in. apart. Longitudinal stringers bear on these transverse members, which in turn support a steel, open-grid deck system that carries the roadway 6 ft below the top of the pony trusses. The sidewalks are cantilevered 5 ft, 6 in. off the trusses, opposite the roadway, at the 10 node points of the trusses. The trusses' back spans have a depth of 17 ft, 2 in. center to center, for three panels west of and six panels east of the pivot point. The forward part of the trusses continue east at the same depth for one panel, then taper to a shallow depth of 12 ft, 6 in. for the remaining five panels.

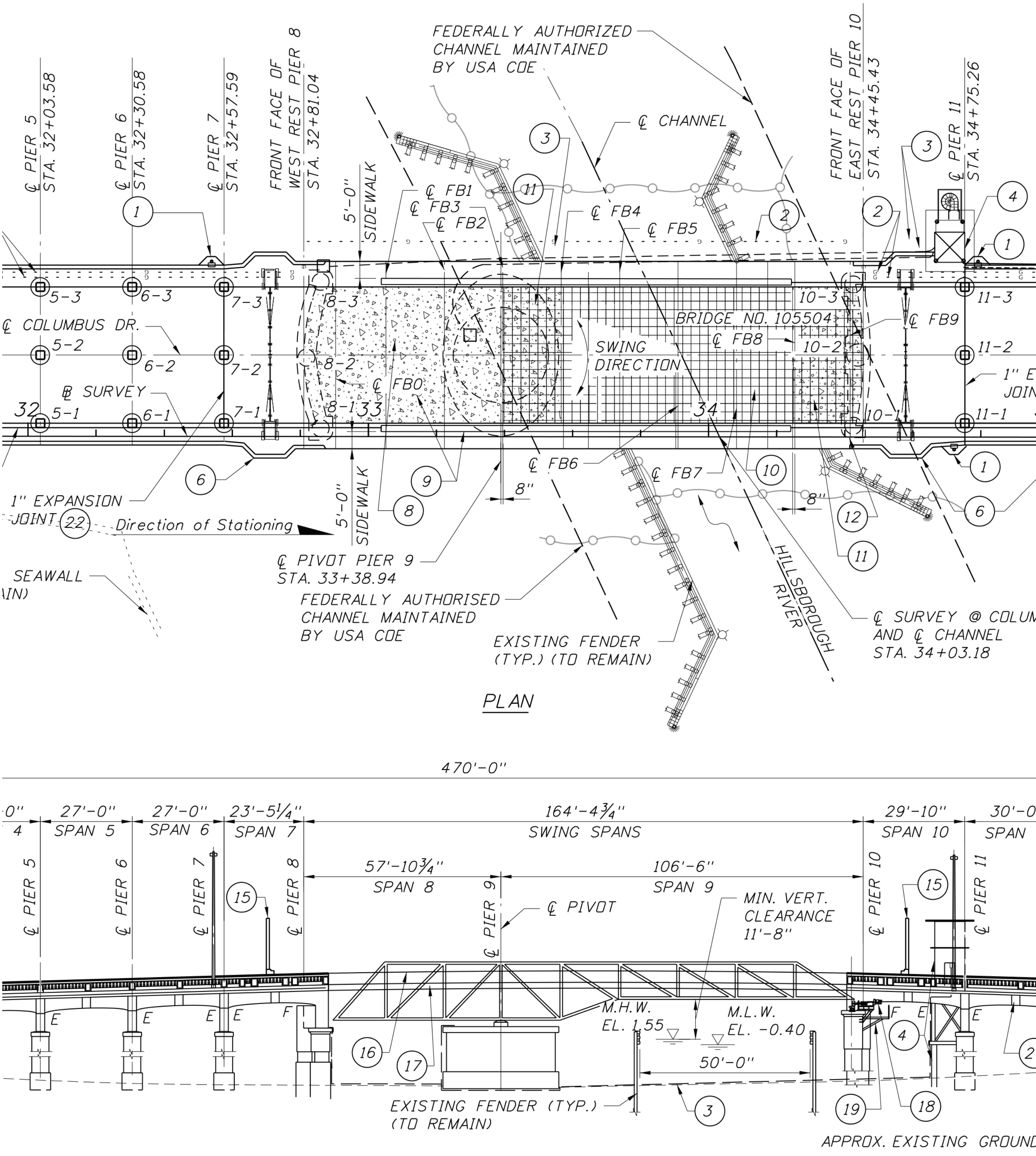
When exploring which elements required replacement, it was discovered that the lower portions of the structure had the most damage from corrosion. This was not surprising, as these areas accumulate dirt and debris, which would hold moisture and foster corrosion over long periods of time. However, corrosion seemed to develop more quickly in the eastbound lanes. A favorite theory is that boaters who used the marina on the west side of the river would pull the drain plug in their boat's hull, and when hauling their boat back over the bridge heading east, the salt water would drain onto the eastbound lane of the open-grid steel deck.

To perform the rivet replacement, the truss was lifted off its center bearing/pivot point and moved to H-pile shoring platforms immediately below the roadway; it was propped up with wood blocks to relieve dead load on the existing fasteners to facilitate the replacement process. Removing the rivets entailed grinding the battered end of the rivets, then applying a chisel to the ground head and striking the chisel with a pneumatic chipping hammer to pop off the head. Once the head was gone, a solid steel bar was matched up with the remaining rivet shank, which was then driven out of the hole by striking the steel rod with a sledge hammer. In all, 14,474 rivets were replaced (about 2,400 more than originally estimated).

While rivets aren't a common connection type with new construction, physical performance was not the cause; surging labor costs following World War II was the reason the labor-intensive rivet fell from favor as a steel fastener. Consider the iconic, steel-framed Firth of Forth Railroad Bridge—built in 1890—which spans its namesake waterway near Edinburgh, Scotland; its 6.5 million rivets serve as a testament to the structural validity of the connection.

**Red Hot**

The original design of the Columbus Drive Bridge was performed in accordance to the 1924 ASCE *Specification* and called for holes to be punched to a diameter of 15⁄16 in. to receive the 7⁄8-in.-diameter rivet. A highly skilled crew of four was required to install a single rivet. The rivet had to be heated for about 20 minutes to a cherry red color, which only an experienced eye could determine, and the required temperature of between 1,850 °F and 1,900 °F. From there, another worker would adroitly sling the hot rivet through the air to another worker, who would catch it in a handheld receptacle and insert it into the aligned holes in the overlapping plates. Once in the hole, the catcher would back up or "buck" the rivet as another worker on the opposite side of the plates would form the protruding red-hot shank into a nicely shaped dome with a pneumatic impact hammer.




Plan and south elevation drawings of the bridge.

Parsons Brinckerhoff

But when steel bridges and buildings from the riveted age do require upgrades, projects like the Columbus Avenue Bridge serve as an example of how they can be rehabilitated for continued service. The connections may change, but the structures themselves can live on regardless of what's holding them together. ■

**Owner**

City of Tampa and Hillsborough County, Fla.

**Structural Engineer**

Parsons Brinckerhoff, Tampa

**General Contractor**

Archer Western, Tampa

**Steel Fabricator and Detailer**

Florida Structural Steel, Inc., Tampa, Fla. (AISC Member/NSBA Member/AISC Certified Fabricator)

A short-span bridge in suburban Pittsburgh comes together over a long weekend.

# The Long and Short of It

BY MARK J. PAVLICK, P.E., MICHAEL DILLON, P.E., AND TYSON HICKS

HDR Engineering

**NOTHING SAYS THANKSGIVING** like football, family, food—and bridge replacements.

While the latter may seem out of place on this list, it was a major part of the long Thanksgiving Day weekend for a construction team in Allegheny County, Pa.

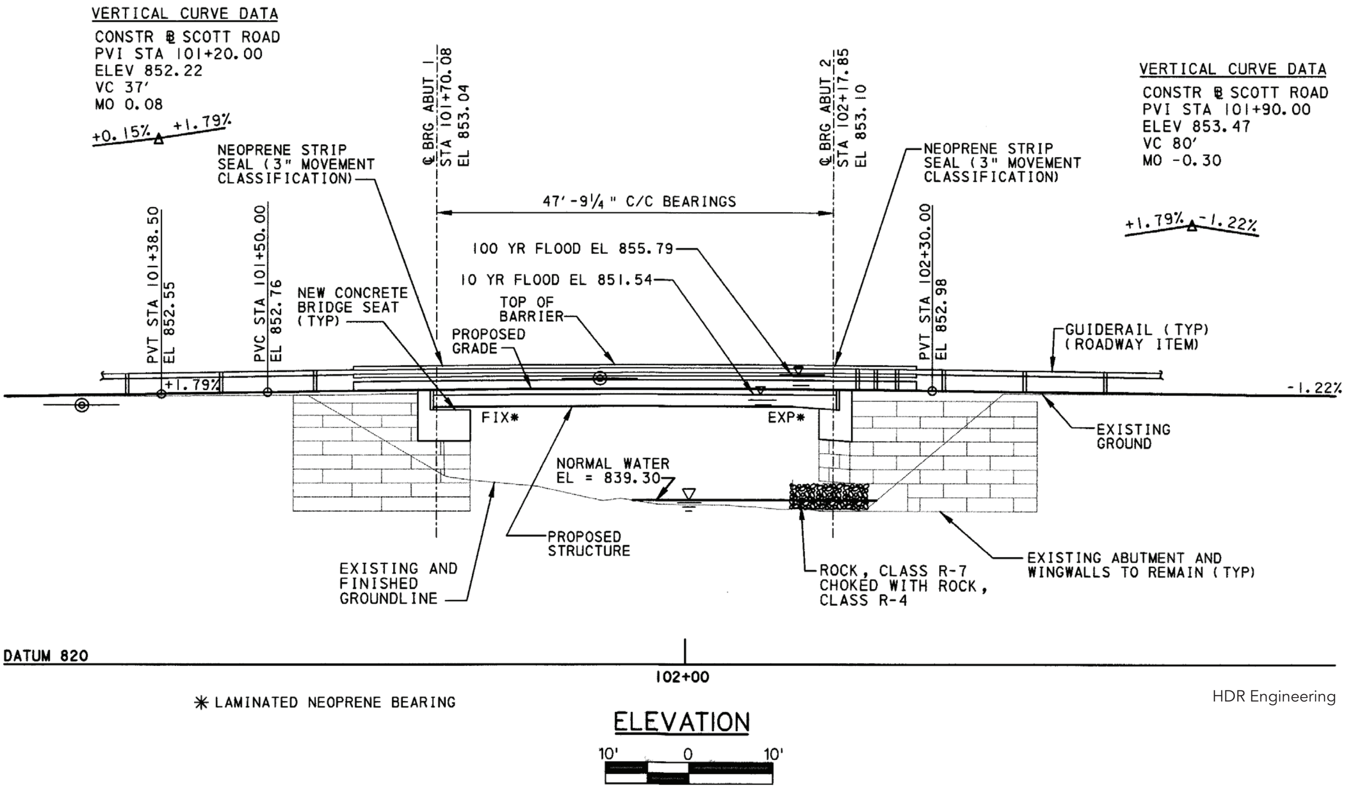
The Montour Run Bridge No. 6 (MT06) carries Scott Road over the Montour Run, a stream in North Fayette Township, Pa., a few miles west of downtown Pittsburgh. The existing bridge needed to be replaced, as the concrete box beams supporting it had become deteriorated; a similar, nearby bridge over Interstate 79 experienced a beam collapse a few years ago, and the county didn't want a repeat of that scenario. Thus, a replacement plan was developed.

## Complete Closure

The bridge serves as the only means of access to five businesses on one side of the stream. To minimize disruptions to these businesses, the design called for prefabricated bridge elements and systems, with the goal of demolishing the old bridge and building the new one in just a few days.

It was initially assumed that the bridge could be replaced using staged construction and maintaining a single 11-ft-wide lane on the existing bridge. However, during preliminary design, one of the five affected businesses notified Allegheny County that they regularly have 15-ft-wide permit loads moving rental equipment to and from their facility. The need to move these wide loads across Montour Run at this location

**Mark J. Pavlick** (mark.pavlick@hdrinc.com) is a professional associate and senior project manager with HDR Engineering, **Michael Dillon** (michael.dillon@alleghenycounty.us) is a bridge engineering assistant manager with the County of Allegheny Department of Public Works and **Tyson Hicks** (thicks@jbfayco.com) is a construction project manager with Joseph B. Fay Company.




HDR Engineering

▲ An elevation drawing of the new Montour Run Bridge No. 6.

◀ The bridge uses 17 tons of structural steel framing.

made staged construction impractical. The affected businesses agreed upon complete closure for a few days for the demolition and erection to take place, and the long Thanksgiving weekend proved to be the best time frame.

At the request of the Allegheny County Department of Public Works. structural engineer HDR investigated using accelerated bridge construction (ABC) techniques to build the new bridge and used Pennsylvania Department of Transportation's BRADD (Bridge Automated Design and Drafting) program to design the superstructure.

Span width for the replacement structure was restricted by a pumping station located on the east side of the bridge, a sewer line interceptor manhole, a power line and a business on the west side of the bridge. The new bridge, nearly 48 ft long, consists of one 11-ft, 6-in. lane, a 6-ft-wide shoulder and a 2-ft-wide shoulder. With an overall width of 22 ft, 6 in., including barriers, the deck is supported by five W18×119 rolled beams spaced at approximately 5 ft. The new superstructure was assembled at a staging area adjacent to the existing bridge and uses 17 tons of steel in all. The deck is a concrete overfilled 5-in. steel grid (7$\frac{3}{16}$ in. total thickness) with reinforced concrete

Allegheny County

▲ The new bridge, in place ahead of time.

▼ Framed superstructure with grid deck, adjacent to the existing bridge.

HDR Engineering

Photos this page: HDR Engineering

The 5-in. steel grid deck.

barriers and was placed on the superstructure and cured prior to placement in its final location.

HDR designed the superstructure and deck assembly to be placed in two sections using normal weight concrete, and the two sections were bolted together and the deck finished with a concrete closure pour. The contractor, the Joseph B. Fay Company, elected to prefabricate the deck in its entirety prior to setting the superstructure in place in order to further expedite the project's completion. The use of steel beams and grid deck kept the crane pick weights to a minimum.

### Weekend Work

The existing bridge was closed at 5:00 p.m., Wednesday, November 21, 2012. The new bridge had to be opened to traffic by 6:00 a.m. the following Monday or liquidated damages of $10,000 per hour would be assessed against Joseph B. Fay.

Demolition of the existing prestressed concrete adjacent box beams and partial demolition of the existing masonry stone abutments was completed by Thanksgiving morning, and the concrete abutment caps were then set and grouted in place. The superstructure and deck were set at 4:00 a.m. on Friday, and the steel rails for the barriers and the approach guiderail were placed on Saturday evening. This put completion approximately a day-and-a-half ahead of schedule, giving all involved something to be thankful for. ■

**Owner**
County of Allegheny, Pa.

**Structural Designer**
HDR Engineering, Inc., Pittsburgh

**General Contractor**
Joseph B. Fay Company, Tarentum, Pa.

**Steel Fabricator and Detailer**
KARD Bridge Products, a division of KARD Welding, Inc., Minster, Ohio
(AISC Member Fabricator/AISC Certified Fabricator)

The bridge site on Thanksgiving morning of last year.

The bridge site the Friday morning after Thanksgiving Day.

Let it rain, sleet, snow...
DuraSquirt® DTIs
A longer lasting squirt for inspection on your schedule.
Because the weather doesn't care about schedules, inspectors or budgets.
* AASHTO Spec Includes Squirters!
* USA's only Quenched and Tempered DTIs per ASTM, RCSC and the Fastener Quality Act.
* Save a Buck a Bolt vs Turn-of-Nut
Florida DOT determined Squirter DTIs increased productivity, reduced rework and were more accurate, saving time and money for installers and inspectors.
applied bolting TECHNOLOGY
the best way to bolt...just got better!
1 800 552 1999
1 802 460 3100
appliedbolting.com
Learn More
TRAINING • FIELD SUPPORT • TECHNICAL EXPERTISE

# Go with the Flow

BY PAUL CHUNG, P.E., AND JASON FANG, P.E., PH.D.

In car-centric Southern California, a highway overcrossing replacement project allows traffic to flow uninterrupted.

**THERE ARE MORE** than 24,000 automobile bridges in California supporting one of the world's most vibrant economies and linking the nearly 45,000 miles of pavement.

Just over a year ago the first steel state highway bridge designed to the AASHTO *LRFD Specification* with Caltrans (California Department of Transportation) Amendments was installed in California, using the accelerated bridge construction (ABC) approach. The project, the widening of an Interstate 10 (I-10) segment that connects central Los Angeles to San Bernardino County, replaced a reinforced concrete overcrossing in the town of Baldwin Park.

The existing Baldwin Park Overcrossing, constructed in 1956, was a two-span cast-in-place reinforced concrete box girder bridge. Its total structural length was 220 ft and it was supported by a four-column (retrofitted by an infilled shear wall) reinforced concrete bent and closed-end cantilever abutment on spread footings.

The new overcrossing, a four-span steel I-girder bridge with a total structural length of 478 ft, adds two high-occupancy vehicle (HOV) lanes and auxiliary lanes in the eastbound and westbound directions to meet increased traffic in the area. The four spans are 89 ft, 160 ft, 153 ft and 91 ft, and the bridge alignment matches the former structure. The new bridge profile is elevated to raise the vertical clearance from the existing 15 ft to nearly 17 ft to meet Caltrans' *Highway Design Manual's* required minimum 16.5 ft of vertical clearance. The assembly, which uses 690 tons of structural steel, consists of six 5.875-ft-deep steel I-girders, spaced at 12.33 ft apart, topped with a 9.45-in. cast-in-place concrete slab with a 1.5-in. hunch, providing an overall structural depth of 6.8 ft.

The steel superstructure is continuously connected and sits on reinforced concrete drop bent caps supported by four 4-ft-diameter columns founded on 6-ft cast-in-drilled-hole (CIDH) pile shaft substructures. The end spans are also supported by seat type abutments on CIDH pile foundations. The use of pile shafts helped avoid conflict with existing foundations and minimized the substructure work space so that four freeway lanes could be operational during construction.

All images: Caltrans

The original crossing, a two-span cast-in-place concrete box girder bridge built in 1956.

The replacement span under construction.

The new Baldwin Park Overcrossing is a four-span steel I-girder bridge with a total structural length of 478 ft.

## No Closure

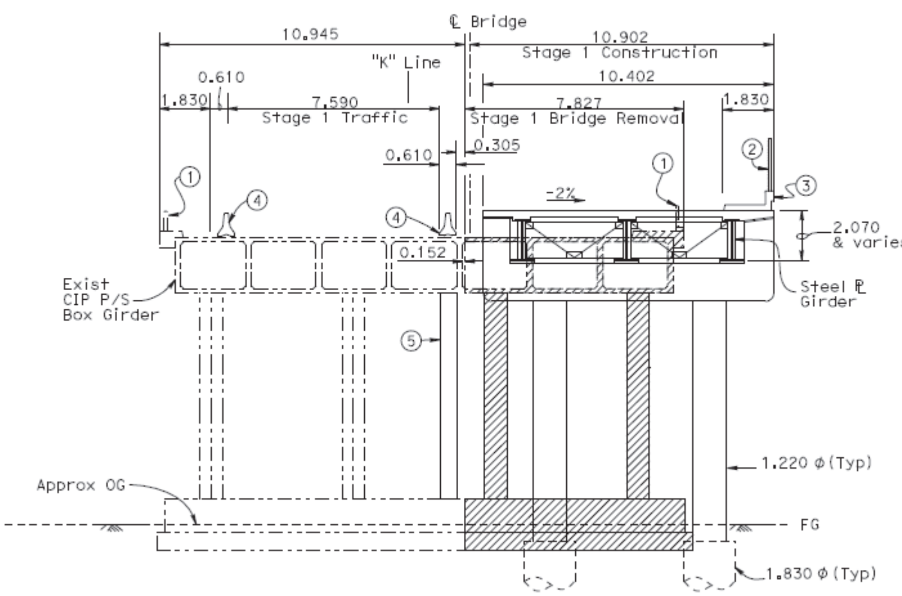
The existing bridge served as a gateway to the Kaiser Permanente Hospital in Baldwin Park, and a full closure of the existing bridge during construction was not permissible since it serves as the main access to the hospital. The steel plate girder bridge type was selected because it was the only feasible option to satisfy the minimum temporary and permanent vertical clearance criteria (15 ft and 16.5 ft, respectively) required by the Caltrans *Highway Design Manual*. Cast-in-place (CIP) pretressed concrete box girders were not feasible because the minimum temporary vertical clearance could not be maintained due to the depth of falsework beams. Prestressed precast Bulb-T girders were also not feasible as they would have required a deeper structural depth and thus would have reduced the permanent vertical clearance to less than the minimum requirement; furthermore it was very difficult for a precast girder bridge to match the curved bridge profile and maintain the desired look.

The new LRFD specification with California Amendments called for increased truck live loads on the bridge, thus requiring heavier plate girders. The bridge is on a constant high 48° skew and thus vertical

**Paul Chung** (**paul.chung@dot.ca.gov**) is the structure design quality manager for the California Department of Transportation in Los Angeles and currently manages the structural program of the Caltrans Design-Build projects in Southern California. **Jason Fang** (**jason.fang@dot.ca.gov**) is the senior bridge engineer for the California Department of Transportation in Los Angeles.

▲ The new bridge raises the vertical clearance from 15 ft to nearly 17 ft to meet current Caltrans requirements.

▲ The crossing stayed open to traffic during expansion.




TYPICAL SECTION - STAGE 1
1:100

load distribution (especially live load) can have irregular load path patterns. A 3D grillage finite-element model was generated in the MDX bridge design program, and the model was analyzed and checked for all LRFD vertical load limit states. The 3D MDX model consisted of girders, cross frames and supports reflected in the design so that realistic load distribution could be used to optimize the girder design by incorporating variable plate sections and matching the plate thicknesses to resist the force/stress demands.

## Seismic Design Considerations

The bridge site is located in a seismically active region of Southern California and close to a number of faults that are active or potentially active. Based on the Caltrans California Seismic Hazard Map (CSHM, 1996), the magnitude of the maximum credible earthquake (MCE) is 7.5, and the design median peak bedrock acceleration (PBA) is approximately 0.6g. The seismic design of the bridge is based on the *Caltrans Seismic Design Criteria* (Version 1.4, 2006). In the transverse direction, the shear keys were provided to transfer lateral seismic force to the substructure during an earthquake. In the longitudinal direction, the seismic force would transfer to both ends of the bridge, where the earthquake energy can be dissipated by combined action of the back wall and soil.

Given the 48° skew, the bridge has the potential to yield an irregular and complex seismic response. In order to accurately predict the response, another 3D grillage finite-element model was generated—this one in CSI SAP2000—and the model was analyzed using elastic response spectrum methods. Earthquake motion spectrum was applied to the model from a range of sources in different directions to ensure that the seismic performance of the bridge met the Caltrans seismic design criteria. The steel girder structure allowed for a relatively smaller (and more cost-effective) substructure than a comparable concrete structure and foundation, which was especially helpful in a region with the potential for high peak ground acceleration.

## Construction

The new bridge was built in two halves (lengthwise) to allow unobstructed traffic flow across the I-10 freeway during the construction period, which lasted nearly seven months. Temporary sheet piling was installed at the median of the new and the existing abutments to retain the roadway embankment used in both stages, and temporary supports were provided at the bent caps of the existing bridge after each half was removed; during each construction stage, the existing half of the abutments and wing walls were removed.

The successful design and construction of the Baldwin Park Overcrossing—again, the first California state highway project built in accordance to the AASHTO *LRFD Specification*—provide an excellent ABC case study in high-seismic region. As owners and contractors continue to meet increasing demands for faster, less disruptive and efficient construction, it is expected that the steel girders will continue to be used in future ABC projects statewide. ■

## Owner and Structural Engineer

California Department of Transportation

## General Contractor

Flatiron West, Inc., San Marcos, Calif.

Placing the preeminent piece of a transit project puzzle.

# Big Roll

BY DIANE CAMPIONE, S.E., PE.

Images courtesy of Alfred Benesch & Company

**A MAJOR INTERSECTION** improvement project on Chicago's South Side hit a major project milestone this past year—and also set a record.

Crews rolled in a massive piece of the transit project puzzle in late summer—a 394-ft-long, 2,375-ton steel truss railroad bridge. The structure is believed to be the largest steel truss bridge span ever rolled into place.

The new bridge is a key component of the 130th Street and Torrence Avenue reconfiguration, a $101 million effort by the Chicago Department of Transportation (CDOT) as part of the Building a New Chicago infrastructure program. The project as a whole includes a total of six new bridges—three railroad, one roadway, one pedestrian-only and one pedestrian/bicyclist—along with a mixed-use path, retaining walls (over 9,000 linear ft), a new drainage system, street lighting, traffic signals, roadway pavement, extensive landscaping and more.

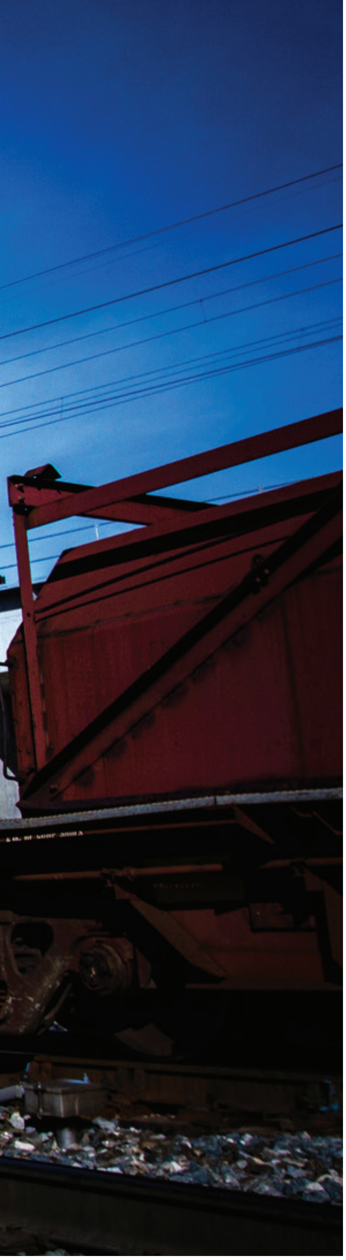
The project is also a part of the CREATE (Chicago Region Environmental and Transportation Efficiency) program, which is a partnership between the U.S. Department of Transportation, the State of Illinois, the City of Chicago, Metra (the Chicago area's suburban commuter train system) Amtrak, and the nation's freight railroads. CREATE aims to invest in improvements to boost the efficiency of the region's deteriorating passenger and freight rail infrastructure.

## Busy Intersection

The 130th Street and Torrence Avenue intersection serves approximately 38,000 vehicles daily, including freight trains and passenger trains via the Norfolk Southern Railroad (NS) and the Chicago, South Shore & South Bend Railroad (CSS&SB). The goal of the project, including the addition of the new steel truss railroad bridge, is to resolve significant traffic congestion issues, which increased when the adjacent Ford Motor Company decided to expand the Chicago Assembly Plant and create the Chicago Manufacturing Campus.

The project solution entailed a grade separation designed to eliminate the two NS at-grade crossings with the two roadways to improve traffic flow. Both the NS and CSS&SB railroads are constructed on offset alignments. "By creating the grade separation, we are hoping it will attract new businesses and industries to the area, because the vehicle and truck traffic will flow much more smoothly, uninterrupted by the 52 daily trains," said Soliman Khudeira, project director for CDOT.

According to Khudeira, when it came to the steel truss

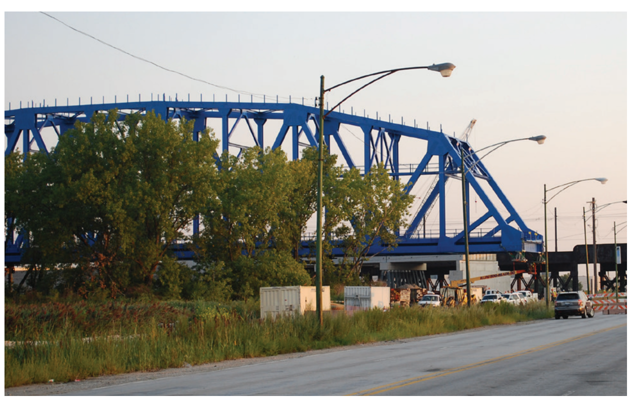


The various crossings of the 30th Street and Torrence Avenue reconfiguration.

The new bridge spans over Norfolk Southern Railroad tracks.

The 43-ft-wide, 67-ft-high structure was rolled into place using four self-propelled mobile transporters.

The new bridge, fully operational and train-ready.



railroad bridge, one option was to build the bridge offsite, near its final alignment, and roll it into place. Another was to build one half of the bridge at a time, then connect the halves into place. The third option was the conventional way of building it one beam at a time onsite over the NS tracks.

The latter option would have increased costs affiliated with staging, safety and labor hours, so the offsite option was selected. This approach significantly reduced the risk of injury, as it kept crews and stakeholders away from potential dangers both on and above the live railroad tracks. Other advantages of the roll-in option included continuous assembly of the truss span, enabling the contractor to control the erection schedule. With two-thirds of the truss spaning over the NS tracks, a built-in-place option would have extended the erection schedule due to limited track closure windows imposed by NS. Quality control was another benefit to off-site truss assembly, which made site access safer and easier for inspectors to test bolts, connections and more. In addition, the large open space for the on-site assembly allowed for an easier, more cost-effective roll-in process using self-propelled mobile transporters (SPMT) technology.

"The staging area for assembly was designed with temporary foundations to support the truss at points of intersecting steel," said Doug West, resident engineer with Alfred Benesch & Company (the bridge's structural engineer), who oversaw construction management of the project. "The truss was assembled day by day when materials were delivered. The schedule of material delivery and assembly were critical to keep everything going smoothly and avoid delays."

It took four months to assemble and paint the truss bridge offsite. Once complete, the 43-ft-wide, 67-ft-high structure was

**Diane Campione, S.E., P.E.,** is a project manager with Alfred Benesch & Company and the project manager for the 130th and Torrence project. You can reach her at **dcampione@benesch.com**.


▲ Rolling in the 394-ft-long, 2,375-ton steel
▼ truss railroad bridge on SPMTs.

rolled into place using four SPMTs, which took approximately two hours. It took another two hours to align and set the bearings in their final locations.

The new double-track, through truss bridge has a ballasted deck and includes five approach spans consisting of 54-in.-deep prestressed box beams. It was determined that steel was the best, most durable and economical material for building the bridge. As it was designed for 100-plus years of service, long-term maintenance was taken into consideration for the design, including the use of high-performance, weathering steel to extend the bridge's life.

The roll-in of the truss structure entailed extensive planning and public involvement, given the project's overall complexity. Benesch's field crew worked with the City to ensure that local residents, businesses, public transit agencies and others were kept informed of the project's progress and how it would impact their daily lives. The company also worked with CDOT to assist with public meetings and distribute flyers.

With the roll-in completed, the next steps were to coordinate with the CSS&SB and Northern Indiana Commuter Transportation District (NICTD) railroads to build the new tracks and tie into their existing tracks to shift the train traffic

▲ Rolling the truss in.

◀ A rendering of the final layout of the Torrence Ave.-!30th St. intersection.

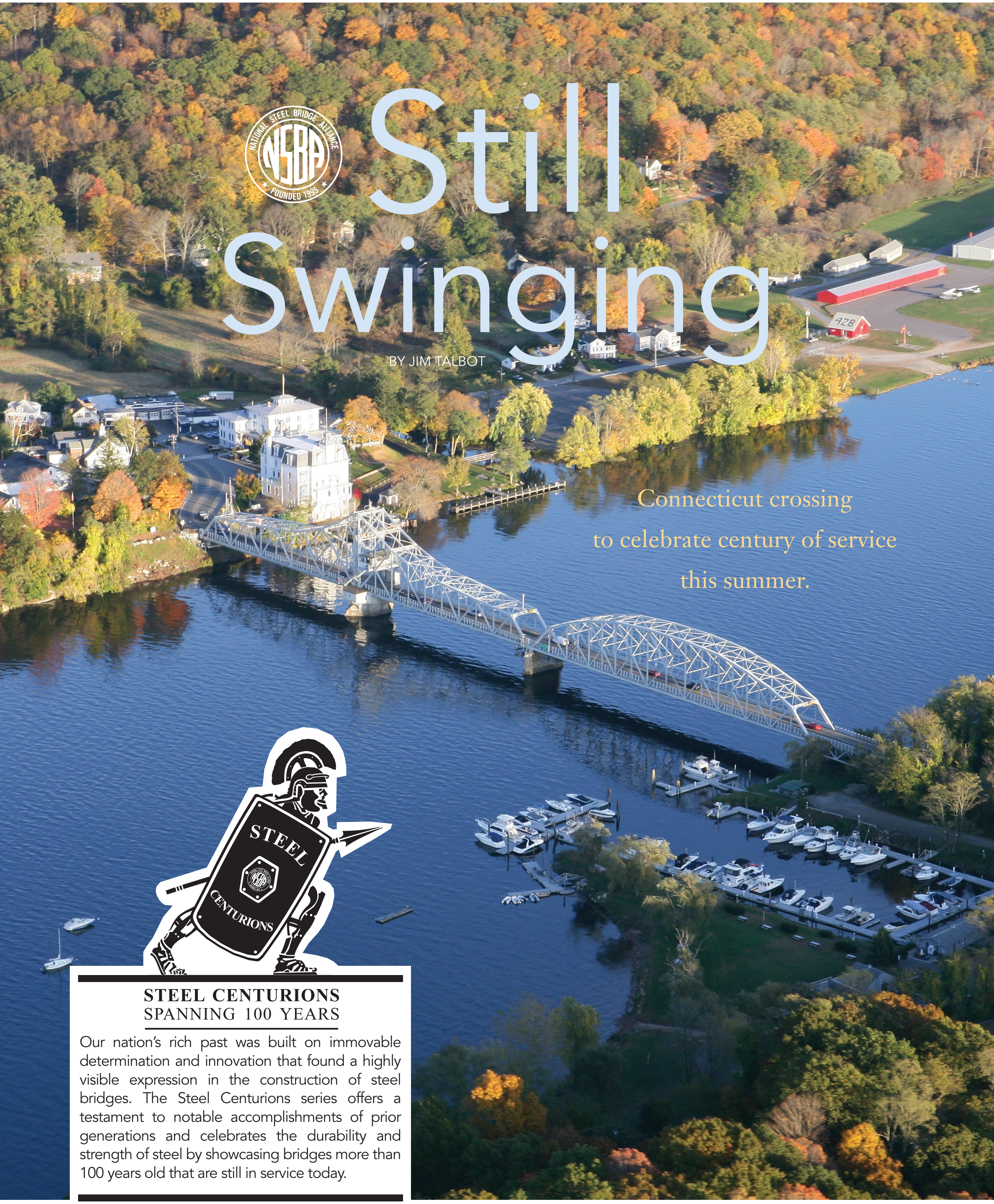
▼ Assembling the truss.

onto the new truss and approach spans. The first train over the new truss span occurred on October 25, 2012, and single-track operation continued until November 8, when both tracks on the new truss span were operational. The next tasks are demolishing the existing CSS&SB bridge then constructing the new NS bridges on their new alignments. Before building the new bridges, the excavation 25 ft to 30 ft below the existing grade will need to be done for the new realigned Torrence Avenue and 130th Street roadways, which will allow vehicular traffic to flow unimpeded near the completion of the project. The depressed new roadways also require a new drainage system, complete with a detention chamber (located below the new 130th street), a 9,000-gpm tri-plex pumping station and a settling basin to adequately manage storm water. Scheduled completion for the entire 130th Street and Torrence Avenue project is slated for 2016. ■

**Owner**
Chicago Department of Transportation

**General Contractor**
Walsh Construction, Chicago

**Structural Engineer**
Alfred Benesch & Company, Chicago



# Still Swinging

BY JIM TALBOT

Connecticut crossing to celebrate century of service this summer.

**STEEL CENTURIONS**
SPANNING 100 YEARS

Our nation's rich past was built on immovable determination and innovation that found a highly visible expression in the construction of steel bridges. The Steel Centurions series offers a testament to notable accomplishments of prior generations and celebrates the durability and strength of steel by showcasing bridges more than 100 years old that are still in service today.

Cianbro

Shoreline Aerial Photography, LLC

**THE CONNECTICUT RIVER** separates the towns of Haddam and East Haddam, Conn. For more than two centuries a ferry service, which started in 1694, offered travel between the two towns.

On Flag Day in 1913, the East Haddam Bridge officially opened, making the ferry service unnecessary; soon thereafter the state retired it. The bridge's opening consisted of a day-long celebration that included a speech by the governor, a 17-gun salute, an automobile parade, a fife and drum team and a band concert. And this June 14 will mark 100 years of service for the bridge.

When the bridge was built, it consisted of two steel spans: a 326-ft riveted Pennsylvania truss and a 461-ft Warren truss with verticals for the swing portion. The superstructure contained 1,200 tons of structural steel, with 715 tons devoted to the swing. Two 50-hp motors powered the turning of the bridge and a 30-in.-diameter phosphor bronze disc supported the bridge at its center in swinging mode. As the operator closed the bridge, he controlled motor-driven wedge bearings that supported the bridge ends. The deck, an open metal grating, was 24 ft wide between the curbs and had trolley rails along the north side.

The East Haddam Bridge was designed by Alfred P. Boller, who designed many large and complex bridges, including several moving bridges in New York City and the first railroad bridge across the Thames River at New London, Conn. Boller's expertise in deep river foundations proved valuable (25 ft to 40 ft where the bridge crosses the Connecticut River), and James Rollins of Holbrook, Cabot and Rollins also contributed to the foundation work. Supervising engineer Edward W. Bush designed the piers and approach roadways. The American Bridge Company built the bridge.

## Broader Base

When it opened, the bridge contributed to the region's growth and commerce. The landing on the east side originally contained the freight offices of the Hartford and New York Transportation Co., a general store, a post office and various office rooms. Local establishments on both sides benefitted from a wider customer base.

This bridge and one other were the first two paid for by the state. Recognizing the regional value of such projects, the legislature soon placed responsibility for such bridges with the State Highway Department rather than with special commissions.

Today, the bridge remains open to vehicles, carrying about 11,800 motorists a day. Its value is even more apparent during openings for river traffic—especially when patrons from the western side are trying to reach the Goodspeed Opera House, a stone's throw from the bridge itself on the eastern side of the river, before the overture (occasionally the Goodspeed staff delays the curtain for ticket holders). The nearest alternate crossings are 17 miles north or 20 miles south.

The bridge operator's house sits atop the swinging span, and operators still log opening and closing events by hand. Unlike a century ago, they can watch TV and ride an exercise bike between openings.

## Undue Stress

The deck was retrofitted with concrete in 1986. However, the added weight placed undue stress on the pivot bearing, which in February 1999 caused the bridge to fail in the open position. The state contracted with Cianbro Companies to fix the situation.

The Cianbro team faced several heavy rigging challenges that included jacking up the 900-ton swing span, installing a 5-ton casting for the center bearing and replacing the spherical center bearing. Cianbro demolished and removed the existing bridge deck and stringers while maintaining one-way traffic during night lane closures and full two-way traffic during the day. The new deck consists of 11,000 sq. ft of 12-ft by 22-ft grating panels, each weighing 10 tons.

The team also installed new variable-speed motor control consoles on the existing motors, as well as new balance wheels in the swing span. Cianbro won the 2001 Build Connecticut Award for this project, which it completed in July 1999. In 2007, Cianbro followed up by painting the entire bridge, provided some structural upgrades and installed a completely new electrical system. As such, the bridge is poised to continue its legacy to its 100th birthday and beyond. ■

**Jim Talbot** is a freelance technical writer living in Ambler, Pa. You can reach him at **james.e.talbot@gmail.com**.

conference preview

# FUTURE FABRICATION

Advancing the state-of-the-art in steel bridge fabrication.

BY PAUL FUCHS, PH.D., AND RONNIE MEDLOCK, P.E.

**WHAT DOES THE FUTURE** hold for bridge fabrication?

Virtual assembly and phased array ultrasonic testing are certainly part of the picture. The first can eliminate bridge assembly steps while the second involves a technology that came to prominence in the medical field. Both can prove beneficial to steel bridge projects.

## Space Saver

To better understand the advantages of the first concept, virtual bridge assembly, it's a good idea to review the current fabrication practice for splice connections, which involves a match-drilling process. A pair of girders to be joined with a splice are laid on their sides and manually aligned based on a string-line reference placed on the shop floor. Once aligned, splice plates with full-sized holes already in the plates are clamped to the girder pair and used as a template to match-drill the holes in both girders. This process is used to make sure that all holes are in alignment and has the benefit of guaranteed hole alignment; however, it is very time-consuming and expensive. Some estimates put the cost of this step at 15% to 20% of the cost of a steel bridge. In addition, match-drilling holes at the end of the fabrication process typically requires inefficient drilling operations or expensive drilling equipment. Depending on the shop, the laydown area may require one-third to half of the floor space of the entire shop. Girders are laid on their sides and set end to end, taking up several hundred feet of space. Curved girders, when set on their sides, need to be appropriately blocked and can be even more difficult to work with as they extend high off the shop floor.

**Paul Fuchs** (paul.fuchs@fuchsconsultinginc.com) is the president of Fuchs Consulting, Inc., a consulting business he has operated for more than 14 years. **Ronnie Medlock** (rmedlock@high.net) is vice president of technical services at High Steel Structures in Lancaster, Pa. (AISC member/AISC certified fabricator/NSBA member). He is also a member of the AWS D1 Structural Welding Committee and the joint AASHTO/AWS D1.5 Bridge Welding Code subcommittee.

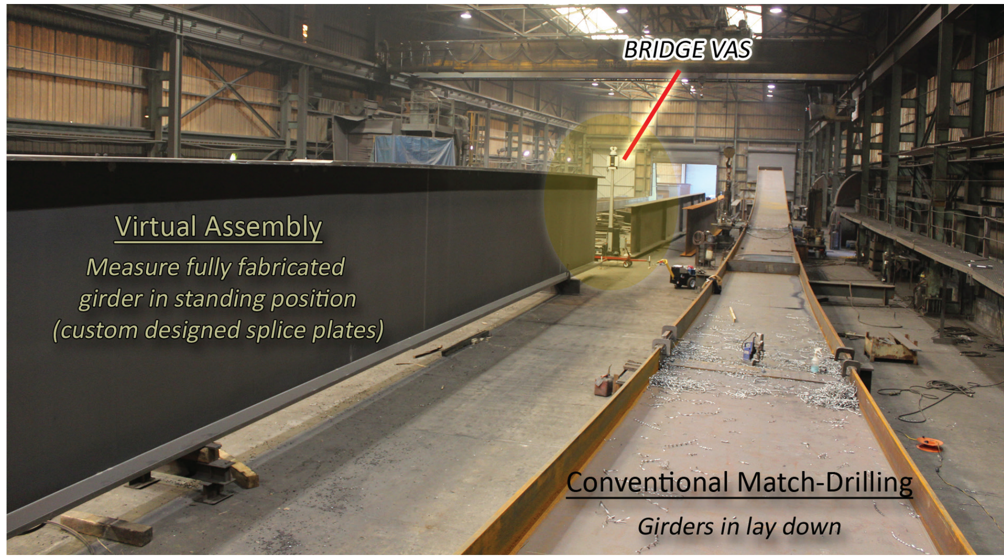
However, by piecing together individually measured girders virtually, the need to physically lay down, align and match-drill spliced pairs can be completely eliminated. Fuchs Consulting, Inc., has delved into this concept and developed BRIDGE VAS (Virtual Assembly System), which measures key aspects of completely fabricated bridge girders and virtually assembles multiple girders by designing custom splice plates to fit the girders together. The system uses a noncontact 3D coordinate measurement system that measures key aspects of a completely fabricated girder, stores measurements as a permanent record and combines these measurements with measurements from other girders to create a virtual assembly. The girders are fabricated with full-sized splice holes and are then measured in the standing position. Software tools interface with existing shop processes, existing 2D shop drawings are automatically converted to 3D CAD models, data is automatically processed and splice plate design files are sent directly to CNC drilling machines.

## Accurate and Automated

BRIDGE VAS can virtually manipulate and align girders and produce a combined camber diagram of a girder pair. Based on the virtual fit-up, it can output custom-designed splice plates and any number of girders can be virtually assembled. Not only can multiple girders in a line be virtually assembled, but multiple lines can be virtually assembled; the system also eliminates the need to bring girders that are fabricated at different facilities physically together at one location. Plus, floor space previously dedicated to match-drilling can be reused for other purposes.

In addition, the system provides substantially more documentation than currently exists, as well as access to types of information that are not available under the traditional process. Conventional measurements are based on string lines, rulers and tape measures. Most records are kept on paper, with handmade notes made on the shop floor. BRIDGE VAS replaces these subjective, limited methods with a full digital record, providing full documentation of what is fabricated. This digital record is certifiable and traceable and can be used to fully document the as-built girder at the fabrication shop, and customized reports can be automatically generated. The system measures all key aspects of a girder—length, camber, sweep, stiffener locations and web panel distortions—and provides immediate feedback of fabrication errors in real time, with actual measurements overlaid on a shop drawing-based model. All girder measurements are made directly on the girder surface, with no special targets or markers, eliminating the need for an operator to manually make any measurements. The system software is flexible and can generate customizable reports and output standardized CAD files.

Perhaps the biggest benefit of the system is its versatility. The system does not require the significant setup and maintenance expenses of a gantry system or a customized measurement room.




BRIDGE VAS measures fully fabricated girders in the standing position (left) and replaces conventional match-drilling and girder lay-down (right).

Instead, it works in virtually any shop, requiring only an open area of shop floor. Minimal changes are required to an existing shop and the system interfaces with existing processes (from converting 2D shop drawings to 3D models to direct output to CNC drilling equipment). And it can measure all girders, from more standard straight and curved plate girders to complex tubs or boxes. The system is designed to work in and around all normal shop processes (welding, grinding, drilling, etc.) and can work with the dust, debris and vibrations typically encountered.

BRIDGE VAS was recently implemented on a job for the State of Tennessee (fabricated by AISC member Hirschfeld Industries—Bridge). This is the first time that a virtual assembly system has been used in a production setting to design custom splice plates and the first time entire lines of girders have been measured, demonstrating that very large, complex girders can be virtually assembled and that the system can be implemented in a typical steel bridge fabrication shop. The Tennessee structure is currently being erected; a second bridge project (in Virginia) that will use the system is being planned as well.

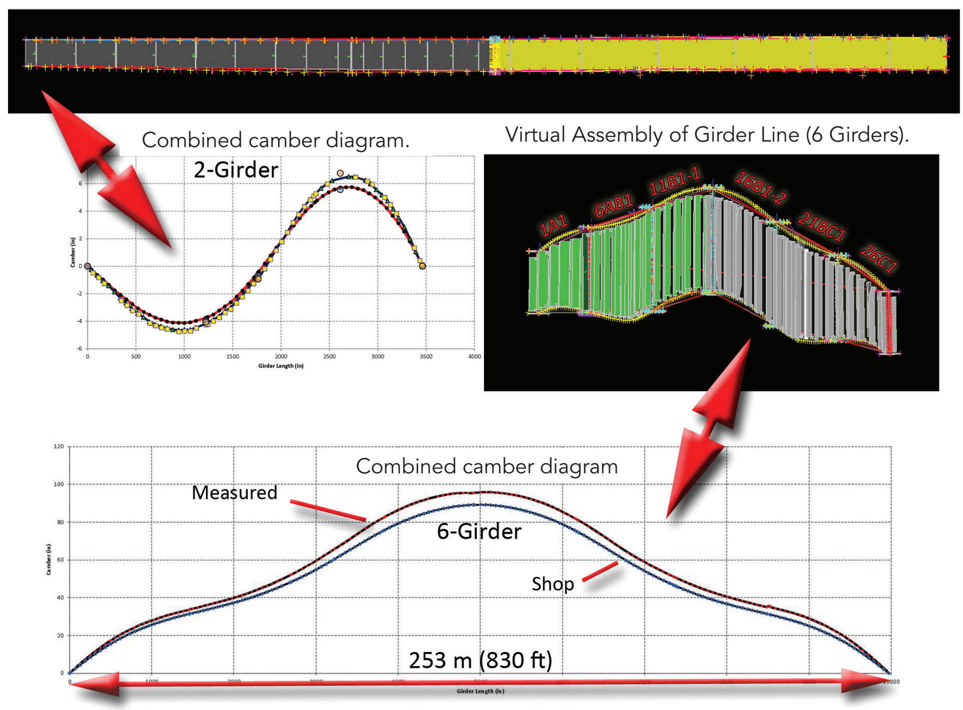
## A New Ultrasonic Option

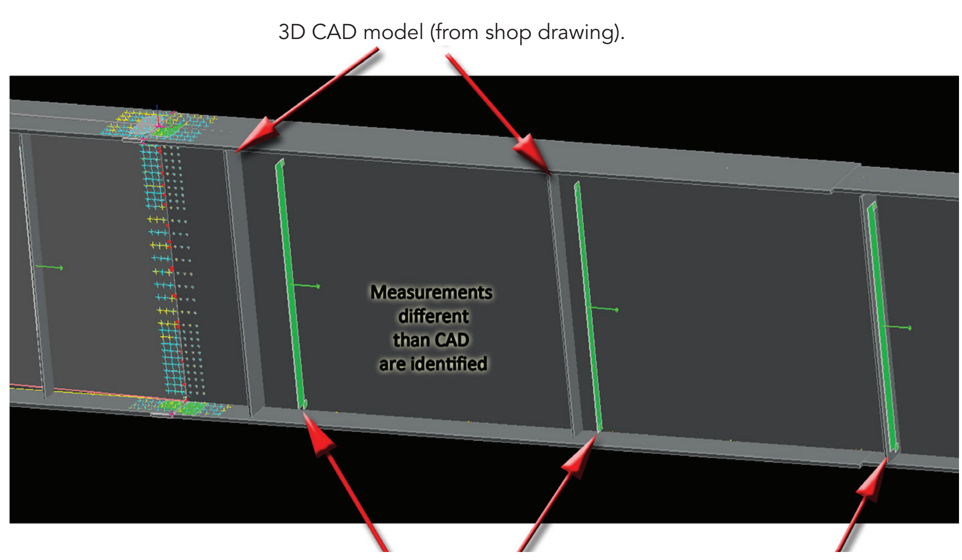
While BRIDGE VAS works to improved assembly efficiency and provides vastly improved documentation, a second emerging bridge fabrication technology focuses on testing efficiency.

Traditional ultrasonic testing (UT) has been used for quality assurance testing of complete joint penetration (CJP) bridge welds for many decades with little change to the technique. However, another type of ultrasonic testing, phased array ultrasonic testing (PAUT), has emerged as a viable option for bridge fabrication.

PAUT has been used in the medical field for many years, including for imaging of internal organs, measuring heart wall thickness and, coupled with Doppler techniques, examining blood flow through heart valves. It uses an array of ultrasonic transducers mounted

Virtual assembly of a girder pair and an entire girder line (six girders).




The BRIDGE VAS software automatically identifies fabrication errors in real time, with actual measurements superimposed on a 3D CAD model.

on a single probe. The transducers provide scanning at a range of angles, allowing a broad scan and increasing the likelihood that sound will be normal to the plane of the defect.

While PAUT is seen as a mature technology in the medical world, it is in its infancy when it comes to bridge fabrication. But its benefits over traditional UT in fabrication—better test documentation, faster testing and improved accuracy—have been recognized and efforts are now underway to bring it to the shop floor there.

Volumetric (through thickness) testing of flange and web butt splices is customary and expected in steel bridge fabrication. Most steel bridges comprise steel I-girder erection pieces that are about 100 ft to 150 ft long and about 5 ft to 10 ft deep, with two to four butt welded splices in each flange and one to two butt splices in each web. The AASHTO/AWS *Bridge Welding Code* (D1.5) requires significant testing of these splices, including:

- 100% of flange tension or stress reversal splices, with either radiography (RT) or UT
- 100% of fracture critical flange splices, with both RT and UT
- Roughly 30% to 40% (depending on girder depth) of web tension or stress reversal splices
- 25% of compression web and flange splices.

Further, additional testing is required if defects are discovered, and all CJPs accomplished by electro-slag welding must be tested by UT and RT, whether they are in tension and compression. The testing adds good value because it helps ensure that bridges are safe and durable. However, it is costly and time-consuming, so fundamental test method improvements have a significant impact on fabrication costs and cycle time.

### Better Test Documentation

The improved documentation offered by PAUT will increase acceptance of UT testing in lieu of RT testing for many bridge owners, thus improving both testing and throughput in the shop. The *Bridge Welding Code* allows either RT or UT for butt splice testing. Many owners prefer and required RT, though others prefer UT because it is much less costly and intrusive to the shop and fabrication workflow than RT (RT requires stand-off for safety for radiation and access to the weld is needed from both sides) and does not require film and processing chemicals, which are expensive.

However, RT test results are read on a medium that also becomes the permanent test record: the RT film. Conversely, traditional UT results can only be read in real time; the inspector finds defects by measuring sound loss of a discrete wave at a given time that he reads on an oscilloscope, and he documents his findings with notations as he proceeds, usually on paper.

Faced with the choice of seeing an actual indication on physical RT film versus documented test results in a UT report, many owners opt for RT. PAUT offers the ability to characterize flaws in multiple dimensions, unlike just one dimension for RT, yet can produce a permanent record format that can be visualized like RT. PAUT can be paired with encoding to capture results as the test is accomplished, and this encoding can be played back at any time to revisit the actual test results. Further, PAUT can generate images of the welds as they are tested, so images of sections with defects can be captured and stored permanently, ready for reconsideration at any time. Thus, implementation of PAUT can significantly reduce RT testing for owners who would like to make the switch from RT to UT but are looking for better test documentation. The data from PAUT can provide a view perpendicular to the plate surface that provides a graphical representation of flaw length and height.

### Faster Testing

Generally, ultrasonic testing, whether traditional or PAUT, is faster than RT, so if PAUT facilitates a switch from RT to UT, this will make testing faster. Further, PAUT is faster than traditional UT.

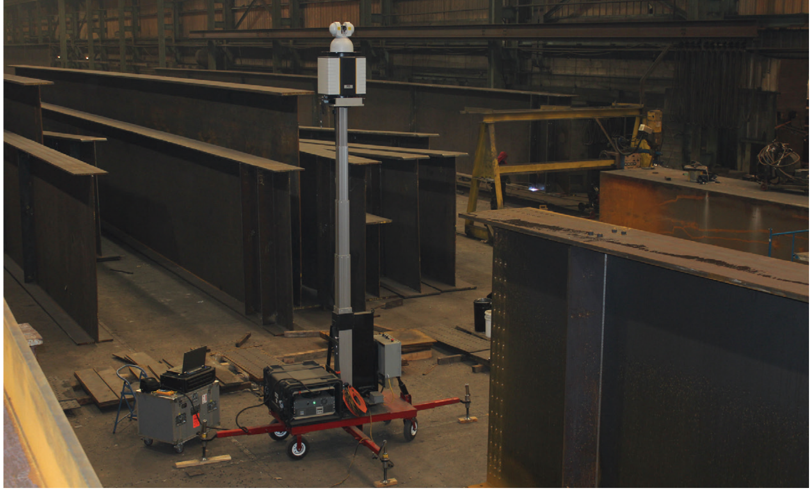
Three factors add considerable time to traditional UT, and PAUT successfully addresses each of them (see table at right).

Faster testing leads to reduced impact on workflow and less testing time, resulting in lower steel bridge costs and improved delivery, and the improved sizing capability and accuracy of PAUT also result in time savings.

| Factor | Traditional UT | PAUT |
|---|---|---|
| Scrubbing | The probe must scrub back and forth to get the testing sound through the complete section of the weld. | The probe makes one single swipe along the length of the weld at the scan index line. |
| Raster scanning | If an indication is discovered, the inspector must raster the probe to direct sound from many angles until the angle of maximum impact is established. | Does not lend itself to raster scanning, but acceptance criteria based on the amount and quality of the test data from PAUT may be defined without this technique. |
| Inspection angles | Sound can only be delivered from one angle at a time, so testing at multiple angles requires testing multiple times; each angle must be tested on its own. | With sectorial scans, dozens of angles are considered at once. |

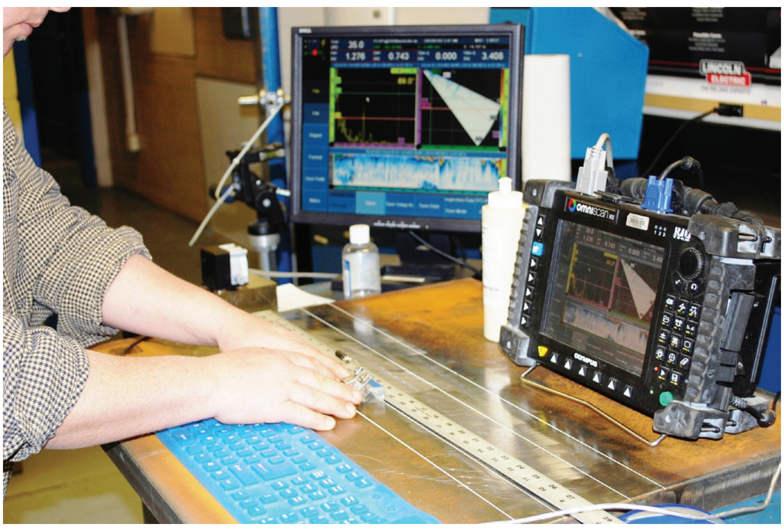
### Finding Flaws

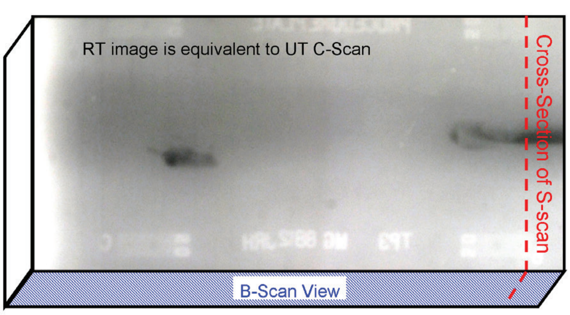
Phased array UT provides superior results in flaw location and characterization over traditional UT. For general purposes, the level of accuracy achieved with traditional UT is sufficient; the D1.5 criteria are pass fail and UT testing simply needs to establish whether or not the joint passes. But better flaw characterization will help fabricators accomplish repairs. Excavating a failed joint takes time, and the better information fabricators have about flaws, the more efficiently and expeditiously the flaws can be addressed. With PAUT, the scan index points are targeted to cover the entire weld section between the angles of 45° and 70° and, using encoded PAUT, the ambiguity of reporting the exact location of flaws that often occurs in traditional UT is eliminated. Further, while it is not current practice, the enhanced flaw characterization of PAUT has the ability to unlock fitness-for-service evaluations of flaws, which would allow educated decisions to be made about whether or not repairs

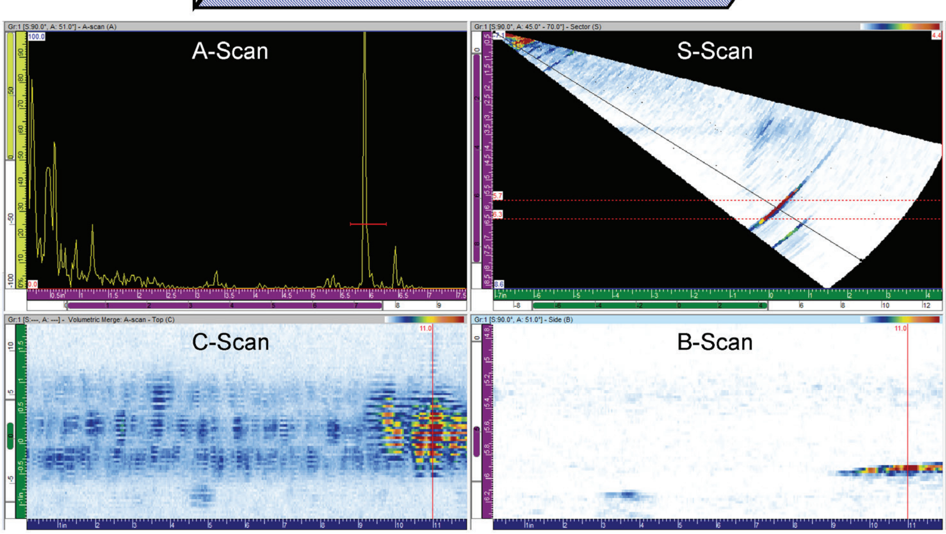


VAS measuring a girder in a fabrication shop.

Phased array ultrasonic testing is conducted by passing a probe parallel to the weld with one single swipe along the scan index line.






As this single examination shows, PAUT significantly enhances weld examinations with reduced effort.

need to be made based on the actual performance demand of the joint. Also, PAUT can converge (focus) or diverge (bend) sound by controlled time-delay firing of the sensor, allowing access to locations that are otherwise difficult to reach.

## Path to the Future

Efforts are underway to bring PAUT to the mainstream of bridge fabrication. Already, the committee responsible for the AWS D1.1 - *Structural Welding Code* has developed language that is under ballot to incorporate PAUT. The same will be done for AWS D1.5, with a slant towards bridge fabrication needs. Key issues to address include acceptance criteria and qualification requirements. Though it is possible to use traditional UT acceptance criteria for PAUT, doing so will not take advantage of the method. One possibility is to base acceptance on RT criteria; another approach might to conduct initial testing with PAUT and then explore and accept defects using traditional UT. These questions need to be addressed to advance the bridge fabrication state-of-the-art with PAUT. ■

*This article serves as a preview of Session B5 at NASCC: The Steel Conference, taking place April 17–19 in St. Louis. Learn more about the conference at* ***www.aisc.org/nascc****.*

product expert series

# REFINING RAPID REPLACEMENT

A Montana fabricator puts its rapid bridge construction system to the test on a fast-track replacement project.

BY PAT SOUTHWORTH

**ABC—OR ACCELERATED BRIDGE CONSTRUCTION—**has become more and more prevalent in the U.S. in recent years. Its overarching principle of reducing onsite construction time, whose goal is to reduce traffic impacts or complete new or replacement bridges within increasingly short closure windows, has been embraced by many in the bridge design and construction world and ardently endorsed by the Federal Highway Administration.

Of course, all stakeholders have an opportunity to contribute to the ABC process in their own way—not just in terms of participation but also via improvement upon the historical techniques and practices that seem to drag out what should be a simple bridge installation. One such idea is that of shipping steel bridge assemblies with deck already attached.

## Topped at the Shop

Montana fabricator Allied Steel has delved into this concept and over the past couple of years has developed the Rapid Bridge System (patent pending), which is fabricated and built using steel girders—wide-flange, plate girder, truss, etc.—and topped with a concrete deck or wearing surface. The weight of what can be picked is limited only by what the chosen crane can safely pick, and the system is applicable for both the single- and multiple-span bridges and in any climate. The difference is in the application of the concrete deck. While deck is normally poured or assembled onsite following erection of the steel superstructure, we have developed a system where the deck is actually poured and attached to the steel at our facility, with the concrete completely cured before shipping the bridge to the site. The system incorporates the general goals of ABC: the use of superior materials for all aspects of a bridge, the capability to be efficiently installed in any climate and features that would save time and money on-site, such as eliminating field welding and field pouring of the deck (and in some cases the abutments and back walls).

Using this technique requires breaking the bridge down into sections or modules due for transportation, thanks to the added size and weight of the concrete; each module includes one or two girders with the concrete deck. While this increases the number of sections that need to be transported, the system's benefits are many. It allows for more rapid bridge erection; the concrete is completely cured in a controlled environment rather than on-site; the bridge site itself is more efficient and less crowded since the deck is already poured—which also means that it is ideal for tight construction sites; and site disruption, from both a time and a "wear and tear" perspective, is greatly reduced. The system is not limited by the depth of the slab, and with our cambering tolerance we are able to deliver a smooth riding surface from pier to pier without any additional overlays.

In addition, the system uses a tight keyway bolted connection (also patent pending) to align the longitudinal joints between each module while still holding the deck elevation. Typical concrete bridges use embedded angle clips with a plate that is field-welded approximately every 5 ft on center down the entire length of each longitudinal joint. Because of the variance in the camber from pretensioning the concrete structure, the bridge erector has to be crafty in their techniques to level the tops of the concrete structure to actually achieve this system. This puts

**Pat Southworth** is president of Allied Steel, an AISC member/certified fabricator and NSBA member in Lewistown, Mont. You can reach him at **pat@alliedsteelmt.com**.

Allied's first project using its Rapid Bridge System: the Maxwell Coulee Bridge, about 20 miles east of Jordan, Mont.

The Maxwell Coulee Bridge was engineered into six modules, each approximately 7 ft by 110 ft and comprised of one girder, with diaphragm bracing and an 8-in. concrete deck.

tension in the direction perpendicular to the beams, making this option more susceptible to deterioration. Current steel ABC systems use a field pour system where concrete is poured down the entire length of the longitudinal joints. This requires forming, inserts in the modular slab, threading and tying rebar and a field cast. Our system only requires a bolted connection approximately 20 ft on center and also incorporates an angle system that holds a piece of rebar down the center of the keyway for additional strength. Once the bolts are in place, all that is required is to pour a non-shrink epoxy grout into the keyways.

## The Test Run

Our first project using the new system was for the Montana Department of Transportation: the Maxwell Coulee Bridge, about 20 miles east of Jordan, Mont. on Highway 200. This new bridge, which replaced an existing wooden span over a small ravine, or coulee, is 40 ft wide, 105 ft long and has a 35° skew. The structure was engineered into six modules, each approximately 7 ft by 110 ft and comprised of one girder—W36×182 with a 1½-in. reinforced bottom flange plate—with diaphragm bracing and an 8-in. concrete deck.

As this was our first "test" of the new system, there were lessons learned, which will be useful in improving the system. The most significant issue was the skew in conjunction with the camber points in the girder, which created problems with lining up the decks from module to module. We addressed this problem by making temporary steel abutments to set the girders in place, supporting the camber points and designing a new forming system. Despite this issue, the project was completed late last year within the allotted 45 days (the asphalt approaches will be completed this spring) and in harsh Montana winter conditions. The rapid bridge techniques proved themselves not only in the shop but also on the road. ■

# Going BIG in Ohio

The largest project in Ohio DOT history replaces an historic Cleveland crossing with a new delta girder bridge.

BY STEVE HAGUE, S.E., P.E., AND JOEL HALTERMAN

Photos: Brad Feinknopf

### CLEVELAND IS A STEEL TOWN.

Steel mills have provided jobs for generations of Cleveland families. One of the most popular shopping areas is even called Steelyard Commons, and nearly every major bridge in the area is steel, including the Interstate 90 Innerbelt Bridge.

Interstate 90 provides major east-west access over the Cuyahoga River and through downtown Cleveland via what has become a functionally obsolete 1959 deck truss, thanks to a nearly 40% increase in vehicular traffic. Originally designed to carry a maximum of 100,000 vehicles daily, it now handles more than 138,000 cars a day.

When it came time to replace the historic structure, citizens were asked to vote on three steel alternatives: a cable arch scheme; a design with the deck supported on a series of slender, parallel beams spanning from pier to pier; and a delta girder scheme (the latter won). According to Dave Lastovka, project manager for the Ohio Department of Transportation (ODOT), the design is intended to complement Cleveland's historic collection of steel river bridges while honoring steel's role in the region's economy.

"It is forward-looking but without clashing with the existing design vocabulary of the river valley," he said.

### ODOT's Biggest

At $640 million, which includes $79.4 million in American Recovery and Reinvestment Act funds, replacing the I-90 Innerbelt Bridge is the largest single infrastructure investment in ODOT history. And because the project is so large, ODOT broke it in two: a westbound bridge, which is under construction, and an eastbound bridge, scheduled to begin later this year.

Splitting the bridge into two "smaller" projects as opposed to one mega-job offered two advantages. First, it allowed for a more competitive bidding environment; it kept the projects from being so large that only a few firms could bid on it. ODOT believed generating more competition could result in a better price. Second, it didn't close down the entire existing bridge all at once. Doing so would have significantly reduced access to downtown. Building the project in phases allows traffic to continue using a portion of the existing bridge while the westbound bridge is built. Then, both directions of traffic will be moved onto the new bridge while the old bridge is demolished and the eastbound bridge is built.

The design-build team of Walsh Construction and HNTB Corporation (the latter also designed the original Innerbelt

▲ The new westbound portion of the Innerbelt Bridge under construction next to the existing 1959 bridge.

▲ The new bridge will replace a crossing that currently carries 40% more traffic than it was designed to.

▲ The crossing is the biggest project in ODOT history.

**Steve Hague** is a project director and vice president in HNTB's national bridge practice. With nearly 30 years of experience in complex bridge design, Hague is widely recognized as a leader in the design of cable-stayed and other complex bridges. You can reach him at **shague@hntb.com**. **Joel Halterman** serves as the Section 2 project manager for the I-90 Cleveland Innerbelt Bridge for Walsh Construction Company, where he supervises on-site teams and manages daily field operations for Section 2 with an emphasis on structural components. You can reach him at **jhalterman@walshgroup.com**.

The westbound bridge will use 20,000 tons of structural steel in all.

Bridge) was awarded the westbound bridge contract in September 2010. Their winning bid of $287.4 million was significantly lower than the engineer's estimate of $400 million and other competitors' bids.

The design-build team also reused materials whenever possible and placed the new bridge's alignment as close to the existing alignment as possible, saving the expense of purchasing adjacent urban real estate; at the narrowest point, the existing bridge and the westbound bridge are only a few feet apart.

The I-90 Innerbelt Bridge replacement also marks the first time ODOT has issued a value-based design-build contract, which combines the technical scores of each proposal with the bid scores to determine the overall best value. According to Lastovka, using design-build procurement saved ODOT approximately $100 million and reduced the project delivery schedule by eight months.

The eastbound portion of the bridge will mark another first for ODOT: It will be delivered using a design-build-finance model, where a private sector venture funds and builds the bridge and ODOT pays the team back with interest.

## Steel Knuckles

Construction on the westbound bridge began in 2011 and many project milestones went largely unnoticed by the traveling public. But when the first steel knuckle girder elbowed its way into downtown Cleveland on a flatbed semi last June, motorists couldn't help but do a double-take. A critical piece of the bridge's delta girders, the 50-ton, 67-ft-long knuckle took up two lanes of traffic and required a highway patrol escort. The main bridge section requires 80 of these knuckles; collectively they weigh 4,000 tons.

Each of the new bridge's 40 signature delta girder assemblies is made up of six steel components: two knuckles, two delta legs, one top girder and one "V" portion. Each delta assembly is connected to the next with a straight girder and the knuckle connects the delta legs with the top girders.

Supported by 14 piers—some eight stories tall with pier caps 143 ft long—the new five-lane westbound bridge will soar 120 ft over the Cuyahoga River at its highest point. In all, it will use 20,000 tons of structural steel, 5,500 tons of rebar and 8,000 tons of steel piling (80,000 linear feet) and will have a life expectancy of 75 years.

While the Cuyahoga River is only about 200 ft wide at the point of the bridge's crossing, the main viaduct is nearly a mile long because it must clear an industrial/rail area known as the Flats. To meet this specification, one span alone will leap 380 ft over a Norfolk Southern Railroad trestle to avoid disrupting train traffic.

"Concrete girders aren't practical for bridge spans of such length," noted Tom Hyland, Innerbelt project construction manager for ODOT.

For the foundations, steel H-piles (supplied by Skyline Steel, a Nucor Company) were driven with a pile hammer as far as 220 ft into the ground to the point of refusal. This process was repeated 12 to 16 times for each leg of each bridge pier. To support the westbound bridge's massive foundations, design specifications called for HP18×204 sections, the largest H-pile section ever rolled by a U.S. steel mill. Made of ASTM A572 grade 60 steel, the H-piles measure 50 ft to 65 ft long with 1-in.-thick webs and flanges; 1 ft of pile weighs 204 lbs. The flanges of the H-shape are 18 in. wide and the depth of the section is also 18 in., forming the H.

"Using larger piles actually saved ODOT money," said Hyland. "Pound for pound, the larger H-pile proved to be less expensive and required less total steel than using more H-piles of a smaller size."

## Downtown Link

The westbound bridge is set to be completed this fall and, along with the eastbound bridge, it will connect downtown Cleveland to Interstates 71, 77, 90 and 490, as well as State Route 176, and will improve access to the Cleveland Port Authority, Burke Lakefront Airport, sports and entertainment venues and Cleveland's Amtrak station. ■

**Owner**
Ohio Department of Transportation

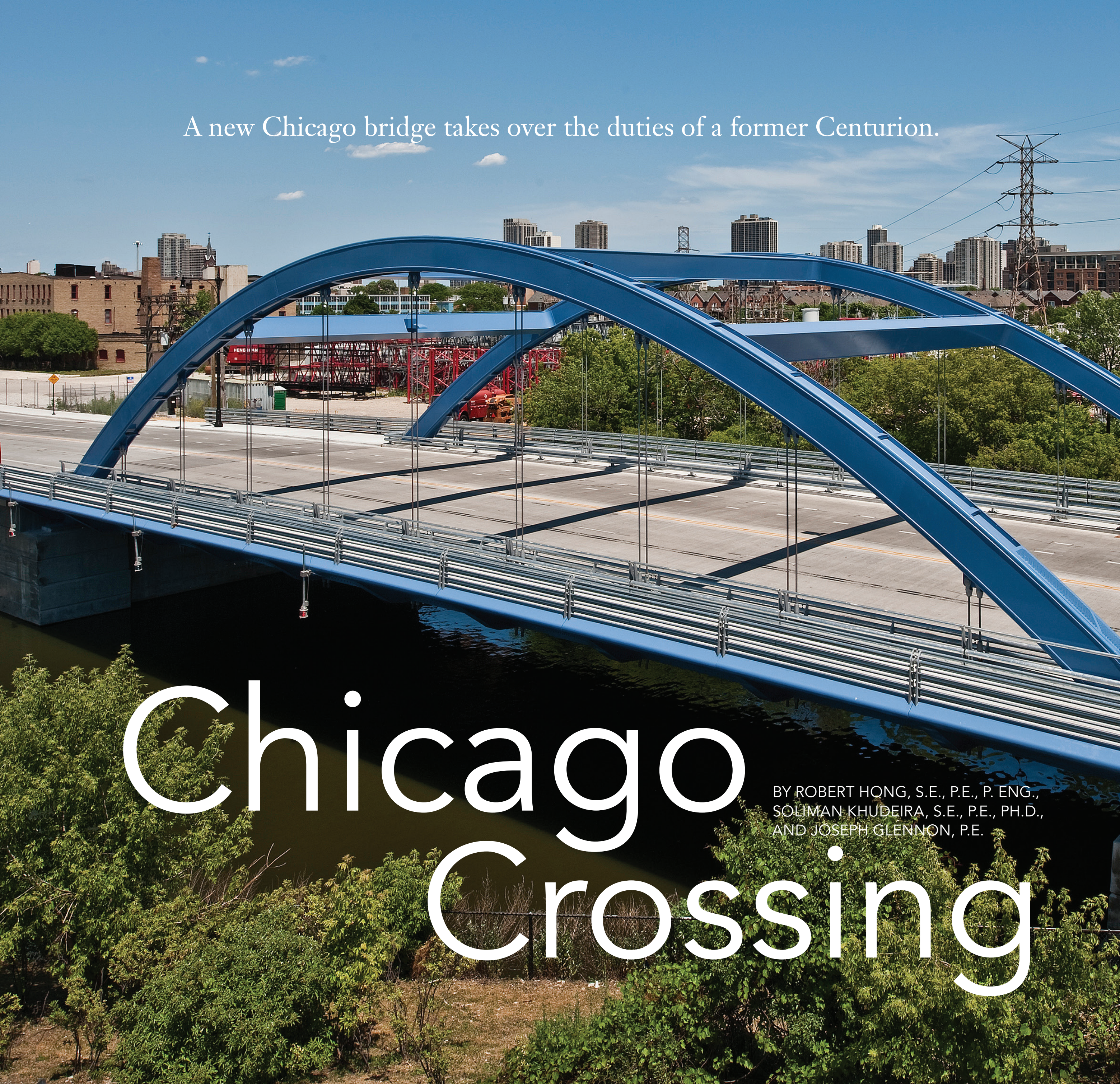
**General Contractor**
Walsh Construction, Chicago

**Structural Engineer**
HNTB Corporation, Cleveland

**Steel Fabricator and Erector**
High Steel Structures, Inc., Lancaster, Pa. (AISC Member/NSBA Member/AISC Certified Fabricator and Advanced Certified Erector)

The five-lane bridge will soar 120 ft over the Cuyahoga River at its highest point.


HAYDON BOLTS, INC.
Proud to be an American Manufacturer since 1864.
Structural Bolts
Major distributor of a full line of Tension Control Bolts ASTM A325-1/F1852 Plain and Galvanized and ASTM A490/ F2280. Heavy Hex Structural Bolts ASTM A325-1, Plain and Galvanized, A325-3, ASTM A490-1 and A490-3. All available with full Manufacturer's Test Reports (MTR's). In-house Rotational Capacity Testing is available upon request.
Fabricated Steel Anchors & Rods
Serving structural and miscellaneous fabricators for over 147 years. Manufacturing anchor bolts and tie rods up to four inches in diameter to ASTM F1554 grades 55 and 105, A449, A588, A354, stainless steel and other materials. All made of steel melted and manufactured in the USA.
Wrenches
Standard TC Wrenches and Torqon Adjustable Control Wrenches for hexagon head structural bolts in stock. Replacement parts and repair services are available.
MEMBER
INDUSTRIAL FASTENERS INSTITUTE
AISC ASSOCIATE
STEEL ERECTORS ASSOCIATION OF AMERICA
Haydon Bolts, Inc.
1181 Unity Street
Philadelphia, PA 19124
215-537-8700 / Fax 215-537-5569
www.haydonbolts.com



A new Chicago bridge takes over the duties of a former Centurion.

# Chicago Crossing

BY ROBERT HONG, S.E., P.E., P. ENG., SOLIMAN KHUDEIRA, S.E., P.E., PH.D., AND JOSEPH GLENNON, P.E.

**A FEW YEARS AGO,** the Halsted Street Bridge over the Chicago River North Branch Canal put in its 100th year of service.

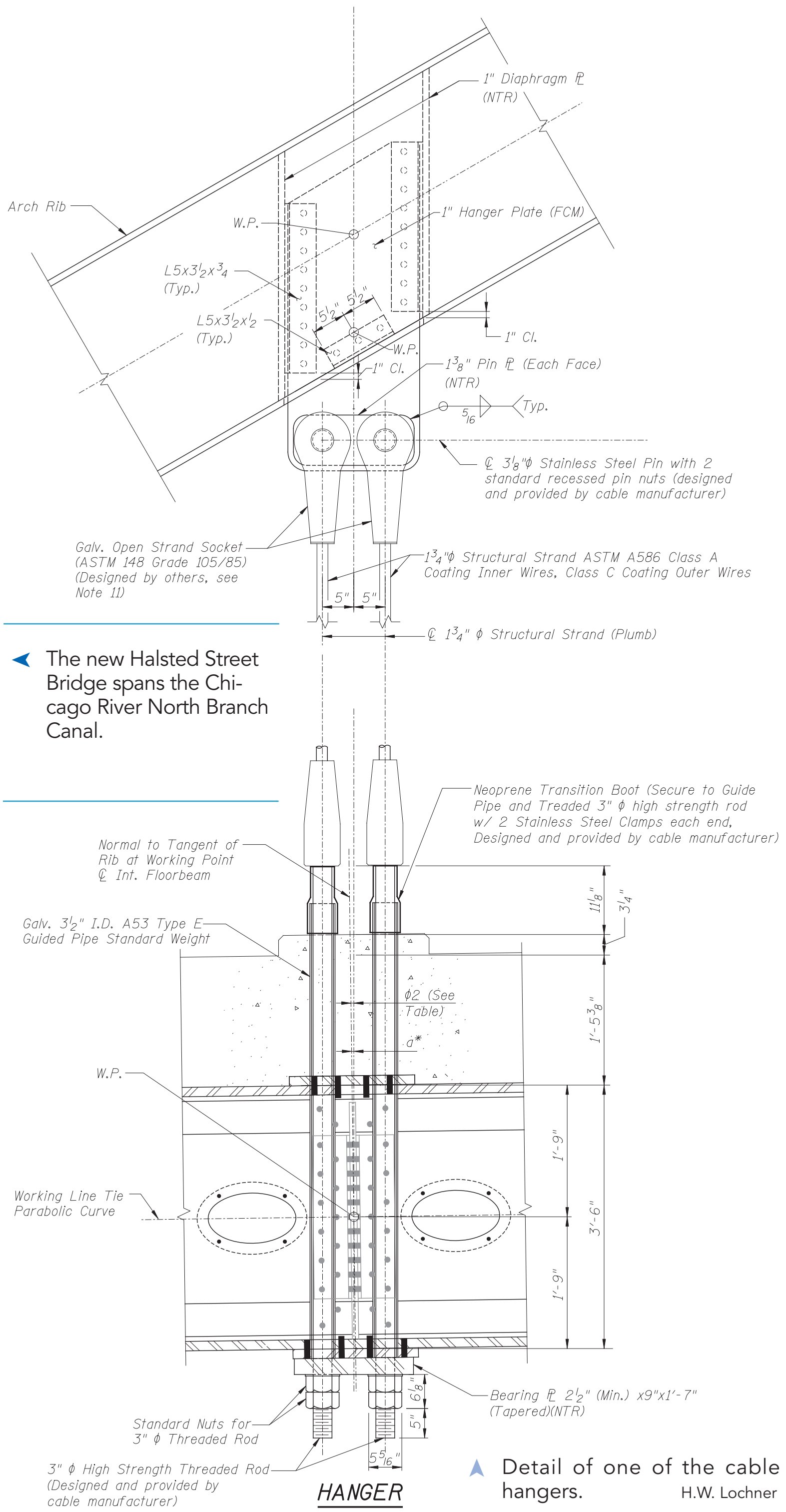
Built in 1908, the movable double-leaf trunnion bascule truss bridge provided navigable waterway accessibility for vessels too high to pass beneath when it was closed. Due to the cost of maintaining a movable bridge and the lack of high-mast vessels using the canal, however, the moveable mechanisms of the bridge were decommissioned over 25 years ago and the movable spans were locked together in the closed position.

More recently, the bridge became identified as the only remaining bottleneck to Halsted Street traffic. Its northern approach consisted of four lanes within a 40-ft roadway converging down to the bridge, which provided one 18-ft lane in each direction separated by a 3-ft median containing the center through truss structure. The southern approach was the same, though with 51 ft of roadway as opposed to 40 ft. In addition, the bridge had become structurally obsolete (in 2007, it earned a sufficiency rating of 25.9 out of 100), and the Chicago Department of Transportation (CDOT) retained structural engineer H.W. Lochner to design a replacement.

Four different bridge alternatives were considered and evaluated for cost, timeline for construction, aesthetic value, constructability and impact on the environment and community: a haunched steel plate girder bridge, a multi-span precast concrete arch bridge, a

The new Halsted Street Bridge spans the Chicago River North Branch Canal.

Photos: Bob Elmore Photography




Detail of one of the cable hangers. H.W. Lochner


**Robert J.Q. Hong** (rhong@hwlochner.com) is an associate vice president/senior structural engineer with H.W. Lochner, **Soliman Khudeira** (soliman.khudeira@cityofchicago.org) is a project director with the Chicago Department of Transportation - Division of Engineering and **Joseph Glennon** (joseph.glennon@hbmengineering.com) is the lead civil engineer with HBM Engineering.


▲ The original bridge.

▲ Construction of the deck.

▼ Cable hangers, up close.

steel through truss fixed span structure and a steel tied arch bridge. CDOT selected the steel tied arch option, and bridge design took place between 2007 and 2009. Construction began in November 2010 and the new bridge was opened to traffic in December 2011.

The new replacement structure consists of a 157-ft-long and 80-ft-wide steel tied arch bridge main span flanked by two 36-ft three-sided precast concrete arch approach spans. With the new bridge deck 22 ft wider than the existing bridge, the replacement bridge carries two lanes each of northbound and southbound vehicular traffic, with one bike lane and pedestrian sidewalk placed on each side. The precast concrete arch approach spans provide the east- and westbound pedestrian access for a future extension of the Chicago Riverwalk under the bridge. A 12-ft, 4-in. vertical waterway clearance is provided, allowing small boat traffic to pass under the bridge main span. As a cost-saving (and environmental) measure, a portion of the existing bridge substructure was reused to support the precast concrete arch approach spans.

## Elegant Arches

The distinguishing characteristics of tied arch bridges have long been regarded as an elegant solution for long-span crossings. However, very few short-span tied arch bridges have been built recently in the U.S. due to concerns regarding redundancy and constructability of the structural system. Three techniques in particular assisted in bringing the Halsted Street Bridge together:

- **Bolted weathering steel tie girders.** Because the two tie girders carry the tension forces to support the weight of the entire bridge, any loss of these members would result in catastrophic structural failure. Hence the ties are classified as fracture critical members (FCMs). (This characteristic prompted a Federal Highway Administration—FHWA—advisory in 1978, recommending the improvement of the redundancy. Since that advisory, few tied arch bridges have been designed until recently.) The 2-ft, 6-in.-wide by 3-ft, 6-in.-deep steel tie box girders of Halsted Street Bridge are built up from four plates joined using bolted angle connections in each corner. This design arrangement provides a higher degree of internal redundancy and helps address the issues raised in the FHWA Advisory. Welded members tend to propagate fractures into the adjacent plates, whereas the discontinuity created at the bolted connections will arrest the crack and prevent losing the entire section. Weathering steel was used to improve the bridge's corrosion resistance and long-term durability.
- **Continuous and composite floor/tie system.** The continuous and composite floor/tie system not only allows the use of a much shallower superstructure to maximize the navigational clearance, but also provides an additional load path to resist global tension force in the event of failure of a tie member. This design mechanism results in a much more economical, durable and redundant floor system.
- **Load path redundancy built into the cable hangers.** Part of the load path redundancy is achieved by providing a pair of ASTM A586, Class A/C structural strands at each hanger location. Each structural strand is fully capable of

▲ Installing the cables.

◄ The new span replaces a bridge that had put in more than 100 years of service.

supporting the full bridge service loading under the temporary condition when the other strand is damaged or decommissioned from service due to maintenance or repair. This design arrangement makes it possible for the maintenance crew to service the cable hangers without closing the bridge to traffic.

## Pleasingly Parabolic

The bridge's arch rib follows a line of parabolic curve with a vertical rise of 35 ft and a span of 157 ft, resulting in a rise-to-span ratio of 1:4.5; within the optimal ratio of 1:4 to 1:5, it poses no unmanageable design conditions. The bridge consists of nine equally spaced hangers at 15 ft, 6 in. The transverse floorbeams and longitudinal stringers act compositely with the deck. The floorbeams are supported from the structural strand hangers anchored at the bottom of the tie girder and attached to the bottom of ribs using steel gusset plates and open sockets. The gusset plates penetrate the rib and are bolted to the stiffener plates that are welded to the inside face of the steel ribs to transfer the hanger forces into the rib. The arrangement of this connection detail ensures a continuous smooth rib surface without the bolt connection being exposed.

To accommodate the roadway with four vehicular lanes and two bike lanes, the arch ribs are spaced at 60 ft center-to-center; the rib element is a 2-ft, 6-in-wide by 3-ft-deep welded steel box. For simplicity, the rib is braced with a lateral system that consists of only four top struts rigidly framed with the ribs. The small size of the closed box section of the tie girder inhibited ironworkers from accessing the interior during erection. As such, hand holes were provided on the web plates of the tie girder at each connection between the floorbeam and tie and at each tie girder field splice location, which allowed the erector to make field connections from outside the box. In addition, the interior of the tie girder is painted bright white for the convenience of future inspection via cameras through the hand holes.

One of the challenges during the design was to control and minimize the large torsional moments imposed on the tie girder. The relatively wide but short bridge geometries led to a large torsional stiffness of the tie girder, and in turn a large torsional moment was produced in the steel tie. Through camber of the floorbeams and rib top strut bracings, temporary global counteracting torsional moments were introduced into the tie girders when the arch members were forced to close during the connection of the top struts. This procedure helped reduce the permanent torsion in tie girder and thus minimize the size of the steel ties and its splice connections.

Other members that were cambered include arch ribs, ties and cable hangers. For tied arch bridges, which are designed as rigid moment frames in nature, member cambering not only achieves a desired final bridge geometry, but also helps to reduce the member forces by injecting a counteracting force into the structural system through erection. Similar to the "prestressing" concept used for the concrete structure, introduction of the counteracting forces imposed on the steel structural

▲ The span was built on-site as opposed to being barged in.

▼ Closing one of the arch ribs.

system during erection allows the design to minimize the structural size and maximize the efficiency of the steel usage. Although the savings on the structural steel was a direct benefit, additional indirect benefits included the use of lighter falsework and a reduction in demand for the crane capacity.

A conventional floating stringer and deck system was used for the bridge, with stringers framed into the floorbeams via bolted shear connections. However, at one end of the connection, short slotted holes were used and the bolts installed in the slotted holes are only finger tightened during steel erection. This allowed the structure to elongate during erection and concrete deck placement, which prevented any accumulation of tension force in the stringer; all dead-load tension force is intended to be carried by the tie girders alone. After the concrete deck was placed, the connection of the bolts in slotted holes were then fully impacted and tightened.

Pot bearings were placed under the knuckles at each of the four corners under the bridge floor system. The bearing stiffeners and jacking stiffeners all needed to be placed in the knuckle, which posed a formidable challenge for the designers to not only meet the requirements of connecting different geometrically configured components, but also satisfy the strength demand for each of these components within a very confined space. Because the knuckles had to be capable of carrying the entire global tensile force in their respective webs, finite element analysis was performed to ensure their structural adequacy.

The original bridge was closed after Thanksgiving Day of 2010. The contractor, Walsh Construction, first removed the existing bridge, then installed the cofferdams for new in-water abutment construction.

Walsh had the option of constructing the main arch span off-site, floating it in and lifting it into place, or constructing the span on-site, over the river. Considering the limitations of the crane capacity and the difficulty of the barge transportation due to the silted river bed, the span was built on-site; this was also the more cost-effective option. Two shoring towers were built in the river to facilitate the steel erection. On Christmas Eve of 2011, the main construction of the project was complete and Halsted Street Bridge was open to vehicular and pedestrian traffic, on schedule, on Christmas Day. The total final construction cost, including approach spans and roadway construction, was $13.7 million, well under the allocated city budget for the project.

## Future Value

The short-span tied arch bridge is a valid design option for enhancing an urban setting with an aesthetically pleasing structure. The successfully completed Halsted Street Bridge demonstrates that a short-span tied arch can be done economically with attention to the steel details that accommodate both accessibility and constructability. Plus, its size speaks to its adaptability and usefulness in tight quarters, and it validates that site issues can be overcome by thoughtful design. ■

### Owner
Chicago Department of Transportation

### Structural Engineers
H.W. Lochner, Chicago (Prime Consultant)
HBM Engineering, Chicago (Subconsultant)

### General Contractor
Walsh Construction, Chicago

### Steel Team

#### Detailer
Candraft Detailing, Inc., New Westminster, British Columbia, Canada (AISC Member)

#### Bender/Roller
Chicago Metal Rolled Products, Chicago (AISC Member)

▲ Floor framing.

▼ Total final construction cost was $13.7 million, well under the allocated budget for the project.

# business issues

# CAPITOL GAINS

BY BRIAN RAFF

The idea of building relationships with your elected officials is more than just hot air. Become their trusted ally and you just might become a part of their construction decision-making process.

**THE PERCEPTION THAT CONGRESS** moves slowly—if at all—to get things done is an old one and certainly not unfounded.

As such, it can be difficult if not impossible to appreciate how important and effective a relationship with your elected officials can be to your business and local economy. But remember that the senators and representatives that you elect (whether they realize it or not) are there for one reason: to represent your interests and those of your fellow employees. By getting to know your members of Congress and educating them on the benefits of steel construction, you have the potential to not only increase your business and bring new projects to your area, but also to raise the profile of our industry as a whole and even help boost the nation's economy.

## Knowledge Gap

Your legislators receive hundreds if not thousands of phone calls, emails and visits from constituents every day on a variety of topics including taxes, healthcare, transportation, jobs and the economy. But remember that one senator or representative cannot possibly be an expert on all of these complex issues.

The same is true of the staffers that work for members of Congress. In many cases the staffers, while highly motivated, are relatively young. According to a recent *Washington Times* article, "Most Senate staffers have worked in the Capitol for less than three years. For most, it is their first job ever. In House offices, one-third of staffers are in their first year, while only one in three has worked there for five years or more." In conjunction with high turnover rates, congressional employment has steadily declined to more than 10% below 1979 staffing levels.

With Congress' diminished industry experience and high turnover rate, AISC/NSBA members have a terrific opportunity to help fill these critical knowledge gaps as they relate to steel design and construction. And it's easy to do. Here are three simple steps for getting in touch with your representatives in Washington to educate them on the benefits of building with steel:

**Step 1:** Identify your elected officials. Visit **www.aisc.org/action**, enter your zip code in the "Find Your Officials" search field and click "GO." Once you have identified your elected officials, you can learn more about them as well as how they have voted on key political and economic issues.

**Step 2:** Write to them. The First Amendment to the U.S. Constitution guarantees the right of all citizens to communicate with their elected representatives. This is a right that Americans are fortunate to have but don't exercise nearly enough. With just one click on AISC's Actions page, you can write your congressmen or congresswoman on predetermined topics like investing in American jobs or strengthening Buy America requirements, or compose your own message.

**Step 3:** Follow up with a phone call or a personal visit. Corresponding by phone or by letter/email can be effective for getting your issue "on the books," but there is nothing like a face-to-face meeting to really communicate your "ask" with a sense of urgency and importance. Keep in mind that visiting Washington, D.C., can be exciting, but inviting your elected official to your design office or fabrication shop can give them critical perspective on what your company actually does to build your community, and will ultimately help you develop a better overall relationship as a fellow neighbor and concerned citizen.

One of the most important things you can do as you build your relationship with your members of Congress is to tell them

**Brian Raff** is the marketing director of the National Steel Bridge Alliance. You can reach him at **raff@aisc.org**.

Some municipalities, like Chicago, have strong relationships with steel for public projects, but others can benefit from outreach from our industry.

what they need to know about steel design and construction in their state or congressional district. They will want to know:

- How many of their voters work at your company or live in the area?
- What are some of the issues your company is dealing with, and how can they help?
- What do they need to know in order to improve the local design and building construction market and improve employment rates?
- How will their votes and key pieces of legislation affect your company and community?

And it works! This spring, Dale Ison, general manager of Florida Structural Steel (AISC/NSBA member, AISC Certified fabricator) met with Congresswoman Kathy Castor (D-Fla.) in Washington, D.C., Congresswoman Castor was very supportive and generous with her time and even expressed interest in visiting Florida Structural Steel's facility, which is in her district. She followed through on her offer later that month, visiting the shop and generating some great local press on infrastructure spending priorities and Buy America provisions.

This is the second year in a row that a representative has visited an NSBA member's facility as a result of NSBA's Washington, D.C., meetings. In 2012, Congresswoman Vicky Hartzler (R-Mo.) visited DeLong's, Inc. (AISC/NSBA member, AISC Certified fabricator) in Jefferson City following a meeting with Gary Wisch, vice president of engineering at DeLong's.

We realize that visiting your legislator for the first time can be intimidating, and we're happy to work with you to help schedule your visit as well as provide talking points, fact sheets and other supporting material (e.g., construction market, labor and employment statistics) to make your "ask" clear and concise.

▲ Building bridges with your members of Congress can help bring their attention and influence to construction in their (and your) home states or districts.

### AISC PAC

In addition to building relationships with our elected officials on a district-by-district or state-by-state basis, AISC also recognizes the importance of a more collective approach. In response to requests from many of our members who want to leverage and pool their individual investments in ways that can give meaningful and long-term support to our industry, AISC has established a Political Action Committee—AISC PAC—to support candidates for federal office who share our appreciation of the vital role of structural steel in our national economy. (Visit **www.aisc.org/AISCPAC** to learn more.)

As an association, we will work hard to help elect supportive candidates as a long-term investment in our industry's future. Investment in the structural steel industry is too important to let other people make the rules that govern it, and every day federal legislators hear from industries and special interests whose goals are not consistent with ours. Whether the issue involves Buy America procurement, trade rules, funding, safety and the environment or even federal building standards, the structural steel industry needs strong and persuasive advocates.

If you would like to set up a visit with your elected officials in Washington, D.C., or at home, please contact AISC and let us help. Let's take action together and ensure that our elected leaders understand how critical the steel design and construction industry is to a full economic recovery. ■

### SteelDay

SteelDay is a great opportunity to get your elected officials better acquainted with structural steel. The steel industry's largest educational and networking event takes place on October 4, 2013. Over the past four years, SteelDay has seen more than 250 events each year all across the country, including visits to structural steel fabrication shops, steel mills, steel service centers, HSS producers, bender-rollers, galvanizers and job sites.

Last year, 11 governors officially recognized the structural steel industry's contribution to America's infrastructure and proclaimed September 18, 2012 as SteelDay in their respective states. Please consider SteelDay as just one of many tools in your belt that you can use to establish and strengthen your relationship with your federal, state and local officials. (Visit **www.aisc.org/steelday** for more information.)


# Take Two

STORY AND PHOTOS BY GEOFF WEISENBERGER

The University of California, Berkeley wins its second National Student Steel Bridge Competition in a row.

**THE LAST TIME** I attended the National Student Steel Bridge Competition, back in 2009, it was in sunny Las Vegas.

This year's competition, organized by AISC and the American Society of Civil Engineers (ASCE) took place at the University of Washington in sunny Seattle. Yes, you heard me correctly. Despite the Emerald City's gray reputation (it averages more than 220 cloudy days per year though less annual rainfall than AISC's hometown of Chicago), the weather couldn't have been more perfect for the 22nd annual competition, which challenges college engineering students with building the best bridge they can in the shortest amount of time.

**Geoff Weisenberger** is the senior editor of *MSC*. You can reach him at **weisenberger@modernsteel.com**.

And for the second year in a row—and the third time since 2008—the University of California, Berkeley team came out on top as the overall winner, buoyed by their first-place finishes in two out of the six categories (lightness and efficiency).

"There are two main reasons that led to this team's success," said Marios Panagiotou, assistant professor of structural engineering in UC Berkeley's Civil and Environmental Engineering (CEE) department and faculty advisor for the team. "First, the continuous transfer of knowledge and experience from team members of previous years to new team members, and second, these new members were motivated by the fact that *staying* in first place is possibly even tougher than coming in first."

The other four categories—stiffness, economy, construction speed and display—were won by New Jersey Institute of Technology, Massachusetts Institute of Technology (MIT), University of California–Davis (UCD) and Milwaukee School of Engineering, respectively. MIT and UCD rounded out the top three overall winners in a national competition of 49 teams, which were picked from 18 regional competitions across the country; schools from Canada and Puerto Rico also made it to the national competition.

"We were happy to host the NSSBC and were very pleased with the way it all turned out," said Jeffrey W. Berman, associate professor with UW's Department of Civil and Environmental Engineering and the UW team's faculty advisor. "The weather

The University of Washington team in action (UW was the host school for this year's competition).

The national competition featured 49 bridge teams.


even gave us opportunity to show off our beautiful campus. The bridges were all very well done and fierce competition made for an excellent overall event."

## Campus Visit

The NSSBC turns out to be a great way to tour a college. On the Friday of the competition, AISC digital content editor Victoria Cservenyak and I made our way all the way across the UW campus to a vast parking lot near the athletic facilities, where students were going through practice runs. This is their final dress rehearsal before the construction competition the next day—a chance to go through the motions in real time, make tweaks and potentially shave seconds off their build time (the fastest team this year, UCD, put their bridge together in just over four minutes, and build times went as high as 25-plus minutes). The various teams marked the asphalt to represent the boundaries of the actual competition, which involves building a bridge over a virtual river; the builders must stay on dry land, including a cofferdam in the middle of the river. The University of Maryland team, perhaps as extra motivation, labeled their practice river as "lava."

From the practice area we made our way to the Husky Union Building, where John Parucki, head judge for the competition for nearly two decades, went over the rules with various judges, including a hands-on demonstration with an actual competition bridge. He also provided plenty of advice, especially useful to first-time judges, and stressed the importance of safety and the need to avoid "coaching" the students in any way.

"Don't talk to them, don't even give them a sad look," he urged. "You do that and they're going to wonder what's wrong with their bridge. As much as your heart bleeds for these students, you cannot help them. Only talk to the captains, but do not give advice."

A strict adherence to the rules, Parucki added, is not only fair but also helps prepare students for the trials and tribulations of real-life work—and it doesn't take away from the fun.

Following the meeting the judges made their way to UW's Red Square, a plaza where all of the teams set up their bridges for the display portion of the competition, and rated the bridges on their visual appeal. Some were painted while some were not, some featured intricate etchings or decoration while others went for a minimalist aesthetic. But of course, all bridges have to stay within


The winning team, the University of California, Berkeley.

AISC director of education, Nancy Gavlin, surveying bridges at UW's Red Square during the display portion.

Judges used the board test on each bridge to make sure there were no elements protruding from the top of the deck.

UC Berkeley, huddling up before the competition.

certain parameters, which are modified slightly every year. This year's entries all had to feature a cantilever on one end and no above-deck elements.

Next came a portion of the competition that, while not factored into the overall score, was fun to watch: the first annual team tug-of-war. Taking place in a wooded area in the middle of campus, but seemingly far from civilization, the tug-of-war, like the NSSBC as a whole, put to rest any silly stereotypes of engineering students being mild-mannered, introverted or not particularly athletic. Give them a rope and an opponent, and they put (or rather pull) just as much effort into it as they do their bridge-building. Luckily no injuries were sustained in the raucous competition aside, perhaps, from bruised egos.

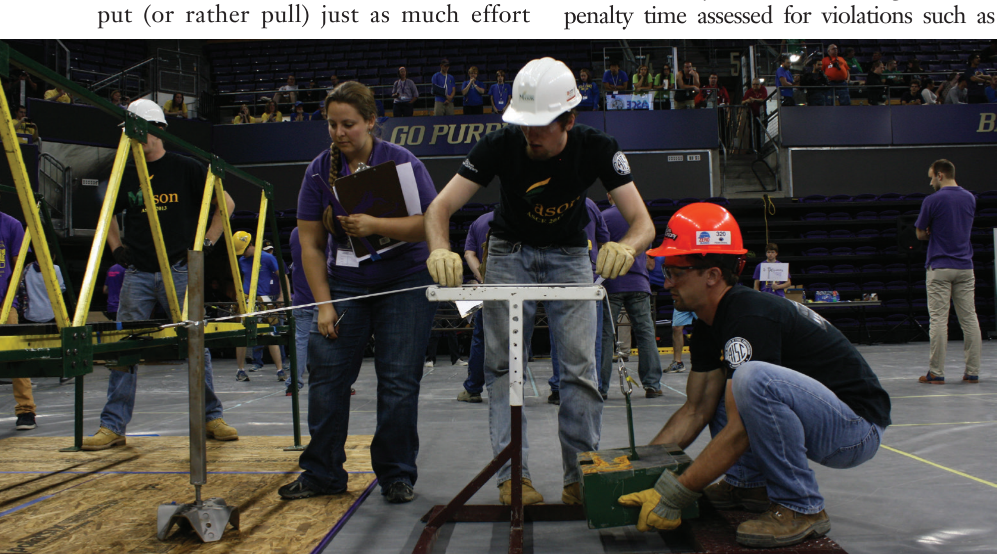
## (Not Much) Time to Build

The next morning, Saturday, the campus was relatively calm and quiet as I traversed it. Not so in UW's basketball arena, Hec Edmundson Pavilion, which lies in the shadow of the recently renovated steel-supported Husky Stadium (home of UW's football team). It was abuzz with activity as the timed construction competition was in full swing. Simply put, the fastest assembly time scores the highest, with penalty time assessed for violations such as dropping bolts or stepping in the water.

While it's typical for a team to bring 10 or more students to the competition, most teams only used five or six at most for the timed construction. In fact, as economy is a factor, several teams (including UC Berkeley) used only three students to build their bridges: one to transport the steel members, tools, temporary pier and bolts from the materials staging area, and two to assemble the bridge. Every year, students find creative new ways to transport and hold the bolts, and this year was no different, with one team using Chick-Fil-A French fry cartons and another relying on metal trays held to the bridge structure via magnets; one team's runner even used a dust pan to put his bolts into plastic cups—multiple solutions to the same problem, just like in real-life construction projects.

Also just like the real world, delays can occur. For example, three of the five vertical load test stations—where students apply 2,500 lb of weight to their bridges and judges measure deflection—went down at the same time, which created a bit of a bottleneck; they were eventually up and running again, which allayed some judges' worries that the competition would go all night and turn the awards dinner into an awards breakfast.

Besides being judged on time, economics and vertical stiffness, bridges were also



The lateral stiffness test.

The University of Texas-El Paso team practices in a campus parking lot.

MIT, which came in second place overall, in action.

assessed in terms of weight and lateral stiffness (weight and the stiffness tests factor into the efficiency category). While the vertical loading test includes a certain element of anxiety—namely that the bridge will collapse—that weight is added gradually. With the lateral test, the weight (50 lb) is added all at once. Attached to the bridge via a cable and lowered via a pulley (this is done twice, once for the back span and once for the cantilever), there's a tense moment as the team member releases the weight, hoping the bridge doesn't sway more than ½ in. (which would result in it not passing the test). The weight test is less stressful: Put the supports on four scales, have the judge take the reading, then take the bridge out of the competition area—and stop thinking about buidling bridges for a while (the weight test is the last one).

Later that night, back at the Husky Union Building, the awards banquet saw the students in more formal attire than their competition hard hats, t-shirts and jeans/pants. AISC president Roger Ferch, a UW alum himself, spoke of the best qualities of the competition: instilling the concept of teamwork in the competitors as well as having engineering students actually building something with their bare hands. Keynote speaker Jon Magnusson, senior principal of Seattle structural engineering firm Magnusson Klemencic Associates, spoke about innovation in structural engineering, discussing several steel-framed Seattle-area MKA projects as examples. And then the winners were announced for each category—again, with UC Berkeley taking top honors. And no doubt contemplating a three-peat. ■

*Next year's competition will take place at the University of Akron. You can view/link to the full results of this year's national and regional conference competitions, as well as the competition rules, at www.aisc.org/steelbridge.*

Blowing off steam during the team tug-of-war competition.

# Building a Better Grid

BY DON WHITE, PH.D., AND DOMENIC COLETTI, P.E.

Proposed improvements to 2D steel I-girder bridge analysis.

**TWO-DIMENSIONAL ANALYSIS METHODS** are a popular choice when it comes to steel bridge design.

They are relatively simple and quick to perform, and there are several commercial software packages that facilitate their use. But many current 2D analysis packages use simplifying assumptions that can significantly reduce the accuracy of their results. Recent research has identified and quantified these limitations and has also led to some proposed improvements that can dramatically increase the accuracy of 2D models.

As part of the recently completed National Cooperative Highway Research Program (NCHRP) Research Project 12-79, 60 different I-girder bridges were analyzed using "1D" (i.e., various approximate analysis methods), 2D and 3D analysis methods, and the results were evaluated to determine the accuracy of the 1D and 2D methods compared to the benchmark 3D analyses. Depending on the geometric complexity of the bridge, the research, published in NCHRP Report 725 (available for free at **www.trb.org/nchrp**), showed that 2D analysis methods could produce noticeably erroneous results in several response categories when analyzing steel I-girder bridges.

Two basic issues were identified as the primary causes of the inaccuracies:

- Omitting warping stiffness, or more precisely the stiffness due to restraint of warping, when modeling the torsional properties of I-girders
- Incomplete modeling of the stiffness of truss-type cross-frames

Fortunately, these issues can be addressed by simple improvements to the modeling of I-girders and truss-type cross-frames in 2D analysis methods. Incorporating these modeling improvements increases the accuracy of 2D analysis methods dramatically, allowing the extension of the use of these popular and useful analysis methods to a wider range of bridges.

## 2D Tutorial

To understand these issues, a basic understanding of 2D analysis methods is helpful. In simple terms, in a 2D analysis, the entire bridge is modeled using a two-dimensional array of nodes and line elements. Both the girders and cross-frames are modeled in one horizontal plane using line elements. In a traditional 2D grid analysis, the bridge deck is also effectively modeled in strips as part of the line elements used to model the girders and cross-frames (see Figure 1). There is also a variant 2D analysis method commonly called the plate-and-eccentric beam method, in which the girders and cross-frames are still modeled using line elements, but the deck is modeled using plate or shell elements, offset from the line elements used to model the girders and cross-frames (see Figure 2). Many of the limitations of traditional 2D analysis methods, including those discussed in this article, are associated with the modeling of I-girders and truss-type cross-frames using single line elements.

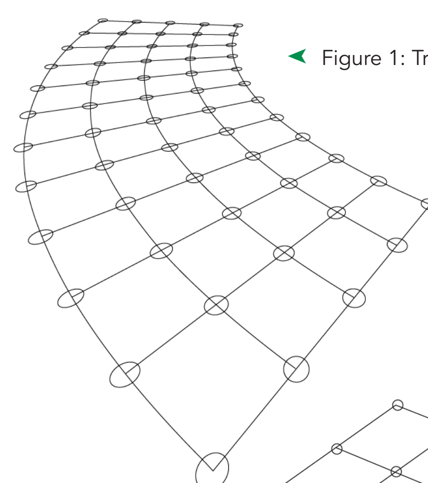


Figure 1: Traditional 2D grid model.

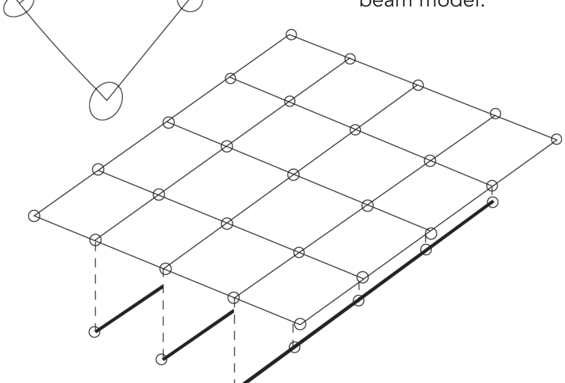


Figure 2: 2D plate-and-eccentric-beam model.

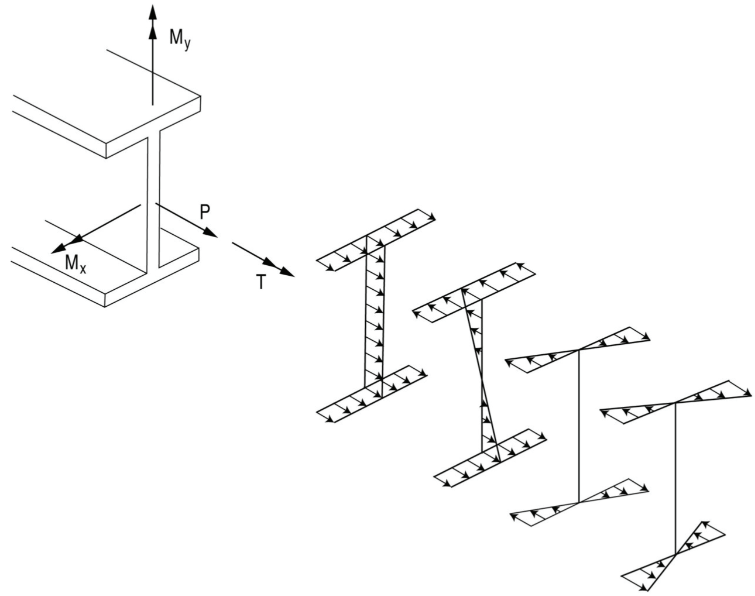
### Modeling Torsional Stiffness

Torsion is carried in I-girders by two mechanisms. The first is St. Venant (pure) torsional shear and the second is warping. St. Venant torsional shear is a shear flow around the perimeter of the cross section, while warping involves a cross-bending of the flanges (i.e., bending of the flanges in opposite directions; see Figure 3) in response to torsion.

The St. Venant torsional stiffness of I-girders is relatively low, due largely to their open cross-section geometry. The St. Venant torsional shear flow around the perimeter of the cross section can only develop force couples across the thickness of any given segment of the cross section. Without a significant force couple distance between these shear flows, the ability of I-girders to resist torque via St. Venant torsional response is limited.

Since I-girders have low St. Venant torsional stiffness, they resist torsion primarily by warping. When an I-girder is twisted, longitudinal stresses develop in the girder as the flanges undergo the corresponding cross-bending actions. In fact, the warping of the flanges is a major source of *flange lateral bending* in I-girders; other sources including actions such as lateral wind loads. The separate bending of the flanges in opposite directions is also associated with corresponding shear stresses acting in opposite directions in each of the flanges. These stresses, multiplied by the distance between the flange centroids, produce a couple that is the warping contribution to the girder internal torque.

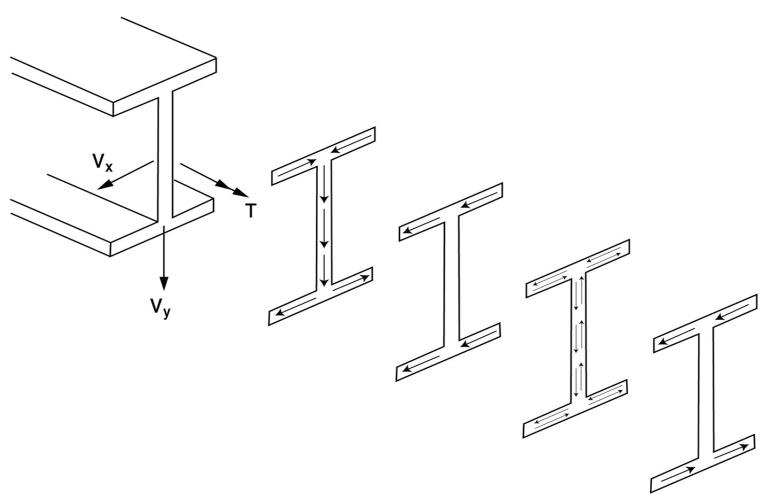
The total state of normal stress in an I-girder is a combination of any axial stress, major-axis bending stress, bending stresses from girder weak-axis moments and warping normal stress (Figure 3). The total state of shear stress in an I-girder is a combination of vertical shear stress, horizontal shear stress, some small amount of St. Venant torsional shear stresses and warping shear stress (Figure 4).




$$\text{Total Normal Stress} = \sigma = \frac{P}{A} + \frac{M_x\, y}{I_x} + \frac{M_y\, x}{I_y} + \text{Warping Normal Stress}$$

▲ Figure 3: Primary normal stresses that can occur in an I-girder. Cross-bending of the flanges is illustrated here.

▼ Figure 4: Primary shear stresses that can occur in an I-girder.




$$\text{Total Shear Stress} = \tau = \frac{V_y Q_x}{I_x\, t} + \frac{V_x Q_y}{I_y\, t} + \text{St. Venant Torsion} + \text{Warping Torsion}$$


**Donald White** (don.white@ce.gatech.edu) is a professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta. **Domenic Coletti** (domenic.coletti@hdrinc.com) is a senior professional associate with HDR Engineering in Raleigh, N.C. They respectively served as the Principal Investigator and Co-Principal Investigator for NCHRP Research Project 12-79.


I-girders in bridges are often subject to torsion. In a curved girder bridge, torsion occurs under vertical loading as a result of the curved alignment of the girders. Torsion can also occur in straight I-girders when the bridge has skewed supports. Since I-girders carry torsion primarily by means of warping (or restraint of warping), omitting the warping stiffness when analyzing an I-girder bridge means that a key stiffness parameter is omitted in the analysis.

The significance of omitting the warping stiffness varies based on the geometric complexity of the bridge. In bridges with significant curvature, significant skew or both, the girders are subject to significant torsional loading, and omitting the warping stiffness can significantly reduce the accuracy of the analysis in several important response categories. The relationship between geometric complexity and the potential inaccuracy of 2D analysis methods was quantified in the NCHRP 12-79 research and presented in a simple scorecard format which will be presented later in this article.

As an example, consider the bridge shown in Figure 5, a three-span curved steel I-girder bridge with skewed intermediate supports. Figure 6 shows a comparison of predicted vertical displacements for one of the girders in this bridge. It can be seen that the traditional 2D analysis (orange dashed line) predicts dramatically different deflections compared to the corresponding 3D analyses of this same bridge (black solid line). The reason is that the traditional 2D analysis omits the warping stiffness in modeling the torsional response of the girders.

To correct this error, the warping stiffness should be considered when modeling I-girders in 2D analysis methods, and there are a number of ways to accomplish this. One approach proposed by the NCHRP 12-79 research team is by means of the development of an equivalent torsional constant, $J_{eq}$, which includes an estimate of the warping stiffness of the girders. A full derivation is presented in NCHRP Report 725; the resulting equations for $J_{eq}$ are presented below. For the case of a portion of an I-girder between two cross-frames within a continuous portion of a span, the equation for $J_{eq}$ is:

$$J_{eq(fx-fx)} = J\left[1 - \frac{\sinh(pL_b)}{pL_b} + \frac{[\cosh(pL_b)-1]^2}{pL_b \sinh(pL_b)}\right]^{-1}$$

where $L_b$ is the length between the cross-frame locations, $p = \sqrt{\frac{GJ}{EC_w}}$, $GJ$ is the physical St. Venant torsional rigidity of the girder cross section, and $EC_w$ is the warping rigidity of the girder cross section.

For the case of a portion of an I-girder between two cross-frames at the end of a span, the equation for $J_{eq}$ is:

$$J_{eq(s-fx)} = J\left[1 - \frac{\sinh(pL_b)}{pL_b \cosh(pL_b)}\right]^{-1}$$

By using $J_{eq}$, the accuracy of a 2D analysis can be dramatically improved, as we'll discuss later.

## Modeling Truss-Type Cross-Frame Stiffness

Another limitation of many current 2D analysis packages is tied to how truss-type cross-frames are modeled. A truss-type cross-frame is an open-web structure featuring a bottom chord, diagonals and possibly a top chord. Many current 2D analysis packages make significant simplifying assumptions when modeling the structural response of these truss structures as a single line element.

One method commonly used to determine the "equivalent" stiffness of a cross-frame modeled as a line element is by calculating an equivalent flexural stiffness. In this approach, the truss-type cross-frame is modeled separately, and a unit force couple is applied to one end. Deflections in the direction of loading are calculated and used to determine an equivalent end rotation. The equivalent end rotation and

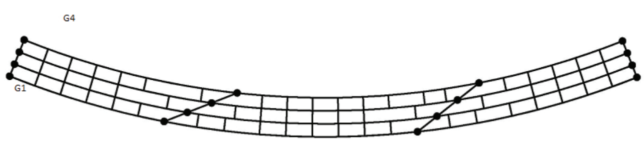
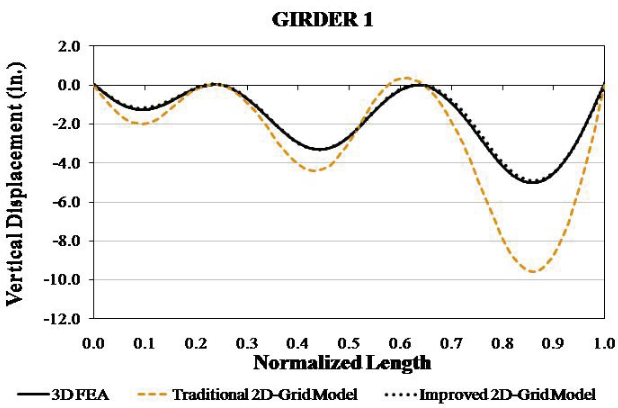
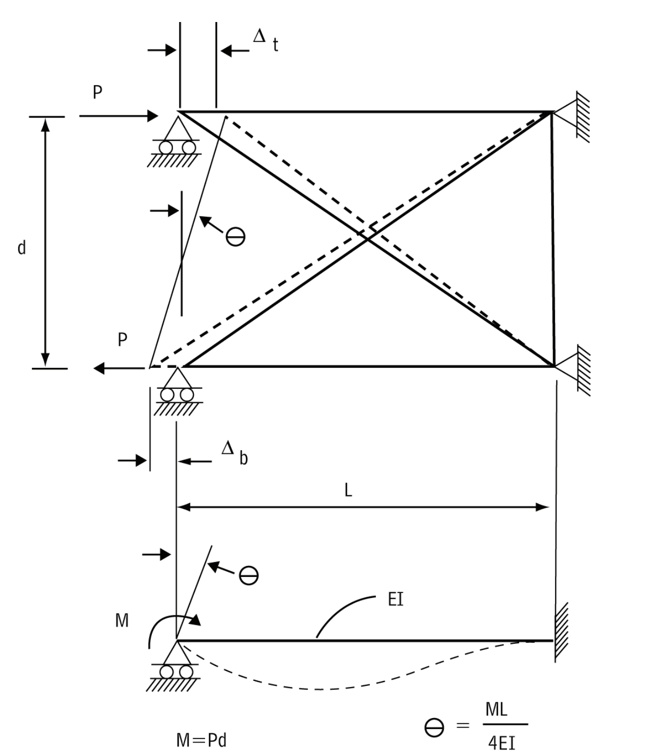



Figure 5: Example three-span curved girder bridge with skewed interior supports.

Figure 6: Comparison of vertical displacement predictions from a 3D analysis, a traditional 2D grid analysis and an improved 2D grid analysis for a girder in the bridge shown in Figure 6.

Figure 7: Current "flexure stiffness method" for approximating the stiffness of a truss-type cross-frame.



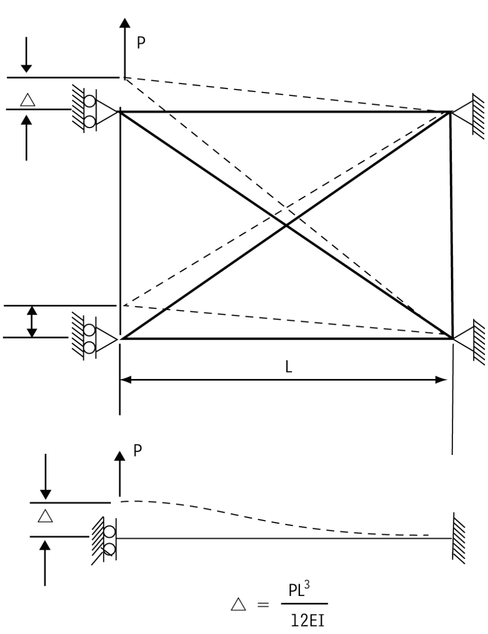
unit force couple are then analyzed as a propped cantilever with Euler-Bernoulli beam theory (i.e., no consideration of shear deformations) to back-calculate the associated equivalent moment of inertia of the cross frame. This moment of inertia is then used as the primary stiffness property of the Euler-Bernoulli line element used in the grid analysis to model the cross frame stiffness (Figure 7, previous page).

A second method is to calculate equivalent shear stiffness. In this approach, the truss-type diaphragm is modeled separately, and a unit vertical force is applied to one end. Vertical deflections are calculated and are used as a transverse deflection to back-calculate the associated shear racking stiffness of the cross frame using an Euler-Bernouli beam element. This is then used as the primary stiffness property of the line element used in the grid analysis to model the cross frame stiffness (Figure 8).

Neither method represents the true stiffness of a truss-type cross-frame, and many key stiffness parameters are omitted from consideration. Also, neither approach considers that there are significant equivalent beam flexure and beam shear deformations in both of the above figures.

For a straight bridge with little or no skew, the effect of these simplified approximations of cross-frame stiffness are negligible since the cross-frames play a relatively insignificant role in the distribution of load through the structural framing of the bridges. But in bridges with significant curvature and/or skew, the girders and cross-frames function together as a system, and the cross-frames play a significant role in the distribution of load through the structural framing. For these types of bridges, incorrect representation of cross-frame stiffnesses can result in incorrect calculation of the loads in the girders and cross-frames.

Figure 8: Current "shear stiffness method" for approximating the stiffness of a truss-type cross-frame.




NCHRP Report 725 provides a complete discussion of this issue and recommends two alternative approaches that can be implemented to provide improved estimates of the stiffness of truss-type cross-frames in 2D models:

1) An improved approximation using shear-deformable (Timoshenko) beam element representation of the cross-frame
2) An "exact" beam element representation of the truss-type cross-frame based on virtual work concepts, and implemented via user-defined beam elements

The shear-deformable (Timoshenko) beam approach simply involves the calculation of an equivalent moment of inertia, $I_{eq}$, as well as an equivalent shear area $A_{seq}$ for a shear-deformable (Timoshenko) beam element representation of the cross-frame. In this approach, the equivalent moment of inertia is determined first, based on pure flexural deformation of the cross-frame (with zero shear). The cross-frame is supported as a cantilever at one end and is subjected to a force couple applied at the corner joints at the other end, producing constant bending moment. The associated horizontal displacements are determined at the free end of the cantilever, and the corresponding end rotation is equated to the value from the beam pure flexure solution $M/(EI_{eq}/L)$.

In the second step of the improved calculation, using an equivalent Timoshenko beam element rather than an Euler-Bernoulli element, the cross-frame is still supported as a cantilever but is subjected to a unit transverse shear at its tip. Using the equivalent moment of inertia, $I_{eq}$, determined from the beam pure flexure solution, and the calculated deflection under a unit shear load, the equivalent shear area is found by solving this equation:

$$\Delta = VL^3 / 3EI_{eq} + VL / GA_{seq}.$$

## Impact of Proposed Improvements

By incorporating the above two proposed improvements, the accuracy of 2D analysis methods can be significantly improved, to the point where their results correlate much better with 3D analysis results for a wide range of bridge geometries. Table 1 shows "scores" for 1D analysis methods, traditional 2D analysis methods and the improved 2D analysis methods. These letter grade scores represent the error indices for the various methods, categories of structural response and bridge geometries. A letter grade of "A" indicates the 1D or 2D method exhibits up to 6% error when compared to a 3D analysis. A "B" indicates 7% to 12% error, a "C" indicates 12% to 20% error, a "D" indicates 20% to 30% error and an "F" indicates greater than 30% error when compared to a 3D analysis.

It can be seen from the table (opposite page) that traditional 2D analysis methods produce reasonably accurate results for a fairly limited range of cases, but the improved 2D methods produce reasonably accurate results for a wide range of cases.

As a specific example of the improvements of the accuracy of 2D methods, consider the three-span curved girder bridge with skewed interior supports previously shown in Figure 5. As mentioned previously, Figure 6 shows the predictions of vertical displacements for a girder in this bridge. The traditional 2D grid analysis (orange dashed line) shows poor correlation with the 3D analysis results (black solid line), but the improved 2D grid analysis (black dashed line) shows very good correlation.

These proposed improvements to 2D analysis methods will be presented in further detail in the upcoming 2nd Edition of the AASHTO/NSBA Steel Bridge Collaboration Guideline G13.1, *Guidelines for Steel Girder Bridge Analysis* and are presented in full detail in NCHRP Report 725.

The hope of the NCHRP 12-79 research team is that these proposed improvements to 2D analysis methods will be incorporated into many of the commercial 2D steel bridge design software packages in the near future. ■

*(Continued on p. 64.)*

Table 1: Recommended Levels of Analysis, I-Girder Bridges, Non-Composite Dead Load Analysis Models

| Response | Geometry | Worst-Case Scores | | | Mode of Scores | | |
|---|---|---|---|---|---|---|---|
| | | Traditional 2D-Grid | ID-Line Girder | Improved 2D-Grid[g] | Traditional 2D-Grid | ID-Line Girder | Improved 2D-Grid[g] |
| Major-Axis Bending Stresses | C ($I_c \le 1$) | B | B | A | A | B | A |
| | C ($I_c > 1$) | D | C | A | B | C | A |
| | S ($I_s < 0.30$) | B | B | A | A | A | A |
| | S ($0.30 \le I_s < 0.65$) | B | C | A | B | B | A |
| | S ($I_s > 0.65$) | D | D | A | C | C | A |
| | C&S ($I_c > 0.5$&$I_s > 0.1$) | D | F | A | B | C | A |
| Vertical Displace-ments | C ($I_c < 1$) | B | C | A | A | B | A |
| | C ($I_c > 1$) | F | D | A | F | C | A |
| | S ($I_s < 0.30$) | B | A | A | A | A | A |
| | S ($0.30 \le I_s < 0.65$) | B | B | A | A | B | A |
| | S ($I_s \ge 0.65$) | D | D | A | C | C | A |
| | C&S ($I_c > 0.5$&$I_s > 0.1$) | F | F | A | F | C | A |
| Cross-Frame Forces | C ($I_c \le 1$) | C | C | B | B | B | A |
| | C ($I_c > 1$) | F | D | B | C | C | A |
| | S ($I_s < 0.30$) | NA[a] | NA[a] | B | NA[a] | NA[a] | A |
| | S ($0.30 \le I_s < 0.65$) | F[b] | NA[c] | B | F[b] | NA[c] | A |
| | S ($I_s \ge 0.65$) | F[b] | NA[c] | B | F[b] | NA[c] | A |
| | C&S ($I_c > 0.5$&$I_s > 0.1$) | F[b] | NA[c] | B | F[b] | NA[c] | A |
| Flange Lateral Bending Stresses | C ($I_c \le 1$) | C | C | C | B | B | B |
| | C ($I_c > 1$) | F | D | C | C | C | B |
| | S ($I_s < 0.30$) | NA[d] | NA[d] | NA[d] | NA[d] | NA[d] | NA[d] |
| | S ($0.30 \le I_s < 0.65$) | F[b] | NA[e] | C | F[b] | NA[e] | B |
| | S ($I_s > 0.65$) | F[b] | NA[e] | C | F[b] | NA[e] | B |
| | C&S ($I_c > 0.5$&$I_s > 0.1$) | F[b] | NA[e] | C | F[b] | NA[e] | B |
| Girder Layover at Bearings | C ($I_c < 1$) | NA[f] | NA[f] | NA[f] | NA[f] | NA[f] | NA[f] |
| | C ($I_c > 1$) | NA[f] | NA[f] | NA[f] | NA[f] | NA[f] | NA[f] |
| | S ($I_s < 0.30$) | B | A | A | A | A | A |
| | S ($0.30 \le I_s < 0.65$) | B | B | A | A | B | A |
| | S ($I_s \ge 0.65$) | D | D | B | C | C | A |
| | C&S ($I_c > 0.5$&$I_s > 0.1$) | F | F | B | F | C | A |

Notes:

[a] Magnitudes should be negligible for bridges that are properly designed and detailed. The cross-frame design is likely to be controlled by considerations other than gravity-load forces.

[b] Results are highly inaccurate due to modeling deficiencies addressed in Ch. 6 of the NCHRP 12-79 Task 8 report. The improved 2D-grid method discussed in this Ch. 6 provides an accurate estimate of these forces.

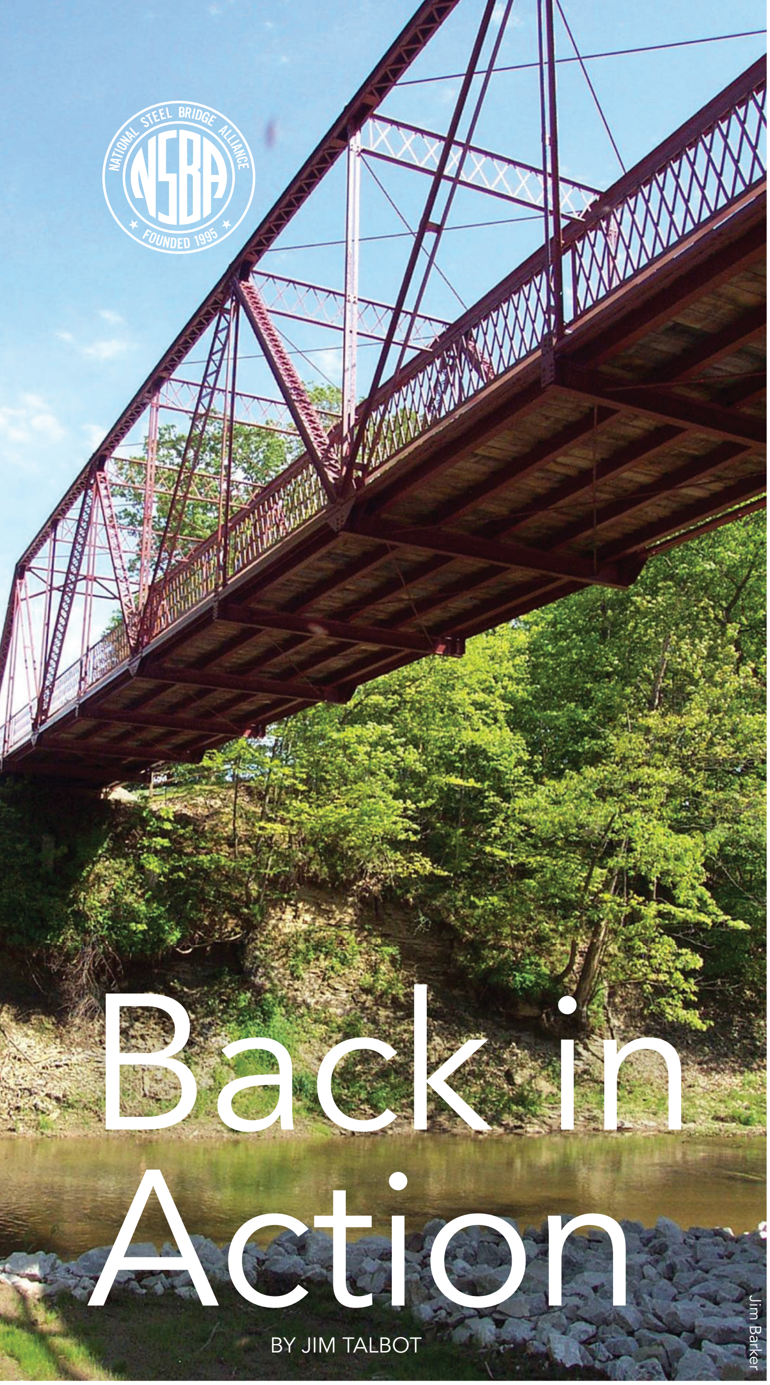
[c] Line-girder analysis provides no estimate of cross-frame forces associated with skew.

[d] The flange lateral bending stresses tend to be small. AASHTO Article C6.10.1 may be used as a conservative estimate of the flange lateral bending stresses due to skew.

[e] Line-girder analysis provides no estimate of girder flange lateral bending stresses associated with skew.

[f] Magnitudes should be negligible for bridges that are properly designed & detailed.

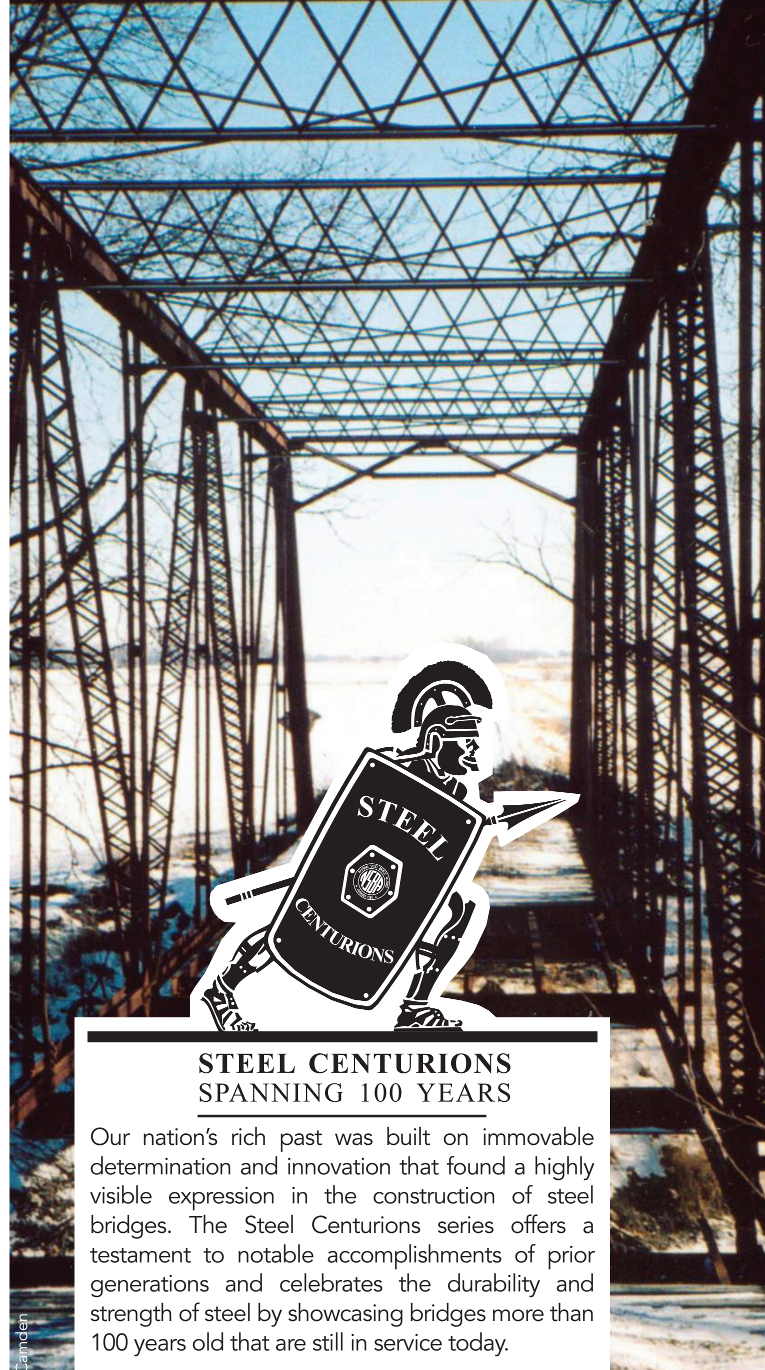
[g] The improved 2D-grid method requires the use of an equivalent St. Venant torsion constant, which estimates the influence of the girder warping response on the torsional stiffness, as well as a Timoshenko beam cross-frame model that accounts for both the shear and bending flexibility of the cross-frames. See Articles 3.11 and 3.12 of the NCHRP 725 Report for detailed discussions of these improvements. In addition, the improved 2D-grid method is limited to the analysis of systems with at least two girders connected by enough cross-frames such that $I_c$ is less than or equal to 20.



# Back in Action

BY JIM TALBOT

Jim Barker




Camden

## STEEL CENTURIONS SPANNING 100 YEARS

Our nation's rich past was built on immovable determination and innovation that found a highly visible expression in the construction of steel bridges. The Steel Centurions series offers a testament to notable accomplishments of prior generations and celebrates the durability and strength of steel by showcasing bridges more than 100 years old that are still in service today.

### A 1913 Indiana steel truss bridge, neglected for years, was rescued from demolition for renewal and reuse in a new Indiana nature park.

**BRIDGE NUMBER 15** almost didn't become a centurion.

Now called the McCloud Nature Park Bridge, this steel truss was nearly cut up and sold for scrap in 2006. Indiana's Pulaski County—its original location—had even scheduled road personnel for the job. A last-minute reprieve, however, came from renowned Indiana bridge historian Dr. James L. Cooper, professor emeritus of history at DePauw University in Greencastle, Ind. He asked John Camden of general contractor John T. Camden Construction Co. to dismantle and store the bridge; Camden collects historical metal bridges like others collect stamps.

Camden paid Pulaski County $10 for the bridge, which was comprised of 15 tons of steel. His crew first removed


**Jim Talbot** is a freelance technical writer living in Ambler, Pa. You can reach him at **james.e.talbot@gmail.com**. (**Jim Barker** of J.A. Barker Engineering also provided input and photos.)



Jim Barker

the wooden deck and its supporting steel stringers, which represented substantial weight, then two cranes lifted the bridge from the metal-capped caissons that supported the four corners. Once the bridge was rested on nearby ground, workers marked the major members to be dismantled in order to ease future assembly in the original configuration. They used rivet guns with chisel-like heads to break and remove major riveted connections, then trucked the bridge parts to the company's shop for storage.

## Big Monon Ditch

The bridge's history began in 1913, when Pulaski County began dredging the Big Monon Ditch, deepening and widening it; the ditch serves to drain water from an aquifer, lowering the water table to avoid the flooding of crops. This project required a new bridge to replace the existing one, and F. M. Williams Contracting Company of Winamac won the contract to build the new metal substructure and superstructure for $2,898.

For the superstructure, Williams erected a riveted Warren through-truss steel span, 120 ft in length. The truss has eight panels with light verticals and the diagonal members are all bolted at their ends to gusset plates. Struts and round-rod lateral braces stiffen the trusses at the other upper panel points. Steel floor beams, bolted to the lower gussets, carry rolled I-beam stringers that support a 14-ft-wide timber deck. Vertical clearance above the deck is 17.6 ft; the structure had no railings.

## Renewal

Years later Pulaski County abandoned the road, and the bridge stood neglected for about 30 years before being purchased by Camden. And recently, Indiana Landmarks recommended that it serve in a park project in Hendricks County as part of a pedestrian and maintenance vehicle trail. The bridge was the right size and of a relatively rare design—and certainly worth preserving.

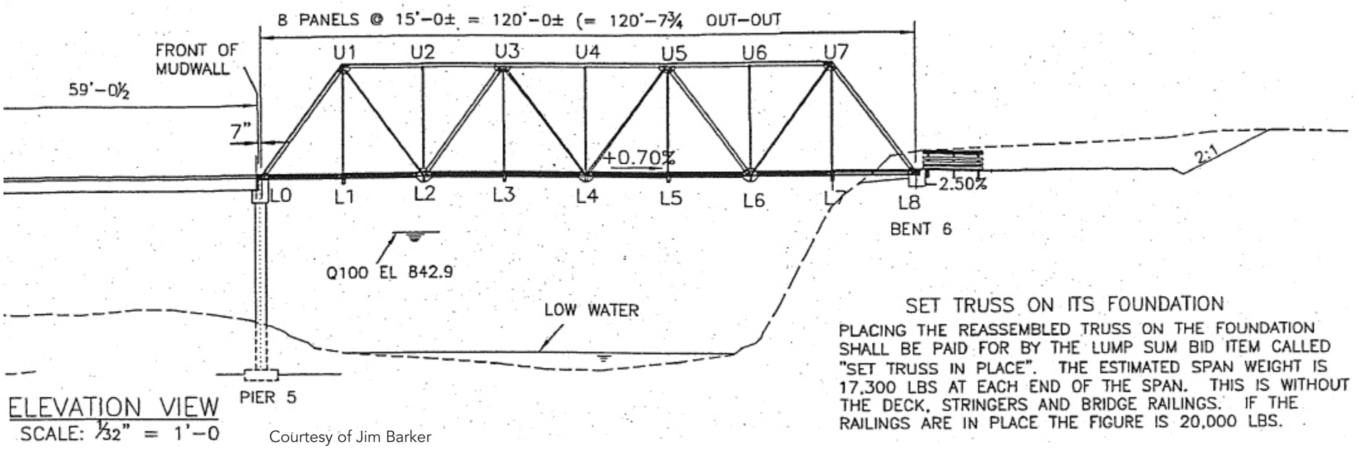
The park, the McCloud Nature Park in North Salem, Ind., consists of 232 acres of woods, glacial ravines, prairie and creek; the Hendricks County Park Board has developed a visionary plan for the park, which is scheduled to be completed in small stages over 20 years. The plan called for the bridge to cross Big Walnut Creek, which divides the park in two. Without such a crossing, visitors would have to leave the park to reach the other half by a different entrance, so the refurbished bridge would tie the park together.

Hendricks County Parks hired Jim Barker of J. A. Barker Engineering for the project, as he has extensive experience in the repair and restoration of historical bridges of all types. The county contracted with Camden Construction, paying for the removal and dismantling work that was already completed, as well as for refurbishing the parts for future assembly.

The company replaced some of the steel bridge members that were beyond repair. These included the deck stringers, top and bottom lateral bracing rods and some of the gusset plates. Lower chord members were also replicated in new steel. Workers then cleaned, prepared and added a first coat of paint to the remaining and new parts.

Landscape architectural firm of Rundell Ernstberger Associates, LLC, headquartered in Indianapolis, created a master plan for the McCloud Nature Park, including placement of the bridge. However, a retired engineer and volunteer for the Indiana Parks, John McCoy, suggested a new location for the bridge. While the original site would have been less expensive, having minimal side spans, it was on relatively low ground and therefore would have been subject to possible flooding and marshy conditions that could potentially limit its use. The new site allowed the bridge to be used year-round regardless of

Jim Barker




Courtesy of Jim Barker

flood conditions, thus Rundell Ernstberger incorporated McCoy's recommendation into its final plan.

The revised plan put one end of the bridge on a high bluff in the park. This end sits on a small, concrete "end bent" set several feet beyond the creek bank, and the other side of the bridge rests on a relatively high concrete pier. Four 59-ft steel approach spans, using a total of 33 tons of weathering steel, reach another point in the park on high ground. The stringers supporting these approaches consist of W27×84 rolled beams of unpainted weathering steel. The approach spans have a composite reinforced concrete deck, and the truss span has a wood plank deck to maintain historical accuracy.

In 2009 Camden received a new contract to locate the refurbished bridge parts to the park site, reassemble them and add a final coat of red paint. This effort took place on level ground near the high bluff. Another contract went to Force Construction Co. to build piers, approach spans and approach trails, as well as to set the truss on its new foundations and construct the bridge floor and railing. Work on these contracts was completed by 2010. The total cost for the bridge project was $817,000, with Camden's relocation, refurbishment and assembly role totaling $193,000 and engineering services accounting for approximately $111,000.

The McCloud Nature Park has become a premier recreational attraction in central Indiana. Visitors can enjoy over six miles of hiking trails, access to Big Walnut Creek, year-round programs at the nature center and a wide variety of wildlife viewing opportunities—and the newly refurbished truss helps bring it all together. ■

business issues

# REPRESENTING STEEL

AISC represents and provides guidance on steel not only to industry experts and the general public, but also to our elected officials.

BY BRIAN RAFF

**A QUICK INTERNET SEARCH** of the term "AISC" appropriately provides a direct link to the AISC home page.

However, most search engines provide other "searches related to AISC," which include the *Code of Standard Practice*, AISC 341-05 (*Seismic Provisions for Structural Steel Buildings*), AISC certified fabricators, seminars, shapes, scholarships and, of course, the AISC *Manual*. What these related searches don't show, and what members of our industry often forget about, is AISC's involvement in government relations and legislative action.

The purpose for our involvement in these issues? To ensure a level playing field for domestically built steel buildings and bridges—a battle that is fought on multiple fronts.

For example, did you know that in 2011, "Wood First" legislation proposed in Oregon would have created a preference for the use of wood for any project up to six stories constructed with any public funds in the whole state? One version of the bill would also have allowed the state to pay up to a 10% premium over the low bid to use Oregon wood. Obviously, this would have had a catastrophic effect on the ability of our member fabricators to compete for the structural framing packages on public projects in Oregon. Not only that, but had this legislation been successful, it could have set the stage for similar initiatives in other states and perhaps even at the federal level.

In response, AISC stated its official position on the matter and shared these points with members of the Oregon state legislature, the state's U.S. senators and representatives in Washington, D.C., and the governor. AISC staff and regional member fabricators also worked with industry allies such as the Ironworker Management Progressive Action Trust (IMPACT) and the American Iron and Steel Institute (AISI) to ensure the entire steel industry was united against this piece of legislation, which would have had an extremely negative effect on our members.

The original bill was voted down, but there is always a chance for reintroduction, and we will continue to monitor the situation in Oregon as well as other states to ensure a level playing field for our members.

Elected officials rely on industry organizations like AISC to provide broad background information as well as acute expertise.

### Better Design

Outside of material interests, AISC also looks for opportunities to support elected officials and federal agencies in their efforts to improve the design and construction industry.

In May, NSBA staff met with Beth Osbourne, Deputy Assistant Secretary of Transportation Policy, in Washington to talk about the requirements under MAP-21 (our most recent transportation reauthorization bill) for developing Performance Measures and Asset Management plans and how NSBA can contribute to that process. Our members bring a great deal of practical experience and technical expertise to bridge design, fabrication and construction, and we have offered our assistance to the U.S. DOT as they work to meet the bridge inspection requirements of MAP-21 and put forth bridge inspection protocols to protect against future disasters.

### Action Against Words

In addition to working with officials and speaking out against unfair advances from other material industries, we also work to ensure that steel isn't unfairly represented in the press. NSBA recently objected to statements published in a June 20 *Wall Street Journal* article titled "U.S. Icons Now Made of Chinese Steel." The article concluded that the U.S. structural steel industry is idle and domestic bridge expertise is lacking, based on New York City's Verrazano-Narrows Bridge project, which features seldom-used orthotropic bridge deck design and is currently being repaired with steel made in China.

NSBA refuted that these assumptions about the domestic steel bridge industry should not be based on a single U.S.

**Brian Raff** is NSBA's marketing director. You can reach him at **raff@aisc.org**.

project. In fact, significant activity in the U.S. building and bridge markets shows that the American structural steel industry is robust and domestic steel fabricators do have the sophistication, diversity, experience and capacity to meet all U.S. project requirements.

NSBA's advocacy efforts, along with those of other industry associations and member companies, prompted U.S. Congressman Michael Grimm of New York to write a letter to the president of the New York Metropolitan Transportation Authority (MTA), urging him to reconsider a domestic source for the 15,000 tons of steel required for this project.

In this letter dated June 26, 2013, Rep. Grimm states:

> "With unemployment still high and our nation just beginning to recover from an economic recession, it is crucial now, more than ever, to ensure we invest American dollars into manufacturing here at home and not overseas in China. Further, the acquisition of this steel from a country such as China, which has long engaged in unfair trade practices, currency manipulation and government subsidization of the steel industry to the detriment of domestic manufacturers, is especially egregious. When combined with their lax environmental and labor standards, I cannot help but call into question the product quality the MTA can expect to receive for the supposed 'cost of savings' associated with purchasing steel in China."

## Accuracy and Advocacy

While AISC focuses the majority of its efforts on technical and market-related design and construction issues, it's crucial to remember our important role in advocacy and legislative action in an ever-increasing competitive political landscape. Elected officials rely on industry organizations like AISC to provide broad background information as well as acute expertise, as they and their staff become inundated with conflicting information and rely on our know-how to minimize confusion and provide an accurate account of our industry—as well as to ensure that others aren't attempting to unfairly legislate a leg up on the competition. (Consider what might have happened if the steel industry decided to ignore the Oregon situation.)

AISC and NSBA look forward to continuing to represent our members on these important issues, and we hope that our members will join us. To learn more about issues that AISC and the steel industry are currently facing, and to get involved, visit our Legislative Action page at **www.aisc.org/Action**.

FHWA administrator Victor Mendez meets with Howard University students at NSBA's 2011 SteelDay event in Washington, D.C.

### AISC PAC

In response to requests from many of our members, who, over the years, have wanted to give meaningful and long-term support to our industry, AISC established a Political Action Committee—AISC PAC—in 2012 to support candidates for federal office that share our appreciation of the vital role of structural steel in our national economy. The fact is that every day, federal legislators hear from industries and special interests whose goals are not consistent with AISC and its members. Whether the issue involves Buy America procurement, trade rules, infrastructure funding, safety, the environment or even federal building standards, AISC believes that the structural steel industry needs strong and persuasive advocates. Ultimately, supporting candidates that support our industry provides a mechanism for long-term investment in our collective future. If you would like to learn more about AISC PAC, visit **www.aisc.org/AISCPAC**.

# people to know
# ON THE RIVER

A bridge designer puts his endurance, strength and mental toughness to the test as a kayak racer.

**DURING THE DAY TRAVIS** Konda designs bridges. In his free time he kayaks under them.

A structural engineer for HNTB's Minneapolis office, Konda began kayaking recreationally in 2002 while at Iowa State University. He began racing in 2006 and since then has been involved in several different types of kayak races, from triathlons that swap swimming for paddling to a 340-mile nonstop race across Missouri on the Missouri River (known as the MR340) to numerous shorter races in the 50- to 90-mile range. He's kayaked in Iowa, Kansas, Mississippi, Missouri and South Dakota, as well as Lake Superior, the Gulf of Mexico and the Pacific Ocean. During races his wife, Ursula, serves as his ground crew, driving ahead to meet him at checkpoints with a new bag of food and water.

Konda explains that unlike sanctioned canoe racing, where the boats have very rigid geometric requirements, the paddle races he participates in are less structured. While some races have divisions based on experience, most are open-class, divided into men's and women's solo, tandem and team (more than two paddlers) categories. Racers must use paddles, either single- or double-blade, and fixed oars aren't allowed.

"Age isn't as large a factor as you might think," Konda notes. "Some of the best paddlers are in their 40s and 50s and even beyond. This is an activity where experience, efficiency and the ability to manage pain and discomfort are more important than pure physical prowess."

These races are, for the most part, nonstop—and grueling. In the 2009 MR340, Konda took third place in the men's solo category, with a time of 51 hours, 5 minutes, sleeping a total of four hours for the entire race. He's done his favorite race, the South Dakota Kayak Challenge—a 72-mile affair from Yankton, S.D., to Sioux City, Iowa, on the Missouri River—twice, once even taking second place with a time of 9 hours, 38 minutes.

"There were rolling checkpoints every 20 miles, where I wouldn't stop but simply throw the used supply ashore and grab a new one on the fly," he says. "Often, you are neck-and-neck with someone and if you fall behind, you can't catch up."

Besides testing strength and stamina, races can also strike a bit of fear into the hearts of the paddlers.

Konda in his Sitka sea kayak.

"I've been terrified a few times and have ended up in the emergency room after a race, but fortunately nothing too serious," Konda says. "Some of these races go day and night, which means paddling on an unknown river in the dark in changing weather conditions, including fog or high winds. Sleep deprivation, dehydration, getting sick due to exertion and blisters are just some of the challenges that a paddler faces on a long race."

"With my wife's help, I have been able to avoid most of these pitfalls, but it is still frightening paddling on the Missouri River at night, with its wing dams, gurgling water, swirling eddies and exploding boils. With a combination of experience, judgment and providence, I have personally remained unscathed."

While kayaking is something Konda came upon in graduate school, he was drawn to engineering at an early age.

"I wanted to be an engineer before I even knew what they did," he says. "As a South Dakota farm kid, I was constantly fixing and constructing all manner of buildings and equipment. While working through my undergraduate studies, I became interested in bridge engineering and have continued with that line of work."

In his eight years with HNTB, Travis has spent four years in the Kansas City office, contributing to the design of bridges such as the under-construction Stan Musial Veterans Memorial/New Mississippi River Bridge in St. Louis and the Amelia Earhart Bridge in Atchison, Kan. (see "Replacing Amelia's Bridge" in the 12/2012 issue). The rest of the time, he's been in the field working as a construction/erection engineer. He's currently working on-site in Hastings, Minn., on a steel tied arch spanning the Mississippi River.

And kayaking has helped him appreciate these bridges from another angle.

"A kayak provides you with great access to view bridges from the underside—be they old, new or under construction," he says.

Konda owns multiple boats, but he's spent the majority of his time in three of them. A used Dagger Sitka sea kayak was his racing boat until he purchased a used Fenn Mako XT surf ski (a surf ski is a swift, specialized sit-on-top kayak designed to ride ocean waves). The vessel that he has the most seat time in is a Cobra Kayak Expedition, which he uses as his training boat. In general, he says, there is a balancing act between boat speed (long and narrow) and stability (wider).

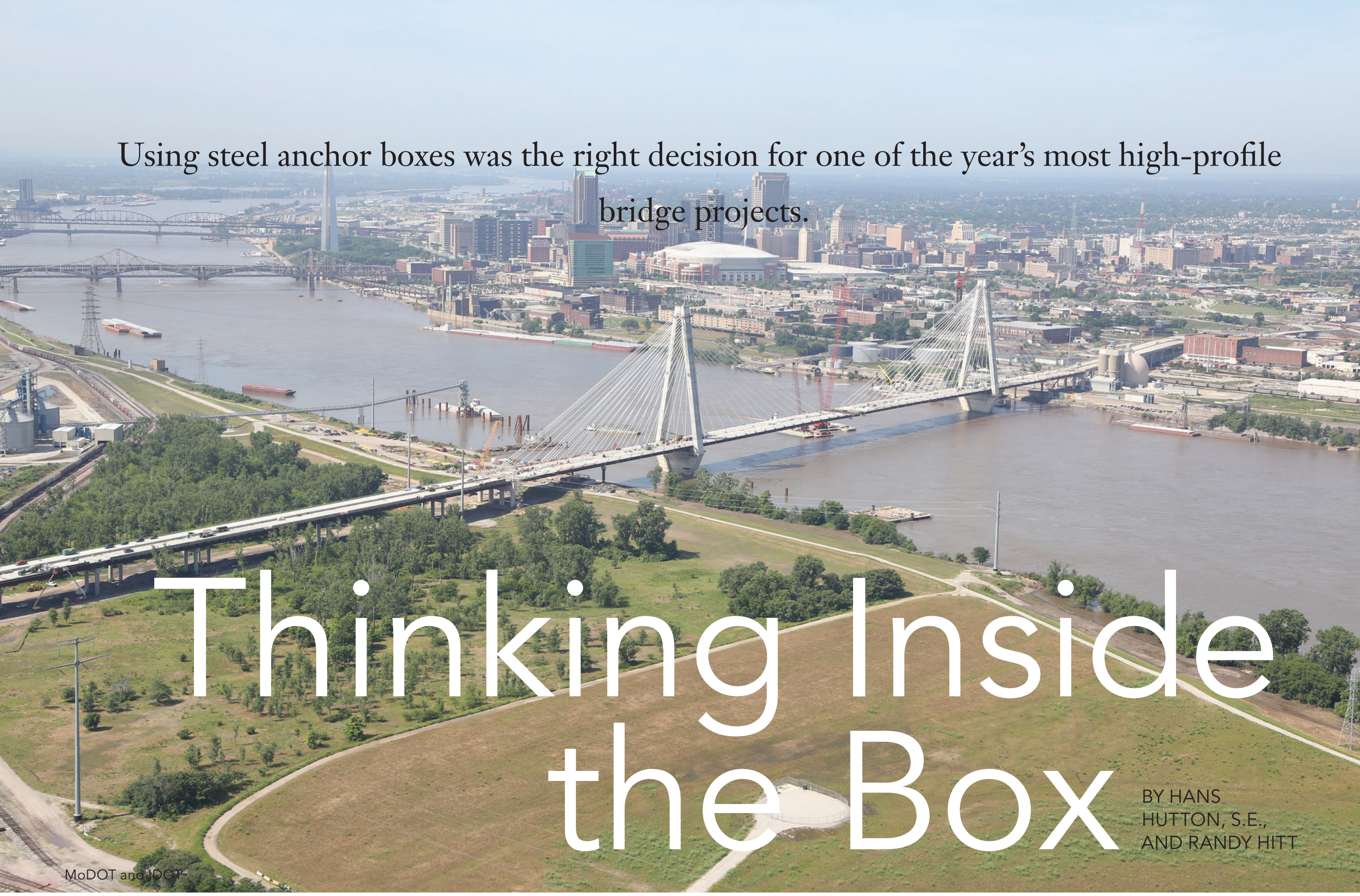
Training regimen depends on the race. With the MR340, for example, Konda started training six months prior, paddling three to four times a week—sometimes for just 45 minutes (sprints) and other times enduring slogs of eight hours or more to test equipment and gain the necessary muscle and mental toughness.

"Kayaking is subtle; one can coast along with minimal effort," he says. "Technique and boat fit-up is important; very small changes can be the difference between being comfortable and efficient—seat position, hand placement, etc.—or being miserable and ineffective." ■

Using steel anchor boxes was the right decision for one of the year's most high-profile bridge projects.

# Thinking Inside the Box

BY HANS HUTTON, S.E., AND RANDY HITT


MoDOT and IDOT

The new bridge will alleviate traffic on the nearby Poplar St. Bridge.

**THERE WAS MUCH DEBATE** over the permanent name for what was once known as the New Mississippi River Bridge.

The bridge connects Illinois with Missouri over the Mississippi River near downtown St. Louis, and politicians on both sides of the river had different ideas for the name. The Illinois side wished to honor military veterans while the Missouri side wanted to name the bridge after the St. Louis Cardinals' legendary outfielder and first baseman Stan Musial, who died in January. In the end both sides won, and this past summer the bridge was officially named the Stan Musial Veterans Memorial Bridge (SMVMB).

The $230 million bridge is being built to alleviate traffic on the nearby Poplar Street Bridge, which carries Interstates 55, 64 and 70 as well as U.S. 40, and will run between downtown St. Louis and East St. Louis, Ill. The plan is to reroute I-70 traffic to the new bridge, which will accommodate two lanes in each direction, with the ability to expand to three lanes. The long-term plan is to build another, adjacent bridge. When completed in February, it will be the third-longest cable-stayed span in the United States.


**Hans Hutton** (hhutton@hntb.com) is a chief engineer with HNTB Corporation. **Randy Hitt** (randy.hitt@modot.mo.gov) is a project director with the Missouri Department of Transportation.

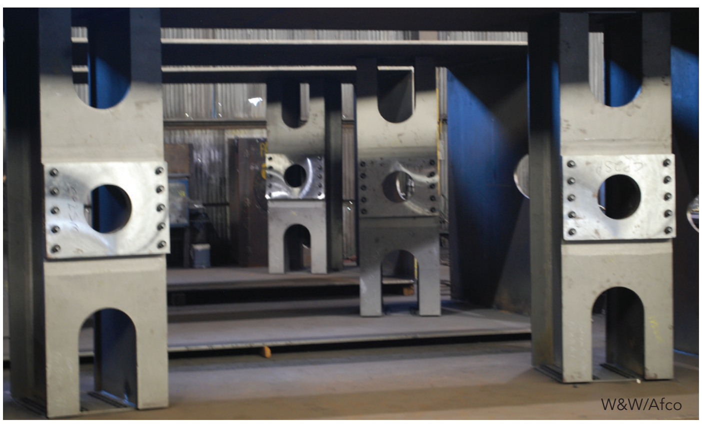
## A Different Type of Box

HNTB Corporation, the bridge's structural engineer, created a design that employed steel anchor boxes inside of the pylons for the stay cable anchorages instead of using formed concrete corbels. The use of steel anchor boxes eliminated the need for complex forming of concrete inside the bridge's delta-shaped pylon legs. Ultimately, the use of steel saved time, reduced cost, increased accuracy in the tight tolerances of the cable geometry and reduced the amount of post-tensioning needed around the perimeter of the pylon legs.

The decision to use steel anchor boxes is a classic example of how recognizing contractors' challenges can inform design. While working on two previous cable-stayed bridges—the Cape Girardeau and Greenville Bridges—HNTB used concrete corbels to anchor the cables inside the towers. Both projects were highly successful, but it was obvious during construction that


▲ The steel anchor boxes ranged from 6 ft to 9.5 ft tall.

▼ There are anchor beams within each steel anchor box.





▲ The bridge carries I-70, with two lanes in each direction.

the tedious and labor-intensive forming and post-tensioning involved with creating the corbels slowed contractors' pace. As good engineers are always seeking feedback and looking for ways to improve the process, HNTB opted for a more efficient approach with the SMVMB.

Certainly, steel anchor boxes have been used on other bridges, but HNTB had never before used them to anchor stay cables on their cable stayed bridge designs. Because the Illinois and Missouri Departments of Transportation (IDOT and MoDOT) have a very aggressive schedule for this bridge, the HNTB design team believed that steel anchor boxes would be appropriate for the project.

HNTB began design in July 2008 and completed its baseline design, including the use of steel anchor boxes, in July 2009. That November, the highway departments awarded the construction contract to a joint venture of Massman Construction, Traylor Brothers and Alberici Constructors.

### Slow to Change

As any contractor will tell you, whenever you have to stop and change a process, progress slows down. Creating concrete corbels requires the building team to stop and switch from forming the lifts of the tower to building forms for the corbels. Concrete also would have required the contractor to form in the air, as the towers for the bridge extend 400 ft. above the water. With steel anchor boxes, however, the team could start at deck elevation with a hollow tower and continue all the way to the top with the same basic shape.

"HNTB designed each box as an individual piece with a vertical dimension from 6 ft. to 9½ ft.," said Dennis Noernberg, bridge detailing manager for W&W/AFCO Steel, which fabricated the steel for the bridge. "That allows for a continuous shaft of boxes from the lowest cable to the cable at the very top of the pylon."

Within each box is an anchor beam. While other designers have typically stipulated welding the anchor beams to the boxes, HNTB designed it so that the anchor beams were bolted to the boxes. "This was a good option, a lot more predictable from a fabrication standpoint," Noernberg said. "We were able to drill holes in the box walls for the anchor beams with digitally controlled equipment, increasing accuracy."

Additionally, there is increased potential for human error when fitting large steel plates inside the boxes, setting them at the correct angle and welding them in place, he explained. "The extensive welding required can actually deform the box and cause you to be out of tolerance. The bolted option was definitely more straightforward and more predictable."

HNTB also used the bolted option to attach the cable anchorage to the edge girder at the deck level. "For the fabricator, it's not as risky as a welded connection," Noernberg said. "The bolted option made it easier to maintain the required tolerances since welding distortion is eliminated."

Tom Tavernaro, project manager for the joint venture contractor, agreed that the steel anchor boxes were definitely a better solution.

"They help maintain the geometry of the stay cables within 0.3 degrees of the theoretical vectors," he said. "The reference planes for the anchor boxes were tied to the anchor geometry in the fabrication shop. After we set the boxes in place, we had to adjust them to the target coordinates, but that's much easier to do than trying to align concrete forms down to the tolerances you need."


▲ Tower construction took approximately 10 months.


▲ All of the structural steel elements on the bridge are made of weathering steel.

"Steel anchor boxes were a better solution than formed anchorages, and they saved us time in the congested, upper portion of the pylon," he added.

"Steel is a good solution because it makes construction of the pylons go faster," Noernberg said. "Since the steel boxes are actually the form for the inside of the pylon wall, they don't have to form inside with some other method."

In addition, all of the structural elements on the bridge are made of weathering steel, which has a 100-year design life and saves on cost of maintenance, materials and interruption to traffic.

## Above Water

Bridge projects often require workers spend their work hours off the ground and over water. Here, steel anchor boxes

▼ Joining the two sections over the Mississippi River.


The Illinois and Missouri sections, before being joined in the middle.


The project uses 8,000 tons of structural steel in all.

provided another advantage: minimizing the work the construction team had to perform in the air. "We were able to pre-tie the rebar and anchor box assemblies on a barge working at a height of 20 ft rather than at several hundred feet" Tavernaro said. "The least amount of work you have to do at the top of the tower, the better off you are."

Tower construction was about a 10-month process, which went quickly for several reasons, according to Tavernaro. "We built plenty of templates to get the prefabrication done off of the critical path, and we were fortunate to have equipment that allowed us to pick up ganged assemblies of these boxes that weighed upwards of 70 tons."

The joint venture contractor worked with W&W/AFCO to gang together the 6-ft-tall boxes in the shop. "We adjusted the tower lift heights on the plans to where they coincided with the tops of the anchor box tops," Tavernaro said. "We set a gang of

The bridge is expandable to three lanes in each direction; the long-term plan is to build an adjacent bridge.


A cable anchorage.


A view from one of the 400-ft-tall pylons, with the Illinois and Missouri sections connected.

two or three boxes and basically poured the whole thing in. We could tie all the rebar and the anchor box and everything for a lift on a barge and then set it all in place in a short time period."

The project used Massman's barge-mounted pedestal crane, a Manitowoc 7000 ringer, which has a 350-ton capacity, 400 ft of boom and 40 ft of jib. "If we didn't have that equipment, we would have had to hoist smaller assemblies or build each one individually in place," Tavernaro said.

Overall, the project required W&W/AFCO to fabricate 8,000 tons of steel, a significant project for the company. "Any fabricator will tell you that the cable stayed bridge is one of the more complex to fabricate," Noernberg said.

The delta-shaped pylons require all cables to strike the deck at both vertical and horizontal angles, which means essentially working in three dimensions and with tighter tolerances. "It's very complex work that demands a high level of skill for people in the shop," Noernberg said. "We did it successfully so that it all went together very well in the field." ■

**Owner**
Illinois Department of Transportation and Missouri Department of Transportation

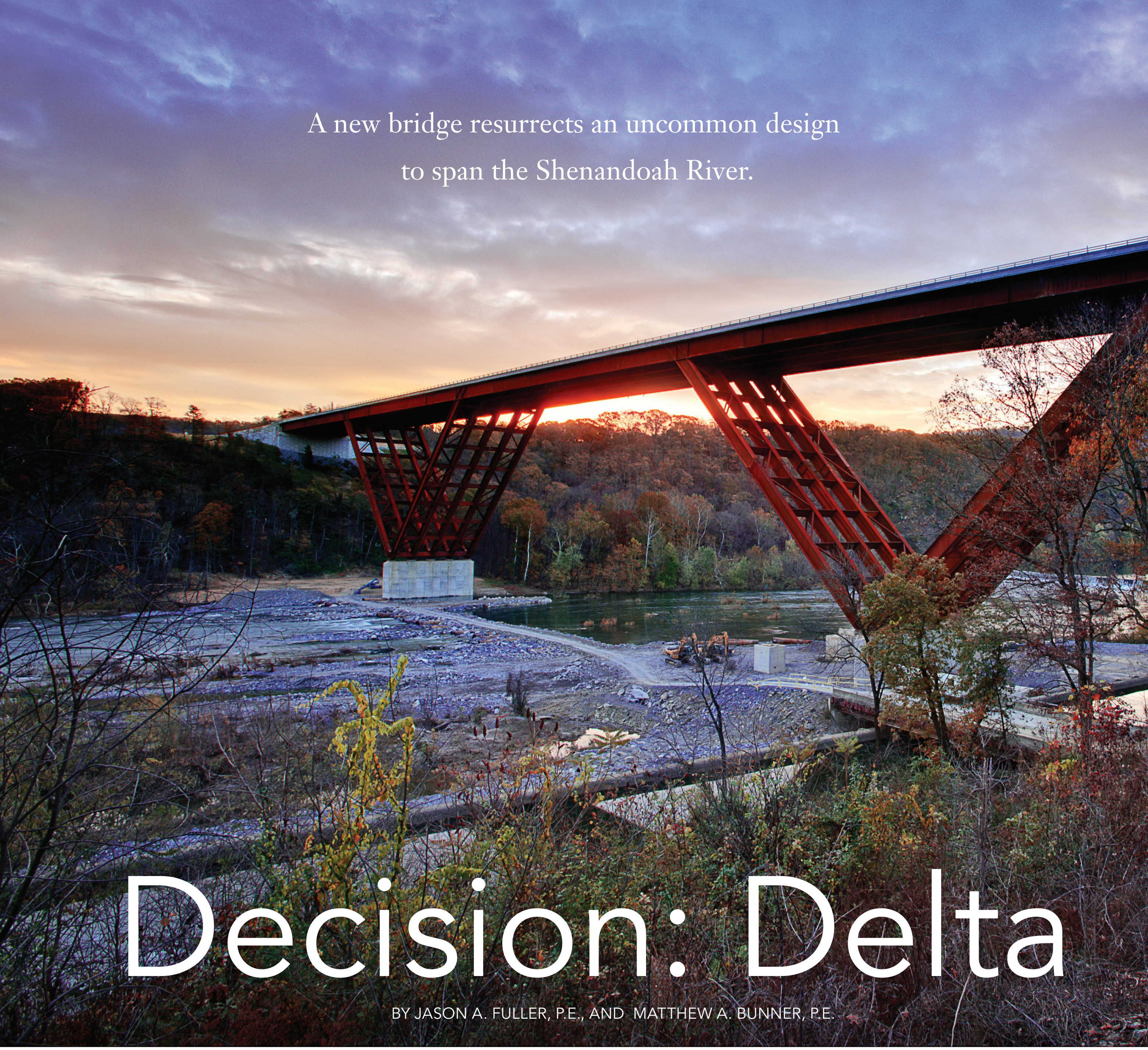
**General Contractor**
Massman, Traylor, Alberici, a Joint Venture

**Structural Engineer**
HNTB Corporation, Kansas City

**Steel Team**

**Fabricator**
W&W/AFCO Steel, Little Rock, Ark. (AISC Member/NSBA Member/AISC Certified Fabricator)

**Detailer**
Tensor Engineering, Indian Harbour Beach, Fla. (AISC Member/NSBA Member)



A new bridge resurrects an uncommon design to span the Shenandoah River.

# Decision: Delta

BY JASON A. FULLER, P.E., AND MATTHEW A. BUNNER, P.E.

**Jason A. Fuller** (jason.fuller@hdrinc.com) is an associate vice president and national program lead for Construction Engineering with HDR and served as the project manager for the Shenandoah River Bridge. Matthew A. Bunner (matt.bunner@hdrinc.com) is a vice president and Bridge Section Manager at HDR and served as the lead bridge engineer for the project.

**JUST AN HOUR'S DRIVE** west from Washington, D.C., the new Shenandoah River Bridge stands in aesthetic harmony with its surroundings.

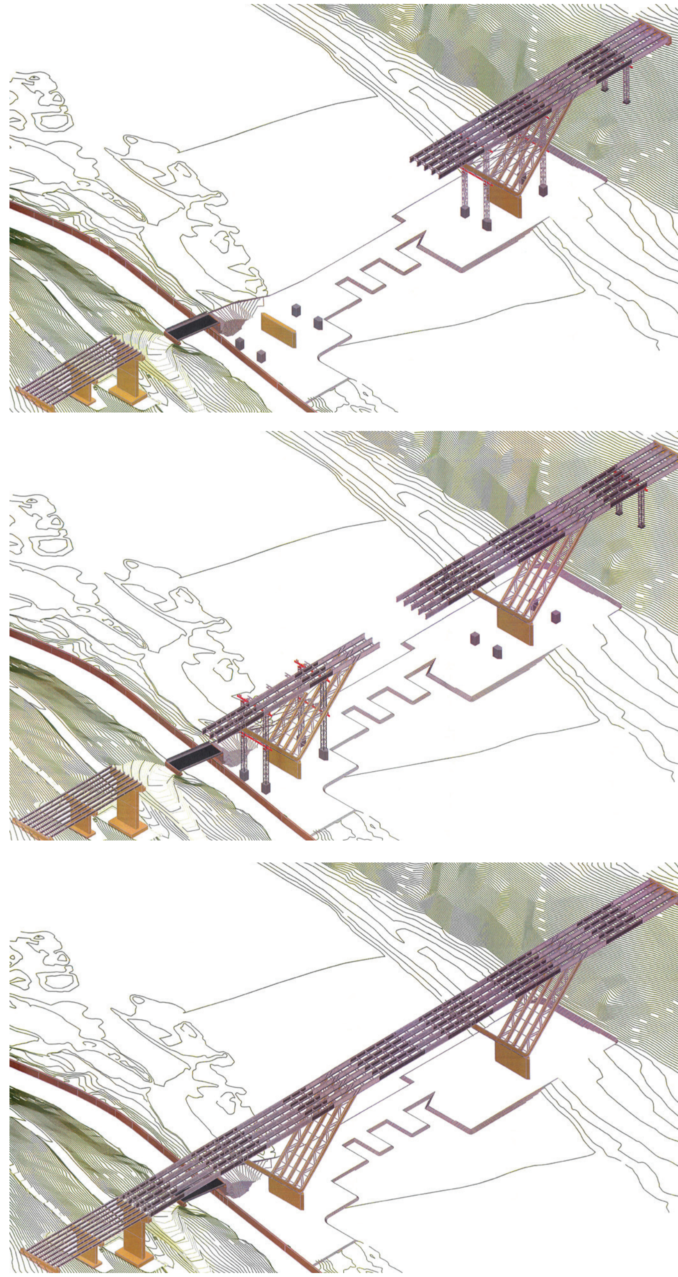
The project exists within a unique ecosystem where the scenic Shenandoah River valley boasts steeply rising wooded mountains, a diverse wildlife habitat, rolling farmland and quaint, historic towns. Not surprisingly, the region has evolved into a desirable getaway from the frenzy of urban life.

With the subsequent increase in traffic, the West Virginia Department of Transportation—Division of Highways (WVDOT) determined that the winding two-lane road that carried West Virginia Route 9 (WV9) through the valley was no longer sufficient. In September 2009, it revealed the design for a new

Photos: Courtesy of HDR, Keith Philpott, photographer

➤ The Shenandoah River Bridge uses 6,325 tons of structural steel.

➤ Various stages of the steel erection.



alignment: a four-lane divided highway using a bridge over the Shenandoah River. At the crossing location, the proposed grade was nearly 200 ft above the river, and the overall bridge length would be nearly 1,800 ft. While there are no navigation requirements for the river, the environmental constraints for the project and the relatively high cost of substructure units located in the valley dictated that the main span be approximately 600 ft in length. To accommodate these constraints, a three-span continuous deck truss configuration (400 ft – 600 ft – 400 ft) with short plate-girder approach units was initially selected during the design phase.

In early October 2009, WVDOT modified the procurement from design-bid-build to design-build and instructed contractors that they could bid the as-designed truss or develop and bid a different structure type, providing they addressed the following criteria:

- The chosen substructure locations for the deck truss bridge generally must be used, with very limited latitude.
- The established horizontal and vertical alignment could not be changed.
- Alternatives that required increased amounts of disturbance to the gorge slopes would not be considered.
- The use of a causeway or cofferdams, other than as shown on the plans for the as-designed bridge and/or in the Section 404 (of the Clean Water Act) Permit, would require re-permitting.
- The design must comply with all previously established environmental commitments.

Following concept approval, structural engineer HDR Engineering developed a delta frame design that delivered significant savings compared to proposals for more traditional designs and also resurrected a tried-and-true form that had been largely forgotten since the 1970s.

## A New Look at an Old Design

HDR and general contractor Trumbull Corporation performed preliminary design and pricing on both concrete and steel options, and found that the anticipated construction costs for the concrete option were much greater; further evaluation

The superstructure consists of a five-girder, four-substringer system supported by five lines of delta legs—one for each girder.

focused solely on the steel alternatives. It was understood that deck configuration and cost would be similar for all of the proposed bridge schemes; therefore, the difference in cost would primarily be driven by the amount of steel, unit cost of fabrication and erection cost.

Based on a database of past projects, the team believed that a steel plate girder option with span lengths similar to the originally proposed truss configuration (400 ft – 600 ft – 400 ft) would result in approximately 145 lb. per sq. ft (psf) of structural steel, or approximately 50% more steel than the truss configuration, which would have been around 100 psf. From a superstructure perspective, the overall length of the delta frame unit would have been ideal for a traditional five-span steel plate girder unit with span lengths of 250 ft – 300 ft – 300 ft – 300 ft – 250 ft. Such a scheme would likely result in only 60 psf of structural steel; however, the design constraints did not allow for additional piers.

While investigating the possible plate-girder arrangements, the team determined that the ideal five-span plate girder option actually could be achieved if supports for the girders were provided 150 ft to either side of the as-designed river pier locations. The supports, envisioned to be steel slant legs at each girder line, could be inclined and meet at the existing river pier locations. With 200 ft of vertical space from the profile grade to the river, the supports could be inclined as much as 45° and still remain above the required river flood elevation (there was no requirement for navigational clearance).

The delta frame design produced 110 psf of structural steel, which was slightly above the original truss weight but facilitated significant fabrication cost savings (the structural steel cost was only about $1.65/lb including erection, which was approximately $0.75/lb less expensive than what was anticipated for the truss). These fabrication cost savings, along with other cost-effective options, offered a total savings of about $8 million (20%) compared to the next low bidder, and more than $13.5 million (33%) when compared to the two bidders that proposed a segmental concrete option.

The final steel superstructure of the new bridge consists of a five-girder, four-substringer system supported by five lines of delta legs—one for each girder. Each individual leg covers a vertical distance of 150 ft and a horizontal distance of 150 ft, creating a girder span of 300 ft between the delta legs. The span lengths between the abutments and piers adhere to the original configuration: 400 ft – 600 ft – 400 ft.

Relatively few rigid steel frames of this type have been constructed over the past few decades, and the singular nature of the bridge design meant there were no directly applicable design codes for portions of the structure. In some cases, such as in the design of the slant legs, the team had to establish design criteria and perform tailored design checks based on an interpretation of the code provisions and the use of other technical research that was available.

## Putting it All Together

The Shenandoah River Bridge's distinctive design demanded unique procedures for erecting the legs and tall temporary works and to accommodate the small site footprint, fluctuating river levels and other challenging site conditions. Modeling and analysis of the staged bridge erection developed as an extension of the final design. The team modified the non-composite detailed model used for analyzing the completely assembled steel framing to perform the staged erection analysis. Falsework towers, tensioned stays and temporary supports were added to the model. All elements of the modular truss falsework tower sections were included in the model as beam elements to facilitate design of the tower elements for all global and local effects. Stays were modeled as tension-only cable elements, and springs were used to model the connection (jacks) of cross girders to structural steel girders or legs. The vertical connection of the cross girder to structural steel was modeled with compression-only springs.

The project team implemented a geometric nonlinear analysis to evaluate the structure, including falsework, piece-by-piece with load tracking. The structure was modeled in 77 stages, where a stage is defined as the amount of work that could be completed during a shift or between any appreciable wind or thermal event. Each stage was then separated into individual steps. A new step was specified each time the lifting crane was released and a new piece was placed. A total of 207 individual steps were further defined in the model.

Many of the benefits of the delta frame scheme were realized not during design but rather during construction. For example, a completed delta frame (two legs and girder between) for one or more girder lines provided a significant amount of bracing to the temporary towers. After closing a delta frame, the structural steel also transferred a large portion of dead, wind and thermal loads during construction to the supports. Even prior to the formation of a delta, attaching multiple lower leg pieces to the falsework cross girder and

Pre-deck...

...and post-deck.

lower knuckle (and river pier) provided significant rigidity to the temporary structural system. The participation of the structural steel as a temporary support helped reduce the size of temporary works and created a stable, stiff system prior to completion.

Additionally, due to structure symmetry about both the longitudinal and the transverse centerlines, four similar quadrants were built. With each section that went up, including temporary works, the crew gained experience that improved production rates for subsequent sections.

## Natural Challenges

As majestic as the Shenandoah River valley is, the topography of the bridge's location posed significant site access and staging restrictions. An access road with multiple switchbacks, a temporary bridge to span a hydroelectric raceway and a causeway spanning the full width of the river, with pipes to accommodate flow, were all required, and steel had to be delivered on demand to accommodate the lack of on-site storage capacity.

Nature itself presented more than its fair share of challenges, as well. During the early stages of erection, in August 2011, a 5.8 magnitude earthquake occurred less than 100 miles from the site. Between 2010 and 2011, the Shenandoah River also experienced four of the top 50 highest watermarks of the last 140 years. Winds exceeding 50 mph were commonly seen during thunderstorms, and the occasional hurricane brought gusts exceeding 70 mph. Through all of these challenges, the temporary works and partially completed bridge proved to be sound.

The team delivered the new Shenandoah River Bridge on time and within the original design budget. Construction began in late 2010, with steel erection from September 2011 to August 2012, and was completed and opened to traffic in November 2012. WVDOT's willingness to use the design-build process—and consider and embrace the delta frame design—was paramount to the project's success. The bridge demonstrates steel's ability to not only be competitive, but notably more efficient and cost-effective in a span range that many believed wasn't possible in today's market. By taking advantage of all of the benefits of a structural steel package, this significant structure, which used 6,325 tons of weathering steel, was delivered at a relatively modest (for bridges with a 600-ft main span) $285-per-sq.-ft price tag, including design and construction inspection costs—and provides a crossing worthy of its spectacular surroundings. ■

**Owner**
West Virginia Department of Transportation – Division of Highways

**General Contractor**
Trumbull Corporation, Pittsburgh

**Structural Engineer**
HDR Engineering, Weirton, W.V.

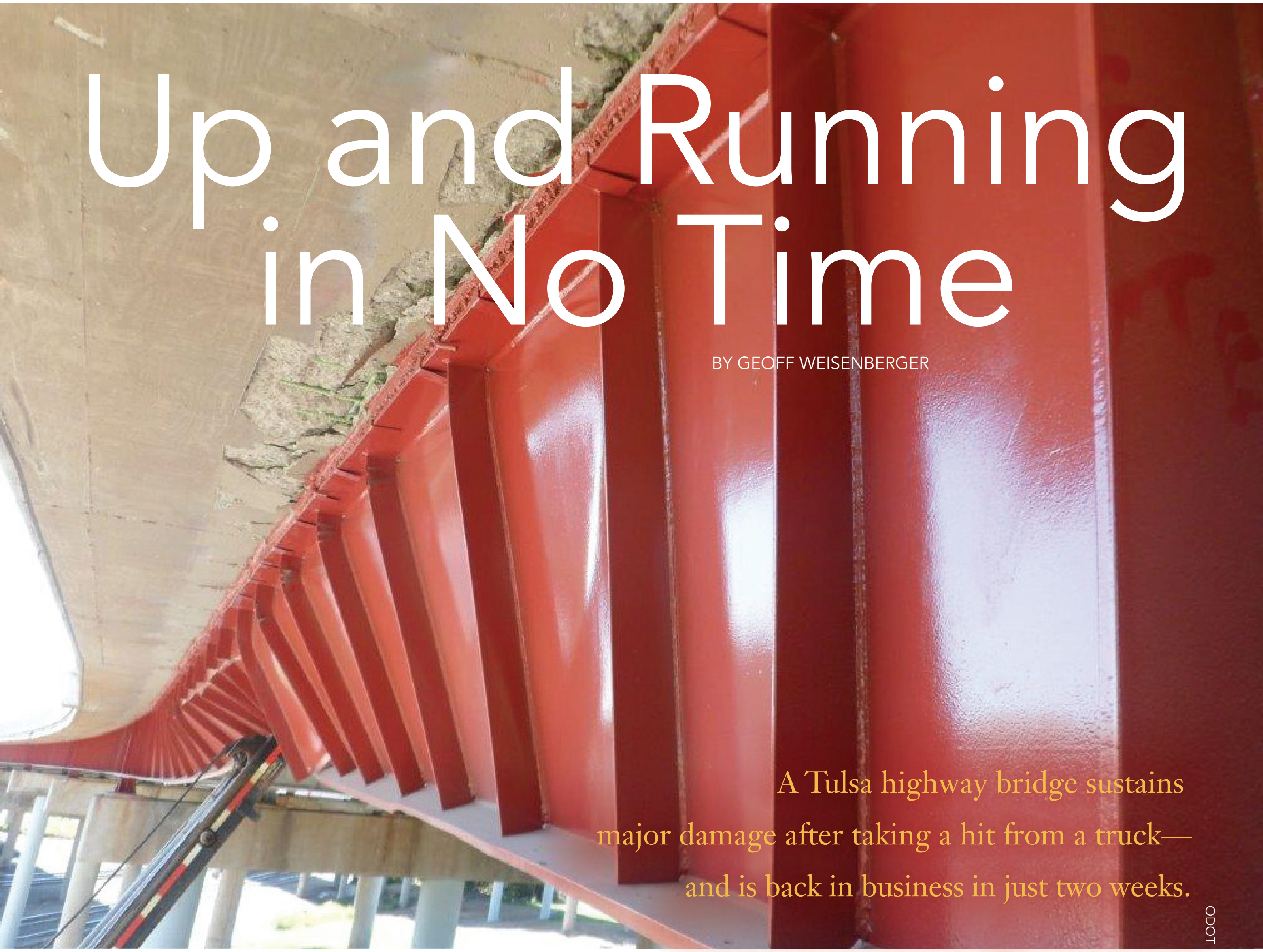
**Steel Detailer**
Tensor Engineering, Indian Harbour Beach, Fla.
(AISC Member/NSBA Member)

The four-lane bridge is part of a new alignment for WV9, which formerly accessed the valley via a winding, two-lane road.

The structure was modeled in 77 stages, each defined as the amount of work that could be completed during a shift or between any appreciable wind or thermal event.

# Up and Running in No Time

BY GEOFF WEISENBERGER



ODOT

A Tulsa highway bridge sustains major damage after taking a hit from a truck—and is back in business in just two weeks.

**Geoff Weisenberger** (**weisenberger@aisc.org**) is MSC's senior editor. **Kenna Carmon** (**kcarmon@odot.org**) of the Oklahoma Department of Transporation contributed to this article.

**THE OKLAHOMA** Department of Transportation (ODOT) knew that the eastbound Interstate 244 bridge over Charles Page Boulevard in Tulsa, Okla., would require some attention on October 15, 2012.

It just didn't realize how much.

That morning, the bridge went through a final inspection for a bridge painting project. A few hours later, a truck, whose bed was raised, slammed into it, damaging one of the girders. While the bridge absorbed a massive impact, it did not collapse. Still, bridge and the road beneath needed to be closed immediately.

This section of I-244 is part of the Inner Dispersal Loop, a vital transportation link for business, commuting and travel around downtown, and Charles Page Boulevard is a major east-west connection in and out of downtown. Additionally, the 948-ft-long continuous-span plate-girder bridge also crosses two other city streets and two rail lines. Further complicating matters was that at the time of the accident, this portion of


◄ The damage to the girder section just after the vehicle hit.

► The contractor field spliced the replacement girder to the existing girder, which only needed a finish coat to restore the structure to pristine condition.

I-244 was itself serving as a detour for two nearby highway construction projects. As such, more than 80,000 vehicles were left scrambling for an alternate route.

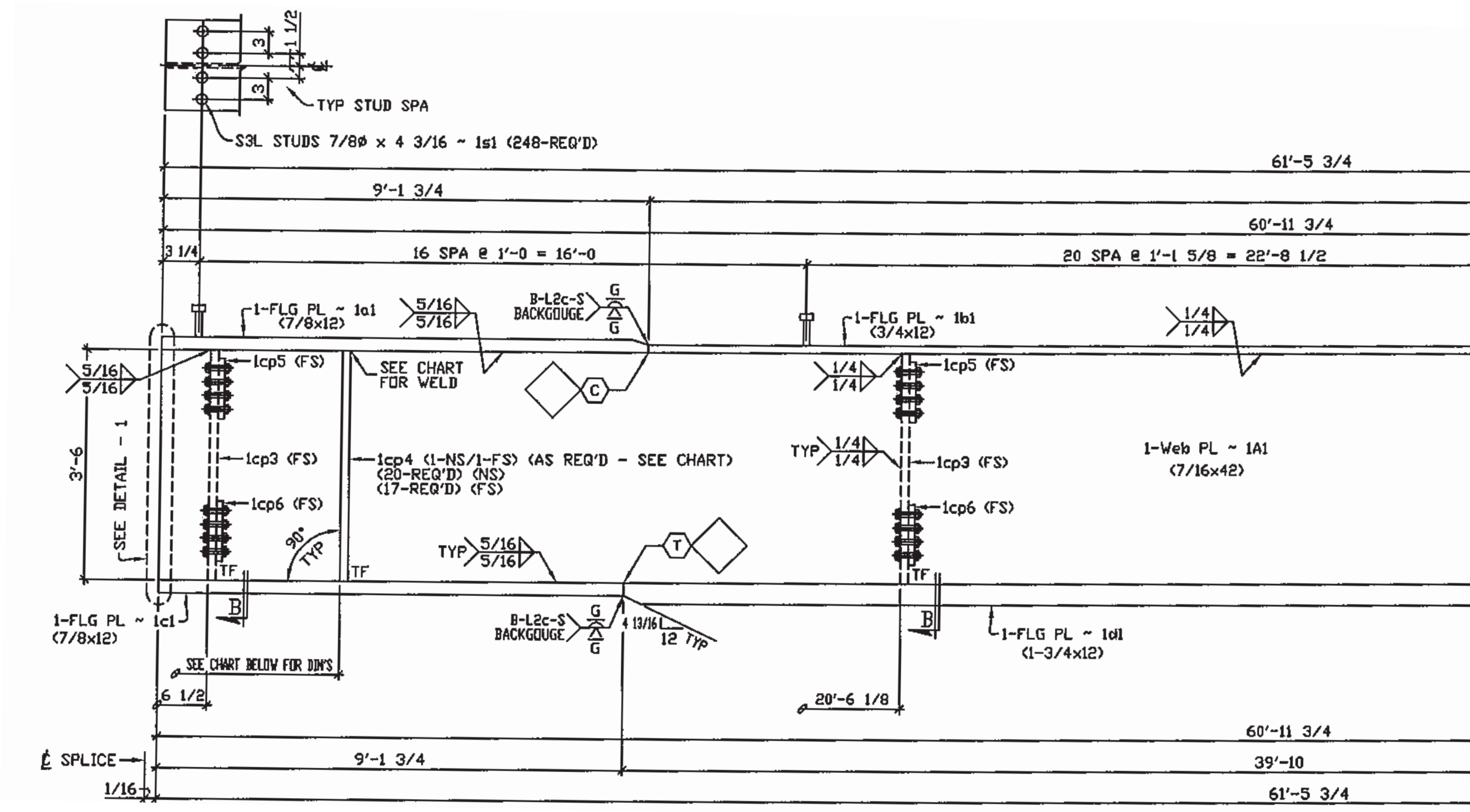
With the truck still wedged under the bridge, engineers were able to get their first look at the damage. Not only was a plate girder rolled up and the web stiffeners crumpled, but the impact also caused the concrete deck to separate from the plate girder by several inches over a length of 80 ft. Their evaluation also involved checking the structural integrity of the bridge to see if it could continue to support itself once the vehicle was removed.

While it was determined the vehicle could be cleared from the scene without the bridge collapsing, the eastbound I-244 lanes above and Charles Page Boulevard would need to be closed until repairs could be made, and temporary steel shoring was put in place under the bridge for safety purposes. This meant traffic on already narrowed detour routes on the loop would have to reroute and squeeze together even more, resulting in significant delays.

ODOT quickly began developing plans to replace the damaged girder and concrete deck. Repairs of this magnitude typically take months to design and for materials to be acquired and fabricated. But realizing the tremendous impact on traffic, all work was expedited and engineering plans and agreements with the contractor, Manhattan Road and Bridge, were underway within the week. Communication played a key role in making the project happen as quickly as possible, and major emphasis was placed on the need for quick responses


▲ W&W/AFCO Steel fabricated, prime painted and delivered a 61-ft replacement girder within 10 days.


► Repairs were completed within 15 days of the crash and 20 days ahead of schedule.



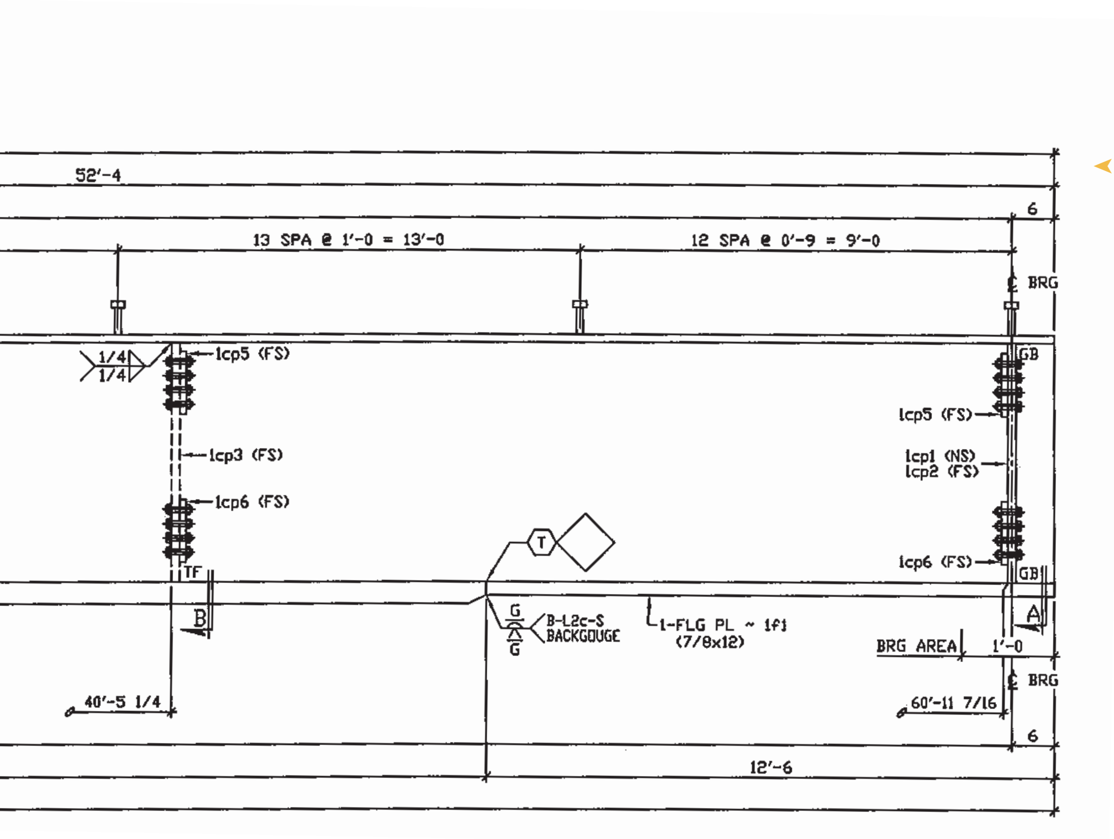

to and reviews of the recommendations, shop drawings and contract language as well as determining concise deadlines to begin and complete the work. An aggressive schedule was developed to have the repairs complete before the Thanksgiving holiday, with a $20,000 incentive/disincentive in place.

Manhattan Road Bridge worked with fabricator W&W/AFCO Steel to fabricate and ship a new section within ten days of the bridge hit. Repairs were completed by October 30th, only two weeks after the crash, and the roadway was able to open to traffic more than 20 days ahead of schedule. ■

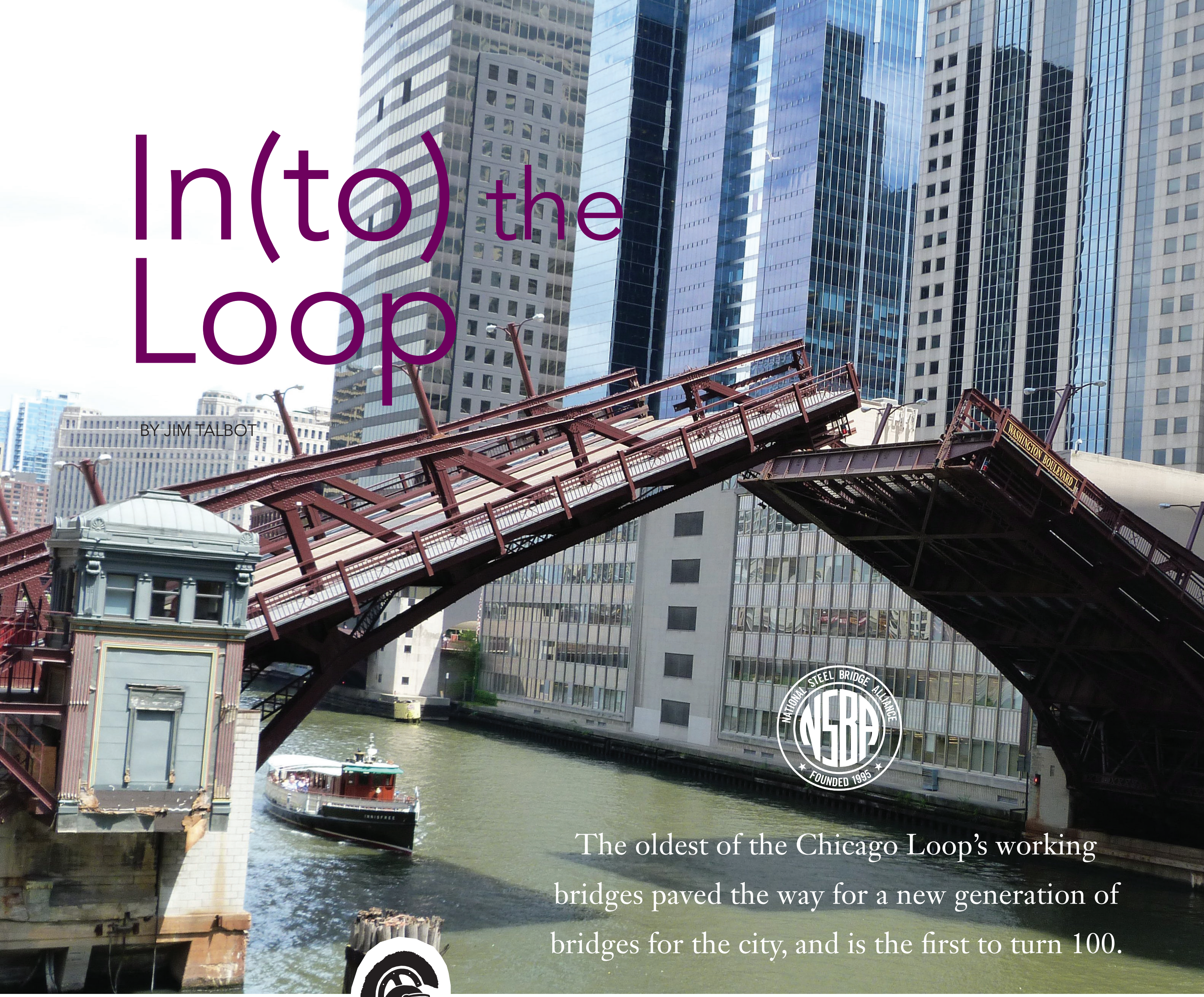
**Owner and Structural Engineer**
Oklahoma Department of Transportation

**General Contractor**
Manhattan Road and Bridge, Tulsa, Okla.

**Steel Fabricator**
W&W/AFCO Steel, Little Rock, Ark. (AISC Member/NSBA Member/AISC Certified Fabricator)




A shop drawing of the replacement girder.




# In(to) the Loop

BY JIM TALBOT

The oldest of the Chicago Loop's working bridges paved the way for a new generation of bridges for the city, and is the first to turn 100.


**STEEL CENTURIONS**
SPANNING 100 YEARS

Our nation's rich past was built on immovable determination and innovation that found a highly visible expression in the construction of steel bridges. The Steel Centurions series offers a testament to notable accomplishments of prior generations and celebrates the durability and strength of steel by showcasing bridges more than 100 years old that are still in service today.

**CHICAGO'S WASHINGTON BOULEVARD BRIDGE,** which crosses the South Branch of the Chicago River, was the first bascule bridge to make use of innovative design improvements patented by Chicago bridge engineer Alexander Von Babo. It turned 100 on May 26, making it the oldest of Chicago's Loop bridges that still move.

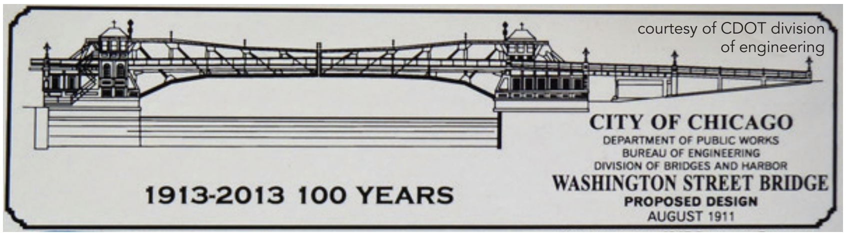
About 700 people attended the centennial celebration, taking advantage of a free day at the McCormick Bridgehouse and Chicago River Museum and also taking home commemorative magnets. A nearby bridge of similar design, the Chicago Avenue Bridge, may soon suffer demolition and replacement. If so, the Washington Boulevard Bridge's preservation becomes that much more important.

### Innovative Engineering

Von Babo immigrated to the United States from Germany in 1886. In 1911 he secured his patent that led to what's known as the second generation of Chicago's trunnion bascule bridges, during which he and others with the Chicago Bureau of Engineers greatly improved bascule trunnions (the fulcrums that balance the movable bridge leaf with its counterweight). Bascule counterweights ("bascule" derives from the French term for seesaw

Several bridges preceded the Washington Boulevard Bridge at the same site, as did a tunnel.

Bascule bridges employ counterweights to minimize the energy needed to lift the bridge leaves.




A magnet commemorating 100 years of service by the Washington Boulevard Bridge.

A Pratt truss has diagonals that slope toward the center vertical. Pony trusses have no top bracing.

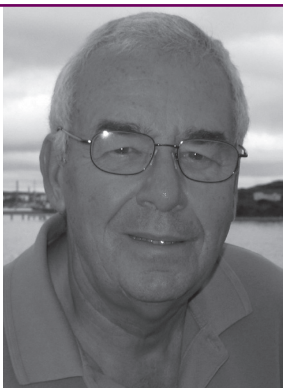
or balance) dramatically reduce the energy needed to raise and lower the bridge leaves.

These improvements made the fixed trunnion bascule bridges more economical than earlier designs—and also greatly changed their appearance. The new designs represented the transition from the lighter-weight and less streamlined designs toward the smoother and more massive designs.

A key feature of the new design was the location of the bascule's rack and pinion. In the first generation Chicago bascules, the location was outside of the truss, which proved to be a design limitation; moving the rack and pinion to the inside of the truss solved this problem. So, city engineers began making use of the new design throughout most of the remaining history of bascule bridge construction in Chicago, and the new design was so successful that it achieved national attention and influence.

Technically, the bridge is a trunnion bascule, double-leaf, Pratt pony truss. The term "pony" means the superstructure contains no top cross-bracing—so the bridge has

**Jim Talbot** is a freelance technical writer living in Ambler, Pa. You can reach him at **james.e.talbot@gmail.com**. Bridge photos are courtesy of **www.historicbridges.org** and its author/photographer/webmaster **Nathan Holth** (**nathan@historicbridges.org**). Holth is also the author of *Chicago's Bridges*, which includes photography and discussion of Chicago's movable bridges, including the Washington Boulevard Bridge.



no height restrictions. A Pratt truss includes vertical members with diagonals that slope downwards toward the center vertical. The span between trunnion centers of the Washington Boulevard Bridge runs 197 ft, and the total structure length is 303 ft. The bridge deck is 36 ft wide and provides 21 ft of clearance above the water.

During its first full year of operation, in 1914, the bridge opened 3,773 times. Today it's raised about 40 times a year for sailboat runs to and from Lake Michigan, and about 14,000 vehicles and 9,500 pedestrians still cross it every day.

## Innovative Construction

Back in 1869, long before the bridge was conceived, the city built a tunnel under the river at what would become the site of Washington Boulevard crossing. The tunnel served wagon and pedestrian traffic, and it even provided an escape path during the Great Chicago Fire of 1871 (residents could avoid the burning bridges). Later the city converted the tunnel for cable and street car systems.

The first bridge to cross the river at this point was an 1875 iron swing bridge. In 1891, the city removed that bridge and relocated a swing bridge from nearby Madison Street to the site. This swing bridge was dismantled in 1907 to make way for the lowering of the tunnel by 9 ft (larger vessels were striking its roof) and for the construction of the new bridge.

The city closed the tunnel in 1953, but substructure construction for the new Washington Boulevard Bridge still had to deal with it. Work began on the substructure in August of 1911 and was completed in about a year. The contractor, Fitzsimmons and Connell Dredge and Dock Co., first sank concrete cylinders on either side of the tunnel. Then workers essentially built a concrete box atop the cylinders, reinforced with steel trusses, and the concrete box straddled the tunnel without putting any load on its roof (these foundation design techniques were later used in similar bridge projects). Work on the superstructure by the Strobel Steel Company began in June of 1912. Workers lowered both leaves into position simultaneously in March of 1913, and pavement and sidewalks followed.

The Washington Boulevard Bridge was the first of Chicago's movable bridges to add aesthetic touches and upgraded materials for the bridge houses, abutment walls, railings and lighting. Its bridge houses, for example, boasted more ornamentation as well as cladding of molded copper sheeting. These aesthetic touches added about $14,000 to the total $238,000 cost of the bridge. Today, based on original plans, the bridge is missing decorative finials that were mounted on top of the trusses at various panel points, but the overall look remains the same 100 years later.

Credit for the longevity of Washington Boulevard Bridge and the rest of Chicago's movable bridges goes to the Chicago Department of Transportation crews that operate and maintain them. CDOT conducts biannual inspections, annual power washing and painting at least once every 10 years. This bridge is now eligible for the National Register of Historic Places. ■

# Stay Ahead of the Curve


Introducing LEAP Bridge Steel, the newest software for bridge design and analysis that makes it easy to explore design alternatives. Adapt to project changes in real time. Make informed decisions at every stage of the project. Get the right information at the right time with an intelligent bridge model. Get the smartest solution for bridge design and analysis – see how much better your steel bridge can be.

Bentley®
*Sustaining* Infrastructure

**Request a free demo of our newest software for steel bridges – LEAP Bridge Steel.**
**www.bentley.com/LEAPBridgeSteel**