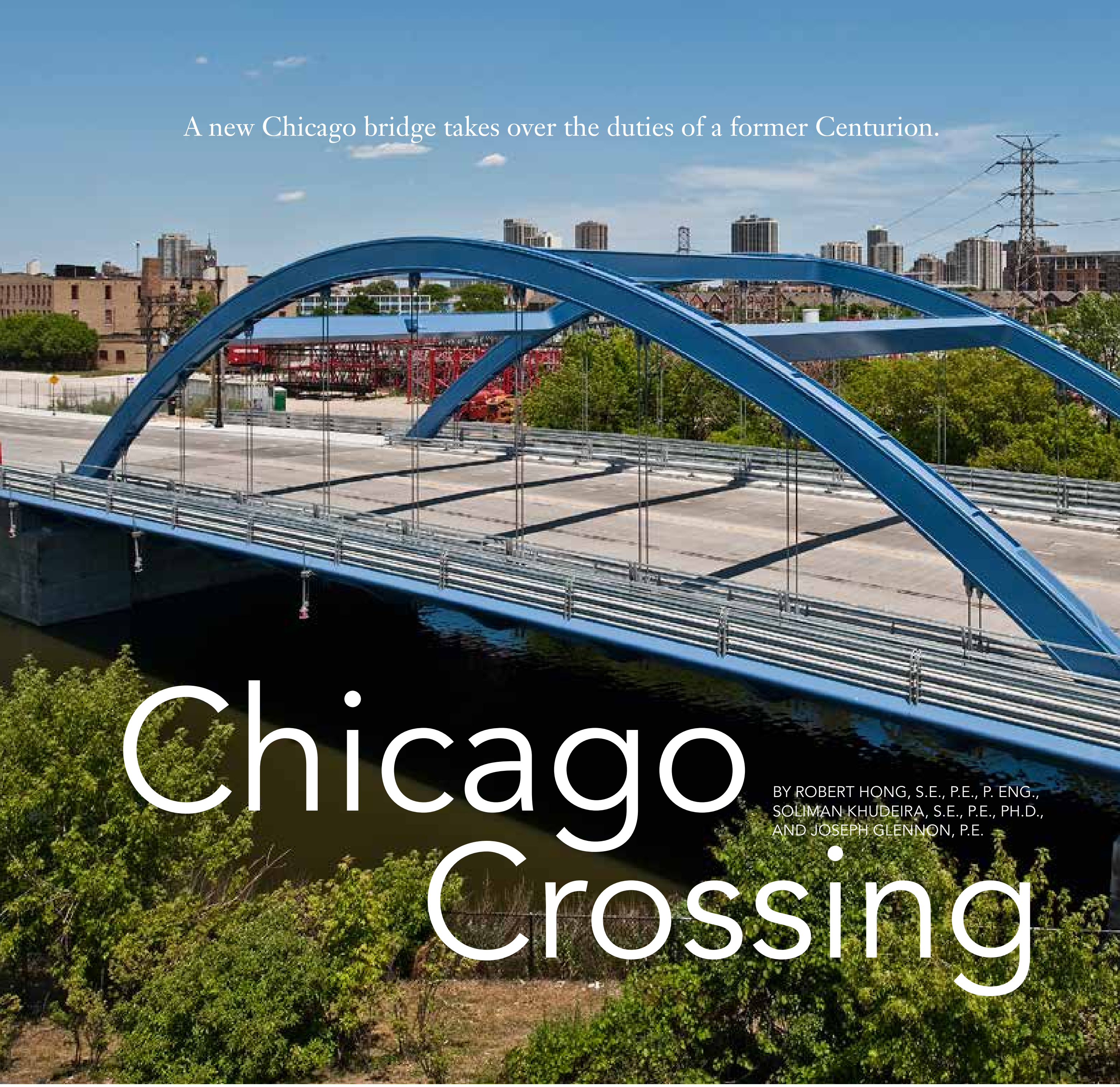


A new Chicago bridge takes over the duties of a former Centurion.

# Chicago Crossing

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

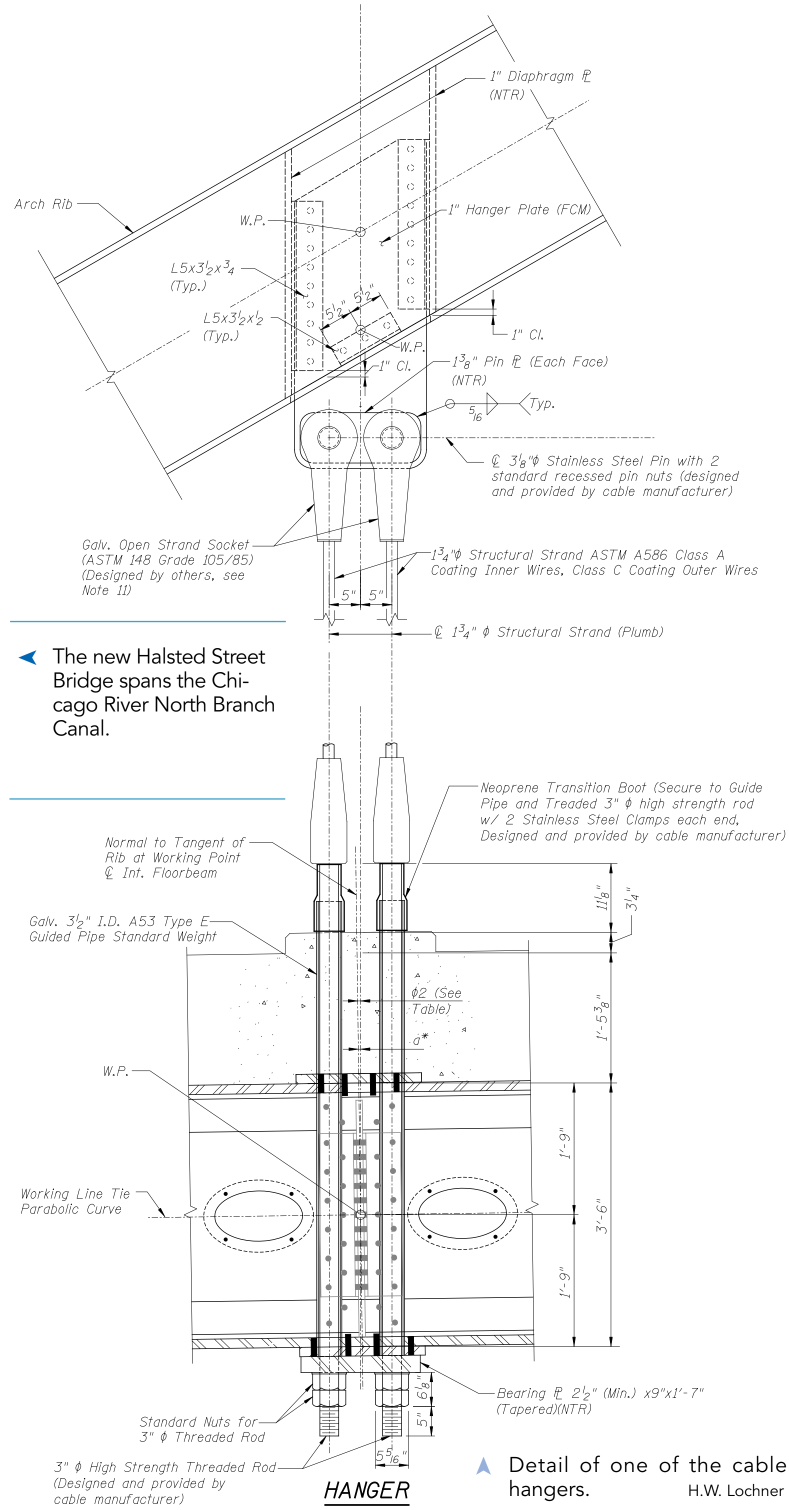
**A FEW YEARS AGO,** the Halsted Street Bridge over the Chicago River North Branch Canal put in its 100th year of service.

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 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.

Photos: Bob Elmore Photography




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

▲ 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.

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 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.

▲ Installing the cables.

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

## 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 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

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

▼ Closing one of the arch ribs.

▲ Floor framing.

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

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. MSC

### 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)