HALSTED STREET BRIDGE OVER CHICAGO RIVER NORTH BRANCH CANAL

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BIOGRAPHY

SUMMARY

The Halsted Street Bridge over the Chicago River was originally constructed in 1908 as a movable bridge, providing navigable waterway. Due to deterioration and lack of river traffic, it had not functioned as a movable bridge for more than 25 years. The existing bridge had become structurally obsolete and functionally deficient.

Different bridge alternatives were considered and evaluated. A modern steel tied arch bridge was eventually selected, due to its cost effectiveness, superior aesthetically-pleasing shape and potential positive economic impact to the local community.

The new replacement structure is parabolically-shaped tied arch bridge. Additionally, two precast concrete arches located under the bridge were designed to provide pedestrian and bicyclists access for future extension of the Chicago Riverwalk.

In addition to the major improvement of bridge accessibility and openness, aesthetic enhancements were incorporated into many elements of the project, including architectural lighting and railings.

STAAD 3D FEM model was used to model the entire bridge. Additionally, SAP2000 3D FEM model was created to analyze the knuckle.

The content of this presentation focuses on the critical design elements and introduce the process of analyzing, design, detailing and erection of the Halsted Street steel tied-arch bridge.
Halsted Street Bridge over Chicago River North Branch Canal

Keywords
Tied-arch bridge, bascule bridge, tie, floor beam, strut, hanger, load path, redundancy, constructability, camber, torsional moment

Abstract
This presentation will discuss the design approach of the replacement bridge, consisting of the Main Span Simply Supported Tied-Arch with North and South Three-Sided Precast Concrete Underpasses, retaining walls and cofferdams. The original Bridge over the Chicago River North Branch Canal was constructed in 1909 as a Bascule Bridge. The existing Bascule bridge is 300ft long and 60ft wide.

The superstructure of the new bridge is a simply supported parabolically shaped steel tied-arch bridge with: 10” deep structural deck slab, composite bolted built-up steel tie box girders (AASHTO M270 Gr. 50W 42”), welded built-up steel box arch ribs, welded built-up steel box rib bracings, welded built-up steel composite floor beams, and structural strands (ASTM A586, Class A/C)

Different bridge alternatives were considered and evaluated, and a steel tied arch bridge was eventually selected. The width of the deck is 80’-0” out to out. 3-D structural analysis was performed for the main span structure to capture the significant unsymmetrical lateral flexure and torsion behavior for the structure subjected to vehicle moving live load, wind load and unsymmetrical pedestrian live load.

Introduction
The Halsted Street Bridge over the Chicago River was originally constructed in 1908 as movable bridge, providing navigable waterway for vessels too high to pass beneath the bridge.

Due to deterioration and lack of river traffic, it had not functioned as a movable bridge for more than 25 years. In 2007, The existing bridge had become structurally obsolete and functionally deficient.

The bridge’s historic status and the waterway underneath were major factors in the preliminary engineering studies. Coordination with the US Coast Guard was made to obtain approval for replacing a movable-bridge with a fixed-bridge. Coordination with the State historic preservation office was made to obtain approval for removing a historic bridge and replace it with a modern bridge. Because the existing roadway profile could not be dramatically changed due to the existing buildings and properties along the approaches to the bridge, there is not much flexibility to optimize the bridge span length. Four different bridge alternatives were considered and evaluated for cost, timeline for construction, aesthetic value, constructability and impact on the environment and community. The bridge options evaluated were: a) haunched steel plate girder bridge, b) multi-span precast concrete arch bridge, c) steel through truss, and d) steel tied arch bridge.

A modern steel tied arch bridge was eventually selected due to its cost effectiveness, superior aesthetically-pleasing shape and potential positive economic impact to the local community.
The new replacement structure consists of steel tied arch bridge main span. With the new bridge deck 22-ft wider than the existing bridge, the parabolically-shaped tied arch replacement bridge carries four-lane vehicular traffic with 2-way bike lane and pedestrian sidewalk. The precast concrete arch under the bridge provides pedestrian access for a future extension of the Chicago Riverwalk. Although minimum navigation clearance is not required by US Coast Guard under the main span, a 12’-4” vertical clearance is kept for the occasional barge and leisure boat traffic under the bridge main span. In addition, aesthetic enhancements were incorporated into many elements of the project, including architectural lighting and railings.

**Figure 3 – New Tied-Arch Bridge**

The only portion of the existing bridge structure to remain and be reused as part of the proposed structure is the existing counterweight pits each consisting of a river pier, anchor pier and the enclosed walls.

**Innovative Application of Various Techniques**

Few short span tied-arch bridges have been built recently in the U.S. due to concerns regarding redundancy and constructability. One of the most significant constraints was the challenge to minimize the closed box section of tie and arch to the economical size but still maintain its constructability despite the access constraint. The reasonably-sized tie and arch box section for the short span bridge is simply not large enough for the iron workers to crawl inside during erection. The carefully thought-out steel details not only present a feasible solution that achieves the constructability, but also ensure sufficient redundancy and improve cost competitiveness. The main span design incorporates several major safety and cost-saving innovations that advance the state-of-the-art tied arch bridge technology. Three of these innovations are:

1. **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 (FCM). This weakness 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 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 to eliminate a critical shortcoming of the tied arch structure.

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. Furthermore, the use of weathering steel for all steel members also improves the bridge corrosion resistance and long-term durability.

**Figure 4 – Interior View of the Tie**
2. Composite concrete floor and 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.

3. Load path redundancy built into the 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 of the two structural strands are fully capable of supporting the full bridge service loading under the temporary condition when the other structural 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.

The end result of all the above is an efficient and durable overall bridge system working as one single unit with a high degree of safety through design redundancy.

Figure 5 – Pair of Cable Hangers at Each location - ASTM A586, Class A/C Structural Strands

Arch Geometry and Details

The arch rib follows a line of parabolic curve with a vertical rise of 35-ft and 160-ft span, resulting in a rise-to-span ratio of 1:4.5, which is within the optimal ratio of 1:4 to 1:5.

The bridge consists of 9 equally spaced hangers. The spacing between the hangers is 15ft-6in.

The transverse floor-beams and longitudinal stringers act compositely with the concrete deck. The floor beams are supported by the tie, and the tie is supported by the strand hangers anchored at the bottom of the tie girder and attached to the bottom of arch using steel gusset plates and open sockets. The gusset plates penetrate the arch.

Figure 6 – Arch with the Top-Struts

Floor-Beam and Top-Strut Camber

The rib element is a 2ft-6in wide by 3-ft deep welded steel box. For simplicity, the arch is braced with a lateral system that consists of only four top struts rigidly framed with the ribs.

One of the significant challenges during the design is to control and minimize the large torsional moments imposed on the tie girder.

The relatively wide but short bridge geometries lead to a large torsional stiffness of the tie girder, and in turn a large torsional moment is produced in the steel tie.

Through camber of the floor-beams and arch top strut bracings, the designers were able to introduce a global counteracting torsional moment to the tie by forcing the arch members to close during erection.

This unique procedure helps to reduce the permanent torsion in tie girder and thus minimize the size of the steel ties and its splice connections.

Floating Stringer System

A conventional floating stringer and deck system was utilized. Stringers are framed into the floor beams with the bolted shear connections. However, one end is made bolted connection in short slotted holes.
The bolts installed in the slotted holes are only finger tightened during steel erection and allow the structure to elongate and prevent any accumulation of tension force in the stringer during steel erection and concrete deck placement.

All dead-load tension force is intended to be carried by the tie girders alone.

After the concrete deck placement occurs, the connection of the bolts in slotted holes are then fully impacted and tightened.

Because the knuckle has to be capable of carrying the entire global tensile force in the web, a finite element analysis was performed for this deep web plate to ensure the structural adequacy.

Figure 7 – Stringers to Flor-Beam Connection Showing the Stringer End Connections with Short Slotted Holes on the Stiffener on One Side Only

Arch-Tie Connection (Knuckle)

The knuckle is where the tie girder and the arch join. It is a critical link to transfer the thrust forces from the arch rib to the tie girder. A 3D FEM model of the knuckle was developed.

Furthermore, pot bearing is placed under the knuckle at each of the four corners under the bridge floor system.

Bearing stiffeners and jacking stiffeners are all have to be placed in the knuckle. This poses a formidable challenge to not only need to meet the requirements of connecting different geometrically configured components, but also satisfy the strength demand for each of these components all within this very confined three-dimensional space.

Figure 8 – Arch to Tie (Knuckle) Details. Also Shown is Knuckle-Tie Splice

Redundancy

The critical aspect in the design of a tied-arch bridge is to provide redundancy in the event of tie girder fracture and failure.

A redundant structure is considered to be one that upon failure of a member or element, the load previously carried by that member can be redistributed to other members or elements temporarily without causing the collapse of the entire structure.

The three measures of redundancy in a structure consist of: internal, load path, and structural redundancy.

In this bridge, internal redundancy is achieved by building up the tie girder using bolts instead of welding.

Load path redundancy is achieved by providing the continuous, composite deck to resist a portion of the tie force in the event of failure of a tie member, although this mechanism was conservatively neglected in establishing redundancy.

In addition, the tie girders are structural redundant in that the hangers provide continuity that allows load redistribution in case a tie is damaged.
Thermal Stresses
The bridge was checked for thermal stresses considering the temperature difference between the exposed rib and shielded tie under the bridge deck. The temperature gradient between these two elements was determined in accordance with the related AASHTO provisions and modeled in the 3D FEM modeling. The corresponding load combination was taken into considerations during analysis.

Generally, if the tie is not shielded under the deck, then the tie and rib are expanding and contracting in the same rate in the bridge longitudinal “X” direction, and, therefore, there is no relative thermal stress between the tie and rib.

In the bridge transverse direction, the guide expansion pot bearings provide adequate lateral movement to accommodate the “Y” direction thermal relative movement between the superstructure and bridge abutments. Therefore there is no restraining force that should be considered in the “Y” direction.

In the bridge vertical “Z” direction, the rib vertical thermal movement is unrestrained. Therefore there is no restraining stress caused by the bridge thermal expansion in the bridge vertical direction.

3D FEM Models
SAP2000 3D FEM model was created to analyze the knuckle. The input forces in the SAP2000 model were obtained from a separate STAAD 3D FEM model of the entire bridge. The forces in the knuckle from the STAAD 3D FEM model are: $F_x$ (axial), $F_y$ and $F_z$ (shear in two axis directions), $M_x$ (torsional moment), $M_y$ and $M_z$ (bending moments along vertical and horizontal axis).

Constructability
Several major constructability issues were carefully studied during the Phase II Design:

One of constraints was the challenge to minimize the closed box section of tie and arch to the economical size but still maintain its constructability without the access to the interior of the steel box during erection.

Hand holes are provided on the web plates of the tie girder at each connection between the floor-beam and tie and at each tie girder field splice location. This allows the erector to make the field connection without entering the inaccessible small box section of the tie girder. The interior of the tie girder is painted bright white for the convenience of future inspection by using inspection camera through hand holes.

Figure 9 – Tie, Floor-Beams, and Hangers
The counterweight of the existing bascule bridge is approximately 370 tons. Considering the difficulty of removing it from the bridge pit during construction, it was decided that a more economical solution would be to leave the counterweight in the pit and bury it under the future pedestrian path.

In order for the existing bridge pit to be able to support the precast concrete approach spans and the live traffic and the counterweight, a number of micro-piles were drilled through the existing slab and a new micro-pile concrete cap was poured to incorporate and strengthen the floor slab of existing bridge pit.

The in-water construction activities at the site had the potential for releasing silt and sediment in the Chicago River.

Cofferdams were utilized to provide a dry work area. To provide filtration of the water, floatation silt curtains were employed.

Figure 10 – Construction of the Abutments
Construction

The contractor first removed the existing bridge, and then installed the cofferdams for new in-water abutment construction.

The contractor had the option of constructing the main arch span off-site, floating it in and lift it into place or constructing the span 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 as it was the more cost-effective option. Two shoring towers were built in the river to help the steel erection.

![Figure 11 – Arch Bridge during Construction, Showing the Arch and the Temporary Supports](image1)

Figure 11 – Arch Bridge during Construction, Showing the Arch and the Temporary Supports

![Figure 12 – Completed Bridge at Night](image2)

Figure 12 – Completed Bridge at Night

Acknowledgments

The successful design and construction of this project is attributed to the competence of the both design and construction team. The team members are:


Summary and Conclusion

The short span tied arch bridge is a valid design option for enhancing an urban setting with an aesthetically-pleasing structure and spurring local economic development.

The successfully completed bridge demonstrates that a short span tied arch bridge can be done economically with attention to the steel details which accommodates both accessibility and constructability.

The innovative design achieved the goals of the owner by allowing for current and future public amenities above and below the bridge, particularly with respect to the accommodation of multi-use crossing of vehicle, bicycle, pedestrian (above and below the bridge) and maritime traffic.

The reasonably-sized and aesthetically pleasing steel members also accommodate the unusual structural demand due to the wide but rather short span. This was done by employing an innovative design techniques.

Similar to the “prestressing” concept used for the concrete structure, introduction of the counteracting torsional moments imposing on the steel structural system allow the design to minimize the structural size and maximize the efficiency of the steel usage.
The total final project cost (engineering, ROW acquisition, force accounts, and construction) was $20M, well under the allocated funds.

Figure 14 – New Bridge with Chicago Skyline

The Three-Sided Precast Concrete Underpasses is expected to provide ready-accommodation for future extension of the Chicago River Walk, without the need to modify the completed bridge structure.

This is a commendable coordination by the design team with a potential future project. The upfront expenditure that was spent as part of this bridge project is well-spend and fully justifiable.

Studying different bridge type alternatives was a necessary step that needs to be considered in any project. As a result of this alternative analysis, the selected steel tied arch bridge was proven to be a successful choice.

Figure 15 – New Bridge Open to Traffic, Accommodating Vehicle and Bicycle Traffic

Figure 15 – Completed Bridge

Figure 15 – River Traffic Remains Open During Construction of the Bridge

References


