A NEW STEEL ARCH BRIDGE FOR THE US 52 MISSISSIPPI RIVER CROSSING

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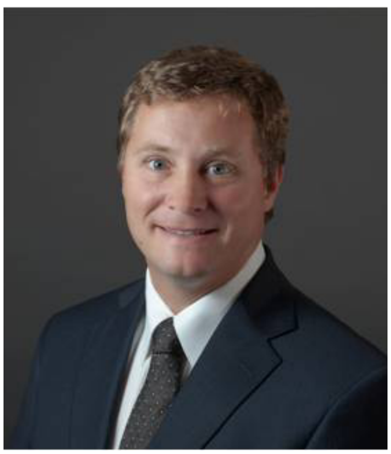

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BIOGRAPHY

Greg Hasbrouck is a Project Manager with Parsons in Chicago and was the Bridge Design Lead for the US 52 Mississippi River Bridge. He has over 14 years of experience working on complex bridge projects including the Hastings Tied Arch Bridge in Minnesota and the Christopher S. Bond Cable-Stayed Bridge in Kansas City. Mr. Hasbrouck received his MS in Structural Engineering from Princeton University and his BS in Civil Engineering from Duke University.

Martin Furrer is the leader of the Parsons complex bridge group in Chicago and was the Engineer of Record for the US 52 Mississippi River Bridge. He has 23 years of experience in the management, design, and construction of complex bridges including 20 bridges over major waterways. Mr. Furrer is leading the owner's bridge team for the new 850-meter span over the Detroit River. He received his MS in Structural Engineering from the Swiss Federal Institute of Technology, Zurich.

Faith Duncan was the IDOT District 2 Project Manager for the US 52 Mississippi River Bridge project. She has been employed by the Illinois Department of Transportation for 18 years and currently oversees a Phase I and Phase II unit in District 2's Bureau of Program Development. Ms. Duncan has managed the development of a wide variety of projects throughout the northwest region of Illinois. She received her BS in Civil Engineering from the University of Wisconsin-Platteville.

SUMMARY

The new US 52 Savanna-Sabula Bridge over the Mississippi River was opened to traffic in November 2017 capping a monumental project for the small river towns of Savanna, IL and Sabula, IA. At over 2400 feet in length, the steel tied arch and plate girder bridge improves mobility and safety while providing a necessary replacement and ensuring a crucial economic link for the region is maintained for generations to come.

The new steel river crossing consists of 12 spans totalling 2,454 feet and extends from a causeway on the Iowa side in the middle of the Upper Mississippi River Wildlife and Fish Refuge to the high bluffs of the Mississippi Palisades in Illinois. A 546-foot main span steel tied arch over the navigation channel flanked by steel girder approach spans was designed by Parsons in coordination with the Illinois and Iowa DOTs and constructed by Kraemer North America.

The influence of the structure depth on the vertical profile along with constructability and maintenance concerns led to the selection of a main span steel tied-arch with floating deck system and steel plate girder approach spans. The steel tied-arch design incorporates redundancy design criteria and seeks to simplify details and provide a durable structure that is easy to inspect and maintain. The entire arch floor system and upper lateral bracing are galvanized for increased corrosion protection, while the box section arches are painted blue in keeping with the color of the old truss bridge.

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Introduction

The new US 52 Savanna-Sabula Bridge over the Mississippi River was opened to traffic in November 2017 capping a monumental project for the small river towns of Savanna, IL and Sabula, IA. At over 2400 feet in length, the steel tied arch and plate girder bridge improves mobility and safety while providing a necessary replacement and ensuring a crucial economic link for the region is maintained for generations to come.

The old bridge was constructed in 1932. It provided a crucial transportation link for the region, with the nearest alternate Mississippi River crossing located 20 miles to the south in Fulton, Illinois. Over the years, a number of repairs had been made to the bridge and it was rapidly approaching the end of its useful life, and in need of replacement.

Parsons was selected by the Illinois and Iowa Departments of Transportation (DOTs) to provide preliminary and final design services for replacement of the old US 52 Mississippi River Bridge. The new replacement bridge, shown in Figure 1 consists of 12 spans totalling 2,454 feet. The new structure extends from a causeway on the Iowa side in the middle of the Upper Mississippi River Wildlife and Fish Refuge to the high bluffs of the Mississippi Palisades in Illinois. A 546-foot main span steel tied arch over the navigation channel flanked by steel girder approach spans was designed by Parsons Chicago office in coordination with the Illinois and Iowa DOTs and constructed by Kraemer North America. The total project construction cost is just over $80M.

Location

The US 52 Mississippi River Bridge is located in rural northwestern Illinois and eastern Iowa about 150 miles west of Chicago. It crosses the main channel of the Upper Mississippi River over Pool 13 between the river towns of Savanna, IL and Sabula, IA. The eastern end of the bridge terminates at the intersection of US 52 / IL 64 / IL 84 against the bluff just north of the City of Savanna. This intersection is located just south of the Mississippi Palisades State Park, crossing over two heavily used BNSF railroad tracks that run along the east river bank. The western terminus of the bridge drops US 52 onto an earthen causeway in the middle of the Upper Mississippi River Wildlife and Fish Refuge in the Mississippi River. The causeway turns south and runs for 2 miles before crossing an overflow bridge into the island city of Sabula, IA, Iowa's only island city.

Figure 1 – New Arch Bridge

Old Bridge

The old Savanna-Sabula Bridge was 2,468 feet in length including the Iowa approach, main truss spans and the Illinois approach. The main river spans consisted of a three-span cantilever truss with a 520-foot navigation span and 320-foot side spans along with a 283-foot simple span truss. The Iowa approach was 947 feet in length with 18 simple span steel beam approach spans with composite concrete deck. A variable width continuous concrete slab structure cast monolithic with the concrete pier caps made up the 78-foot long Illinois approach. The main channel spans are shown in Figure 2. The structure carried two 10-foot lanes of traffic, one in each direction, with no shoulders as shown in Figure 3. The narrow traffic lanes forced trucks and wider vehicles to encroach into the opposing lane, resulting in a safety hazard and combined with the steel grate decking on the truss spans reduced overall traveler comfort when crossing the bridge.

Figure 2 – Old Bridge Truss Spans

The old bridge was constructed as a private toll bridge by the Savanna-Sabula Bridge Company before being turned over to the State of Iowa. Illinois took over jurisdiction in 1987 and is currently the lead state for maintenance and repairs or replacement; Iowa also participates in the funding of the maintenance and construction activities associated with the structure.

With the old structure's deteriorating condition, substandard geometric configuration, and repair challenges, Illinois and Iowa DOT's recommended total replacement of the Mississippi River crossing at this location. It was proposed that the new bridge be constructed on a parallel alignment, allowing the old structure to remain in place until completion to minimize inconvenience to motorists. This realignment also provided an opportunity to improve the geometric configuration of the intersection at the Illinois terminus.

Figure 3 – Old Bridge Substandard Width

Cross Section and Type Selection

The old structure consisted of two 10-foot lanes with no shoulders and while projected traffic volumes for the area do not warrant more capacity, improving the cross section to meet policy standards was a priority to ensure safety and mobility for users of the facility. The new cross section consists of two 12-foot lanes with 8-foot shoulders on each side to allow for improved safety for users and to accommodate bicyclists on the shoulders.

The old navigation channel span located closer to the Illinois riverbank provided a 508-foot horizontal clearance and a 64.6-foot vertical clearance above the normal pool elevation. As part of the studies to improve the geometric configuration of the new bridge and roadway, the desire was to minimize the vertical profile grades on the bridge. To help achieve this goal, the Parsons team approached the US Coast Guard and facilitated the coordination of a 150-foot shift of the navigation channel toward the center of the river to bring down the maximum grade to 4% and allow for a 7.5-foot superstructure depth over the channel.

Deep girder spans were eliminated from consideration due to the minimal structure depth leaving tied arch and cable-stayed structure type options for the main span. After a type study evaluation, a steel tied arch was selected for the main span due to a slightly lower overall cost and perceived advantages in constructability and IDOT

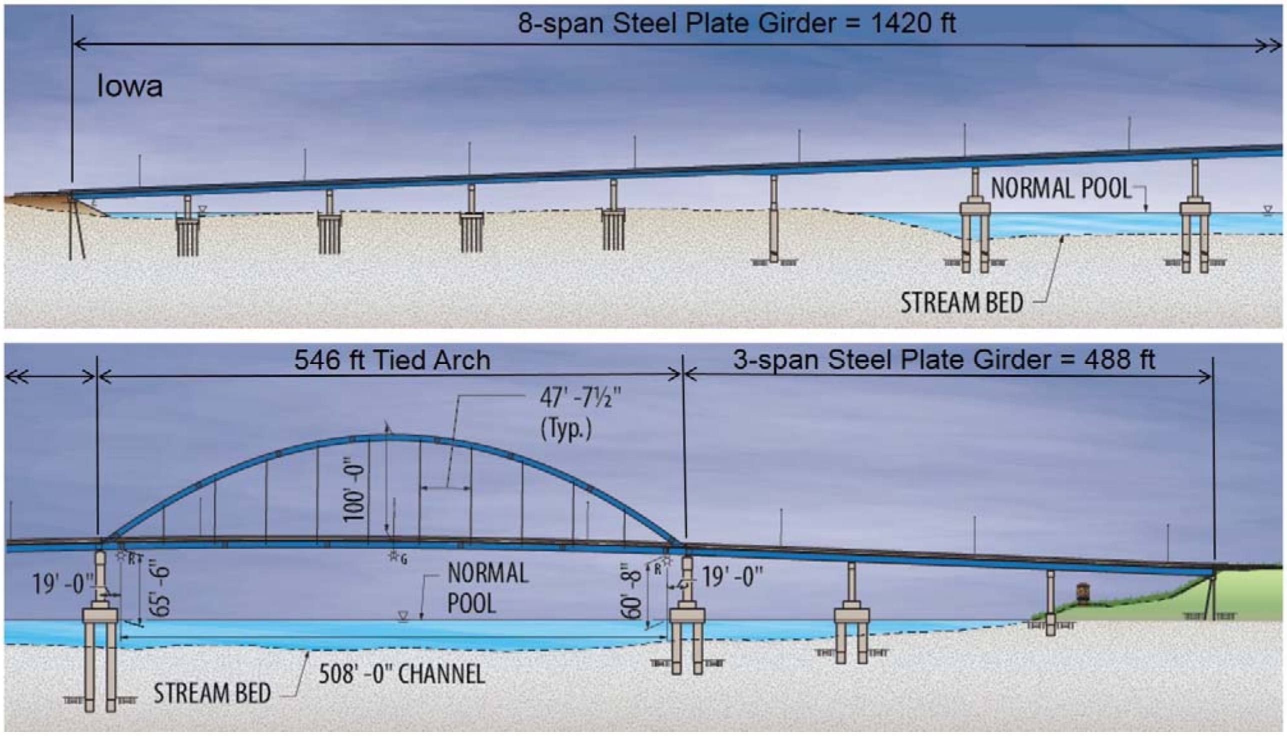

Figure 4 – New Bridge Span Layout

familiarity for maintenance and ability of future deck replacement if necessary.

New Bridge Layout

The new bridge structure consists of an eight span 1420-foot steel girder approach structure on the Iowa side, a 546-foot main span steel tied arch over the navigation channel, and a three span 488-foot steel girder approach structure on the Illinois side including a span over the BNSF rail road. The span layout is shown in Figure 4. The cross section consists of a 6-girder layout with girders spaced at 7'-3" (Figure 5). The use of six girders allows for the bridge deck to be replaced one half at a time, while maintaining bi-directional controlled traffic on one lane and three girders to maintain a redundant structure and eliminate the need for total closure for future maintenance and repairs.

Iowa Approach Structure

The use of PPC I-beams and steel girders was evaluated for the Iowa approach structure. Longer spans upwards of 200 feet are warranted adjacent to the main span to limit the number of foundations in the main branch of the river subject to large vessel collision loads. Smaller span lengths were necessary near the west abutment touching down on the existing causeway to provide shallower beams to meet vertical clearance freeboard requirements over the flood elevations.

Comparisons using a longer span steel girder unit near the main span with a shallower PPC I-beam unit near the abutment with published Illinois PPC I-Beam shapes and strand patterns resulted in similar overall costs compared to a single unit steel girder approach. This was primarily due to the increase number of substructures for the PPC beam structure to minimize the girder depth and the requirement to use 6 girder lines for future deck replacement while maintaining one lane of traffic. With similar cost estimates, the IDOT Bridge Office preference not to mix structure types (PPC I-Beams and Steel) and to reduce the number of substructures in the overbank flood plain area, the 8-span 1420-foot single unit steel girder structure was selected for the Iowa approach spans.

Illinois Approach Structure

The Illinois approach spans 488 feet from the navigation span over a portion of the main branch of the river and over the BNSF railroad tracks along the river bank to the east abutment at the intersection of IL 84. To minimize piers in the

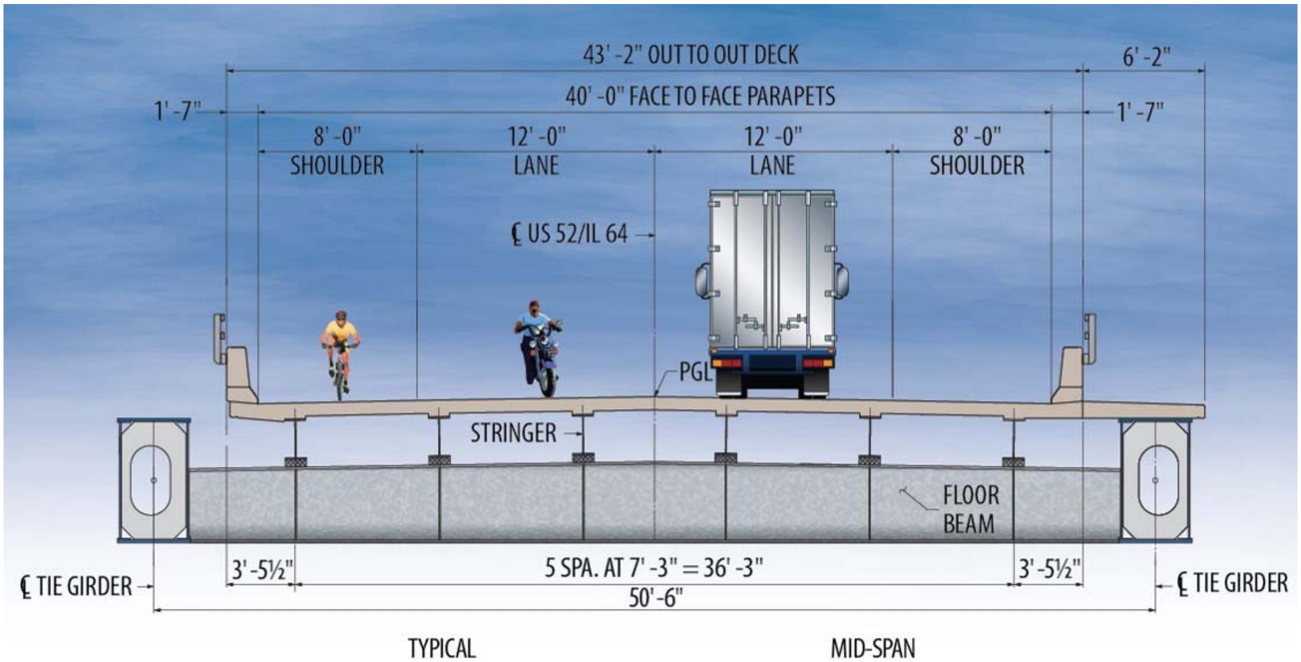

Figure 5 – New Bridge Cross Section at Arch

main branch of the river a 3-span layout of 153 feet – 185 feet – 150 feet was selected which places the last pier on the east river bank between the river and the railroad tracks and out of the water during normal barge operations, eliminating large vessel loads on this pier. After spanning the railroad tracks, the bridge structure widens over the last 100 feet to allow for the proper turning movements at the intersection of IL 84. The longer spans, span layout and widening over a portion of the last span lends itself to a steel girder superstructure.

Tied Arch Structure

A 546-foot tied arch span is required to provide the USCG mandated 508-foot permanent navigation clearance and the 350-foot navigation clearance during construction while allowing for waterline footing construction in the river. A vertical arch with lateral bracing was selected over the basket-handle arch for the following reasons. The inclined nature of a basket-handle arch provides aesthetic enhancement and increased lateral stability of the bridge under transverse loading; however, it has only minor impacts on the vertical behavior. The basket-handle arch would have required a fifteen percent wider structure at the deck level than vertical arches to allow for the incline of the arch over the roadway and the truck cab intrusion zone. As a result, the floor beams would span a longer distance between the tie girders, requiring more steel and greater structure depth. The vertical ribs with lateral bracing still provide a graceful structure, have no lateral stability concerns, and provide a more economical option. Moreover, the detailing, fabrication and erection of the vertical arches is simpler and more straightforward compared to a basket-handle arch.

Arch, Tie and Hanger System

A steel box section arch rib and tie girder were selected to provide an efficient section for both the arch in compression as well as redundancy of the tie girder in tension. The consistent 3’-4” interior width provides continuity of the force flow through the web plates in the knuckle and simplifies connection details. The depth and width of the arch and tie girder sections were sized to provide maintenance and inspection access through the sections with a 5-foot deep rib and 6-foot deep tie.

The arch consists of a welded box section with a longitudinal web stiffener, while the tie girder consists of a bolted built-up section. The bolted built-up section provides internal redundancy such that a fracture in one plate does not propagate to any of the other plates in the tie girder. High performance Grade HPS50W steel is specified for the tie girder and knuckle plates for improved toughness. The tie girder is designed for the loss of any single plate (web or flange) and the resulting eccentric loading on the remaining section. The remaining section of the tie girder is checked against progressive collapse under the following extreme event fracture load combination:

1.25 DC + 1.5 DW + 1.3 (LL+IM), where

LL+IM = full live load in striped lanes (2 lanes).

Since the bridge is a relatively narrow structure with a modest span length and the box shaped rib and tie members were sized for inspection access sufficient bending capacity was available and live load deflections were not critical or controlling. Therefore, no substantial benefit of using network hangers to minimize deflections or reduce rib flexural moments under live load was necessary. It is also noted that hanger loss with network hangers produces the same magnitude of force effects in the rib and tie as a vertical hanger loss and the network configuration only helps reduce the moments under live load and no additional benefit to redundancy. A traditional (vertical) hanger system with a pair of 2¾” diameter structural strand hangers was determined to be preferred over a diagonal (network) hanger configuration to simplify details and connections to the rib and tie.

Structural strand hangers allow for the entire hanger assembly and connection to be visually inspected and it is also easy to adjust the length of the member at the deck level with a jack and shim plates. A pair of hangers at each location reduces the size of the individual hangers so lighter equipment can be used for mounting and adjusting. The dual strand system also provides redundancy at the hanger connection in the event of a sudden fracture of single hanger since the other hanger picks up the load with a higher stress in the temporary extreme event condition.

The structure was designed for the sudden loss of one hanger under the extreme event load combination:

1.1 DC + 1.35 DW + 0.75 (LL+IM) + 1.1 CLDF;

and the gradual loss of a pair of hangers under the extreme event load combination:

1.1 DC + 1.35 DW + 0.75 (LL+IM).

The sudden loss represents a fracture or cutting while the gradual loss represents a possible fire situation on the structure. The load combinations are based on and loads determined in accordance with the cable loss provisions of the Post-Tensioning Institute (PTI) Guide Specification Recommendations for Stay Cable Design, Testing and Installation, 5th Edition, where

LL+IM = full live load in striped lanes, and

CLDF = Cable Loss Dynamic Force.

The hangers are also designed to be replaced one hanger at a time with one operational lane of traffic on the bridge. The lane and shoulder adjacent to the hanger under exchange would be closed.

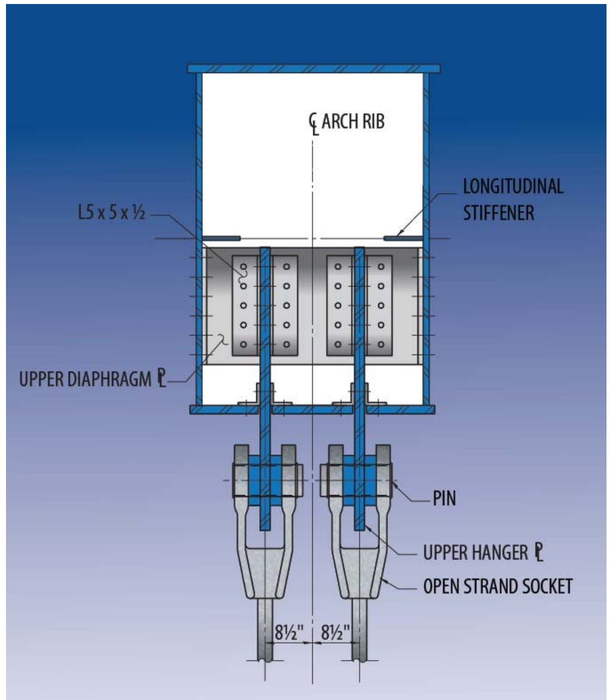

Figure 6 – Upper Hanger Connection

The hanger spacing and connection of the hangers to the rib (Figure 6) and tie (Figure 7) are offset from floor beam and lateral bracing connections to simplify load paths, detailing and fabrication at these critical connections. The hangers are spaced at 47’-7 ½” while the floor beams are spaced at 31’-9”, resulting in 1½ floor beams supported at each hanger location. The upper hanger connection uses a standard open strand socket attached to a pin plate that protrudes through the bottom flange of the arch and is attached to a diaphragm with bolted connections to eliminate the possibility of plate fractures propagating between the elements and into the arch. Pulling the socket outside of the rib allows for the socket to be easily inspected outside of the structure and visible from the deck. This minimizes the opening in the rib bottom flange and reduces congestion inside the arch rib to allow easier access through the rib.

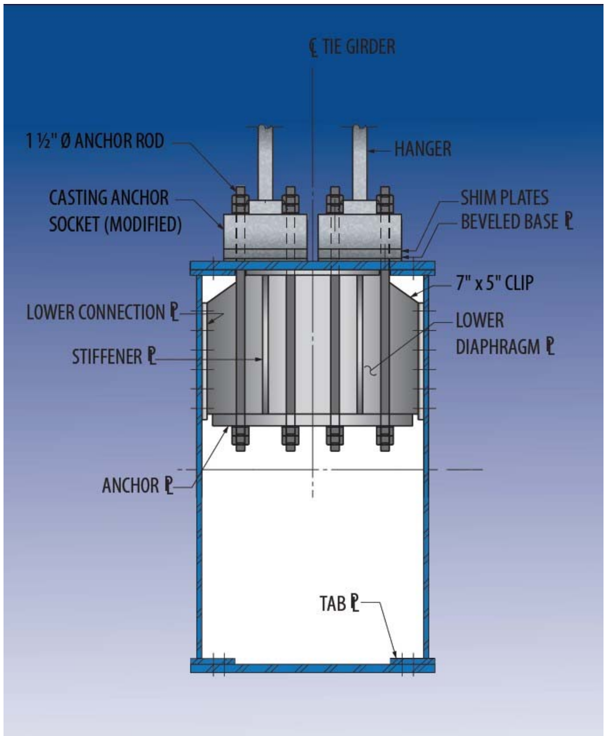

Figure 7 – Lower Hanger Connection

The lower hanger connection uses a modified anchor socket that is clamped to the tie girder diaphragm plate with four anchor rods per hanger. The anchor rods are tensioned such that the clamping force is larger than the maximum hanger force to eliminate any significant fatigue stress range in the rods. Multiple anchor rods provide redundancy in the connection. Clamping the sockets to the diaphragm plate also eliminates any direct tension in plates at the lower hanger connection with only the anchor rods in tension. Adjustment of the hanger length is provided for by adjusting shim stack heights at the connection.

Floor and Deck System

It was determined early on that a main priority was to provide a deck on the arch structure that could be replaced one half at a time to maintain one lane of traffic on the bridge at all times during future repairs. A floating deck system over the floor beams was selected to meet this requirement. In this system, continuous stringers span over top the floor beams and the deck is supported by the stringers (Figure 5). The floating deck system allows the deck stringers to be independent of the arch system and for the use of a conventional transverse deck design over the stringers.

Six lines of stringers are provided to allow for partial replacement of the deck while maintaining one lane of traffic on three stringers on the other half of the structure. Maintaining a traffic lane is important to avoid the over 40-mile detour. The stringers are fixed longitudinally at the center two floor beams and rest on elastomeric bearings over the remainder of the floor beams to allow for any differential movements of the arch and floor system during service. The stringers at the elastomeric bearings have slotted holes to allow axial movement between the arch and stringers during deck pouring, with the bolts tightened after pouring the deck. The arch span deck was poured in one continuous pour from the center of the span out to each end.

At midspan of the arch, the deck is extended and connected to the tie girders to transfer longitudinal loads from the deck directly to the arch system through diaphragm action of the deck. This deck connection was poured last in the construction sequence to minimize tension transfer to the deck.

With the floating deck system, the lower lateral floor system bracing is designed to transfer the entire floor system lateral loads in the in-service condition of the bridge since the deck is not rigidly connected to the tie girders to provide full diaphragm action. The lower lateral bracing uses a K-bracing configuration to brace each interior floor beam top flange at the midpoint. Each bracing member is designed for tension and compression.

Since the deck is not continuous over the tie girders, it leaves the tie girders and the floor beams exposed to weather, debris, and chlorides from salt-spray and plowed snow. The tie girder and floor system elements use protective coatings of a 3-coat paint system and galvanizing respectively to enhance the service life and minimize future maintenance. The floor beams, stringers and lower lateral bracing were all detailed with lengths under 60 feet to permit hot-dipping in local galvanizing tanks. The built-up bolted tie girder sections are much longer than 60 feet.

Rib Bracing

The upper lateral rib bracing braces the arch ribs against buckling and out-of-plane forces such as wind. X-bracing was chosen as it provides a modern, light and efficient bracing system using simpler pin connected tension and compression truss elements and smaller member sizes than a Vierendeel bracing system. 16” square box HSS sections are detailed to provide an efficient member section for long compression members and a consistent appearance with the box section of the rib in a highly visible portion of the structure. The HSS sections are galvanized to provide a protective coating on both the inside and outside surfaces and a unique visual contrast between the painted blue arch rib and silver galvanized bracing. The bracing is sloped to allow any water entering the members to drain out, while the galvanizing minimizes future maintenance. The interior of the member is inspectable from each end with a borescope camera.

Arch Erection

Parsons provided a bottoms-up cost estimate and construction access review and the tied arch plans allowed for either float-in or cantilever construction. Kraemer North America elected to construct the arch through cantilever erection (Figure 8) with stay towers erected on top of the main river piers and tied back to the approach superstructure steel girders two piers away. The tension in the back stays is then resisted by compression in the approach girders back to the main piers creating a balanced system with the compression in the arch during erection.

Figure 8 – Cantilever Arch Erection

River Pier Foundations

Piers 6 through 10 are in the main navigable portion of the Mississippi River and are subject to large vessel collision loads and up to 50 feet of scour. The underlying soil profile consists of a top layer of very soft to stiff silty clay loam over loose to dense to gravelly sand overtop of Dolostone bedrock. The depth of bedrock varies from 25 feet to 120 feet below the normal pool elevation of the river from Pier 10 to Pier 6 respectively.

With the large vessel loads, large diameter driven pipe piles and drilled shafts are the most economical solutions. The shallower depths to bedrock for Piers 8 to 10 result in no soil overburden to resist lateral loads and provide stability during scour events. Thus, driven pile foundations were not appropriate and drilled shafts with rock sockets into bedrock were selected as the viable solution.

Due to the depth of the main portion of the river, ranging from 15 feet to 30 feet at the pier locations, footings at or below the mudline would require design for larger scour depths and large expensive cofferdams and seal slabs. To reduce cost and risk, a waterline footing foundation (Figure 9) with drilled shafts constructed to just below the normal pool elevation and a footing constructed at the water elevation was chosen.

Figure 9 – Completed Waterline Footing

The drilled shafts are cast in the permanent casings up to the river level and a concrete cell to form the footing can be floated in or assembled in place, supported from the shaft casing, and sealed around the casing to form a dry coffercell for constructing the footing. Minimal dewatering is required as the bottom of the footing cell only sits a couple feet below the water line and the top of the cell is higher than a typical cofferdam cell reducing the risk of flooding.

Waterline footings eliminate the need for large expensive cofferdams and reduce the risk associated with large cofferdams that are prone to flooding resulting in significant schedule delays and increased cost. The final river pier foundations consisted of 2x3 and 2x2 groupings of 8-foot diameter drilled shafts with 15-foot deep rock sockets and the first use of the waterline footing construction method for the Illinois DOT.

Structure Aesthetics

Structure aesthetics and community involvement were not a large driving force in the type selection or overall structure development, however smaller less costly ideas were incorporated to improve on the bridge aesthetic. The tied arch superstructure provides the prominent signature look of the crossing with its graceful arch over the navigation span. The closed box sections above deck enhance the clean lines of the arch, while the X-bracing provides a distinct interest overhead. The large spacing between hangers enhances the openness of the relatively narrow arch. Furthermore, the contrasting painted blue arch with galvanized hangers and upper bracing provide a distinct contrast and look for the user driving across the bridge (Figure 10). The painted blue arch and fascia girders were selected to carry on one of the striking features of the old truss bridge.

A portal shape pier was selected for the piers supporting the Unit 2 arch span (Figure 11) to differentiate the arch piers and provide enhanced visual aesthetics. The pier shape chosen provides inclined legs at a 6:1 slope that narrows the pier footprint at the water line footing. By bringing the pier legs in at the foundation, the shaft spacing and overall footing length has been decreased by 8 feet resulting in a savings in footing concrete. The pier cap is deeper at the column legs and becomes shallower at the middle of the cap creating an arched opening between the pier legs. The cap and column are a constant 8 feet thick, providing a solid support for the superstructure and the required seat length.

Figure 10 – Completed Arch

Figure 11 – Pier Shapes

The other piers consist of a pier cap supported by vertical columns. The standard IDOT piers have been modified to provide a cohesive look with the aesthetics of the arch piers, by using square columns instead of circular columns to match up with the rectangular legs of the arch piers and also providing a 6:1 end cap taper to mimic the slope of the arch piers. Neither of these modifications affects the constructability or cost of the piers in a substantial way.

Conclusions

Maintaining the vertical clearance over the river while minimizing grades, along with the desire to have a replaceable deck and minimize future inspection and maintenance, led to the selection of a steel tied arch main span. The steel arch design incorporates redundant load paths and simplifies details while providing a structure that is easy to inspect and maintain. The floating floor system on the tied arch allows for future replacement of the deck, half at a time, while maintaining one lane of traffic and eliminates the necessity for closure of the bridge and significant user delay costs that would otherwise be associated with future repairs.

Due to the relatively deep pool in the Upper Mississippi River at the bridge site and varying levels to rock, drilled shafts with waterline footings and floating coffercell construction for the river pier foundations was selected over deep cofferdams and traditional footing construction. This provided substantial construction cost savings and minimized risks of flooding during construction.

The new steel bridge provides a cost-effective, operationally functional, safe and reliable Mississippi River crossing for the traveling public that will connect and meet the local and regional economic needs of these rural communities into the future.

Acknowledgements

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