I-74 MISSISSIPPI RIVER BRIDGE: A STATE-OF-THE-ART DESIGN

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BIOGRAPHY

Norman McDonald is the Bridge Engineer for the Iowa Department of Transportation. He has worked for the DOT for 28 years with the last 13 years as State Bridge Engineer. Mr. McDonald is a member of the AASHTO Subcommittee on Bridges and Structures and serves as Chairman on the Technical Committee for Structural Supports for Signs, Luminaires and Traffic Signals (T-12), Vice-Chair of the Technical Committee for Structural Steel Design (T-14), and is a Region III member on the Technical Committee for Bridge Preservation (T-9).

Ahmad Abu-Hawash is the Chief Structural Engineer with the Iowa Department of Transportation. Ahmad received his BS degree in Civil Engineering from the University of Iowa and his MS degree in Structural Engineering from Iowa State University. He started his career at Iowa DOT in 1983 and held various positions in highway construction, bridge rating, and bridge design. Current responsibilities include overseeing the design of major bridge projects, design policies review, coordination of bridge research, and the resolution of structural fabrication issues.

Dr. Philip Ritchie is an Associate with the firm Modjeski and Masters, Inc. with 20 years of bridge design experience. Dr. Ritchie received his Bachelor of Science from Drexel University, and his Master of Science and PhD from Lehigh University. Dr. Ritchie has experience engineering a variety of bridge design types including arches, cable-stayed, suspension, truss, and girder. Dr. Ritchie's expertise encompasses finite element analyses of complex structures, and steel bridge analysis, design, and detailing.

Dr. Thomas Murphy joined Modjeski and Masters, Inc. in 2000, and is a Senior Associate with the firm. Dr. Murphy's professional experience has included the analysis, design, and detailing of a variety of bridges including cable-stayed, suspension, arch, truss, and girder bridges with special emphasis on seismic analysis and design. Dr. Murphy has been involved in all stages of the bridge design process; from the development of design specifications, to the completion of conceptual studies for specific crossings, preliminary and final design, and construction stage issues.

Andrew Keaschall is a Project Manager at Benesch with nine years of experience in structural engineering. He earned his BS and MS degree in Structural Engineering from the University of Illinois at Urbana-

Champaign. He specializes in the rating, analysis and design of complex structures. Recently, Mr. Keaschall served as an adjunct professor for a bridge design course at the University of Illinois-Chicago. He has also won numerous awards for his outstanding work in the structural engineering field including, the 2011 ASCE-IL Young Civil Engineer of the Year Award, the 2012 SEAOI Young Engineer Award and the 2014 UIC –Urbana-Champaign Young Alumnus Achievement Award.

Kyle Smith is a Project Manager at Benesch with 12 years of experience in structural engineering. He earned his BS and MS degree in Structural Engineering from the University of Illinois at Urbana-Champaign. Mr. Smith specializes in the design and inspection of highway structures. He is a member of American Society of Civil Engineers and is also a certified SAVE VE Associate Value Specialist and NBIS Bridge Inspection Program Manager.

Ihab Darwish is a Senior Project Manager at Benesch with 19 years of experience in structural engineering. He received his MS and PhD in Civil Engineering from the University of Nevada. He is a member of American Society of Civil Engineers, Structural Engineering Institute and Post-Tensioning Institute. Dr. Darwish specializes in the analysis and design of complex bridge structures including bridge health monitoring.

SUMMARY
This project consists of the reconstruction of a 7.8-mile segment of I-74, from 67th Street in Davenport, Iowa, to 12th Avenue in Moline, Illinois. The focal point of the reconstructed I-74 corridor is the new dual 795' Steel Basket Handle True Arch bridges over the Mississippi River, which incorporate numerous innovative design elements including state-of-the art structural design and analysis, structural health monitoring, and an integral inspection and maintenance system.

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Introduction

A national historic landmark and a vital component of the transportation corridor in the Quad Cities, the existing I-74 Mississippi River Bridge has served the community very well by providing reliable daily access across the Mississippi River for over eighty thousand vehicles travelling between Bettendorf, Iowa and Moline, Illinois. The twin suspension Iowa bound and Illinois bound bridges, built in 1935 and 1960, respectively, have become functionally obsolete and structurally deficient and require significant financial investment to maintain the desired level of service. To address the condition of the Mississippi River bridges and the overall I-74 corridor capacity, an engineering study was commissioned in the late 1990's by the Iowa Department of Transportation (Iowa DOT) and the Illinois Department of Transportation (Illinois DOT) to evaluate improvement options. Total reconstruction of a 7.8 mile segment of I-74 starting from 67th Street in Davenport, Iowa to 12th Avenue in Moline, Illinois was recommended. The reconstruction will improve capacity, travel reliability and safety along I-74, and provide consistency with local land use planning goals. The need for the improvements is based on a combination of factors considered key to providing better transportation service and sustaining economic development.

The Iowa and Illinois Department of Transportations (DOT) are joint owners and thereby jointly responsible for the design, construction and maintenance of many of the bridges spanning the Mississippi River between the two states. As a means of managing the DOT bridges in an equitable and efficient manner, Illinois and Iowa generally assume lead responsibility for alternate bridges crossing the river. A similar arrangement is established between the state DOTs for the other border bridges. In the case of the I-74 Bridge over the Mississippi, the Iowa DOT takes the lead in its management and the Illinois DOT is consulted by the Iowa DOT in regards to any major decisions regarding the structures. Iowa is the lead agency for the I-74 Corridor Reconstruction project with Illinois playing an active role in the design and construction. For the final design of the I-74 project, the Iowa DOT selected a design team consisting of 10-firms led by Alfred Benesch & Company who assumed the role of corridor design manager and provided design services for various components of the corridor. As the lead state, design standards for the proposed new I-74 bridges over the river will be in conformance with the Iowa DOT's standards while the funding will be split 50/50 between the two states. The Iowa DOT will let the river bridge contracts and assume the oversight role during construction. Corridor improvements that fall entirely in Illinois will be constructed to Illinois standards, go through an Illinois letting and will be fully funded by the Illinois DOT while corridor improvements that fall entirely in Iowa will be constructed to Iowa standards, go through an Iowa letting and be fully funded by the Iowa DOT.

The centerpiece of the reconstructed corridor is the new dual 795' Steel Basket Handle True Arch bridges over the Mississippi River navigational channel consisting of a total of twelve vehicular traffic lanes (eight lanes and four full size shoulders) and a multi-use trail. The navigational channel span is flanked by fourteen approach spans and multiple span viaducts including ramps (see ***Figure 1***); all made up of welded plate girder sections.

Studies were conducted in the early stages of the environmental documentation process using three different bridge types to determine "ball park" level cost estimates. Cable-Stayed, Tied Arch, and Suspension alternates were evaluated using set clearances and roadway widths. In the initial phase of the formal type study, twelve feasible bridge types were investigated and then scored using an approved evaluation criteria matrix which included financial, performance and aesthetics considerations. This process advanced five of the bridge types to be further evaluated. The second phase expanded the five initial bridge types to a total of 16 schemes to allow variations of the five types to be studied in detail. Four of the schemes were selected as finalists for presentation to the public for comment.

A public meeting was subsequently conducted and attendees expressed a strong preference for either the Basket Handle True Arch Twin Bridges or the Cable Stayed Single Bridge with Semi-Fan Stay Arrangement, citing their aesthetic and architectural

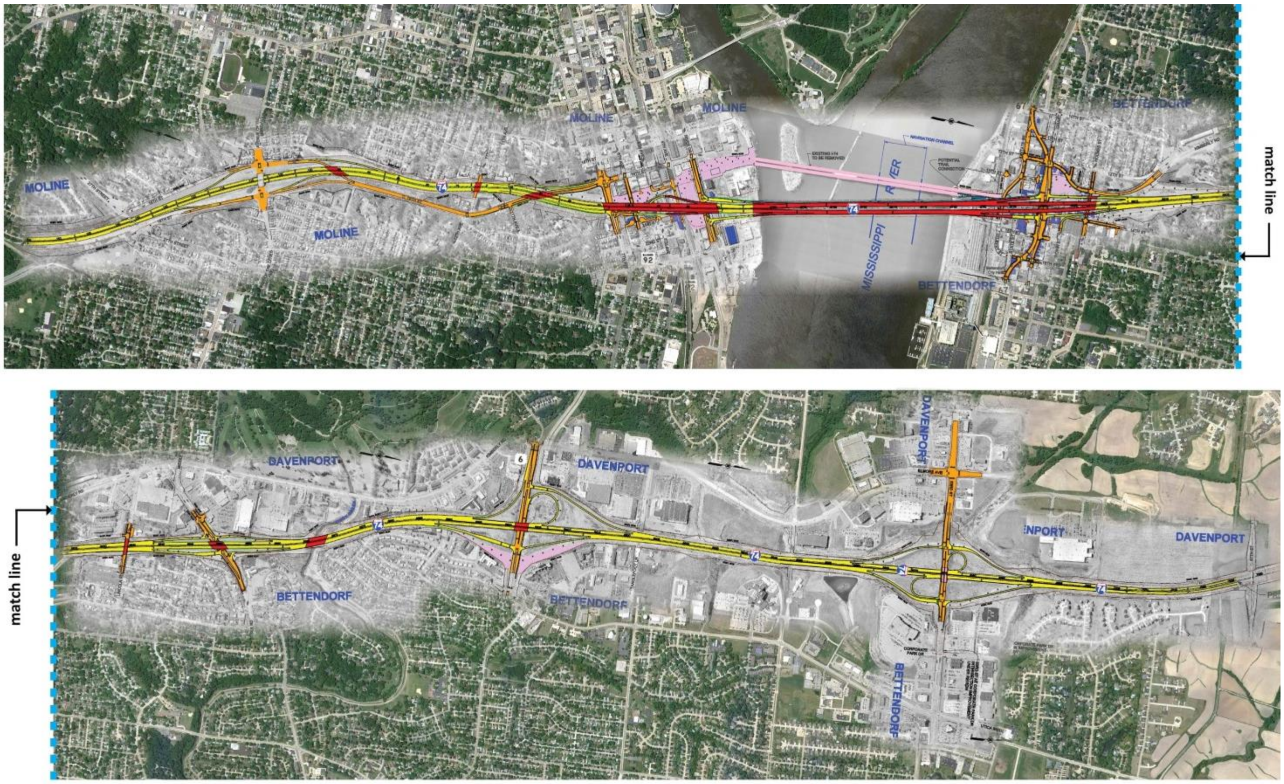

Figure 1: General plan of the bridge

characteristics. Additional studies in the areas of hydraulics and foundation design were then conducted. After careful consideration by both the Iowa and Illinois DOTs, the Basket Handle True Arch was selected as the Recommended Bridge Type for the new I-74 Mississippi River Crossing due to the pleasing aesthetics, inherent construction staging and redundancy advantages associated with its twin roadway, dual structure arrangement.

In addition to the basket handle arch, other aesthetic features include an overlook on the arch multi-use trail with a glass oculus, eccentrically intertwined Y-shaped pier columns, and special LED lighting.

The design team tackled complex arch design issues such as buckling behavior of the minimally braced arch rib, evaluation of dynamic wind loads, mitigation of wind vibration effects, and a detailed construction analysis of both arch spans. The multi-use trail is asymmetrically cantilevered off the eastbound arch bridge before converging into a monolithic bridge deck on the girder approach spans.

Modjeski and Masters performed final design of the arch superstructure while Benesch performed a peer review of the arch superstructure in addition to final design of the arch substructure and the approach bridges.

A comprehensive structural health monitoring (SHM) system was designed to integrate with the corridor-wide intelligent transportation system (ITS). The SHM system will monitor performance/serviceability issues, such as corrosion and movements, and structural behaviors, such as load distribution. It will also enhance security. Motorized travelers, water line, and an extensive walkway system provide easy access for improved inspection and maintenance.

In the following sections, the authors will discuss the unique design challenges and features of the signature structure, highlighted above, such as the arch's state-of-the art structural design and analysis, the SHM system, the integrated inspection and maintenance system, and the aesthetic features.

Arch Superstructure Design Considerations

The main spans of the I-74 Mississippi River Bridges are basket handle configuration true steel arches spanning 774'-5" from steel arch bearing to steel arch bearing. Beyond the steel arch bearings the ribs continue as concrete down to the foundations which span about 870’ center to center. A post-tensioned concrete strut spans between the concrete ribs where the approach girders, arch stiffening girders and wind tongues bear and concrete deck slabs interface at expansion joints. The 72’ wide roadways span 795’ from strut to strut. The arch ribs are inclined at an angle of almost 13.5 degrees. The general plan, elevation and cross section of the bridge are illustrated in ***Figures 2A-2C***.

Hangers consist of two socketed structural strands at each hanger location in the plane of the arches and range from 1 15/16” to 3 3/8” in diameter. Floorbeams are suspended from 27 hangers spaced at 26’-8” on each arch. Seven W24x55 stringers spaced at 8’-7 3/4” support the concrete deck slab and run continuously between the floorbeams. Two stiffening girders double as exterior stringers and run continuously from strut to strut. The floorbeams are the same depth as the stiffening girders and are spliced continuously across them. Herringbone pattern diagonal bracing runs between the floorbeams culminating in a wind tongue at the concrete strut.

The deck consists of an 8” structural slab and a 2”overlay for a total of 10”. The floorbeams, stringers and stiffening girders are all composite with the concrete deck. Because the crown of the deck is not at the center of the roadway, the stiffening girders are different depths to account for the almost 6” difference in cross-slope elevations. Their stiffnesses are similar, however. Note the 14’ wide multi-use trail and a 20’ wide overlook cantilever off the eastbound structure. The

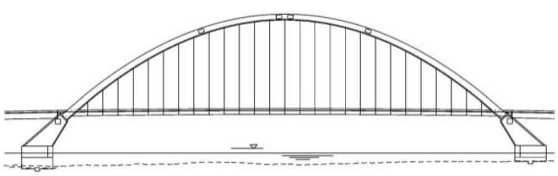

Figure 2A: Arch Structure Elevation

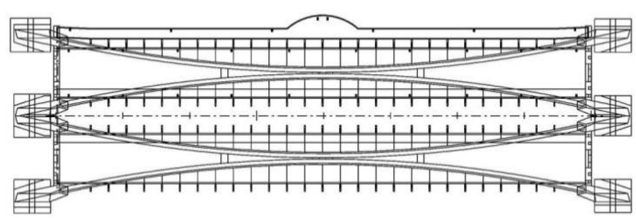

Figure 2B: Arch Structure Plan View

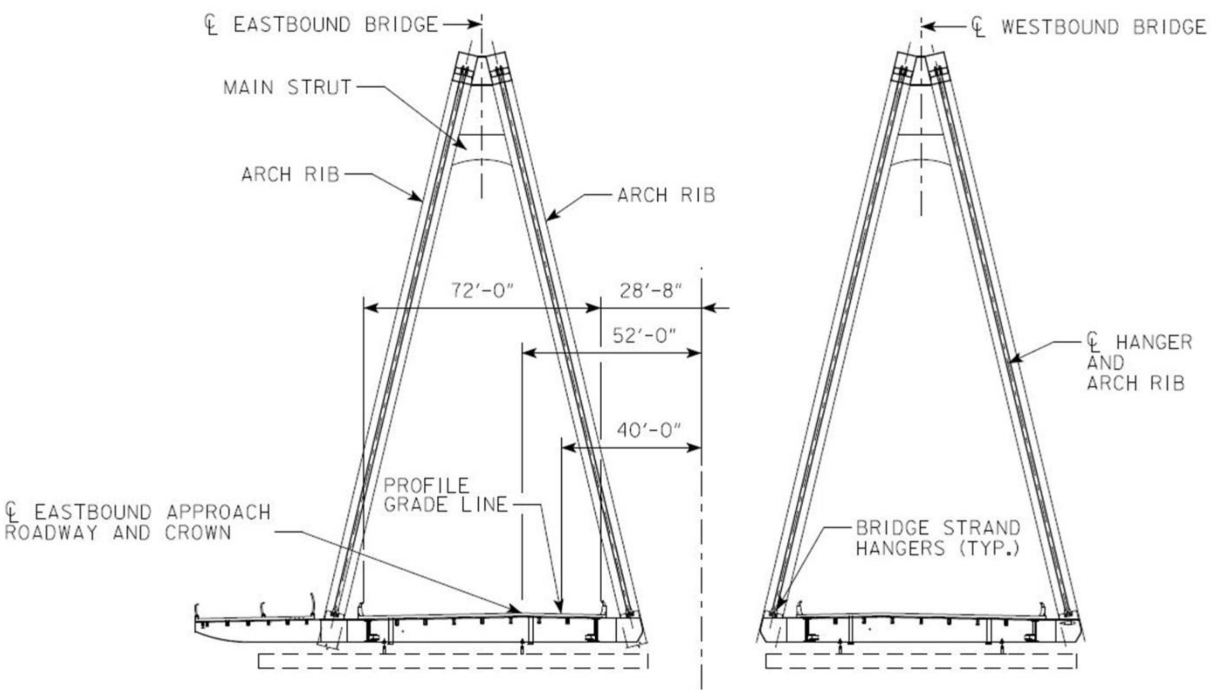

Figure 2C: Arch Structure Cross Section

unbalanced force from the bike trail results in a permanent lateral force due to the inclined hangers and is reacted at the wind tongues at the struts.

Grade 50W steel is used for the majority of the structure. Grade HPS70W steel is used in the arch rib and the stiffening girder in high load regions, generally near the base of the arch and at the ends of the stiffening girders, as well as for the wind tongue. Grade HPS70W is also used for the bottom flange of all floorbeams, although the increased strength was not accounted for in the design. The reserve strength and high fracture toughness of the HPS70W is being used to provide a higher level of safety against failure of the non-redundant floorbeams. In fact, the project specifications require additional fracture toughness beyond that normally required of HPS70W.

The arch ribs are internally stiffened steel boxes 6'-0" wide and varying from 12'-0" deep at the supports to 9'-0" deep at the crown (***Figure 3***). The arches have minimal bracing, only braced at the crown and about 2/3 of the way up the arch. Due to the geometry, the braces at the crown are not very heavily loaded. It is the lower braces that shoulder the burden. Under lateral loading, the arch ribs and the lower brace must act as a portal frame. This results in large bending demands at the base of the arch, as well as at the connections of the brace and arch. Complicating matters was an architectural requirement that the brace have an upward arched curvature on the underside.

The high bending forces in these arches presented several design challenges, since the forces were not the predominant compression usually encountered in arches.

A wide range of solutions are available when designing stiffened boxes to meet stability requirements. Making the overall dimensions of the cross-section as large as possible helps with global stability, but as the plates get wider and thinner, local stability limits the design. Local stability can be handled in different ways as well, with thin plates requiring many light stiffeners, and thicker plates requiring fewer heavier stiffeners. The shape of the stiffeners can also be varied. Shapes that maximize moment of inertia while minimizing area, such as T-sections, are preferable from a material efficiency standpoint, but not necessarily from a fabrication standpoint.

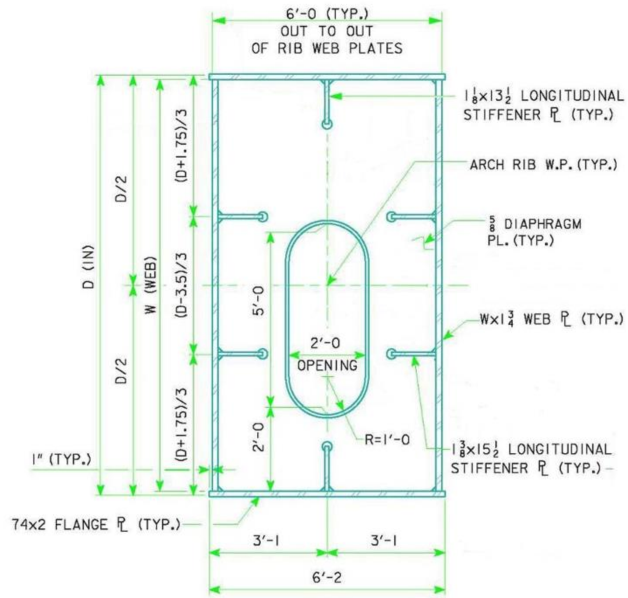

Figure 3: Section through Arch Rib

For the I-74 bridges, the outer dimensions of the cross-section were set in preliminary design. The American Association of State Highway Transportation (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specification contains provisions for one or two stiffeners on the webs of solid web arches. This is not to say that more stiffeners could not be utilized, as references other than AASHTO LRFD could be used to guide the design. However, with two stiffeners along the web, and one on the flanges, the resulting plate thicknesses required were reasonable, and the sizes of the stiffeners were also practical. This will limit the amount of labor costs required to fabricate and install the stiffeners.

The most effective shape of the stiffeners was then investigated. Flat plate, WT, and bulb flat sections were considered. The availability of bulb flats, a shipbuilding section, was questionable, and the efficiency was about equal to a WT, so it was eliminated as an alternative. Of the two shapes remaining, the WT sections had the advantage of material efficiency, but the flat plates had the advantage of ease of fabrication. As the arch ribs are on a true curve, and not segmented, the stiffeners needed to be fit to the ever-changing radius of the

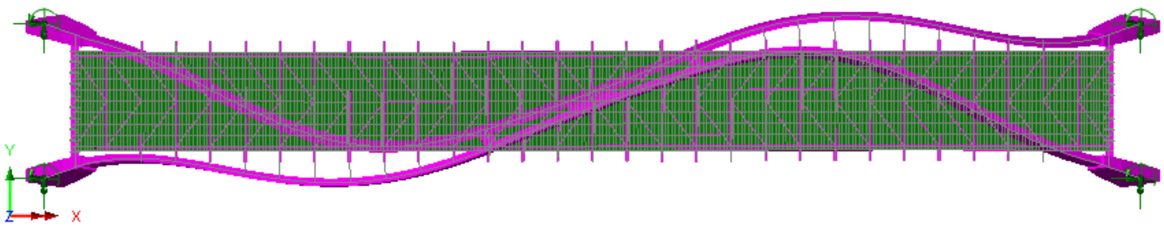

Figure 4: First buckling mode of the arch

parabolic arch shape. After careful consideration, the flat plate stiffeners were chosen due to the expected reduction in overall cost and the modest plate thicknesses required. One additional advantage is the ease of inspection and maintenance with plate stiffeners, as there are no flanges to interfere with visual inspection or access.

The stiffeners were designed to carry load, so they were fully connected across splices. The design of the stiffeners also took into account the AASHTO LRFD design provision that allows local stability to be based on the maximum stress in the member, rather than the yield stress, to optimize the sections.

Two arch ribs were designed; a heavier rib for the arch adjacent to the multi-use, and a “typical” rib for the other three arches. Both grade 50 and grade HPS70W steels were utilized where appropriate. The target was to limit the weight of field sections to 110 tons or less, which was substantially met using 15 field sections with 14 splices per arch. Because of the high out of plane bending forces, the steel splices were designed to carry 100% of forces across the connections, no steel to steel bearing was assumed.

The steel/concrete interface was also a particularly challenging design, as the connection had to accommodate tension at extreme loadings. Post-tensioned grouted grade 150 bars anchored deep into the concrete were used to achieve the required connection. On the steel side, the bars were anchored to stiffeners that transfer the load into the arch rib over a 6’ length.

One of the main structural challenges in the design of the arch bridges was ensuring the stability of the arches, despite the minimal amount of bracing between them. The basket handle arrangement does provide some inherent stiffening of the ribs, but the presence of only 3 Vierendeel braces between ribs required a careful examination of their behavior. Using the analysis software LUSAS, several different analyses were used to examine the stability behavior of the arches, and to find ways to improve that behavior. The original configuration of the bridge had the lower pair of braces placed relatively close to mid-span, which resulted in the lowest buckling mode consisting of an asymmetrical lateral deformation (***Figure 4***). This mode was found using an eigenvalue buckling analysis.

In order to verify the results of the eigenvalue buckling analysis, a fully geometrically nonlinear analysis was conducted with the applied loads increasing in a constant proportion. A reduction was applied to the modulus of elasticity for the arch ribs themselves, in order to account for the softening effect of residual stresses. However, for a box girder with welded connections at the corners, the residual stresses are expected to be more favorable than for a rolled I-shape, which is what the approximate reduction factors were developed to model.

Figure 5 shows a plot of the total applied load versus the lateral deflection of one of the arch ribs for one of the analyses. Several analyses were conducted with different patterns of loading in order to find the lowest overall buckling load. From ***Figure 5***, it can be seen that the buckling behavior is very much a bifurcation type instability, with little lateral deflection occurring until the buckling load is approached. For the pattern of loading analyzed, the buckling load was approximately 2.8 times the factored loads.

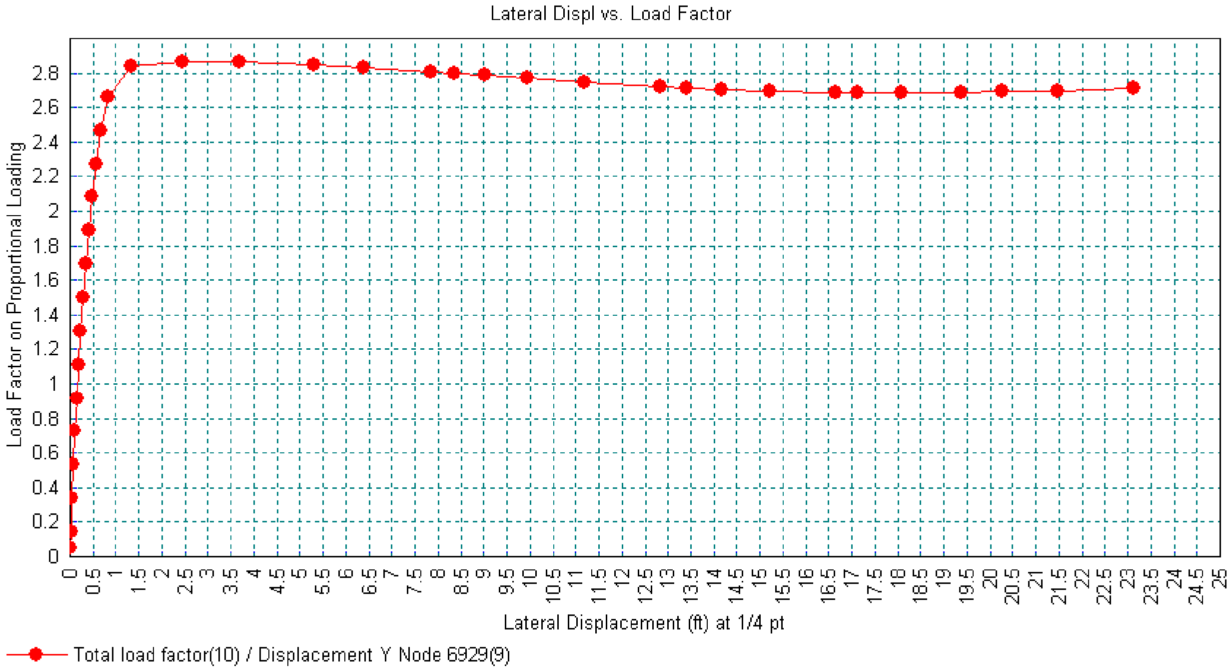

Figure 5: Applied load vs. lateral displacement of arch rib

A minimum factor for the arches in the original configuration was found to be approximately 2.5 over the factored applied loads. This is more than sufficient to satisfy the requirements of the AASHTO LRFD Specifications; however an investigation was made to determine if the performance of the bridge could be improved further. It was found that by moving the lower braces slightly further away from mid-span, a relatively large increase in the stability of the arches could be achieved. By shifting these braces two panel points, the buckling load increased by more than 30%. Additionally, the moments caused by wind in the arch rib at the critical steel-to-concrete connection decreased by almost 20%. Thus, for essentially no increase in structural costs, significant improvements in performance could be realized. ***Figures 6A -6B*** shows the before and after views of the brace relocation. It is of interest to note that further movement of the braces, while reducing the wind moments, results in a shift in the mode of buckling to one primarily, including the upper portions of the arch, and hence no further reduction in the buckling load. Thus, the adopted position of the braces is very close to optimum.

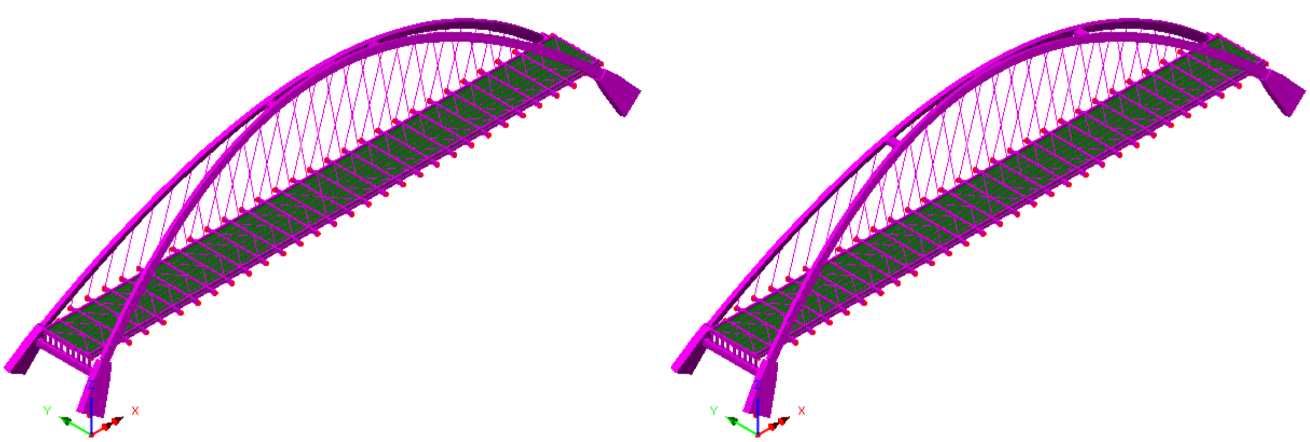

Figure 6A-6B: Original (left), and modified (right) location of Vierendeel bracing between arch ribs

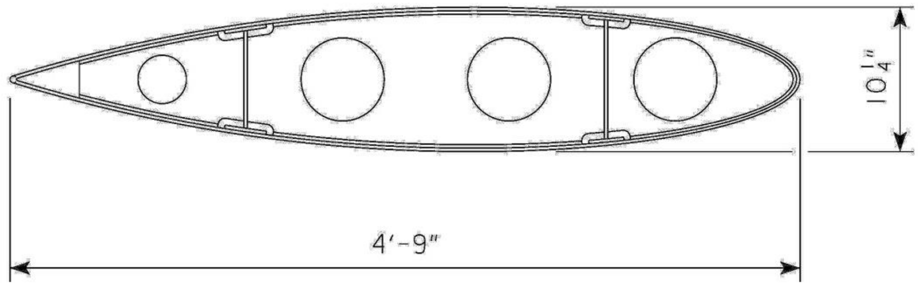

Figure 7: Winglet cross section showing NACA 0012 airfoil

The results of the buckling analyses were distilled down to equivalent kL values for use in the AASHTO design equations. This provided a simple way to incorporate the results of advanced buckling analyses into the typical design process, allowing the designers to adjust the arch section properties as required to meet the design objectives in an intuitive way.

A complete set of wind tunnel studies was performed on the design, in order to quantify the stability of the structure against flutter, the magnitude of forces and displacements due to buffeting winds, and the susceptibility of the bridge to vortex-induced motions. No flutter instabilities were uncovered during the testing, and the structural forces resulting from the buffeting responses were included in the design of the bridge. However, a susceptibility of the bridge to vortex-induced motions was found.

Vortex-induced motions are generally self-limiting, and are not typically dangerous to the structure, but can be very uncomfortable for pedestrians or vehicular travelers. When the wind is blowing from the west, the cantilever multi-use trail serves as a type of winglet, and produces a stabilizing influence on the structure. However for east winds, there is no multi-use trail, and for a wind speed of 37 mph, the westbound bridge was experiencing vibrations with a peak acceleration of over 30% of gravity. This is far in excess of the comfort criteria of 10% for that frequency and wind speed.

The solution adopted was to utilize winglets along the windward edge of the westbound structure. The winglets span between the floor beam extensions, which anchor the arch hangers and will not be highly visible from the roadway. Because only east winds cause the vibrations, the winglets could adopt an airfoil shape for efficiency and provide the structural depth to span between floor beams. The adopted airfoil shape for the winglets is a National Advisory Committee for Aeronautics (NACA) 0012 airfoil, which incidentally is the same airfoil used in the design of the B-17 bomber. A cross section of the winglets is shown in ***Figure 7.*** With the winglets in place, the maximum acceleration is limited to below the 10% of gravity threshold.

Arch Substructure Design Considerations

The design of the foundations for the main span true arch is truly unique. A thrust arch, with large lateral loads, will be constructed in a riverbed without the benefit of the conventional forms of lateral restraint from adjacent soil or a rock face. The depth of the river varies at this location from approximately 40’ at the deepest footing to 18’ at the shallowest footing. The riverbed is essentially bedrock as there is virtually no soil overburden at the bottom of the river.

Two foundation alternatives were developed in the preliminary engineering phase. The first utilized drilled shafts, whereas the second specified a spread footing on bedrock. As the design advanced and the thrust loads were refined, spread footing on rock was selected in order to mitigate the unknowns associated with lateral deflection and creep that could exist with the drilled shafts.

As the spread footing design was developed, concerns arose regarding the feasibility of being able to place the footing in the dry. The rock is fractured in this area and the lack of overburden would make cofferdam construction very difficult. A rock trench was specified in order to seat the sheeting with

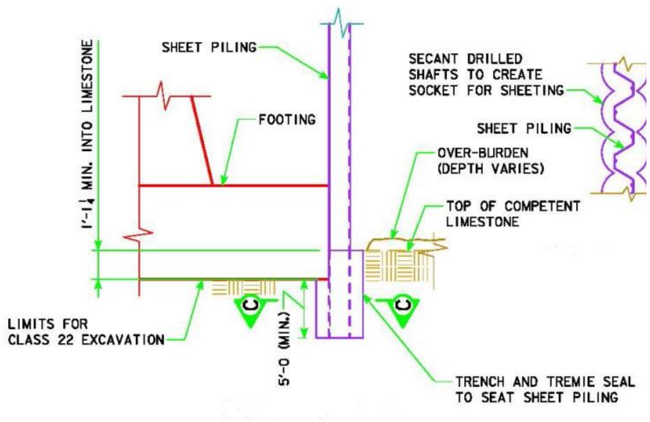

Figure 8: Spread footing design

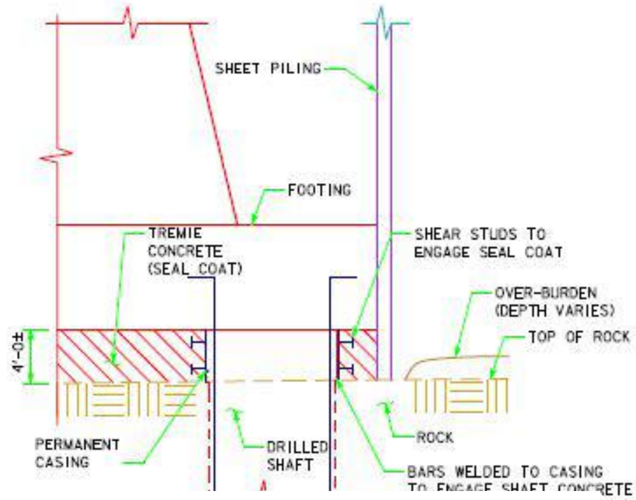

Figure 9: Hybrid foundation alternative

tremie placed concrete. This detail (See ***Figure 8***) will stabilize the cofferdam and also provide a seal to protect against horizontal water infiltration via the bedding planes in the rock.

With the understanding that the cofferdam detail will require substantial amounts of rock excavation (to be done via secant drilling) there was a desire to see if the efficiency of the foundation could be improved. A "hybrid" alternative was developed that eliminated the need to seat the cofferdam sheeting into the rock (***Figure 9***). Drilled shafts, or sockets, can be used in order to provide both vertical and lateral resistance in the bedrock. The shafts are limited in height, almost behaving more as a shear key, in order to alleviate concerns about lateral deflection. A seal coat was specified around the shafts, using studs or bars to take advantage of the shaft uplift capacity. This allows for conventional cofferdam construction and dewatering. A footing (or shaft cap) is then placed on top of the shafts, resting on the seal coat concrete.

The hybrid alternative also provides lateral load path redundancy. The shafts were designed to resist the entire thrust load, but friction between the footing and the seal coat then to the bedrock, is also adequate to resist the thrust loads.

Development of the hybrid alternative was a team effort that incorporated ideas and comments from multiple design consultants, the FHWA and the Iowa DOT along with feedback from contractors with regard to what is practical to expect in this particular river environment. The solution resulted in a foundation with improved performance at a cost savings when compared to the spread footing alternative.

Approach Bridges

A true arch has length limitations, so half a mile of approach structure is needed to fully extend the bridge over the 3400' river crossing. The approaches consist of a 10", two course, cast-in-place slab supported by 90" continuous hybrid, weathering steel plate girders with semi-regular span lengths of approximately 200'. The girders and bracing are primarily Grade 50W except that Grade HPS 70W flanges are specified in negative moment regions. To ensure reliability of this critical crossing, the eccentrically intertwined Y-shaped "reflection piers" were designed to resist vessel collision loads as well as provisions for blast resistance.

The multi-use trail structure moves off of the arch section of the structure, presenting a challenge in the design of the approach bridges. It was not desirable to carry a separate structure, with separate foundations, all the way to shore. Instead, the converging multi-use trail structure is fused together with the roadway structure at the first pier of the approach spans on either end of the arch. The independent portion of the multi-use trail structure is supported by a 3-girder system to provide the desired level of structural redundancy before framing into the continuous girder system of the roadway structure. The depth of the girders, coupled with their span length, led to significant potential lateral deflections under wind load. To guard against damage during construction, the flexible bike trail girder system will be temporarily braced against the roadway system.

Aesthetics

The I-74 Mississippi River crossing is the largest, most visible structure in the Quad Cities, making aesthetics of this landmark structure paramount to the community. The project stakeholders selected the basket-handle arch structure as an aesthetic option due to its inherent elegance, and a white and blue color scheme was chosen to enhance the appearance of the arch against the backdrop of river and sky.

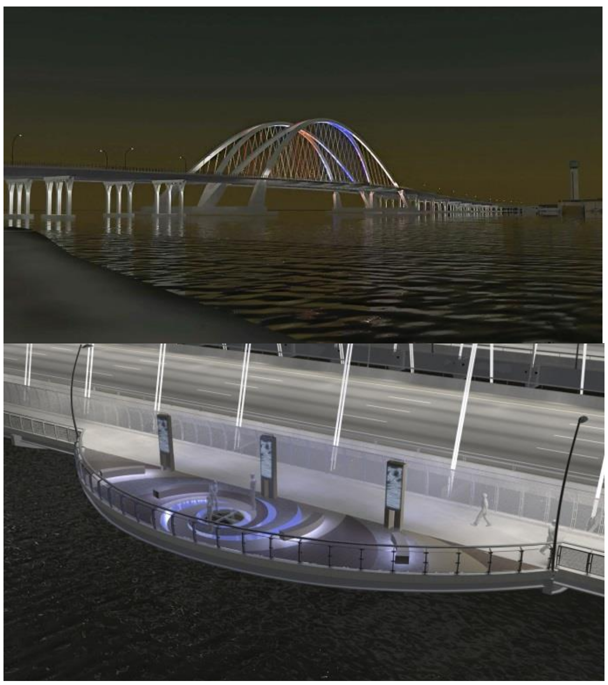

Figure 10A-10B: Aesthetic Lighting

A pedestrian overlook cantilevers off the midpoint of the arch on the multi-use trail to make the bridge attractive to pedestrians and cyclists. The arch is also equipped with aesthetic lighting that illuminates the silhouette of the arch without drawing undue attention (***Figure 10A-10B***).

With the arch established as the centerpiece, a theme of understated curvature permeates the surrounding project elements as a complement to the subtle elegance of the arch. These principles are infused into design elements ranging in scale from the landscaping and shapely columns of the reflection piers down to the contours of the steel railings, fences and light poles. The cumulative effect creates a stylish functionality that can be seen in ***Figure 11A-11B***.

Maintenance

Of course, the benefits of an attractive structure are reduced if its long-term health is not considered. While the overt effect of the project aesthetics ensured that one group of stakeholders was satisfied, the practicality of future maintenance also had to be addressed.

To improve its service life and reduce future rehabilitation costs, the structure is equipped with a piping system to facilitate a bridge washing program. However, the traffic volume on I-74 coupled with the bridge's location over the Mississippi River presented an access problem associated with future maintenance and inspection initiatives. To overcome this obstacle, an inspection walkway/traveler system was devised to provide access. This system includes a network of

Figure 11A- 11B: Arch elements throughout the design

approximately seven miles of galvanized steel catwalks and tie-off cables, concealed between the approach bridge girders, which supplement a state-of-the-art mechanical traveler under the arches.

The traveler system was designed for both structures to provide access to the main span of the arch bridges. The travelers span the full width of each vehicular superstructure, and allow a hands-on inspection of the entire floor system. In the parked position, the travelers are tight up against the arch piers, and can move from one pier to the other along the full length of the suspended structure. To improve inspector's access to the floor system, a rolling vertical scissor lift is provided on the traveler. Overturning is prevented by a rail system embedded in the traveler floor, and powered by the traveler's generator. The lift allows inspectors to access the full height of all floorbeams, as well as the stringers, without the need for ladders, ropes, or technical access.

The travelers are powered by independent diesel generators. The batteries for starting the generators are connected to permanent trickle chargers powered from the approach electrical service to ensure more reliable starting when needed. Other amenities include: swiveling maintenance lighting, LED floodlighting, and access platforms for performing preventative maintenance on the traveler end trucks. The design of the traveler included the provision for replacing the generators in the future, if needed, without the need for heavy equipment. The total cost of the inspection access system is estimated at approximately $8.5 million of which $2 million is earmarked for the mechanical travelers.

Bridge Health Monitoring

Accurate assessment of bridge condition is essential in increasing the life span of the bridge and enhancing public safety. Current bridge inspection techniques consist of labor intensive and generally subjective measures for quantifying deterioration and assessing health of various bridge elements. Several advanced techniques for assessing and monitoring the condition of bridge infrastructure have emerged including remote sensing technologies. These technologies significantly improve the efficiency of inspection, repair, and future rehabilitation efforts. Monitoring the condition of bridges using remote sensors also eliminates the need for traffic disruptions or lane closures.

Traffic forces on the arch bridges and the forces in the arch members will be monitored through a SHM system developed for the bridge. Both structures will use current wireless communication technology and sensors to store data at a common collection point for processing. The total cost of the I-74 SHM system is estimated at $3.5 million. Its benefits include:

1. Efficient scheduling and deployment of maintenance resources
2. Asset management
3. Safety enhancement through early detection of any structural abnormalities
4. Safety enhancement through monitoring bridge deck conditions
5. Validation of the design of the bridge by comparing sensors data against design parameters
6. Validation of historical and future bridge designs
7. Load rating of the bridge
8. Increased public confidence
9. Preserves the DOT's assets and provides support for field inspection programs

The main focus of the SHM is on the following areas of the structure:

Corrosion sensors will be installed into the deck to monitor corrosion potential of deck reinforcement. The sensor is directly embedded into concrete at the top level reinforcing steel mat. It monitors five factors in corrosion; linear polarization resistance, open circuit potential, resistivity, chloride ion concentration, and temperature. The sensor is tied to a small cage of #3 bars. The cage is directly attached to the reinforcement mat and holds the sensor at the appropriate level.

Wheatstone bridge load cells will be used to measure hanger forces due to permanent and live loads. The load cell consists of a cylinder of high strength steel or aluminum with 3-6 electrical resistance strain gages located around the circumference of the cell and connected together in a Wheatstone Bridge Circuit.

Moisture inside the arch ribs will be monitored using temperature and relative humidity probes in addition to leaf wetness sensors. These sensors are designed to determine the percentage of time a surface is wet versus the time it is dry. The sensor consists of a circuit board with interlacing gold plated fingers. The resistance between the fingers is lowered when condensation on the sensor occurs.

Vibrating wire displacement transducers will be used to measure displacement at expansion joint locations and relative movement between stiffening girders and pier cross beams at the arch piers. The transducer consists of vibrating wire in series with a tension spring. The tension spring is stretched as displacement occurs.

Vibrating wire surface mounted strain gages will be used to measure slow speed, long-term strain measurements, while strain transducers will be used to measure live loads strain. A strain transducer consists of full Wheatstone Bridge circuit with four active foil gages, all pre-wired in a rugged housing. The foil gages use the relationship between electrical resistance and conductor length to measure changes in strain.

Vibrating wire tilt meters will be installed for measuring change of rotation at the arch piers. This particular model has a pendulous mass that can move in one direction with gravity. A vibrating wire gage is used to restrain movement on the elastic hinge and is calibrated with regards to degree of rotation.

Superstructure vibrations will be measured using accelerometers attached to some of the floor beams. The accelerometers are capable of measuring accelerations along the three axes of the member (3-axis accelerometer).

Thermocouples will measure temperature gradient along the gradient profile of stiffening girders. They are metal resistance thermometers that change their electrical resistance dependent on temperature.

Data from all the sensors installed throughout the bridge will be collected using a data acquisition system, which also stores and provides remote access to the data to the Iowa DOT. Iowa State University will collect and analyze data from the SHM. They will also pre-establish threshold values for each sensor with the assistant of the bridge designer.

SHM is a relatively new technology. According to sensor manufacturers, sensors are rated same life expectancy as structures they monitor. However; some factors that may affect their life expectancy include location within the structure, weather conditions, noise, etc. Battery sources will be replaced every few years and the SHM system will require routine inspection and maintenance in order to preserve its life expectancy.

Conclusion

A steel design solution was found to be the most suitable option for replacing the Mississippi River crossing between Bettendorf, Iowa and Moline, Illinois. The basket handle true arch provides the elegance of a signature structure that is expected by the community to replace a national historic landmark. Along with the arch, a welded plate girder design proved to be the optimal solution for replacing the approach spans and viaducts on both sides of the river.

This $1.5 billion corridor construction project includes $125 million for the arch bridge and another $140 million for the approach structures. These estimates equate to approximately $930/sqft for the arch bridge and $295/sqft for the approach bridges. The design is scheduled for completion in 2014 with an accelerated 3-year construction timetable set to begin in 2017.