DESIGN, CONSTRUCTION AND STRUCTURAL HEALTH MONITORING OF A STEEL ARCH BRIDGE

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BIOGRAPHY

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SUMMARY

As part of designing, constructing and maintaining the bridge infrastructure in Iowa, the Iowa Department of Transportation (Iowa DOT) has focused efforts on investigating the use of new high performance materials, design concepts and construction methods, and various maintenance methods. These progressive efforts are intended to increase the life span of bridges in support of the Iowa DOTs objective of building and maintaining cost effective and safe bridges.

Under a contract with the Iowa DOT, HDR Engineering, Inc. performed a bridge replacement Type Study and final design services for the replacement of the existing concrete arch bridge on US 65 crossing the Iowa River in Iowa Falls, Iowa. The existing bridge was structurally deficient and functionally obsolete, leading the Iowa DOT to opt to demolish the existing bridge and build a new bridge on the existing alignment. The replacement option consisted of a Partial Thru Steel Arch Bridge.

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Introduction

Under a contract with the Iowa Department of Transportation (Iowa DOT), HDR Engineering, Inc. performed a bridge replacement Type Study and final design services for the replacement of the existing concrete arch bridge on US 65 crossing the Iowa River in Iowa Falls, Iowa. In addition, and under a separate and different contract, Iowa State University instituted a field test program to focus on the structural performance evaluation of several critical components during construction of the bridge for correlation with expected design performance.

The existing bridge was structurally deficient and functionally obsolete, leading the Iowa DOT to opt to demolish the existing bridge and build a new bridge on the existing alignment. The replacement option consisted of a Partial Thru Steel Arch Bridge.

This paper will discuss the scope of the Type Study that included demolition and replacement options, selection criteria for the constructed option, site constraints, collaboration with stakeholders, structural system for the chosen steel thru arch, special conditions, field testing and monitoring of the structural health of the structural system, construction vibration monitoring, incentives for early completion as well as construction and construction related issues.

Existing Bridge

This bridge is located in Iowa Falls, Iowa and was built in 1928. It is a 235-foot reinforced concrete open spandrel deck arch structure with a 24-foot-wide roadway and 5-foot-wide sidewalks on each side of the roadway.

Figure 1

Elevation of Existing Bridge, Looking West

The reinforced concrete deck is supported by reinforced concrete floor beams, which are a part of the spandrel bents. The spandrel bents frame into the reinforced concrete arches and the arches are supported by reinforced concrete abutments (thrust blocks). The abutments are founded in the native rock out-cropping. The existing bridge had undergone rehabilitation on seven different occasions with the major rehabilitation in 1976 and 2000. Original construction expansion joints were placed transverse to the deck at the ends of the deck and at 6 other locations along the deck. The joints deteriorated over the years and caused major deterioration in the floor beams and columns directly below the joints. However, subsequent rehabilitation eliminated all the intermediate expansion joints. Costs of repairs and strengthening of the existing bridge were a major factor that played into the decision to replace the bridge. The existing bridge was listed on the National Register of Historic Places.

Figure 2

Existing Bridge, Looking North

Bridge Replacement Type Study

The purpose of the study was to evaluate feasible options for the replacement of this bridge as well as various feasible demolition concepts. The evaluation of the various demolition concepts focused on costs, and timeline of demolition taking into consideration the known site constraints. The evaluation of the bridge replacement options focused on the advantages and disadvantages associated with each option which included costs and timeline of construction, site constraints and the shareholder opinions.

Constraints and Constructability Issues

At the time of the type study, four major site constraints were identified:

- Access to the river at bridge site was not fully understood. The bridge sits approximately 40 feet above the normal water level, with abutments set into vertical rock walls lining the channel. The water level is currently controlled by a dam located just downstream from the bridge site. It

would be later determined, that the bridge site could be accessed from a city boat ramp located about 2,000 feet upstream of the bridge.
- Located at the northwest corner of the bridge, is Saint Matthew's Episcopal Church, also listed on the National Register of Historical Places
- Sanitary sewer was located downstream and adjacent to the existing structure. Replacement of this utility line would have been very difficult and cost prohibitive.
- A hydro-electric dam is located about 1,000 feet downstream, where a certain water level is needed to maintain its proper operation.

In addition to the above major constraints, there are many residential properties and businesses within close proximity of the bridge site. Therefore, the demolition of the existing bridge and the construction of the new bridge needed to include measures to minimize the impact on these properties, minimize disruption to the dam operation and mitigate any environmental impacts.

Demolition Concepts

As a part of the type study, Iowa DOT wanted to explore feasible options for the demolition of the existing bridge. The demolition methods were evaluated for cost, time, access, environmental concerns, and constructability as discussed above. To explore the feasible options, certain assumptions were made, such as assuming the river would be navigable with barges launched from the city boat ramp, no prohibition on the use of explosives, and no environmental restrictions. Methods would be employed during the construction phase to document the condition of existing buildings prior to and during demolition.

Five feasible options for demolition were identified:

1. Removal of the existing bridge deck using conventional concrete sawing and removal of the arches using engineered explosives. After removal of the deck and supporting columns, arches would be dropped into the water and retrieved using a barge mounted crane.
2. Removal of the existing bridge deck using conventional concrete sawing and removal of the arches using engineered explosives. After removal of the deck and supporting columns, arches would be dropped onto segmental barges placed beneath the existing bridge.
3. Removal of the existing bridge deck using conventional concrete sawing and removal of the arches by tying them back to a temporary anchored tower. After removal of the deck and supporting columns, the arches would then be saw-cut out in segments and lifted off with a barge mounted crane, progressing from the center of the arches toward the abutments.
4. Removal of the existing bridge deck using conventional concrete sawing and removal of the arches by tying them back to a temporary anchored tower. After removal of the deck and supporting columns, the arches would be temporarily supported by falsework erected in the river. The arches would then be saw-cut out in segments and lifted off with a barge mounted crane, progressing from the center of the arches toward the abutments.
5. Removal of the entire existing bridge using engineered explosives and dropping it into the river. Debris would then be removed using a barge mounted crane.

After careful consideration, the contract specifications required vibration monitoring, disallowed the use of explosives, and required no debris be allowed to fall in the river.

Bridge Replacement Alternatives

The town of Iowa Falls prides its self as the scenic city with the Iowa River at the center of its beauty. The Iowa River is a scenic river with two arch bridges and one suspension bridge that span across it within the small city limits. River cruises are a major city attraction in Iowa Falls. Cruises navigate the river and pass underneath many of existing majestic and beautiful bridges. The city prides itself in historical preservation and is committed to maintaining a beautiful scenic river.

Any replacement option that did not fit the aesthetic and the community expectation would have been very difficult to sell. However, Iowa DOT wanted to explore the options available to them for the replacement of the structure. Through a brain storming session between the Iowa DOT and HDR, it was decided that the type would be limited to girder and arch type bridges. Four different alternatives were considered. The alternatives were then evaluated for cost, timeline for construction, aesthetic value, constructability and impacts on the community. The five alternatives are as follows:

A Prestressed Concrete Girder Alternative

Figure 3

A Haunched Steel Girder Alternative

Figure 4

A Concrete Deck Arch Alternative

Figure 5

A Partial Thru Steel Arch Alternative

Figure 6

In an effort to engage the community and solicit opinions on the type of bridge to replace the existing arch bridge, the Iowa DOT held a public information meeting to showcase each of the options considered. The attendees favored the thru steel arch bridge over any of the other options.

Therefore, taking all considerations into account, the Iowa DOT decided on the Partial Thru Steel Arch option. Preliminary plans were prepared. The replacement bridge required the construction of numerous retaining and stabilizing walls to allow for the skewbacks of the arch to be placed as well as to protect the adjacent properties. A preliminary rendering of the final steel superstructure is shown in Figure 7.

Figure 7

Conceptual rendering of the Partial Thru Steel Arch Bridge

Site Constraints and Retaining Structures

While the historic arch bridge was to be replaced with a suitable structure, there were serious concerns about protecting the historical church located adjacent to the bridge. Two main concerns were protecting the church from undermining during the excavation for the bridge foundation and limiting vibrations from the construction activities. To this end, numerous rock cuts and retaining walls were constructed to preserve and stabilize the ground adjacent to the church and nearby properties and minimize the construction zone footprint.

The new bridge is approximately 30 feet wider than the existing bridge, and with intersecting city streets just off each end of the bridge, Saint Matthew's Episcopal Church on the northwest corner and private property owners on the both the southeast and northeast corners, space was a precious commodity. With the arch foundations required to be set approximately 30 feet below grade and maintaining access to the east side of the church building, vertical cuts in the rock were required to allow room for the footings and yet leave sufficient space for access. See Figures 8 and 9.

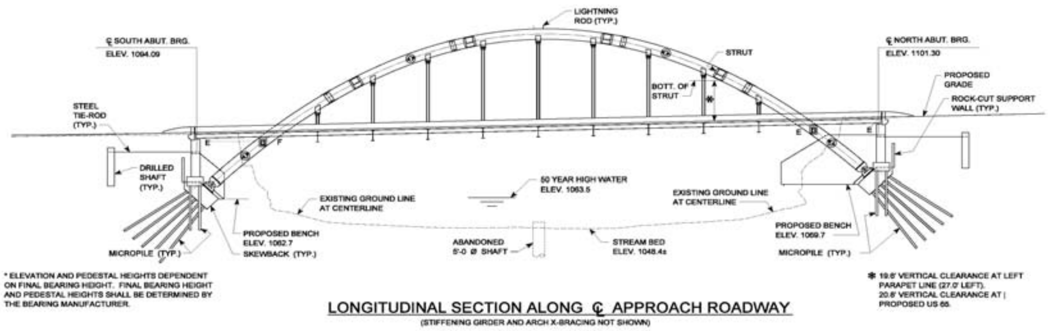

Figure 8

Longitudinal Section of the Partial Thru Steel Arch Bridge

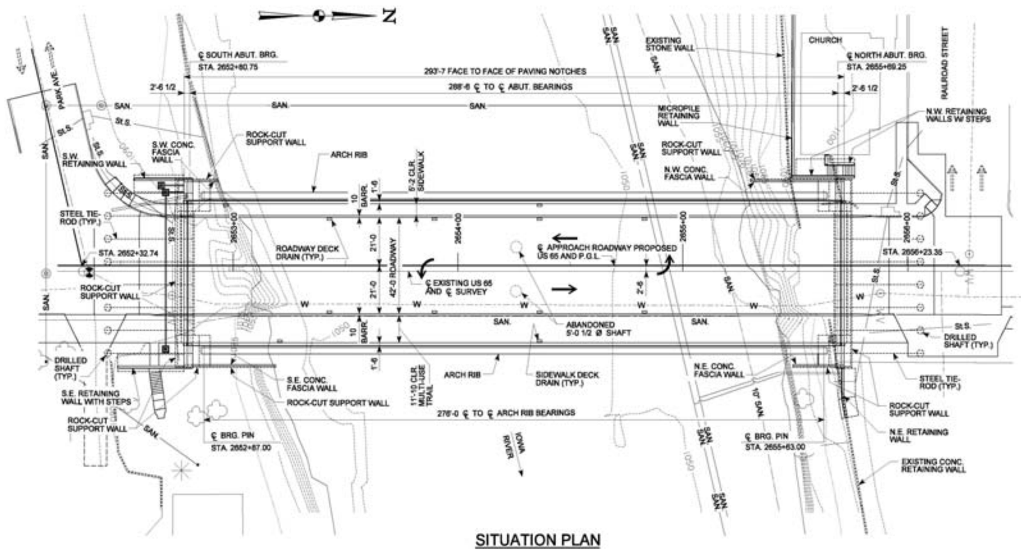

Figure 9

Situation Plan of the Partial Thru Steel Arch Bridge

Rock nail soil support walls with reinforced concrete fascia walls were used to provide a continuously supported vertical excavation as well as a smooth finished wall. The ends of the concrete anchors were fitted with shear studs on their anchor plates to hold the concrete fascia wall in place. The concrete fascia wall was designed to resist the load of 4 feet of sloping vertical overburden as well as a pedestrian handrail. This load is carried down the concrete fascia wall and transferred as a tension load to the top row of rock nails. See Figure 10.

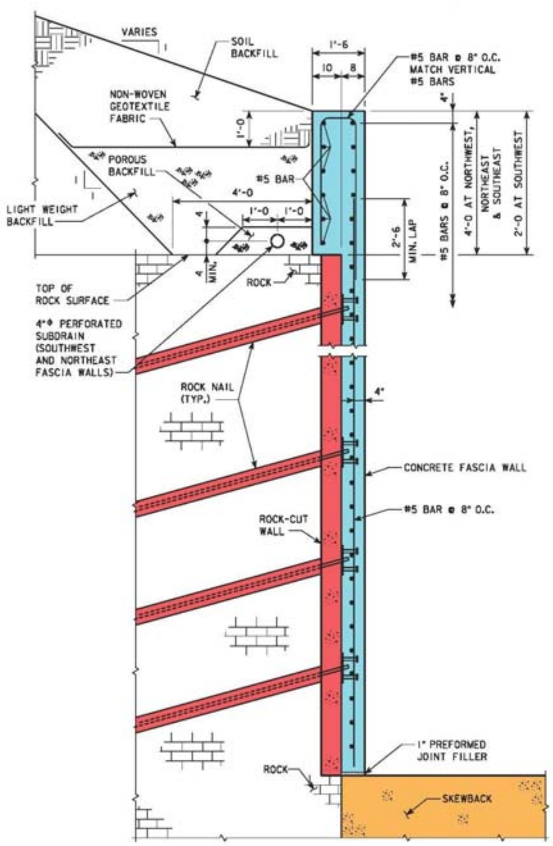

Figure 10

Rock Nail and Concrete Fascia Walls

The existing stacked stone retaining wall located on the river side of the church providing access around the building was also at risk. This wall showed evidence of sloughing off the rock below and it was deemed at risk of failure during construction, especially as construction would require removing part of the wall to make room for the foundation of the bridge. In order to both replace the wall and provide additional support for the church during construction, a micropile system with lagging wall was installed along the south side of the church. This wall would extend to the rock nail and concrete fascia walls at the edge of the bridge footing. See Figure 11.

Figure 11

Rendering of the Micropile Wall on the South Side of the Saint Matthew's Church

Partial Thru Steel Arch

The partial thru steel arch is 67 feet-10-inches wide between the centers of the two arch ribs and 276-feet-0 inches long between the bearing pins. The structure supports a 63-foot-8-inch bridge deck consisting of a 5-foot-2-inch wide sidewalk, 11-foot-10-inch wide multiuse trail and a 42-foot-0-inch wide clear roadway. For design and aesthetic reasons, a height factor of 0.25 was used for the parabolic curve of the arch ribs. The arch ribs are braced by four struts above the bridge deck, two framed-in floor beams and one set of cross bracing below the bridge deck. See Figure 12.

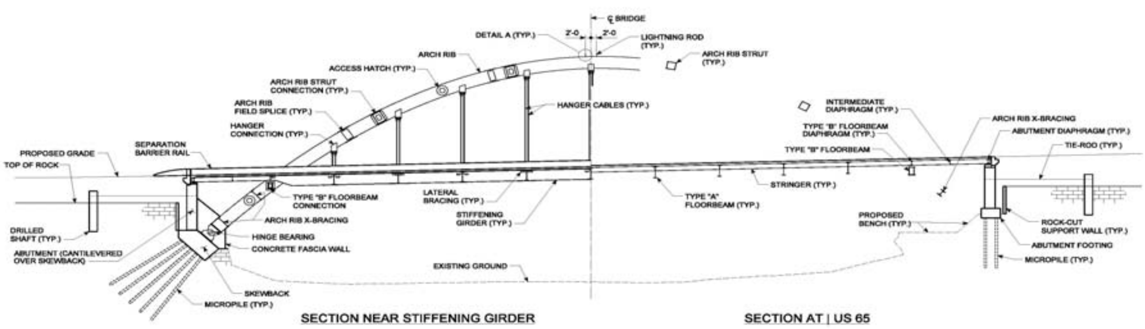

Figure 12

Component Elevation of the Partial Thru Steel Arch

The bridge deck is supported on a steel stringer and floor beam system. Nine of the floor beams are hung from the arch rib while the two end floor beams are framed directly into the arch ribs. The interior stringers connect to the interior floor beams with simple shear clip angle connections and run continuous over the top of the end floor beams. The exterior stringers are actually stiffening girders designed to distribute vehicular loads from the deck to multiple hanger cables as well as minimize local live load deflections. See Figure 13 for the deck cross section.

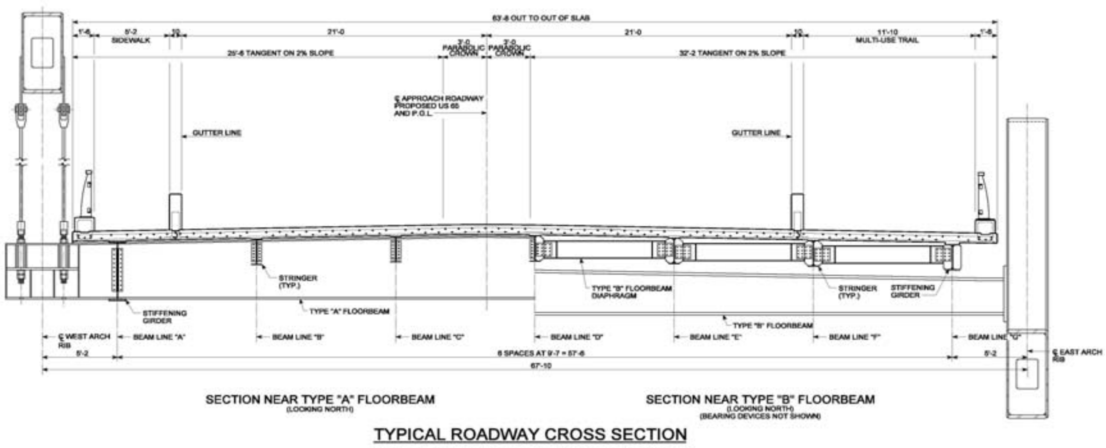

Figure 13

Typical Roadway Cross Section

The stiffening girders were designed in tandem with the hangers from both a functional and a theoretical stand point. The more rigid the stiffening girder, the more distribution of live load across multiple hangers occurs, and the more costly the stiffening girder becomes. The arch ribs are protected from vehicular traffic by traffic separation barrier, either a sidewalk or a multiuse trail and finally by a steel handrail on a raised concrete parapet. To allow ease of maintenance and in case of damage to the hanger cables, the cables were designed to allow for full roadway traffic with any one of the 4 cables in a set removed or damaged.

The stiffening girder design was governed by the effects of the HL-93 live load causing differential deflections in the hanger cables as the load moves over the bridge deck. A baseline analysis was performed on a conventional girder bridge on rigid supports. In this analysis, the hanger cable connections were modeled as rigid supports in the vertical direction. The results from this analysis were used in the design of the end spans where the stiffening girder passes over the rigid end floor beam. For the locations where the interior floor beams are supported by the hanger cables, however, a second model was created to capture the effect of the cable elongation under load and the distributing effects of the stiffening girder. The moment demand on the stiffening girder generated by the live load was approximately 5 times higher than the baseline analysis due to the effects of strand elongation.

The design of the arch rib had a few added complications due to the geometry of the bridge. The arch rib used on this structure is less rectangular and more of a square shape than many traditional arch ribs. Additionally, the web plates, specifically toward the base of the arch, are thicker than normally expected. This is because most arch ribs are primarily compression members, and while all arch designs have some load cases imparting out of plane stresses in the arch rib, many do not develop a net tension. There are situations in this arch bridge where the conventional design practices used to minimize out of plane loads could not be followed. One case is the wind bracing between the arch ribs. In many arch bridges the bracing system is trussed to limit weak axis bending as a result of wind loads perpendicular to the arch rib. However, due to the width to span ratio, a trussed bracing system was deemed inefficient and impractical. Therefore, 4 struts were provided between the arch ribs to allow them to share the lateral loads, but the resistance to those loads would be in the weak axis bending of the arch ribs. This resulted in an arch rib with tension at service load. This complicated the requirements for testing on the arch rib as it became a fracture critical component.

A second area where the large width to span ratio caused the design to diverge from conventional thinking was with the end floorbeams that frame directly into the arch rib. A shorter bridge span allows for a smaller arch rib, but a larger bridge width requires a larger end floorbeam, thus a larger end floorbeam connection. The result was the end floor beam needed to be both as narrow and shallow as possible and yet it would still impart larger than normal out of plane bending forces into the arch rib. To minimize the size of the end floor beam as well as provide it with increased toughness and fatigue resistance, it was designed to be made of A709 Grade HPS50W. While the design limits of HPS steel are similar to those of standard weathering steel, it inherently has a higher fatigue and fracture resistance. Initially, the potential for higher yield strengths of the HPS steel were also considered, however to limit deflections, a higher moment of inertia with a lower yield strength was deemed the better option for this situation. See Figure 14.

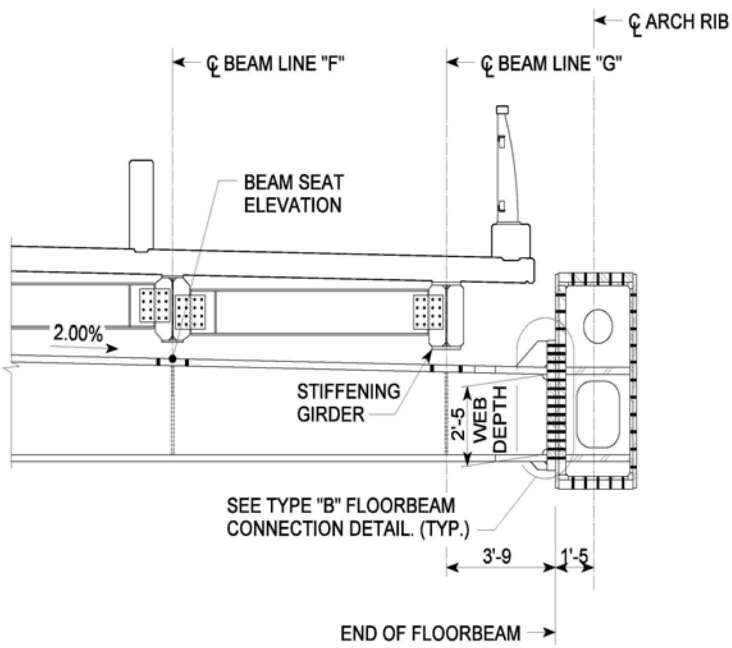

Figure 14

End Floorbeam Framing into Arch Rib

A third cause of the more square arch rib is the use of pinned bearings as opposed to fixed bearing connection. Often, with longer spans, the reduced "k" value for the "kL/r" ratio obtained by use of a fixed bearing will more than offset the additional steel required to resist the higher moments developed at the arch skewback due to the fixity of the bearing. However, after much iterative analysis, it was determined the reduced moments from a pinned connection saved more steel weight than a fixed design. The additional benefit of the pinned bearing connection is the effect it has on the load transfer to the substructure. Removing the moment from the primary direction greatly reduced the size of footing required. Due to the tight geometric constraints, a smaller footing footprint was required to lessen the impacts to the adjacent properties, particularly near the historic church on the north side. See Figure 15.

Figure 15

Pinned Bearing Constructed in Place

Substructure

The site of the Iowa Falls Arch Bridge was very conducive to the high load foundations required for an arch bridge. The walls of the Iowa River channel are very steep and formed of a competent weathered limestone. This rock allowed for a very high bearing capacity. However, the river below created a complication. The Iowa River flow is controlled by a dam just downstream from the bridge site. As opposed to the natural rise and fall of the stream, the dam has kept the river to a fairly constant depth under the bridge. This has allowed the water to infiltrate the weathered limestone and undermine portions of the existing historical bridge's abutments. See Figure 16.

Figure 16

Existing Arch Bridge North Abutment Showing Undermining

Although the new bridge was proposed to have a longer span, thus removing all areas presently undermined, it was desirable to design a structure less susceptible to undermining than a spread footing founded on the rock wall.

The solution was high capacity steel micropiles founded into the rock below the stream bed and thus not susceptible to undermining. The high capacity nature of the micropiles allowed the skewback to remain relatively small. The design of the skewback itself then became that of a pile foundation as opposed to a spread footing. Unfortunately, the majority of the current use of micropiles is for foundations in soil. The standard procedures from FHWA for micropile design for transfer of load between the micropile and the surrounding soil focus on the interaction between the soil and the grout. This was not the controlling condition for this bridge. The interaction between the grout and the weathered limestone produced such a high capacity; the attention had to shift to the interaction between the grout and the steel casing of the micropile. Very little known research has been performed in this area and to achieve a reasonable and documentable value, input was requested from FHWA and a limit was established. This required the micropiles to extend a couple feet deeper than originally anticipated. See Figure 17.

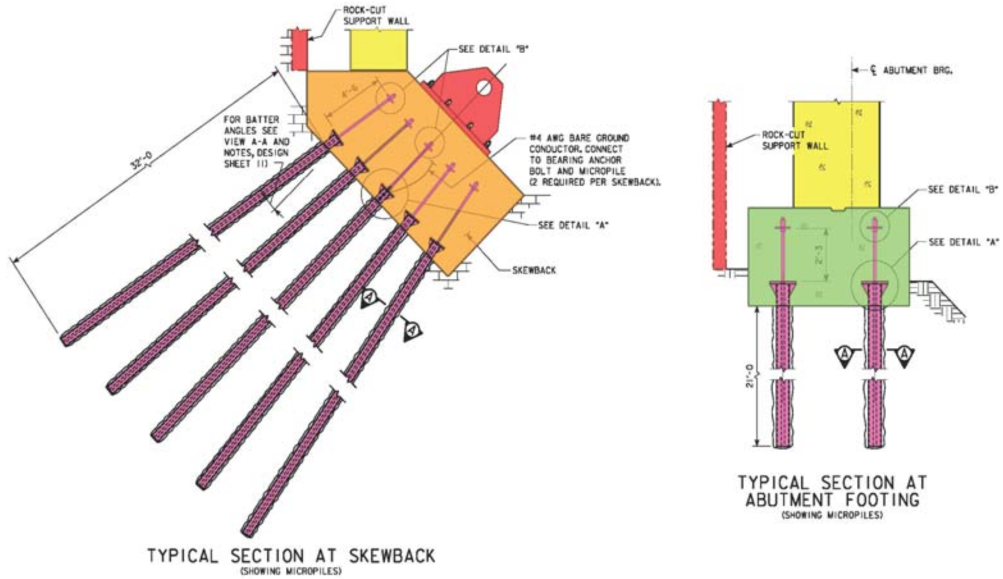

Figure 17

Section of Skewback and Abutment Showing Micropiles

The abutments are high walled, tied back, concrete retaining walls as much as they are abutments. Continuity between the skewbacks and the abutment backwall was not feasible due to the nature of the loads being imparted. The thrust on the skewbacks is in the opposite direction of the soil load on the back of the abutment wall. There is a relatively small vertical load on the abutment backwall, mainly just from the short span from the arch end floor beam to the abutment bearing location. Therefore, it was possible to separate the soil retaining portion of the abutment from the skewback and support the abutment on a smaller footing between the two skewbacks. This footing is also founded on micropiles extending below the depth of possible undermining. The upper portion of the abutment back wall is tied back to a row of eight drilled shafts by means of a #14 Grade 75 threaded rods. These rods were pretensioned prior to backfilling the abutment to achieve a vertical face on the abutment after backfill material was placed behind the abutment. Conventional backfill would have required both a greater number of drilled shafts for anchoring tie rods as well as a larger abutment footing to resist the pretensioning moment. Therefore, the backfill on both ends of the bridge was specified as a light weight granular backfill with a unit weight of less than 50 pcf. See Figure 18.

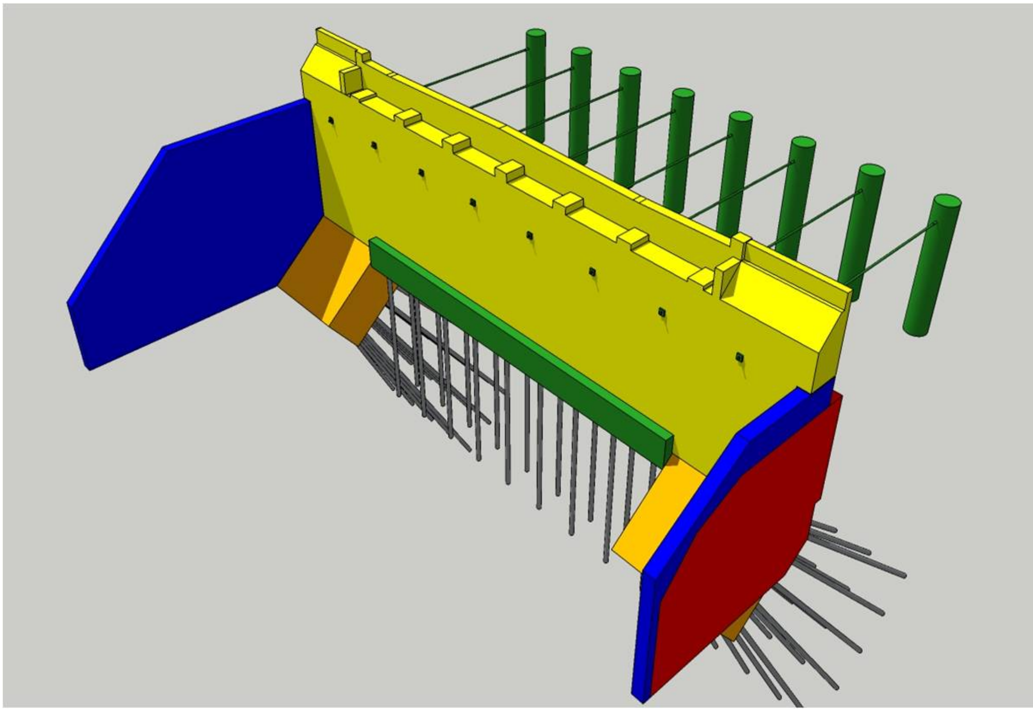

Figure 18

Rendering of Abutment, Drilled Shafts, Skewback and Micropiles

Member and Corrosion Protection

To achieve longer than expected service life, a number of corrosion resisting systems were incorporated into the design as well as some impact resistant features.

The structural steel is A709 Grade 50 weathering steel. Additionally, the areas exposed to salt spray and runoff are painted with a 3 coat paint system to further protect the structure. The inside of the arch rib is also prime coated for its entire length. The sockets, pins and threaded rods connecting the hanger cables to the arch rib and interior floorbeams are galvanized. The cables have a Class A zinc coating on their interior strands and a Class C zinc coating on the exterior strands for additional corrosion protection.

Impact resistance was designed into the hanger cables and tie backs at the abutment as well. The possibility of vehicular impact to the hanger cables and the ability of the bridge to withstand damage to the cables was elaborated on earlier in this paper. The tie backs at the abutment were also designed to withstand small impacts such as those associated with small tool excavation in the event of having to access the buried utilities off the end of the bridge. The tiebacks are encased within a steel tube and grouted to add additional section and inertia in the event of an impact. Additionally, through the use of the light weight backfill, the failure of one of the ties will not result in a zipper effect on the remaining ties in the abutment.

Construction Contract and Special Provisions for Construction

Written into the language of the construction contract were requirements for the contractor and his subcontractors to perform a variety of additional services related to the construction of the bridge. Some of the required provisions are as follows:

- In order to facilitate the communication among all project team members: Iowa DOT, HDR Engineering, Inc., the contractor and fabricators; the contract required a project website based software be used to manage the electronic submittals, process requests for information (RFIs), store contract documents, other submittals and meeting minutes.

- The contractor was required to coordinate with Iowa State University for the installation of a multi-sensor continuous monitoring system to monitor the structural health of the structural elements of the bridge. This system will be further described later in this paper.
- Vibration monitoring was required for the purposes of protection of property, mainly Saint Matthew's Episcopal Church at the northwest corner of the bridge and a residential property located at southwest corner of the bridge. This included a pre and post construction surveys of these vulnerable properties.
- The Contract plans required a sequence of construction in order to further protect properties and preserve the integrity of existing bedrock.
- The use of explosives was allowed for the purposes of rock excavation conditional on approval of a controlled blasting plan. However, the use of explosives and chemicals were not allowed to be used as means to demolish the existing bridge.
- The contractor was allotted 190 contract days to complete construction with contract start date of August 23, 2010.
- There were incentive provisions for a drop dead date to open the bridge to traffic in the form of "No Excuse Bonus" and are not adjusted for additional scope, delays and circumstances beyond anyone's control.

Construction

Although the contractor would not be allowed to close the bridge to traffic until September 28, 2010, the contract was let early to allow lead time for fabrication. The contract was let on July 20, 2010. Three Iowa based contractors with experience in constructing bridges over major rivers competed for the project. Cramer and Associate, Inc. of Grimes, Iowa was the low bidder. The total bid difference between the winning bidder and the second lowest bidder was less than 3%, and less than 5% difference between the winning bid and the third bidder. Bridge contract cost on bid day was $12,789,942 which works out to $604/Ft^2 of bridge deck (without existing bridge removal and approach roadway).

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

In accordance with the contract plans, the contractor first constructed the micropile retaining wall on the south side of the historic church. Following this construction, the contractor was able to proceed with the demolition of the arch. Conventional methods were used for the removal of the existing deck and columns. The concrete from the deck removal was then used to line the channel underneath the bridge, as it was the contractor's intent to drop the arch pieces onto the rubble pad built under the bridge. The arches were jack hammered at strategic location near the end thus allowing them to fall under their own weight onto the earthen pad constructed underneath the existing bridge. See Figure 19. The contractor then proceeded to perform the excavation for the abutment and construct the rock walls around the abutments. Concurrently with the excavation and abutment construction, the contractor constructed the falsework supports to aid in the erection of the steel arch, and the deck framing.

Figure 19

Demolition of the Existing Bridge

PDM Bridge of Eau Claire, Wisconsin fabricated the structural steel members of the bridge. The installed cost of the superstructure steel was $3.25/ Lb.

The steel erection began in mid-July with the placement of the south bearings. Utilizing falsework towers in the river, the first two segments of the arch were erected from both sides of the river. The falsework towers were designed to allow the segments of the arch to be adjusted vertically to facilitate the setting of the crown section. See Figure 20. After both arch ribs were erected along with the end floor beams, lower cross bracing and the cross struts, the contractor started erecting the floor system. The floor system was erected in a panel by panel method from south to north.

Figure 20

Structural Steel Erection

The concrete for the bridge deck was placed using two finishing machines starting at the center of the arch. The use of two finishing machines and the starting point was a contract requirement in order to balance the load to the arch rib during concrete placement. The contractor was able to access the bridge from both sides during the bridge pour and accomplished the deck pour with no difficulties.

The contractor opened the bridge to traffic on November 18, 2010 and therefore was eligible for the "No Excuse Bonus" of $250,000.

Health Monitoring System

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

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

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

With respect to the Iowa Falls Bridge project, the goal was to implement a multi-sensor continuous SHM system for the soon to be constructed Iowa Falls Arch Bridge. The pilot monitoring system will be developed for general performance evaluation (structural, environmental, etc.) so that it can be easily adapted to other bridge types and other monitoring needs. The system will allow easy access to real time data and will provide data in a format for immediate implementation by the Iowa DOT. It is noteworthy that the results of this study will be critical for the development of a similar SHM System for planned construction of other highway and interstate bridges.

To this end a SHM system was developed by the BEC and is currently being deployed. The general attributes of the sensor system are as follows (see figures for typical sensor placement locations):

Environmental

a) Wind speed and direction
b) Bridge deck potential icing conditions

Structural

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

Vehicle Classification System and other communication

l) Vehicle geometry/volume, alert for delays, etc.
m) Web-based “dashboard” (i.e. real-time reporting for operational center management)

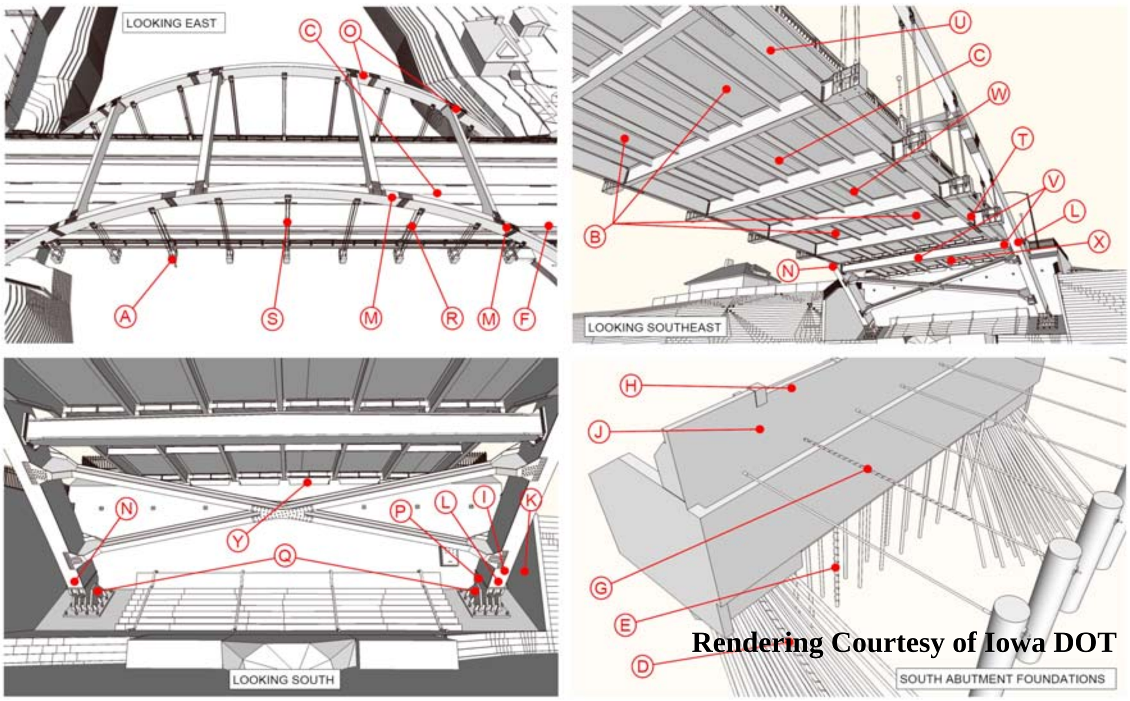

Figure 21

Locations of Instrumentation

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

One critical product developed for this project is a web-based “dashboard” (i.e. real-time reporting for operational center management). There will be one primary web page containing web links designed for each appropriate DOT Office to utilize the SHM field data. Each appropriate DOT Office link will contain a web page that will allow the real-time data to be implemented effectively. For example, the bridge rating engineer within the Office of Bridges and Structures could update the bridge rating at any time using the real time data. The format of the data is based upon structural performance parameters (e.g. live load distribution, member live load forces, vehicle position on the bridge, etc.) which could be used directly in updating the rating. The format of data to be collected for use by the bridge maintenance engineer within the Office of Bridges and Structures will also be based upon critical inspection performance indicators (e.g. corrosion growth and moisture accumulation, as well as structural response indicators such as stress (strain) that might exceed acceptable thresholds.

Conclusion

The Iowa DOT met its goals by replacing an existing functionally obsolete and structurally deficient structure with an economical solution that met the community expectations. The communication among stakeholders and the tools employed during the process from concept to completion were key to achieving the goals set. Information gathered from the health monitoring system will aid in future designs to help achieve even longer life from bridges in general.