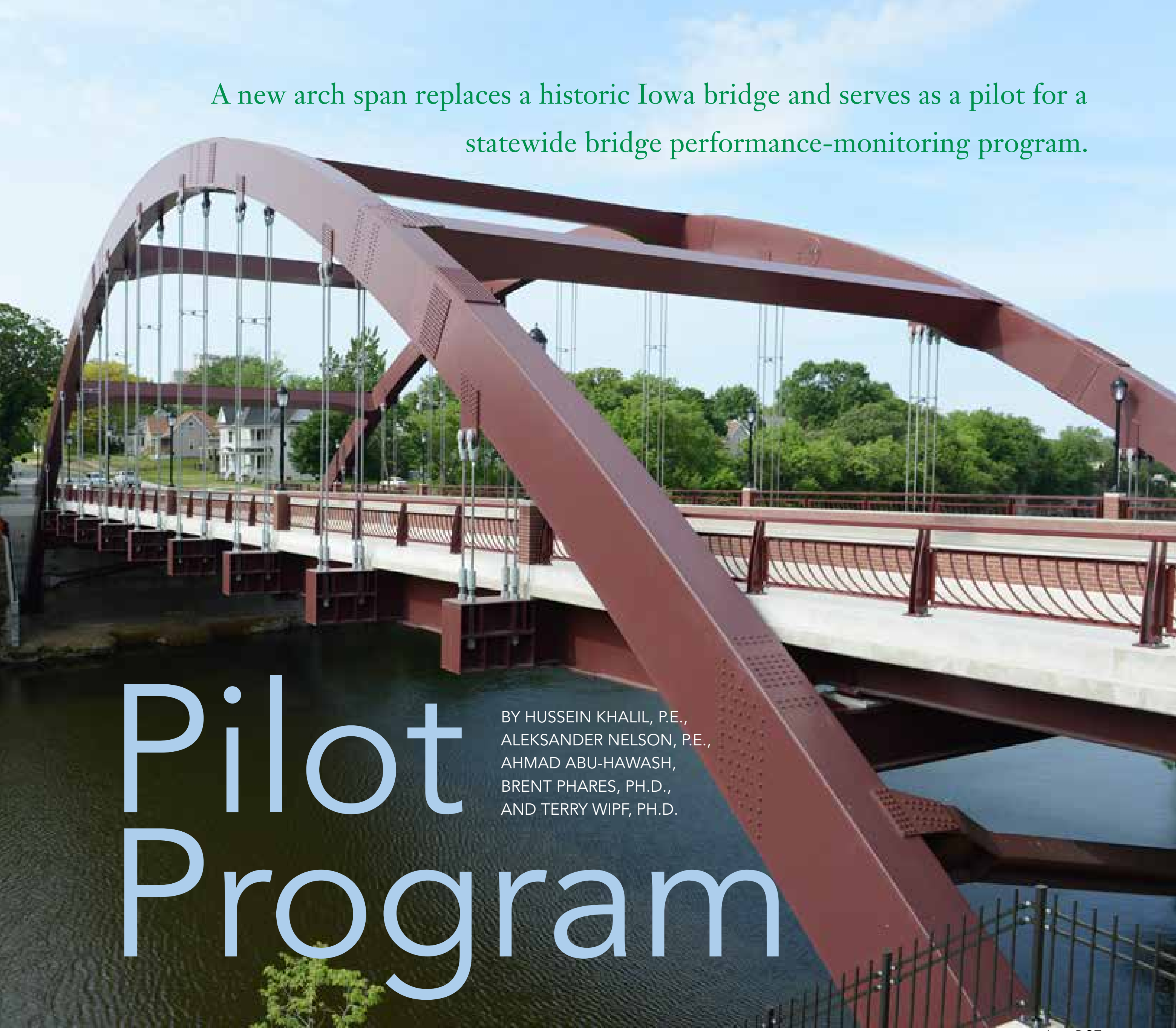
A new arch span replaces a historic Iowa bridge and serves as a pilot for a statewide bridge performance-monitoring program.



Pilot Program

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Iowa DOT

REPLACEMENT DECISIONS AREN'T ALWAYS EASY— especially when the structure in question is listed on the National Register of Historic Places.

In the case of the Iowa Falls Bridge, which crosses the Iowa River on U.S. Highway 65 in Iowa Falls, Iowa, it had to happen. The bridge, a 235-ft-long reinforced concrete open spandrel deck arch structure (with a 24-ft-wide roadway and 5-ft-wide sidewalks on each side), was built in 1928 and was considered a local landmark. The existing bridge had undergone rehabilitation on seven different occasions, including major ones in 1976 and 2000. However, by 2007, the bridge had become structurally deficient and the costs of repairs and strengthening were deemed high enough to warrant replacing it rather than rehabilitating it yet again.

Under a contract with the Iowa Department of Transportation (Iowa DOT), HDR Engineering, Inc., performed a study of feasible replacement options and demolition concepts as well as final design services for the new span. (In addition, and under a separate contract, Iowa State University instituted a field test program to focus on the structural performance evaluation of several critical components during construction of the new bridge for correlation with expected design performance. See the sidebar for more.)

Iowa Falls prides itself as a scenic town with the Iowa River at the center of its beauty, and is committed to historical preservation; any replacement option that did not fit the desired aesthetics and community expectations would have faced strong opposition. Through a brainstorming session between Iowa DOT and HDR, it was decided that replacement options would be limited to girder and arch type bridges. Four different bridge alternatives were considered and evaluated for cost, timeline for construction, aesthetic value, constructability and impact on the community. The bridge options evaluated were: a prestressed concrete girder, a haunched steel girder, a concrete deck arch and a partial through steel arch.

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 partial through steel arch bridge, and this ended up being the chosen design.

Tight Quarters

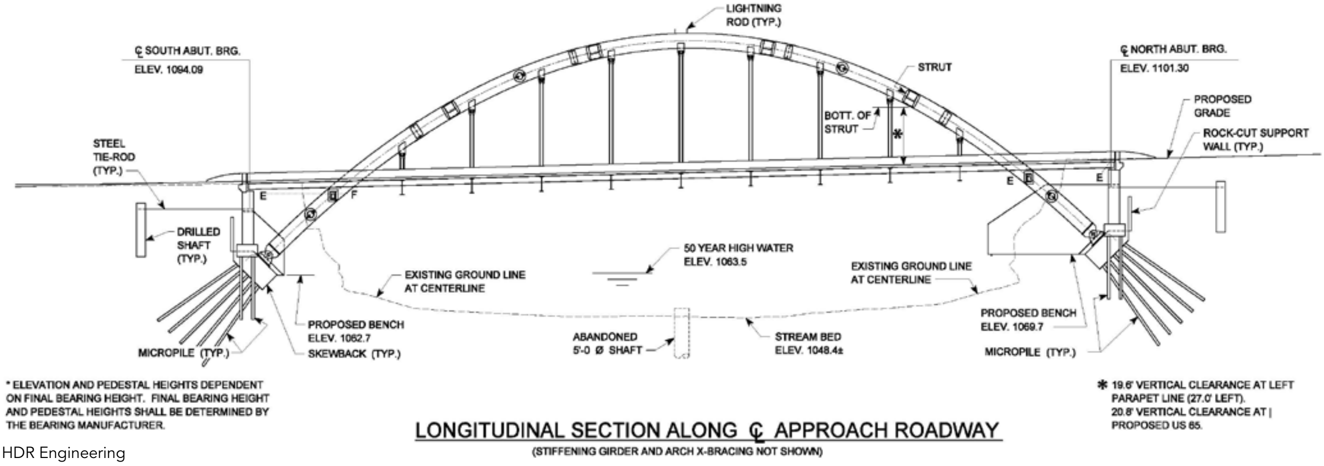
The new bridge is approximately 30 ft wider than the existing bridge, and with intersecting city streets just off each end, Saint Matthew's Episcopal Church on the northwest corner and private property owners on both the southeast and northeast corners, available room for the proposed span was a precious commodity. With the arch foundations required to be set approximately 30 ft below grade, coupled with the need to maintain access to the east side of the church, vertical cuts in the rock were required to allow room for the footings and yet leave sufficient space for access. In addition, retaining walls were constructed to preserve and stabilize the ground adjacent to the church and nearby properties.

The partial through steel arch is 67 ft, 10-in. wide between the centers of the two arch ribs and 276 ft long between the bearing pins. The structure supports a 63-ft, 8-in. bridge deck consisting of a 5-ft, 2-in. wide sidewalk, 11-ft,10-in.-wide multi-use trail and a 42-ft-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 at each end of the bridge.

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 stiffening girders designed to distribute vehicular loads from the deck to multiple hanger cables, as well as minimize local live load deflections.

The Iowa Falls Bridge replaces a reinforced concrete open spandrel deck arch structure.

A drawing of the longitudinal section of the new partial thru steel arch bridge.



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The four bridge alternatives that were considered. Clockwise from upper-left: a prestressed concrete girder, a haunched steel girder, a partial through steel arch (the selected design) and a concrete deck arch.

The stiffening girders were designed in tandem with the hangers from both a functional and a theoretical standpoint. The arch ribs are protected from vehicular traffic by a 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 sized to allow for full roadway traffic with any one of the four cables in a set removed or damaged.

The stiffening girder design was governed by the effects of the live load causing differential elongations 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, and 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. However, for the locations where the interior floor beams are supported by the hanger cables, a second model was created to include the effects 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 five times higher than the baseline analysis due to the effects of hanger cable elongation.

Geometric Issues

The design of the arch rib had a few added complications due to the geometry of the bridge. There were situations in the bridge where 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 bridge's width-to-span ratio, a trussed bracing system was deemed inefficient and impractical. Therefore, four 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 with minor tension in the corners at service load. This complicated the requirements for testing on the arch rib as it became a fracture-critical component.

Another area where the large bridge width-to-span ratio caused the design to diverge from conventional thinking was with the end floor beams 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 floor beam, and thus a larger end floor beam connection. The result was that the end floor beam needed to be both as narrow and shallow as possible and yet still impart significant 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

Healthy Bridges

As part of designing, building 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 structures. 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 and 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 that can also be applicable to assessing general conditions (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. This pilot monitoring system was 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 has been functioning successfully and plans are currently underway for implementing it on a second bridge). It allows easy access to real-time data and provides the data in a format that allows for immediate implementation by the Iowa DOT.

The general attributes of the sensor system are as follows:

Environmental

- Wind speed and direction
- Bridge deck potential icing conditions

Structural

- Corrosion potential on one micropile foundation
- Corrosion potential in substructure element at one bridge end expansion joint and at tie-back rod connecting abutment to drilled shaft
- Corrosion of bridge deck
- Moisture in arch rib
- Relative movement between south and north abutments
- Behavior of concrete anchors for rock cut support wall
- Arch Forces (strain gages)
  - At mid-span
  - 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
- 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
- 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

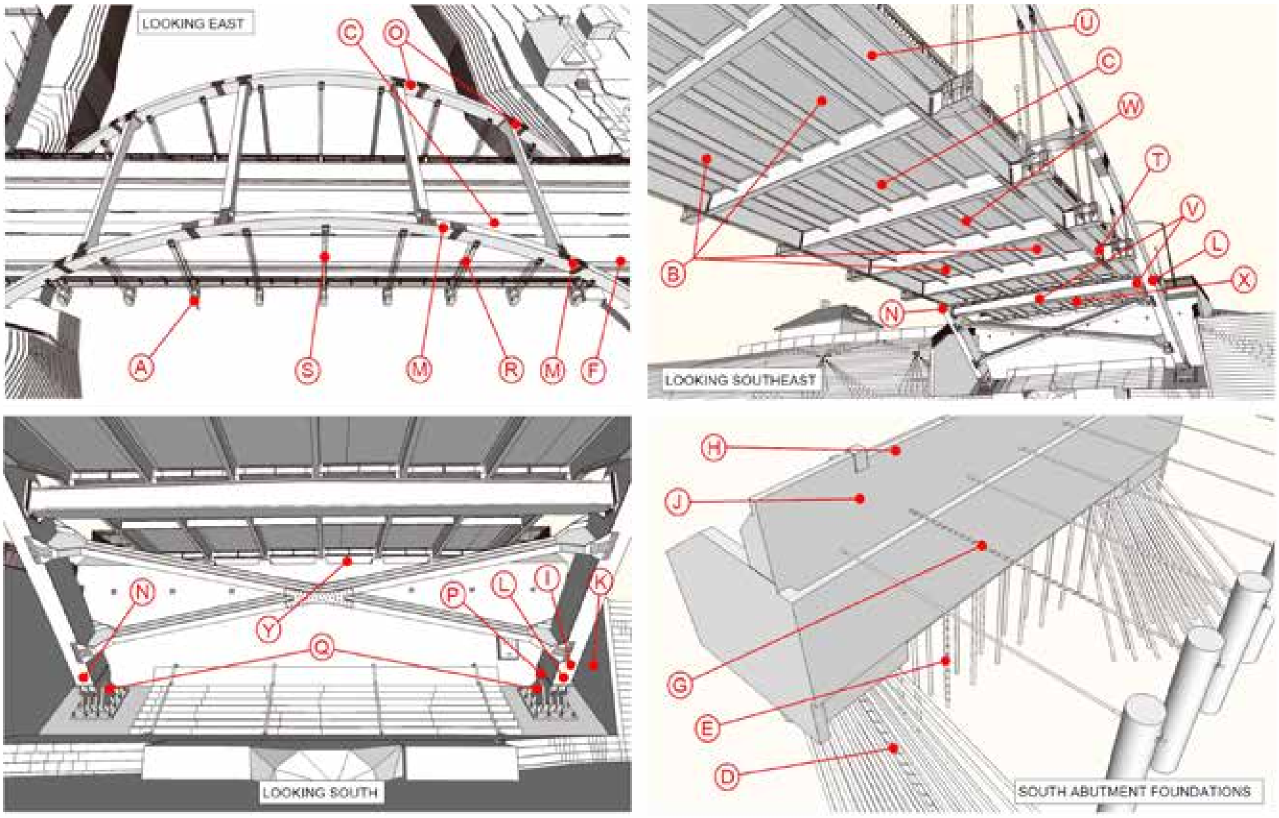
- Vehicle geometry/volume, alert for delays, etc.
- Web-based "dashboard"

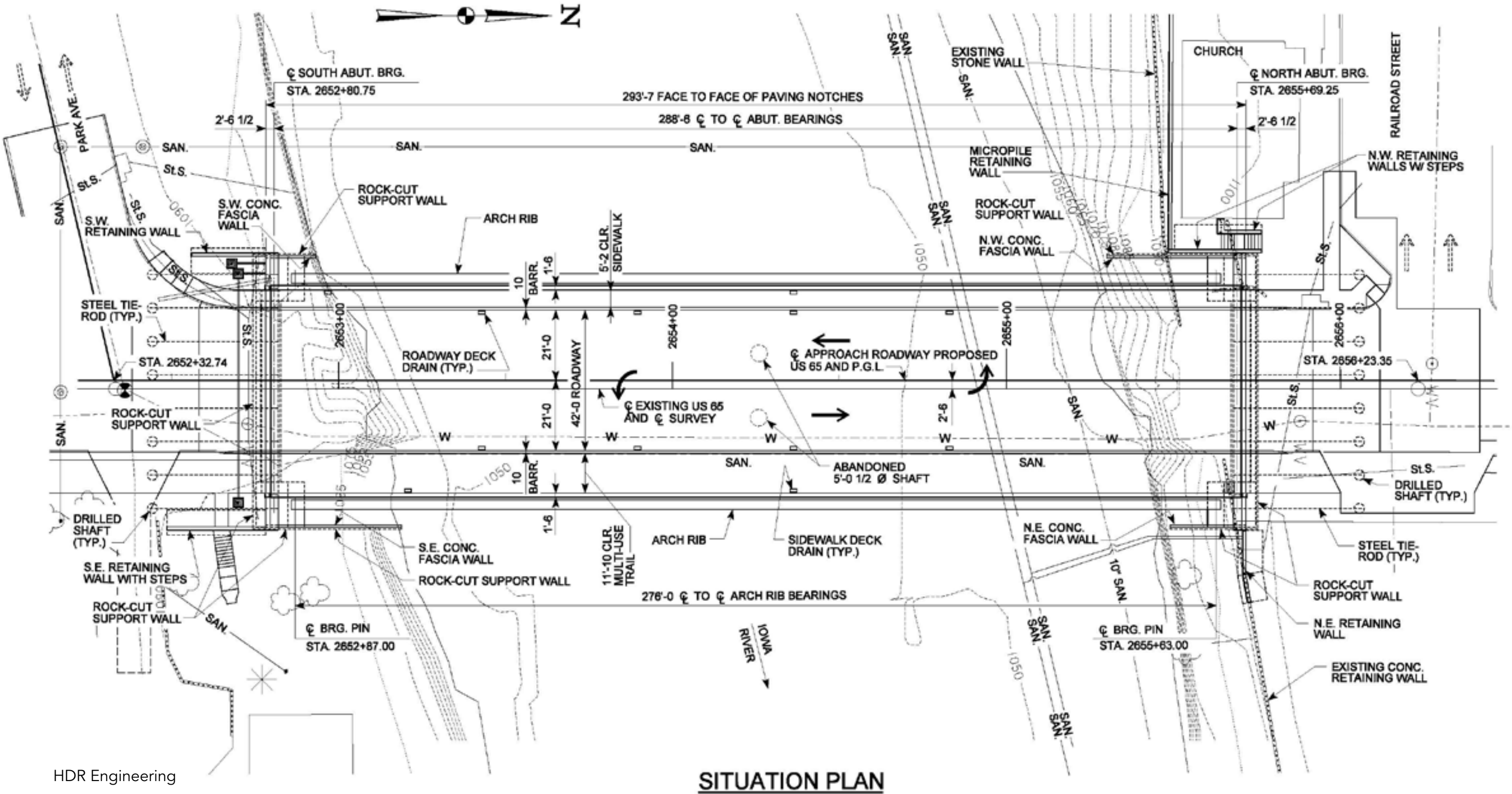
Custom software was developed for this SHM system deployment and was made to be generic enough such that transfer to other applications is seamless. One critical component is the proprietary damage detection algorithm developed at the BEC. This algorithm is included in the software such that the entire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

One critical product developed for this project was a web-based "dashboard" (i.e., real-time reporting for operational center management). There is one primary web page containing web links designed for each appropriate DOT office to use the SHM field 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 can be used directly in updating the rating. The format of the data is also based upon critical inspection performance indicators (e.g,. corrosion growth and moisture accumulation), as well as structural response indicators, such as stress, that might exceed acceptable thresholds.

Locations of the health monitoring instrumentation for the Iowa Falls Bridge.

Iowa DOT





A stuation plan of the bridge.

Aerial rendering of the project. Available room on either bank was a precious commodity.

to those of standard weathering steel, it inherently has 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 and a lower yield strength were deemed the better option for this situation.

Another design challenge was deciding on the type of bearing used to support the arch ribs. 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. After much iterative analysis, it was determined the overall weight of structural steel for the bridge would not be significantly impacted by the choice of bearing. However, the pinned bearing connection removes the primary moment from the footing, resulting in a smaller required

A pinned bearing constructed in place.

▲ Demolition of the existing concrete bridge.

➤ Erection of the new steel bridge.

footing. This benefit, in conjunction with the aforementioned tight geometrics, was the ultimate reason for choosing a pinned bearing connection.

Construction

The contractor, Cramer and Associates, Inc., of Grimes, Iowa, accessed the bridge site from the city boat ramp identified early in the concept stage as a possible means of access. Cramer 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.

Cramer first constructed the micropile retaining wall on the south side of the historic church. This wall's purpose was more than just replacing a crumbling wall impacted by the bridge construction; it was also needed to stabilize the foundation of the historical church to limit the risk from vibrations during demolition of the existing bridge. Following this construction, they proceeded 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 Cramer's intent to drop the arch pieces onto the rubble pad built under the bridge. The arches were jackhammered at a strategic location near the end, thus allowing them to fall under their own weight onto the earthen pad constructed underneath the existing bridge. The construction team then proceeded to perform the excavation for the abutment and construct the rock walls around the abutments. Concurrently with the excavation and abutment construction, Cramer constructed the falsework supports to aid in the erection of the steel arch and the deck framing.

The steel erection began with the placement of the south bearings. Using 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. 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. The new bridge used 835 tons of structural steel in all.

The Iowa DOT met its goals by replacing an existing functionally obsolete and structurally deficient bridge with an economical solution that met the community expectations. Cramer was allotted 190 contract days to complete construction. It opened the bridge to traffic on November 18, 2010, and was therefore eligible for the "No Excuse Bonus" of $250,000 for completing construction within the required timeframe. MSC

Owner
Iowa Department of Transportation

Structural Engineer
HDR Engineering, Inc., Omaha, Neb.

General Contractor
Cramer and Associates, Inc., Grimes, Iowa