I-88 BRIDGE OVER THE FOX RIVER

Brent A. Kunz, MS, SE, PE, Bowman, Barrett & Associates Inc, Chicago, IL
Celeste Spaans, MEng, IE, Janssen & Spaans Engineering, Inc., Indianapolis, IN

ABSTRACT

In March of 2007, the Illinois State Toll Highway Authority advertised for a new I-88 Bridge over the Fox River, located in Kane County, Illinois. It was to be built adjacent to the existing bridge, providing one structure for each direction of traffic.

The new bridge is 1,345 feet long and carries three lanes of traffic. The setting of the two structures led the Toll Authority to emphasize aesthetics, ideally leading to the selection of a design which matched the old one in several ways, such as the pier location, vertical clearances and appearance. Two bid alternates were permitted: a beam span alternate or an arch alternate. The beam span alternate had an additional $3 million dollar pay item attached, the value the Toll Authority placed on matching the arches of the existing bridge.

A precast, concrete arch structure was successfully designed and built. There are ten spans, five comprised of two segment, precast concrete arches, with precast IDOT girders used throughout. The box-shaped arch segments use only plain reinforcement and were precast off-site. The precast arches are the key component of this design that make it a simple, cost-effective solution, completed within a short time frame.

Keywords: Aesthetics & Finishes, Creative / Innovative Solutions & Structures, Design-Build

INTRODUCTION

The I-88 Bridge over the Fox River is located approximately forty miles west of downtown Chicago, Illinois, north of the city of Aurora. The original structure was opened to traffic in 1958 and provided two travel lanes in each direction. It was an eleven span structure, with the third through sevenths spans comprised of concrete arches. In March of 2007, the Illinois State Toll Highway Authority (ISTHA) advertised for work on the Ronald Reagan Memorial Tollway (I-88) that included the: 1) construction of a new EB I-88 Bridge over Fox River, 2) replacement of the IL Route 31 Ramp Bridge over I-88, and 3) replacement of the IL Route 31 Bridge over I-88. The design and construction of the new EB I-88 Bridge over the Fox River is the focus of this paper.

Fig. 1 Original Bridge over the Fox River[1]

PROJECT BACKGROUND

PROJECT SCOPE

The Toll Authority prescribed that the new I-88 Bridge over the Fox River be built adjacent to the existing bridge, providing each direction of traffic with its own dedicated structure. The new bridge would serve the eastbound traffic and the existing bridge would serve the westbound traffic. The adjacent setting of the two bridges led the Toll Authority to highly value the aesthetics of the new structure. Ideally, the new structure would be an arch structure that matched the original. ISTHA determined it was willing to pay an additional $3 million dollars to achieve this goal. Two alternates were accepted for bidding, a beam type alternate and an arch type alternate. Bids based on the beam type design received a $3 million dollar penalty in the form of an additional pay item, while bids based on the matching arch type design were not altered.

The project was designed and constructed using the “Performance Based Delivery” method. Teams submitted 30% complete plans for bidding, with the low bidder furthering plans to

100% completeness. This delivery method enabled the project to be completed very quickly, as design, quality control and construction all took place within a short timeframe.

Fig. 2 Rendering of Proposed Design[2]

The scoping documents clearly defined the design loads and specifications. The design was based on HS20 loading and Alternate Military live loads. Twenty five pounds per square foot was assumed for the future wearing surface. All design work was completed in accordance with the following specifications, listed in order of governance:

1) ISHTA Bridge Design Criteria, June 2000
2) AASHTO Guide Specifications
3) AASHTO Standard Specifications for Highway Bridges, 17th Edition
4) IDOT Guide Bridge Special Provisions

The new bridge is 1,345 feet long and can carry up to four lanes of traffic with appropriate shoulders. The location is in seismic performance category A, has a site coefficient of 1.0 and a bedrock acceleration coefficient of 0.04. Construction was permitted to begin in the Summer of 2007 and had to be completed by December of 2008. Some of the controlling design considerations were:

1) Substructure units for the new bridge must be parallel and along the same centerlines as the existing.
2) There shall be no more than 9 piers between the abutments (one less span than the number in the original structure).
3) Only one pier type is allowed in the new design, and it shall have at least two vertical elements protruding from the ground.
4) With the exception of a deck arch structure, no section of superstructure may be deeper than 10’-0”.

Additional design criteria was provided for the arch type alternate. First, “the span arrangement for the new design would conform to the span arrangement for the existing, parallel structure,” meaning that the spans between Piers 1 through 6 must include arch elements. Second, the centerline of the arch ribs must be within +/- 2’-0” of the existing Spring Lines, +/- 1’-0” of the existing Arch Crowns, and +/- 3’-0” of existing intermediate points. Arches must also be load bearing, not provided for purely aesthetics.[3]

Both types of alternates were investigated prior to selecting the final bid design. The beam span alternate was analyzed in both steel and concrete, using a variety of beam sizes and arrangements. A precast, concrete arch design was also successfully developed. Based on estimated pricing, including the $3 million dollar pay item for the beam span type, the arch design was the most economical design choice and was the final design pursued by the team.

PARTIES INVOLVED

James McHugh Construction Company has long been known as a major player in the construction of large private projects in the Chicagoland area. They have also more recently emerged as a very competitive bidder and successful constructer of structure-heavy public transportation projects for the Illinois State Toll Highway Authority, the Illinois Department of Transportation and other local agencies. Combining their experience on large construction projects with their familiarity with working for public agencies put McHugh in an excellent position to assemble a very competitive bid, regardless of the design.

McHugh teamed up with Janssen & Spaans Engineering, Inc. (JSE) of Indianapolis to advance both alternates to a stage detailed enough to decide which alternate should be selected for the bid. JSE would also serve as the lead design engineer if the bid was successful. JSE was a logical choice, as they have a reputation for pioneering innovative construction technologies throughout the United States, have extensive previous experience on design-build projects and had recently been involved with the design and construction of another concrete arch bridge.

Since the project specifications called for the team to include an independent QC designer, JSE formed a team with Bowman, Barrett & Associates, Inc. (BBA) of Chicago. By creating a team of two engineering firms, the team was truly able to perform an independent QC review. JSE and BBA had previously teamed up on other successful ISTHA design-build and value engineering projects, and the relationship developed in those projects only strengthened the team for this job. Having previously been selected by ISTHA for many traditional design-bid-build projects as well, BBA also provided a local presence to the engineering component of the team.

These three primary companies formed a team which had an excellent chance in the competitive bidding phase. All parties were familiar with the ISTHA requirements and the expeditious manner required for work under a performance based delivery timeline. JSE and BBA worked very closely with McHugh throughout the design process, continually checking that the design was as cost-effective as possible to construct, an effort which ultimately proved very successful.

SITE CONDITIONS

The I-88 Bridge site provided numerous design challenges. The bridge crosses two channels of and an island in the Fox River, an industrial road that required relocation, a freight railroad, Illinois State Route 25 and the Fox Valley Park District bike path. Construction of the new bridge was also planned to occur while I-88 traffic continued to use the adjacent, original structure. In addition, the rock elevation in this area sits just below the shallow riverbed, making the installation of both temporary and permanent works more difficult.

The Fox River itself provided the biggest challenge to construction. Two piers fall within the river banks under normal water elevations, and a third pier is adjacent to one of the banks on the island. Cofferdams were required to install the pier and temporary support foundations. In addition, temporary work platforms were necessary in the river in order to provide construction access for the delivery and erection of the arch segments and beams, as well as the construction of the piers, spandrel caps, deck and other miscellaneous bridge items.

Fig. 3 Pipe Cofferdam for Substructure[4]

Fig. 4 Aerial View of River[5]

Due to the above described work in and around the river, permits from the Army Corps of Engineers, the Illinois Department of Natural Resources and the Illinois Environmental Protection Agency were required. Temporary facilities could not be constructed using erodible material, and the materials used had to be 100% recoverable. Additional accommodations included: tree mitigation requirements, the Fox Valley Park District's annual canoe race, as well as a 2½ month river blackout period on work in the river, so as not to disturb fish spawning season. The strict erosion control requirements of the Kane-DuPage Soil and Water Conservation District were followed as well.

Detailed hydraulic calculations assessing the impacts of contractor-designed temporary works in the river were required for submittal. The temporary work platform chosen by McHugh consisted of stacked, 4-foot by 4-foot by 4-foot precast concrete blocks, which retained large aggregates. This platform effectively shifted the river banks in towards the center. Access to the island was provided by means of a temporary work bridge, which spanned over one of the channels, between the concrete block retaining walls. The hydraulic analysis dictated the allowable channel constrictions, work platform elevation and temporary bridge elevation.

Fig. 5 Temporary Work Platform[6]

Fig. 6 Temporary Work Bridge[7]

PROJECT SPECIFICS

SUBSTRUCTURE

The bridge piers were modeled with the RCPIER program, which was used to check all AASHTO load combinations. The pier columns were designed using a P-Delta analysis, with each pier column/shaft modeled as a tall column. It was assumed that the fixity point of each shaft was at the river rock elevation. A separate lateral load analysis of each shaft was also necessary in order to verify that the assumed fixity point was appropriate. The program COMP 624 was used to perform the lateral analysis. This program performs soil-structure interaction analyses (allows input of p-y nonlinear curves of soil properties), which was needed to perform the fixity point check. The I-88 Bridge piers were also analyzed for dynamic ice force, due to the moving ice-sheets and ice-floes carried by stream flow throughout the year.

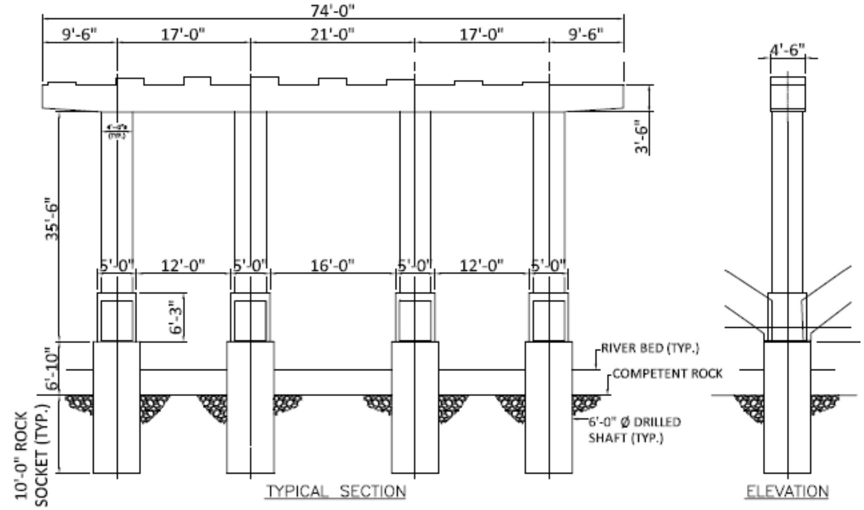

Fig. 7 Typical Section & Elevation of Substructure[8]

The typical section and elevation of the final, cast-in-place concrete pier design is included in Figure 7. The pier consists of four vertical columns, supported on six foot diameter drilled shafts. The shafts are socketed into the underlying rock a minimum of ten feet. The thrust block of the arch sits at the top of the shafts. All of the columns are connected by a cap, which is stepped at Piers 1, 6, and 7 to accommodate different depth beams. The team considered using precast columns and caps, yet determined that no significant economic benefit was gained. The small quantity of work and the ability to use readily available standard forms both contributed to this determination.

END SPANS

Although the bridge has ten spans, ISTHA specified that only five be arches. The other five spans ranged in length from 70 feet to 106 feet. These span ranges permit the use of ISTHA standard 42-inch and 54-inch precast, prestressed concrete (PPC) beams, which were quickly determined to be the most cost-effective short-term and long-term superstructure type. These beams would also match the material used in the adjacent arch spans, providing an aesthetic benefit.

The beams were spaced at 7’-8” centers, had a concrete strength equal to 7,000 psi at 28 days, and were conventionally designed, i.e., simply supported for self-weight and slab loads and continuous for all superimposed loads.

There were some features of the design and construction of these spans that are atypical in Illinois. These features include the diaphragm and continuity detail at the piers, the PPC beam strand size and the use of stay-in-place forms.

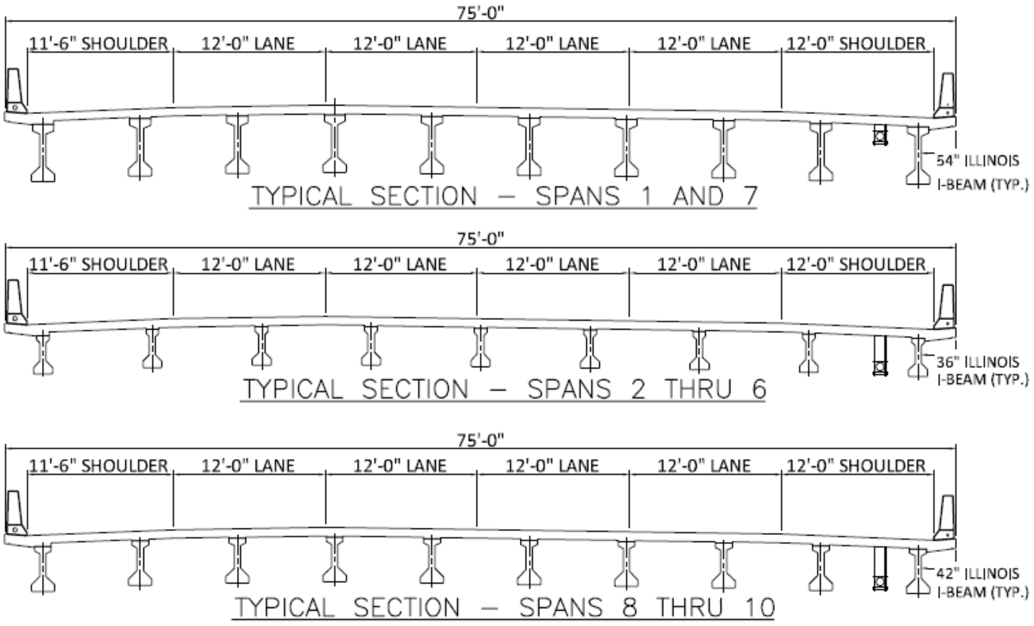

Fig. 8 Typical Bridge Sections[9]

DIAPHRAGM AND BEAM CONTINUITY DETAIL

To provide stability before and during the concrete deck pour, each beam was braced via a combination of steel diaphragms and wood blocking to the adjacent beams. The steel diaphragms were installed directly over the piers and were used as permanent diaphragms in lieu of typical concrete diaphragms that extend between adjacent beams and encase the beam ends. The compressive force required for continuity was transferred between the beam ends through a cast-in-place concrete closure pour of equivalent dimensions to the cross-section of the beam. This detail significantly reduced forming and concrete material costs in addition to greatly expediting construction of the superstructure.

PPC BEAM STRAND SIZE

The PPC beams utilized 0.6 inch nominal diameter strands as opposed to the 0.5 inch strands typically used in Illinois beams. This increased diameter was requested by the prestressed beam fabricator to reduce the number of strands requiring tensioning. With proper detailing of mild steel bars in the ends of the beams to resist bursting forces, the fabricator was allowed to use the larger diameter strands. Given the number of beams that required fabrication, this relatively small change resulted in significant overall savings.

STAY-IN-PLACE FORMS

Stay-in-place metal forms for construction of the deck were used in these spans. The use of these forms was strongly preferred by McHugh. The additional dead weight on the beams was accounted for in the beam and substructure design, and the forms themselves were conservatively assumed to carry no permanent loads. Therefore the deck reinforcement was designed to carry the entire design load, as for a conventionally formed deck. Although metal forms are not routinely used in Illinois, the owner allowed their use on this bridge and the result, considering the large deck area, was a significant savings in cost.

Fig. 9 Precast Beams[10]

Fig. 10 Precast Beams & SIP Metal Forms[11]

ARCH SPANS

Concept Development

The I-88 Bridge over the Fox River project presented an interesting challenge, given the $3 million dollar bid advantage for implementing an arch structure instead of a beam span structure. While the use of an arch shape is by no means unique, past project experience indicated that making it the more cost effective solution could be difficult. JSE recently finished work on an arch bridge over the Cleveland Zoo, which also utilized the precast arch rib concept. Experiences from that project helped clarify the key areas that needed improvement for the successful application of an arch design for the I-88 project.

The bridge over the Cleveland Zoo is a three segment, post-tensioned, arch structure. The arch segments were installed with the use of tie-downs and drop-ins and also required two temporary construction towers for support. The thrust blocks at the base of each arch were cast as part of the foundation and hung outwards until made continuous with the arch. While successful in its own setting, this design would have easily exceeded the $3 million dollar window of opportunity over a beam span design for the I-88 project. The arch design was pursued, but with several key changes aimed at cutting costs.

A major difference and key success in the I-88 design is that the arch spans are comprised of two, mildly reinforced segments. The elimination of post-tensioning made the precasting and installation cheaper, simpler and more efficient. The use of two segments, instead of three, eliminated the need for tie-downs and any drop-ins. It also enabled the contractor to use only one temporary support tower instead of two. The tower design itself was also dramatically simplified, lowering costs and increasing the ease of construction. In addition, the thrust blocks at the base of the arches were tremendously simplified. Rather than having the blocks previously cast and hanging from the supports, the arch segments rest directly on the foundation and the thrust blocks are cast directly after.

Fig. 11 Cleveland Zoo Bridge Arch Base[12]

Fig. 12 Fox River Bridge Arch Base[13]

Arch Segment Design

The analysis of the I-88 Bridge was performed using three computer models. A two-dimensional (2-D) model was developed by using the program BRUCO. Two additional three-dimensional (3-D) models were developed using the Stardyne program, one analyzing the arch segments under cracked conditions and the other under uncracked conditions. BRUCO (BRidge Under COnstruction), is a 2-D finite element program for staged construction analyses that allows the user to consider the influence of changes in the statics of the structural system occurring during construction and the inclusion, change, and removal of any temporary supports. It also allows the user to include time-dependent effects for concrete such as creep and shrinkage. The effect of geometric nonlinearity associated with changes in configuration, such as large deflections of a slender elastic beam can also be included. Stardyne, on the other hand, is a 3-D finite element analysis software used for linear static, P-Delta, and buckling analyses.

The advantage of using 3-D models is that the interaction that occurs between the arches, which is attributed to the presence of the spandrel frame, can easily be included. Since Stardyne does not have a staged construction analysis option, separate analyses were performed for each construction stage in BRUCO. Using superposition, all the linear structural systems representing each construction stage were combined to obtain the cumulative internal forces and displacement results. The method of superposition allows combining any number of structural systems without disturbing equilibrium.

Second-order effects were considered for both Stardyne 3-D models by performing P-Delta (or second-order) analyses. The importance of the P-Delta analyses is that the secondary effect of axial loads and lateral deflections on the moments in slender members can be included. Second order analysis is advantageous because it bypasses the moment magnification procedures of AASHTO, which are not well suited to arch structures in which the base of the arch ribs are connected to flexible piers.

Loads were applied and combined per AASTHO Standard Specifications for Highway Bridges, 17th Edition. Results from every construction stage for the three computer models were used for the structural design of the arch segments. Arch segments were checked against serviceability (fatigue stress limits and distribution of flexural reinforcement) and strength (flexure, shear, and torsion) requirements.

Lateral stability of the arch segments also required special consideration. Lateral stability depends on the spring line fixity and lateral support conditions which varies during the erection of the arch segments as well as the structural components of the bridge.

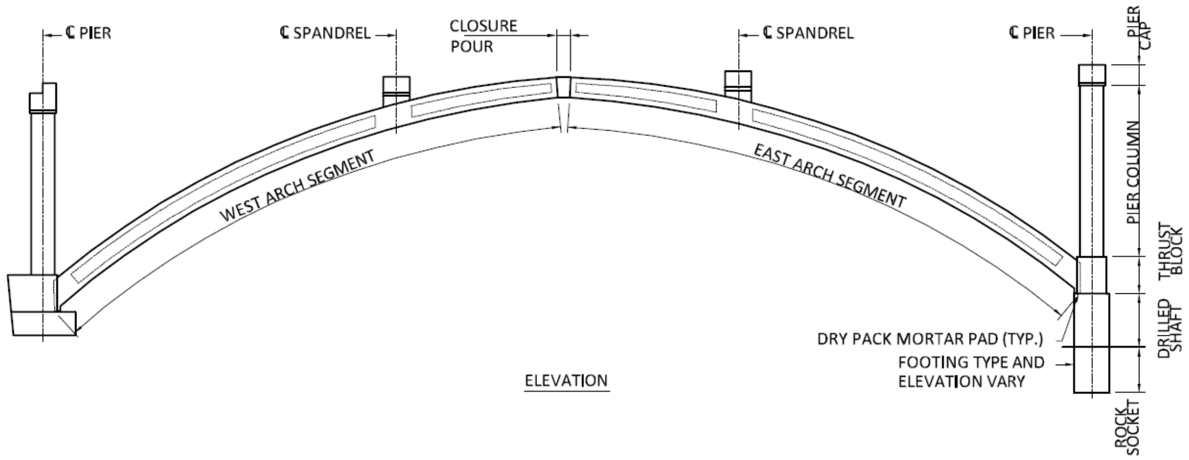

Fig. 13 Elevation of Typical Arch Span[14]

Each arch segment contains approximately forty eight cubic yards of concrete, weighing around ninety two tons each. The segments are slightly larger than ninety three feet in length. The arch section is four feet wide and tapers in depth from three and a half feet at the crown to four feet at the base. The "hollow" core makes the individual segments slightly more complex and expensive during casting, but the reduction in weight results in major cost savings, especially relating to handling costs. An additional cost saving measure is that all the segments are identical. Forming, casting, transporting and installing the segments were all easier and more efficient since no segment was designed for only one specific location.

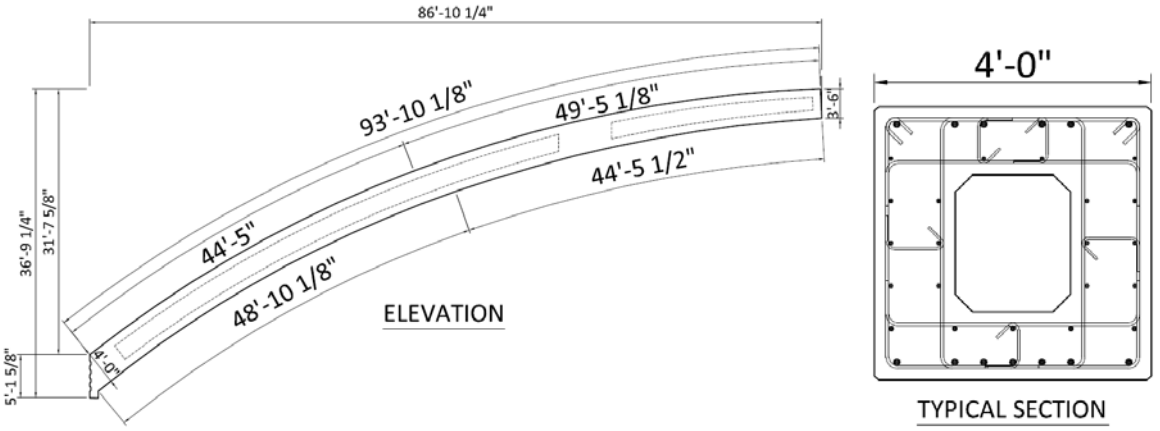

Fig. 14 Arch Segment Elevation & Section[15]

Arch Segment Fabrication

The arch segments were precast by the contractor, McHugh Construction, at the trailer location a few miles away from the site. It was determined to be more cost effective for the segments to be made in house and trucked to location, rather than obtaining them elsewhere.

The arch segments were cast on their sides, used using plywood and steel formwork. The top of the forms, the side of the segment, was troweled smooth during finishing for aesthetics. Once poured and adequately set, the formwork was stripped off and moved to the side, where it was reconstructed and the next arch segment was begun. A total of forty segments were required for the job. In Figure 15, the Styrofoam at the center of each arch piece is visible. Due to limited space at the site, the completed arch segments were stored at the casting yard until the time of installation.

Fig. 15 Empty Arch Form[16]

Fig. 16 Segment Pour & Finish[17]

Fig. 17 Finished Arch Segments[18]

Arch Segment Rotation

One of the main challenges encountered during construction was getting the arch pieces, which were cast on their sides, into a vertical position for installation. Due to site constraints, the segments needed to be vertically oriented upon arrival on location. This led to the design of an “arch rotation device,” shown in Figure 18. The device is a set of two, right angle braces. The braces are constructed from HP10x42 and 12x74 sections, and mounted to a stand by means of a 3 1/8” diameter pin connection. One device is provided at either end of the arch segment.

During casting, lifting loops were cast in the top of the form (side of the segment). These loops were used to lift the segment onto the rotation device. The two point vertical crane pick can be seen in Figure 19. After placing the arch segment on the device, the lifting bridle was moved from the arch segment and attached to the rotation device. One cable of the lifting sling was slack on the top leg of the brace, while the other cable was taut on the bottom leg of the brace. As the crane slowly began to lift, the bottom leg of the brace, which was previously horizontal, raised into the air. At the point when the load was equally distributed over the two cables, the crane boom gently moved laterally. The crane then began lowering, slowly transferring all of the load to the other cable of the sling. The leg of the brace which was previously vertical was then horizontal, leaving the arch segment in the necessary position.

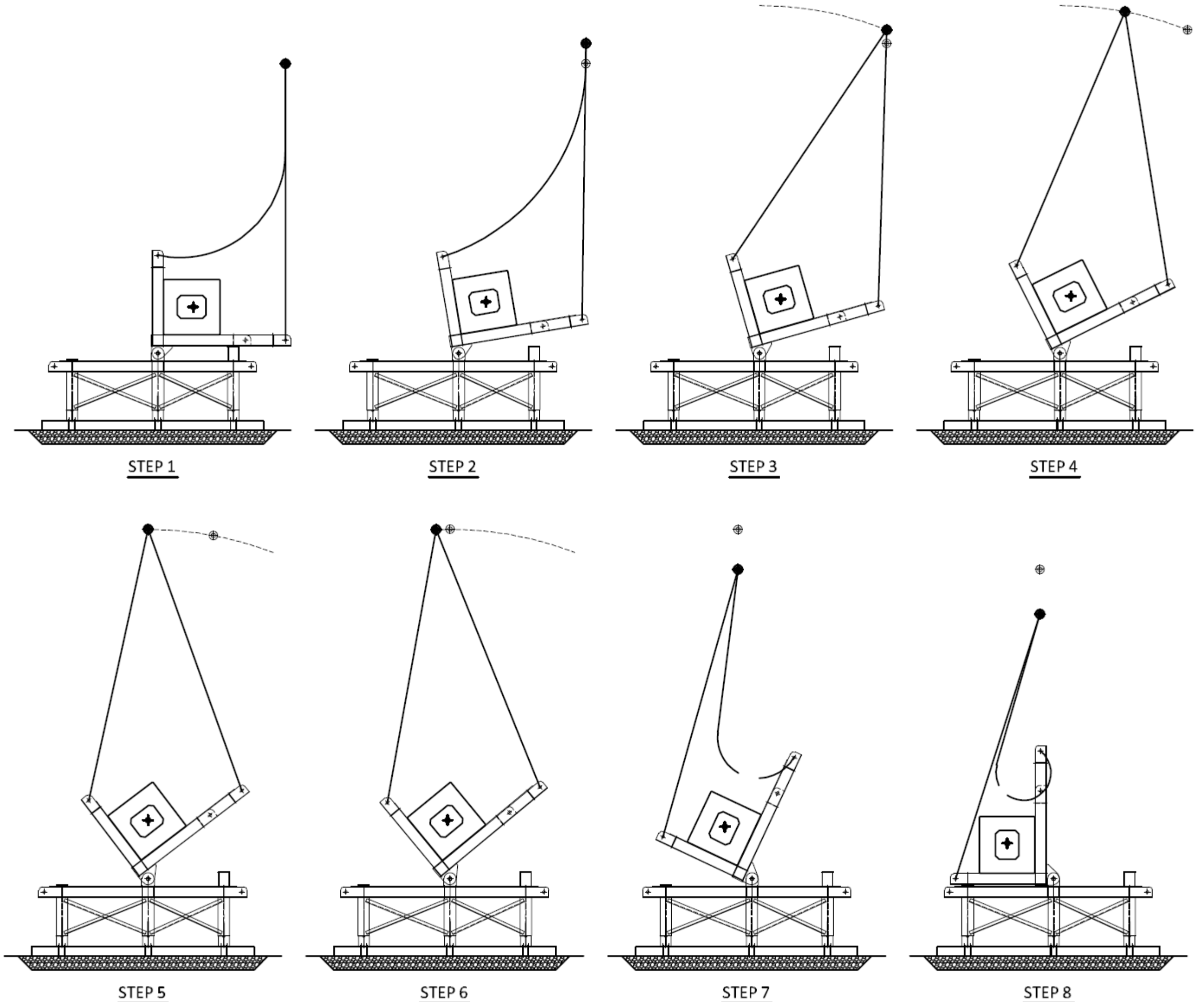

Fig. 18 Arch Rotation Device[19]

Fig. 19 Crane Lifting Segment to Device[20]

Fig. 20 Arch Segment Rotating[21]

Arch Segment Transportation

After an arch segment was oriented vertically, it was ready to be moved to an awaiting truck. A second crane lift was performed, again a two point vertical pick, using a second set of lifting loops that were previously cast in the top of the arch segments (side of the form). The key component to the transportation is the trailer "bolsters," or the bright blue supports seen on the truck in Figure 21. Ninety foot long, special heavy-load semitrailers were used, equipped with thirteen axles and rear steering.[22]

Fig. 21 Arch Segment Lifted onto Truck[23]

Fig. 22 Segment Moving to Fox River Site[24]

The bolsters' design was checked using another 3-D model in the Stardyne program. The model was analyzed with an arch load of 100,000 pounds, a truck pull / push load of 30,000 pounds and a side load of 20,000 pounds. It was determined that the bolsters were adequate to resist the above loads. In addition to the bolster analysis, the truck route was thoroughly investigated, to ensure that the arch segments could handle the loads and that the necessary clearances were met during transportation.

Arch Segment Installation

Upon arriving at the site, arch segments were immediately lifted off the trucks and moved into position. As seen in the figure below, the crane used the lifting loops on the top of the arch segment to lift the piece, while workers positioned the pieces over the foundation and temporary tower before lowering.

Fig. 23 Lifting Arch Segment[25]

Fig. 24 Positioning Arch Segment[26]

The temporary frame consisted of four vertical pipe sections, supporting double W24x104 stringer beams across the top. The pipes were two feet in diameter and were embedded a minimum of five feet into the bedrock. One tower was provided at the center of each arch span. There were three-inch cross bracing angles tying the pipe sections together diagonally. At the top of the W beams, restraining clips were placed on either side of the arch segment, which prevented the arch segments from sliding laterally off the tower. The tower carried the load of the arch segments only until the arches were made continuous at the top and bottom. They were later removed, prior to the application of the deck loads. Figure 25 shows the closure pour at the crown of the arches, while Figure 26 a thrust block waiting to be cast until the right side arch segment is in place.

Fig. 25 Continuous Arch Span[27]

Fig. 26 Arch Thrust Block Rebar[28]

Construction After Arch Installation

Once the arch segments were installed and made continuous, the spandrels on top of the arches were formed and poured in place. The spandrels serve as not only as lateral bracing for the four individual arch ribs, but also as the supports for the prestressed deck beams used in the arch spans. For these spans, a third size of ISTHA PPC beams was used, 36-inch. As shown in Figure 27, the spandrel is seventy four feet wide and a little over three feet deep. Each side of an arch span has one spandrel, requiring a total of three PPC beams to make up one arch span. The spandrels were cast-in-place and sit on pedestals, which vary in height, to account for individual arch deflections. The team investigated precast spandrel pieces, yet determined that it did not create a significant benefit. Precast pieces most likely would have required a middle splice which, when compared to the ease and cost of the field forming, did not provide a large enough economic advantage.

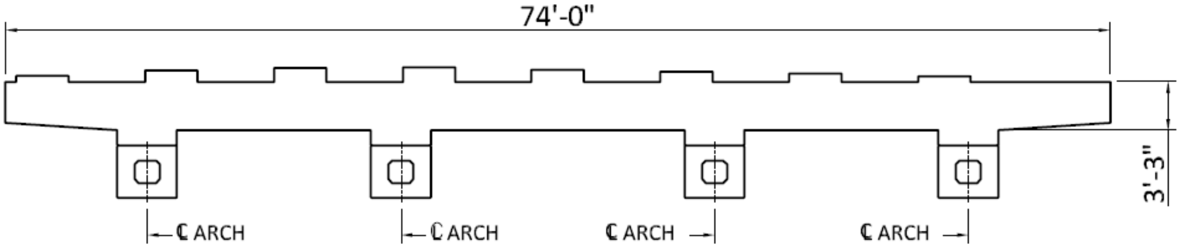

Fig. 27 Section of Typical Spandrel[29]

Fig. 28 Forming of Spandrel[30]

Fig. 29 Completed Spandrels[31]

After the spandrels and the 36-inch PPC beams were installed in the arch spans, the construction became similar to that of the end spans previously discussed.

PROJECT SUMMARY

FINAL PROJECT DETAILS

The bid for the arch bridge alternate developed by the design-build team was approximately \$44.5 million dollars. This compared favorably against a \$45.7 million dollar competing bid for a design that did not require arches or span lengths that matched the existing structure, as well as a \$59.7 million dollar competing bid for an arch bridge alternate. Note that these bids included several construction items besides the Fox River Bridge. These items included the reconstruction of two grade-separation bridges over the Tollway, approximately 1,800 feet of three and four lane mainline pavement along with two interchange ramps, two state route and two local roadways crossing the project site and a bike path, not to mention the relocation of several utilities. Also note that all engineering fees associated with the alternates are included in the above costs.

Construction of the project began in July of 2007 and was completed 17 months later in December of 2008. The project was completed on time, before all Tollway traffic was shifted onto the new bridge at the beginning of a subsequent contract to reconstruct the existing structure. A particularly noteworthy fact is that that both design and construction were completed without delays to the project in the same amount of time it would have taken to construct a traditional design-bid-build project.

Fig. 30 Completed I-88 Bridge over the Fox River[32]

CONCLUDING THOUGHTS

The benefits of precast, reinforced concrete that comprises the arches and prestressed concrete beams have been illustrated above in detail. Through the innovative use of precast concrete, ISTHA saved approximately \$1.2 million dollars over the next lowest bid and provided the distinctive landmark bridge it preferred, with nearly maintenance-free precast components, instead of a typical stringer-type structure.

It must be mentioned that ISTHA laid the proper framework for achieving their goals in the construction documents. By thoroughly specifying the geometric requirements for the arches but allowing the details to be designed by the contractor's engineer, ISTHA did not unnecessarily restrict the contractor from constructing the bridge in a manner that best suited his means and methods. ISTHA also had the resolve to adopt the performance based delivery method of construction, a method that is uncommon in the state of Illinois. It is evident from the success of this project that there is much for an owner to gain, from schedule to cost to aesthetics, by utilizing this process. This is particularly evident if precast, prestressed concrete is allowed to compete on a level playing field with other superstructure types.

More specifically, this project's design and construction proved so successful and cost efficient, that the ISTHA decided to replace the original structure with a new bridge identical to the structure discussed here. The bridge presented in this paper is currently being used by both directions of traffic. Construction of the second, precast arch structure was started in the Spring of 2009 and is expected to be completed in the Summer of 2010.

REFERENCES

---

1. Original Fox River Bridge. Photograph by Unknown Author.
2. Rendering of Proposed Bridge. Rendering by Cordogan, Clark & Associates.
3. Contract No: I-06-5472. Advertisement. The Illinois State Toll Highway Authority. 22 Mar. 2007.
4. Pipe Cofferdams. Photograph by James McHugh Construction Company.
5. Aerial View of Fox River Site. Photograph by James McHugh Construction Company.
6. Temporary Work Platform. Photograph by James McHugh Construction Company.
7. Temporary Access Bridge. Photograph by James McHugh Construction Company.
8. Plan Sheet of Pier. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
9. Plan Sheet Typical Sections. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
10. End Span Beams. Photograph by James McHugh Construction Company. 19 Aug. 2008.
11. SIP Metal Forms. Photograph by James McHugh Construction Company. 10 July 2008.
12. Cleveland Zoo Bridge Support. Photograph by Janssen & Spaans Engineering, Inc.
13. I-88 Bridge Over Fox River Support. Photograph by James McHugh Construction Company.
14. Plan Sheet Elevation of Arch Span. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
15. Plan Sheet of Arch & Arch Cross Section. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
16. Empty Arch Form. Photograph by James McHugh Construction Company.
17. Arch Segment Pour & Finish. Photograph by James McHugh Construction Company.
18. Finished Arch Segments. Photograph by James McHugh Construction Company.
19. Arch Rotation Device Plan Sheets. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
20. Crane Lifting Arch Segment. Photograph by James McHugh Construction Company. 20 Apr. 2008.
21. Arch Segment During Rotation. Photograph by James McHugh Construction Company. 20 Apr. 2008.

---

22. Hale, Tom. “McHugh Building Arch Bridge Over Fox River.” *Construction Digest* Sept. 2008.
23. Arch Segment Lifted onto Truck. Photograph by James McHugh Construction Company.
24. Segment Moving to Fox River Site. Photograph by James McHugh Construction Company.
25. Lifting Arch Segment. Photograph by James McHugh Construction Company.
26. Positioning Arch Segment. Photograph by James McHugh Construction Company.
27. Continuous Arch Span. Photograph by James McHugh Construction Company.
28. Arch Thrust Block Rebar. Photograph by James McHugh Construction Company.
29. Plan Sheet of Spandrel. Drawing by Janssen & Spaans Engineering, Inc. 5 Oct. 2008.
30. Forming of Spandrel. Photograph by James McHugh Construction Company. 13 June 2008.
31. Arch with Completed Spandrels. Photograph by James McHugh Construction Company. 27 June 2008.
32. Completed I-88 Bridge over the Fox River. Photograph by James McHugh Construction Company.