REPLACEMENT OF THE HISTORIC GREENFIELD BRIDGE: USING STEEL TO REFLECT THE PAST AND MEET THE NEEDS OF TODAY

BILL BEINING, PE

TONY REAM, PE

BIOGRAPHY

Bill Beining, PE, is a Project Manager and Associate in HDR's Weirton, WV office. Bill has 20 years of experience in the design and management of bridge projects ranging from small culverts to large interchanges and river crossings. Bill served as HDR’s Project Manager for the City of Pittsburgh’s Beechwood Boulevard/Greenfield Bridge Replacement Project. In this role he oversaw both the Alternatives Analysis Phase of the project that studied possible rehabilitation options for existing concrete arch, as well as the Preliminary and Final Design of the new steel arch.

Anthony Ream, PE, is a Senior Structural Engineer and Senior Professional Associate in HDR's Weirton, WV office. Tony has 18 years of experience working on complex bridge projects including analysis, design and rehabilitation. Tony served as HDR’s Senior Structural Engineer for the Greenfield Bridge Replacement Project leading the design of the steel superstructure.

SUMMARY

A bridge has linked the Pittsburgh neighborhood of Greenfield to historic Schenley Park for approximately 120 years. In 1922, a monumental concrete arch that reflected the city’s growth and the grandeur of the time was built. Located under the bridge, Interstate 376, known locally as the Parkway East, is the main artery linking downtown Pittsburgh to points east.

By the early 2000’s, the historic concrete arch was showing its age. Previous rehabilitations had stripped some of the bridge’s grandeur and deterioration of the concrete arch rib meant much of it was wrapped with protective netting. A “bridge under the bridge” was put place to further protect motorists on the congested parkway from falling debris. By 2012, it became apparent that it was time for a new structure to span the historic valley and act as Pittsburgh’s next gateway to the east.

A new steel arch was chosen to replace the existing structure. This structure type, in conjunction with historical details from the original structure, provided a context sensitive design that was able to accommodate the traffic and time restrictions of modern day bridge construction. The use of steel, carefully thought out details and contractor methods allowed for the erection of the entire steel structure over one weekend closure of the critical interstate below.

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Introduction

The Greenfield Bridge project began in 2010 with an in-depth inspection of the existing reinforced concrete open spandrel arch that had connected Greenfield to neighboring Schenley Park since 1921 (Figure 1). Formally known as the Beechwood Boulevard Bridge, the existing bridge had seen the surrounding neighborhoods quickly grow due to the booming steel industry. Originally just spanning over a neighborhood street and stream, by the 1950's the structure carried traffic over one of the busiest stretches of Interstate in Western Pennsylvania. Interstate 376, known locally as the Parkway East, would grow under the bridge to become the main artery linking downtown Pittsburgh to all points east, and the bridge would become known as the city's gateway to the east.

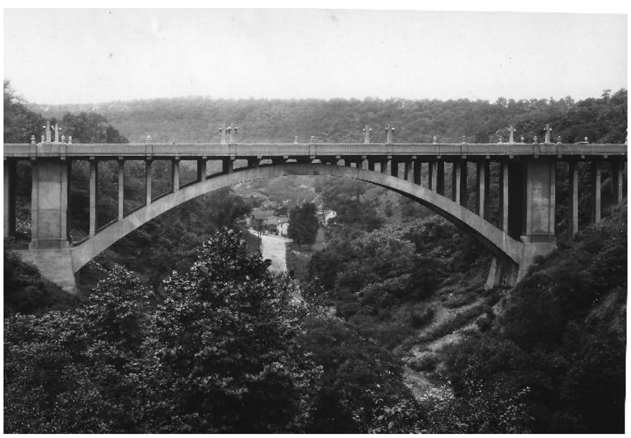

Figure 1: Existing Concrete Arch in 1923

By 2011, when HDR began studying alternatives for rehabilitation or replacement of the concrete arch, Interstate 376 carried nearly 85,000 vehicles per day under the structure. By this time, the aging concrete arch that was originally conceived of as a grand entrance to Schenley Park was showing its age. A much needed rehabilitation in the 1980s stripped many of the original architectural elements during a complete replacement of the floor system and deck. Of even greater concern, by the 1990s, the arch ribs were wrapped with protective netting due to the deteriorating concrete (Figure 2). A "bridge under the bridge" originally designed for another rehabilitation was even left in place due to concerns with falling concrete. This structure under the bridge became symbolic of the ongoing deterioration of the old structure.

Figure 2: Existing Arch and "Bridge under the Bridge" in 2010

In 2012, after years of study, it became apparent that it was time for a new structure to span the historic valley and act as Pittsburgh's next gateway to the east. In designing the new Greenfield Bridge, the City of Pittsburgh and HDR were faced with numerous challenges. These challenges, or constraints, ranged from needing to maintain the historic nature of the site, to the absolute necessity of minimizing disruptions to the congested Parkway under the structure.

Contextual Design

A bridge has linked the Pittsburgh neighborhood of Greenfield to historic Schenley Park for approximately 120 years. Much like the surrounding city, the bridges and site have evolved with the changing times. Schenley Park, consisting of 456 acres of woodlands, trails and botanical gardens was established in 1889. The first structure to span the valley and link Greenfield to the park was constructed a short time later. The bridge consisted of a utilitarian 15 span wooden viaduct. In 1921, this utilitarian wooden viaduct gave way to a monumental concrete arch that reflected the city's growth and the grandeur of the time.

This structure featured decorative urns, architectural pedestals, and lighting fixtures along its length, creating a grand promenade linking Greenfield to the popular park just to the north (Figure 3).

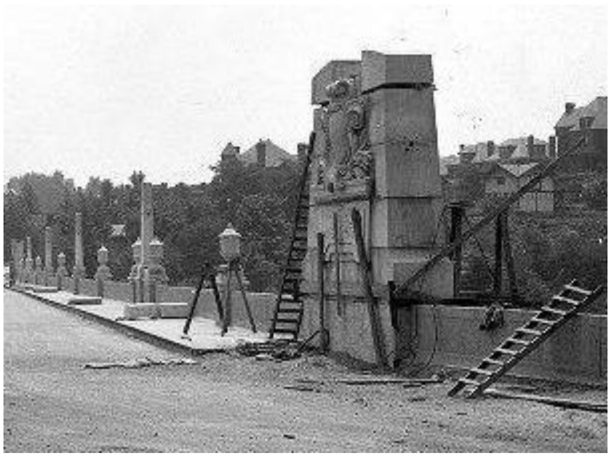

Figure 3: Architectural Features Being Constructed on the 1921 Structure

Through the years, the bridge's role as an entrance to Schenley Park, and its prominent location spanning one of the busiest stretches of Interstate in Western Pennsylvania, established the bridge as a local landmark. With this in mind, an extraordinary level of community involvement was incorporated into the design and construction process to ensure that the new Greenfield Bridge was sensitive to its many roles.

A context sensitive design considers the community and all stakeholders when making decisions regarding infrastructure improvements. By all accounts, the stakeholders and design team involved in the replacement of the Greenfield Bridge strived to create a context sensitive design that reflected the unique nature of the site through an extensive public outreach campaign.

Public meetings were held several times throughout the design phase to share ideas, gather feedback, and maintain an open line of communication with the community and stakeholders. Through this process it became clear that the bridge was an integral part of the community, linking the neighborhood to surrounding communities as well as Schenley Park and its associated cultural and recreational amenities.

The first public meeting was held early in the design phase, in January 2013, with the intent of introducing the project and project team to the community; presenting options for the typical section; and sharing other early concepts for the new bridge. A preferred deck section emerged from this meeting, in part based on consideration of feedback received from the meeting. The proposed deck section took into account the needs of both vehicular and pedestrian traffic, widening the footprint of the existing bridge slightly to incorporate bike lanes and an extra wide sidewalk. This improved access to the park, creating a safe multi-modal link between Greenfield and Schenley Park.

The link between the park and community was further improved by incorporating some of the grandeur of the original 1921 design in the new structure. Reuse of remaining architectural pillars and urns from the 1921 structure, as well as decorative fencing and lighting, were incorporated into the design at a relatively early stage, and were shared with the public as a way to maintain the historical and cultural significance of the site (Figure 4).

Figure 4: Architectural Features Reinstalled on the 2017 Arch

Similar to the previous bridge, a decorative bush hammer finish lines both faces of the bridge barrier, with the five remaining stone urns reset at prominent locations on top of the barrier. The existing stone pillars that acted as an entrance to the 1921 bridge are similarly reset on specially designed pedestals attached to the new bridge abutments.

These design decisions, as well as others, were discussed at a second public meeting in February

2015. With the construction of the new bridge quickly approaching, this meeting allowed attendees to see specific details of the new structure, with renderings of the arch and associated design elements on display. These elements included not just the architectural details, but also greatly improved pedestrian and bicycle facilities at each end of the bridge, allowing safer and more easily recognizable routes for all types of users to access the bridge and park. As a part of this improvement, dedicated bicycle and pedestrian paths were clearly marked at the intersection of Greenfield Road and Pocusset Street at the north approach, with bicycles having unobstructed access to the newly created bicycle path along Pocusset Street.

While the bridge's role as an entrance to Schenley Park was important, the bridge also played another role as an eastern gateway to the City of Pittsburgh. To the thousands of motorists traveling between the city and its suburbs, the grand arch served as a welcoming entrance to the city from the east. Early in the design of the new bridge, based on feedback from stakeholders and the general public, it was decided that an arch was once again the most appropriate form for the new structure.

An arch would both meet the structural needs of the site, and maintain the gateway nature of the bridge at this historic location. With an overarching goal to minimize impacts to the underlying Parkway, steel was selected as the material of choice for the new arch in part to simplify and expedite erection and minimize closure time of the Parkway. These advantages will be discussed in detail later. The new bridge consists of a 287 foot open spandrel arch span.

The color of the bridge was also of popular interest within the community. At the first public meeting, the design team presented three options for color; a contextual blue or green, an infrastructure gray or black, or an iconic color such as black and gold. The community voted for the obvious color: a contextual green, but surprisingly opposed a black and gold bridge (Figure 5).

To further involve the community with the project, as well as reinforce the impending closure of the bridge, a party was thrown at the bridge site the day prior to the official closure of the bridge. The party was thrown by the Greenfield Community Association on October 17, 2015 and was billed as the "Rock Away the Blues" party. The party included free music and games, as well as an informational booth with the design team sharing information about the new bridge and impending construction. This extraordinary measure of public involvement in the project promoted the community that would be most impacted by the closure, shared information on the project with the public, and provided a sense of optimism leading into the impending construction.

Finally, in the fall of 2017, almost exactly two years

Figure 5: The New Steel Open Spandrel Arch in fall of 2017

after the "Rock Away the Blues" party, one final measure of extraordinary public involvement welcomed the new bridge to the community. With signs proclaiming "The Bridge is Back", another party at the bridge site allowed community members to tour the new bridge, talk with the design team, and officially open the structure to traffic. Similar to the closing party, the grand opening included music, informational booths (including children's activities such as coloring pages featuring the new bridge), and food. This party culminated with a ribbon cutting that once again established the bridge as a prominent landmark linking Greenfield to Schenley Park and neighboring communities and serving as Pittsburgh's eastern gateway. Members of the community more than welcomed the new bridge, commenting that the new bridge "restored pride in their community".

Engineering and Construction Constraints and Solutions

While a design that captured the historic nature of the site was desired, it was also imperative that the new bridge incorporate beneficial design elements in order to provide a new landmark structure that will last well into the 21st century and beyond. Additionally, the design (and demolition of the existing bridge) needed to consider the constraints of the site, minimizing impacts to the underlying Parkway and surrounding neighborhoods.

With 85,000 vehicles per day crossing under the structure, demolishing the existing concrete arch and erecting the new steel arch while limiting disruptions to the Interstate was one of the primary goals of the project.

Demolition

Prior to preparing the contract specifications for imploding the existing bridge, a VEACTT (Value Engineering Accelerated Construction Technology Transfer) meeting was held with contractors and city, county, state and federal agencies to assess safety considerations and means and methods for explosive demolition of the bridge. The two day workshop included a field view, a review of the structural condition of the existing bridge, its urban context, and the proposed demolition schedule.

This meeting was instrumental in developing a sound strategy for safely demolishing the bridge while minimizing closure time of the Interstate. The preliminary demolition schedule prepared by HDR for the meeting recommended implosion during the week between Christmas and New Year's. During this week, the Interstate has the lowest traffic volumes for the year.

With this in mind, The City of Pittsburgh and PennDOT established a ten day window of opportunity for the implosion. Within the ten days between December 25th and January 4th, the demolition contractor could select any five consecutive days to close the Interstate and remove the structure. Within this five day timeframe, the contractor had to finalize bridge prepping over the travel lanes (including weakening structural members); set charges and wrap points of detonation; place a five to eight foot thick mat of timber, gravel, and dirt to "cushion" the falling debris; implode the bridge, dispose, recycle, and/or store the imploded mass; and reopen the interstate to traffic. If the interstate remained closed beyond the five days, the contractor would be assessed significant roadway user liquidated damages.

Ultimately, the demolition was a great success. In order to safely control the expected community crowd hoping to view the demolition, the city established viewing areas overlooking the Interstate and demolition site. A 1000 foot security zone was established, with way-finder signs directing onlookers out of this zone and to the approved overlook areas (Figure 6).

Figure 6: Way-Finder Sign Directing Onlookers to a Safe Area to View the Demolition

The actual implosion occurred on December 28th, 2015 (Figure 7). The goal of the implosion was to drop the bridge and pulverize the concrete into manageable pieces that could be quickly removed from the Interstate. Both of these objectives were successfully achieved with great precision. Clean up began immediately, with a caravan of heavy equipment working around the clock to open the Interstate to traffic well within the five day window.

Figure 7: Implosion of the Existing Concrete Arch

Steel Design

Throughout the design of the superstructure, careful consideration was given to elements that would reduce the impacts on the travelling public during erection. Once the arch form was selected as the structure type, steel was the obvious choice at this location to achieve the task.

As discussed previously, the structure spans over Interstate 376, which is a critical link between the eastern suburbs and downtown Pittsburgh. Any disruption to this facility requires extensive coordination and has potential ripple effects to traffic throughout that portion of the region. Minimizing the required closure time mitigated these impacts.

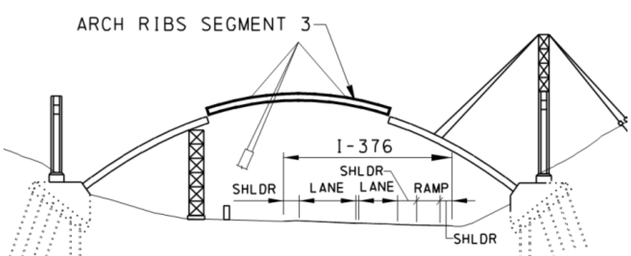

Figure 8: Assumed Erection Procedure for Design

The contract allowed for two full weekend closures to erect the structure over the interstate. Using a steel arch rib minimized the amount of false work, the number of field pieces to lift and connect, and the weight of those field pieces. The arch rib was detailed with three pieces for each rib (Figure 8).

During design, the assumed erection procedure included erecting the initial rib piece not over traffic on a false work tower, outside of the weekend closure window. The other end piece and associated struts would be erected during the first weekend closure and temporarily support with false work, stays and the adjacent pier. The base plate connections of these two rib pieces would then be grouted at the thrust blocks in the no-load position. After curing, the central arch rib piece would be lifted into place and the spandrel columns and floor system directly over the interstate would be stick-built during the second weekend closure. Additional single nighttime closure would be utilized later to install deck forms.

Figure 9: View of Vierendeel Bracing System

Additional detailing choices were made during design to simplify and accelerate the erection. This included wider spacing of spandrel columns along the structure to eliminate the number of elements and the use of a Vierendeel system to brace the arch ribs (Figure 9). The bracing system consists solely of transverse struts connecting adjacent ribs. While this system increases the size of transverse struts, it eliminates all diagonal bracing and their end connections associated with a conventional truss-style bracing system. This design choice significantly reduced the number of crane picks required over the interstate.

Additionally, the transverse struts, which typically occur at the spandrel locations, where offset 4 feet along the rib centerline from the spandrel connection. This allowed for simple splice plate connections for flanges and clip angle connections for the web. The connection is shown in the Figure 10 with the strut attaching to the rib from the left and the spandrel column attaching from above.

Figure 10: Spandrel and Vierendeel Strut Connections

Connecting the struts at the spandrel locations would have required complex welded connection shapes and/or multiple splice plate plies that would have complicated the erection and reduced flexibility for making the connections. The eccentricity of the strut connection from the spandrel column was directly considered in the design forces for the arch rib.

In addition to the reducing number of spandrels, the number of floor beams was minimized by using a relatively long stringer span length of 42 feet in relation to the overall length of the structure. Additionally, a framed floor system was employed where the stringers were framed directly into the floor beams, which eliminates work associated with stringer bearings and potential future maintenance issues. However, the use of widely spaced floor beams leads to a designation as fracture critical, which was mitigated as discussed later.

For the connection of the stringers to the floor beams, a robust connection was detailed to minimize its complexity and require only rectangular splice plates for the flange and web connections (Figure 11). This was accomplished by slightly upsizing the rolled stringers and framing them into the floor beams, which were detailed at a depth slightly below optimal. This simplified robust connection had the added benefits of aiding in redundancy and allowing the contractor and erector to further reduce the number of picks during the weekend closure. These two items will be discussed below.

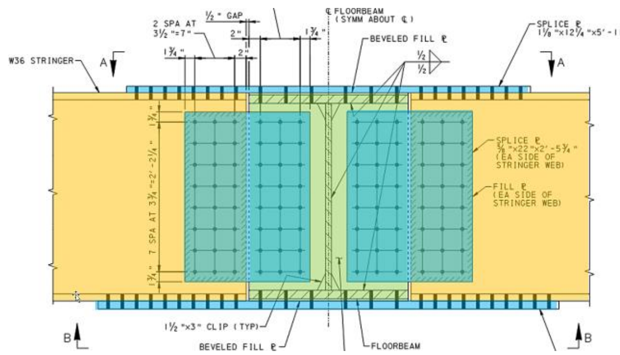

Figure 11: Stringer to Floor Beam Splice (Floor Beam Cross Section and Connection Plates in Green, Stringer Elevations in Orange and Splice Plates in Blue)

As mentioned, steel floor beams spaced widely apart are generally considered to be fracture critical members (FCM) requiring special material testing and fabrication in addition to costly periodic hand-on inspection of the elements. While a hybrid floor system consisting of concrete floor beams and potentially stringers would have eliminated the fracture critical elements, a steel floor system is light-weight; beneficial to reduced erection times; and does not require time consuming closure pours or post-tensioning.

A 2012 memo from the Federal Highway Administration (FHWA) (1), restates the definition of an FCM member from AASHTO as a "*component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function*." The memo continues on to define a system redundant member (SRM) as one *"…which is a non-load-path-redundant member that gains its redundancy by system behavior*." Or stated another way, a member is an SRM if the remaining structure has the ability to transfer and carry the forces typically carried by the fractured member. Per the FHWA memo, SRMs are not considered to be FCM for in-service inspection protocol.

To label a traditional FCM as an SRM, the FHWA memo requires a refined analysis. For the Greenfield

Bridge, this analysis was performed in accordance with the FHWA memo and PennDOT design manual, DM-4[(2)]. The methodology and detailing was discussed with the FHWA Office of Bridge Technology during the design process to ensure conformance with current guidance.

The redundancy of the floor beams was achieved and verified through a combination of robust line girder analyses and detailed three dimensional finite element analyses (3D FEA) accounting for the dynamic effects of a floor beam fracture. Line girder analyses were used to verify the ability of the stringers and their splices to effectively span two floor beam bays and also confirm the strength of the remaining floor beams to support the increased loads. The connections of the stringers to the floor beams were detailed to resist the high loads. In the event of a floor beam fracture, the stringer connection effectively becomes a splice at mid-span. The simplified and robust stringer to floor beam splice described previously aided greatly in accomplishing this connection under a fracture event.

In addition to the line girder analyses, 3D FEA simulations were used to capture the behavior of the structure during a complete fracture event. The analyses considered dynamic effects and multiple fracture locations (floor beam mid-span and spandrel support). The 3D FEA indicated that the simplified line girder analyses resulted in a floor system design that provided sufficient resistance during a fracture event while also confirming that the arch ribs, struts and spandrel columns were adequate as well. The forces in all elements and connections during the fracture event were below their strength limit state capacities, remaining elastic.

While the floor beams were still required to be fabricated as fracture critical members, the analysis method allowed them to be termed system redundant members per FHWA guidelines, eliminating the need for any in-depth fracture critical inspections. In addition to future cost savings, the elimination of the in-depth inspections reduces the disruption to the interstate below over the life of the structure.

Finally, early analyses showed that the short, stiff spandrel columns near the middle of the arch took a large share of the longitudinal force effects when acting as fixed supports. This fixity would require these members and their associated connections to be significantly larger than those at the remaining spandrel columns. In order to alleviate this concern, the central spandrel columns were released longitudinally using expansion disc bearings. The bearings at the tall, architectural end piers were then fixed to carry a significant portion of the longitudinal load. This atypical arrangement takes advantage of the significant capacity of the concrete end piers, which were already large due to architectural considerations, to carry the longitudinal loads, while allowing the spandrel columns to remain relatively slender with reasonable connections.

Erection

With a tight window of two permissible weekend closures and a critical interstate to contend with, the contractor and erector developed innovative solutions to improve on the example erection scheme proposed in the design drawings to minimize the crane lifts and connections made over the interstate. These solutions required only one weekend to erect all of the steel over the interstate, allowing the second weekend closure to serve as a contingency and provide time to accomplish other tasks without traffic below.

Figure 12: Erection of Arch Rib

The first modification was the method for erecting and grouting the arch rib into place. While the erector chose to lift the first rib piece as shown in the design plans, they spliced the other two pieces on the ground away from traffic and outside of the closure window. This entire piece was lifted into place with a large crane and no additional false work, resulting in a completed rib when the rib splice was made and the crane released (Figure 12).

As mentioned previously, the design plans called for erecting the end rib pieces in the first weekend and grouting them in place in the no-load position. After curing the base plate connections, the rest of the structural steel over the interstate would be erected in the second weekend. The erector proposed and executed a plan to use the leveling nuts at the base plate connection to induce the proper deflections and forces in the arch rib so that the steel structure could be erected in full before the grouting took place. This allowed the grouting to be completed outside of the weekend closure and off the critical path (Figure 13).

Figure 13: Grouted Base Plate Connection

Finally, the erector used the robust floor system and associated connections, designed to provide system redundancy, to their advantage. Due to the size of the connections, the erector was able to assemble two continuous stringer spans on the ground away from traffic and then complete a second two-span piece on top of the first. Overhang brackets were attached to the fascia stringers where possible. Then, during the actual closure, a large crane lifted the two-span units into position, requiring only two picks to install the floor system and associated overhang brackets located directly over the interstate (Figure 14).

Figure 14: Lifting of Floor System Two-Span Piece

Conclusion

The Greenfield Bridge Project offered a unique opportunity to implement state-of-the art design practices while creating a landmark structure at the entrance to one of Pittsburgh's most historic parks. This setting encouraged an innovative, context sensitive design that embraced the bridge's role as not just a transportation facility, but as a part of the community. The reuse of architectural elements from the previous bridge in the new design reestablished the bridge as a grand entrance to the park. Additionally, innovative design concepts and contractor solutions allowed the steel arch and floor system to be erected in just one weekend closure of the interstate below.

Acknowledgements

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- Federal Highway Administration
- Mosites Construction Company (Contractor)
- Amelie Construction (Erector)
- High Steel Structures (Fabricator)
- Michael Baker (Construction Inspection)

References

1. FHWA. “Clarification of Requirements for Fracture Critical Members,” HIBT-10. Federal Highways

Administration Office of Bridge Technology. June 20, 2012.

2. PennDOT. “Design Manual, Part 4, April 2015 Edition).” Pennsylvania Department of Transportation. April 29, 2015