ACCELERATED BRIDGE CONSTRUCTION (ABC) OF THE SHORE LINE BRIDGE BOSTON, MA

MALEK AL KHATIB, PE

PHINEAS FOWLER, PE

BIOGRAPHY

Malek Al-Khatib, PE, is a Louis Berger vice president and the firm's national structural engineer resource director. He has more than 30 years of technical and managerial experience and has worked on engineering design and construction projects of various sizes and complexity. During the course of his career, he has developed an in-depth knowledge of state and federal codes and regulations, approaching challenges by focusing on client needs to provide responsive, practical solutions. He has successfully completed several ABC projects for the Massachusetts Bay Transportation Authority and has managed several design-build projects.

A principal structural engineer, **Phineas Fowler, PE** has more than 28 years of progressive engineering experience in the design, inspection, and construction of bridges. A seasoned structural engineering professional, he is a proponent of ABC techniques. Phineas uses innovative planning, design materials and construction methods to reduce traffic impacts, improve site constructability and reduce costs and construction time.

A licensed professional engineer, Phineas is an active member of Structural Engineering Certification Board (SECB) and the American Institute of Steel Construction (AISC). Phineas holds Bachelor Degrees in Civil Engineering and Architectural Engineering from the University of Miami.

SUMMARY

Utilizing Accelerated Bridge Construction techniques, the replacement of this circa 1898 bridge was successfully completed on time, on budget and with no disruption to Amtrak or MBTA's revenue service. The historic Shore Line Bridge was a steel single-span, six-panel, pin-connected eyebar, Baltimore through truss with a span of 140 feet, a width of 18 feet, and with a 56-degree skew. It spans over three mainline tracks that form Amtrak's Northeast Corridor servicing high speed Acela trains powered by high voltage overhead contact system and MBTA regional commuter rail.

Innovative applications of the items below that lead to the successful completion of the project include: extensive coordination with owner and stakeholders, in-depth site investigations to eliminate potential construction issues, prefabrication and assembly of steel superstructure in shop, and completing superstructure demolition and new bridge placement overnight and within the designated non-revenue hours.

ACCELERATED BRIDGE CONSTRUCTION OF THE SHORE LINE BRIDGE, BOSTON, MA

Project Description

The Shore Line Bridge replacement was a project that had many challenges and complexities an engineer can sink their teeth into. Replacing this 1898 railroad bridge was a study in accelerated bridge construction techniques, commercial and freight rail coordination on and below the bridge with no disruption, as well as reuse of abutments; cost, budget and schedule restrictions; and utility coordination and maintenance.

Louis Berger was the lead design consultant providing the Massachusetts Bay Transportation Authority (MBTA) with overall project management, including structural, civil, environmental, and cultural design, quality control/quality assurance and construction phase services.

Figure 1: Shore Line Bridge Site Location

The Shore Line Bridge is MBTA Railroad Bridge No. B-16-475 located on the southerly side of the Readville commuter rail station in the City of Boston and carries the Fairmount and Franklin Lines commuter rail service, and CSX freight service. It spans over three mainline tracks that form Amtrak's Northeast Corridor servicing high speed Acela trains powered by high voltage overhead contact system and MBTA regional commuter rail known as the Shore Line.

The historic Shore Line Bridge was a steel single-span, six-panel, pin-connected eyebar, Baltimore through truss with a span of 140 feet, a width of 18 feet, and with a 56-degree skew. The four interior panels had intermediate floor beams suspended from sub-tie hangers braced by sub-tie diagonal members that linked three floor beams together. The floor beams were built-up steel I-shape sections. Multiple eyebars provided the load resisting capacity of the particular element of the truss. The increase in load of the interior panels was supported by using an increased number of eyebars that share pin connections, vertical members, upper chords and hangers.

Figure 2: Existing Bridge Built in 1898

The sub-ties met at pinned connections at the center of each panel. Sway bracing and upper lateral bracing, made of built up beams with lacing, provided stability at alternate upper truss panel points. Two built-up steel I-shape stringers were located at approximately third points below the deck. Angles located below the floor beams and stringers provided lower lateral bracing linking the three floor beams of each central panel. Portal bracing provided lateral support at the inclined end posts as well. The truss compression members are built-up steel sections with lacing bars. The deck was open with tracks supported on timber ties and timber planks were used as a walk way on each side of the single track.

Figure 3: Truss Underside with Amtrak 25,000 Volt Overhead Catenary Wires

Shore Line Bridge History

Initially invented in 1871 by engineers of the Pennsylvania Railroad, the Baltimore truss was so named because the Baltimore & Ohio Railroad used it extensively. In use into the 1930s, the pin connections of this type of bridge were replaced by riveted connections. Eyebars were replaced by I-beams.

The Shore Line Bridge was constructed at this location was part of a project to eliminate at grade crossings for the lines approaching Boston from the south as mandated by legislation from 1896 (Allen 1900:55; Tuttle 1901:163). It was fabricated by the Pennsylvania Steel Company, an early pioneer in the production of steel and a well-known bridge design and fabrication company. J.J. O’Brien and Company erected the bridge under the supervision of G. R. Hardy, Bridge Engineer of the New York, New Haven & Hartford Railroad (MACRIS 2012; McGinley Hart 1990; Tuttle 1901:182).

Figure 4: Historic photo

The existing substructure contains a gravity abutment constructed of granite masonry blocks. The east and west abutments are approximately 170 feet and 154 feet long, respectively. The back of the abutments are vertical, not battered as is typically the case. Both abutments have a constant width of approximately 10 feet over their heights except at the toe where the overall width increases to 13 feet and 11 feet for the east and west abutments, respectively. The height of both abutments is approximately 18 feet measured from existing grade to beam seat. The embedment depth at the abutment toe is approximately 6 feet and 5 feet for the east and west abutments, respectively. The height of the back wall at both abutments is approximately 3 feet. There are wing walls at three of the abutment corners.

Figure 5: Truss View with West Abutment

Located in the middle of the abutment, the bridge carries what was once the center track of a five-track crossing over the Shore Line. The five-track crossing was supported by six trusses as evidenced by the lengthy abutment and described in contemporary accounts (McGinley Hart 1990; Tuttle 1901:182). The two trusses that comprise the bridge are the sole remnants of the original six-truss bridge. A closer examination of the structure revealed that each truss once provided support for the adjacent tracks using continuous floor beams. Evidence of this method of construction is clearly seen in the cut-off ends of each floor beam. Cut-off gusset plates below the floor beam indicate that bottom lateral bracing was shared across the bridge.

Figure 6: Cut-off Floor Beam Ends

Rehabilitation Requirements

Louis Berger's evaluation of the existing gravity abutments showed inadequate capacity to meet current AREMA standards. The bridge superstructure was at the end of its useful and safe life and displayed asymmetrical and excessive loading, material fatigue, and cracking/rusting in the steel.

Bridge replacement versus rehabilitation alternatives were governed by numerous constraints. One of Amtrak's restrictions to the project execution was "No Disruption to Amtrak's Revenue Service" and MBTA required "No Disruption to MBTA Revenue Service" leaving five hours maximum non-revenue time for work over the Northeast Corridor tracks and four hours maximum non-revenue time for work on the bridge and within MBTA right-of-way during weekdays. However, MBTA track outage on the bridge was allowed on weekends except for late Sunday CSX freight train.

Figure 7: Relocation of Amtrak System Cables

In addition, 25,000 volt Amtrak overhead catenary wires, spanning between portals on independent foundations outside the bridge envelope, were supported on the underside of the bridge. The presence of these high-voltage overhead catenary wires limited the means to perform repairs on the existing bridge. Furthermore, there were several fiber optic utility cables, signal and communication trough, and several unidentified underground cables running under the bridge that required identification and possible relocation during construction. The presence of MBTA's Fairmount Line Readville Station outside the bridge restricted any changes to the horizontal and vertical alignment of the track on the bridge.

Rehabilitate or Replace

A cost evaluation for repair versus replacement was made taking project constraints into consideration which resulted in the decision to replace this historic bridge in its entirety. Historic documentation and agreements were obtained to secure bridge replacement.

Amtrak and MBTA restrictions on windows of construction operation necessitated that demolition and placement would be possible using steel structures and accelerated bridge construction methods (ABC). Lifting superstructures weights was recognized to be a controlling factor. The existing steel truss bridge could be stripped and lifted and the proposed steel superstructure weight would also be at a manageable level. Had either superstructure been constructed of reinforced concrete elements, it would have been more complex to remove and replace the superstructures within the available windows of construction operation.

From project inception detailed construction and staging activities must be developed at the early phase of the design and extensive coordination and collaboration of all stake holders was required for the successful completion of this project. The plan was to replace the bridge over a weekend shut down to the Fairmount Line Readville Station and without interrupting the Amtrak Northeast Corridor train operation under the bridge. Track outage on the bridge was extended to Tuesday morning. The Sunday CSX train was rerouted to the mainline and bussing was required on Monday between Fairmount Line Readville Station and the next station.

The subsurface investigation program was completed and included test pits to explore the underground cables. Several cables were identified and relocated during construction. In addition, an underground storage tank (UST) was found in close proximity to the bridge abutment could have impaired the heavy lifting operation. The UST was abated and filled with concrete.

Bridge Replacement

A conceptual bridge replacement study revealed that the most cost effective solution was to construct new abutments on drilled shaft foundation in front of the existing abutment. This would shorten the bridge span to 116 feet, reducing the superstructure lifting weight and eliminating the need to rehabilitate the existing abutments. However, the bridge's 56-degree skew remain unchanged. The design proceeded with the following construction activities:

Figure 8: Test Pits to Discover Presence of Unknown Utilities

- High-voltage wires from the underside of the existing bridge were relocated to new portals outside the bridge envelope.
- New independent foundations to support the Amtrak new catenary poles were designed for the relocation of the catenary lines off the bridge. The relocation of the catenary support was part of Phase I of construction.
- Cables identified as interfering with construction were relocated as part of Phase II.
- A safety shield system and support of excavation between the Northeast Corridor tracks and the existing abutments was designed. After their erection as part of Phase III, the contractor performed the substructure work for Phase III without encroaching on railroad operation**.**

Figure 9: Vertical Safety Shield System

- The proposed abutments, each with two, 6 foot diameter drilled shaft footings were 48 feet apart and approximately 100 feet deep, supporting concrete walls 55 feet wide in front of each existing abutment. The new abutments were designed with the assumption that the existing abutments act as a fill with no soil retaining capacity. Also, the number and locations of the drilled shafts were selected in such a way that the contractor could perform the work from the bridge superstructure level over weekends.

Figure 10: Proposed Abutments

- The bridge steel superstructure was designed as pre-fabricated bridge elements, completely assembled in the fabrication shop, disassembled and shipped to the site where it was reassembled in a staging area adjacent to the bridge. The staging area was selected to allow the new superstructure to be lifted and placed on the new bearing within the bridge replacement weekend.

Figure 11: Prefabricated Steel Bridge Superstructure in Staging Area

Figure 12: Prefabricated Backwalls

- The precast backwalls were shipped to the site.
- The precast approach slabs were cast in the staging area.
- Phase IV was the final construction phase and was performed in one long weekend shutdown to the Fairmount Line.

Figure 13: Bearings

- By mid-day Friday the Fairmount Line was shut down at the bridge
- Lifting cranes were moved closer to the existing bridge abutments
- Existing truss superstructure was stripped and reinforced
- The catenary was de-energized after the last Amtrak train.
- Existing truss superstructure was lifted and moved away
- The catenary was re-energized and Amtrak trains resumed on schedule
- Saturday the team returned for the preparation of bearings backwalls and all incidentals

Figure 14: New Superstructure in Lifting Position

- Lifting cranes were moved into position to lift the new superstructure
- The catenary was de-energized after last Amtrak train
- Newly assembled, proposed superstructure was lifted and placed on the bearings
- The catenary was re-energized and Amtrak trains resumed
- Backwalls, approach slabs, and laying ballast on the new bridge was completed Sunday and Monday
- Fairmount Line resumed normal operation on Tuesday morning

Project Challenges

Steel Superstrate

As previously mentioned, the Shore Line bridge is a highly traveled bridge with Amtrak lines below. The severe site constraints posed several challenges, beginning with the steel superstrate design. Existing track alignment could not be changed due to the presence of the station. In addition, the MBTA requires all open deck bridges to be a ballasted deck system when reconstructed. Underneath the bridge, Amtrak dictated the minimum distance between the bridge deck and the high voltage catenary. The bridge deck was sandwiched within these constraints. This required shallow floor beams and sloping of the beams for drainage. The U frame analysis was utilized to check the rigidity of the kickers and the unsupported length of the top flange required a balancing act as not to increase the lifting weight of the bridge. To compensate for the flexibility of the deck and to provide lateral stability, the ballast plate was designed as a horizontal diaphragm. To further reduce the weight and provide aesthetic appearance, the through girder height was made parabolic (fish belly) shape.

Figure 15: Backwall Placement

Complete penetration groove joint (CJP) welds were limited to the extent practical and fillet welds were used at most locations. Attention to details was extremely important considering the bridge 56-degree skew, the need for additional bearings for the end frame supporting the end panel' floor beams, and the predicted twist since the bridge was assembled on the ground. Considering the limited access to the bridge for maintenance, weathering steel was used for the superstructure. It was also painted for durability and aesthetics.

Construction Schedule

A detailed construction schedule was developed during the design that included hourly breakdown for the weekend shut down. The breakdown accounted for all activities and the responsible party for each activity during the bridge replacement to ensure successful completion of the project. The planned construction methods, schedule, and staging were approved by the MBTA, Amtrak, CSX, and the City of Boston.

The contractor followed all construction stages that were developed in the design phase except for the lifting method. Single crane versus multi-crane lift was considered during the design phase and it was decided to assume multi-crane lift due to the availability of such a large size crane. The contractor decided to use a single lift crane that was shipped from Europe in time to meet the project schedule.

Bridge Prefabrication

Steel shop drawing and fabrication went relatively smooth with minor requests for information and requests for minimizing CJP. However, collaboration between the design team, the contractor and fabricator helped to resolve design intent issues and other minor issues due to fabrication errors.

The bridge was preassembled in the shop and all necessary adjustments/corrections were made. Ballast plates were welded to the floor beams to the extent practical. The bridge was disassembled and shipped to the site for reassembly. In the staging area, final welds including CJP were completed and all necessary paint touch ups and spray applied waterproofing were made prior to lifting the bridge.

Replacement Weekend Success

On a selected Friday in November 2016, a long weekend outage was implemented for MBTA commuter rail. Track outage on the bridge commenced by noon and bussing was provided between Readville Station and Fairmount Station. Contractor stripped all nonstructural elements from the existing truss and prepared the truss for pickup.

Friday night, after the last Amtrak Acela train passed, the catenary lines were de-energized.

The massive Mommoet LR11000 Crane with super-lift began the pick of the existing 470,000 pound truss and completed the relocation to a designated location in roughly two hours.

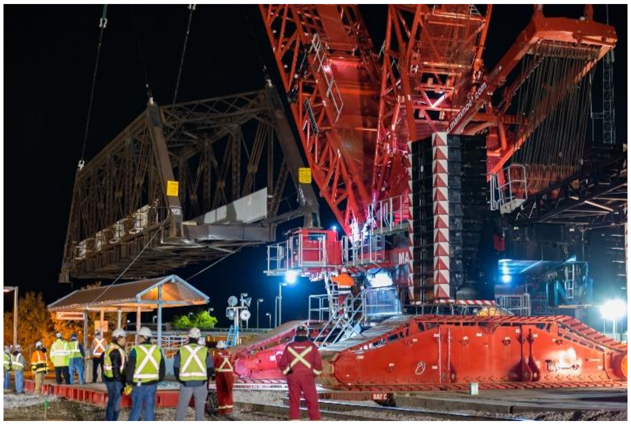

Figure 16: Existing Superstructure Removal

The crew worked during the next day placing the bearings, and precast back-walls. Overnight on Saturday, after the last Amtrak revenue train, the new superstructure weighing 615,000 pounds was placed into position and completed the installation in two hours. Over the next weekend the precast approach slab, ballast, and track were placed to open the bridge for service.

It was the detailed planning and attention to details during the design, the collaborative efforts between the Louis Berger, MBTA, Amtrak, CSX, Keolis, and the contractor Barletta Heavy Division that ensured the successful completion of this project.

Figure 17: Completed Shore Line Bridge