

REHABILITATION OF SHELBY STREET BRIDGE - COMBINING THE “NEW AND THE OLD”

Edward P. Wasserman, P.E.¹, M.ASCE and Joseph J. Pullaro, P.E.², M.ASCE

Bridge Description and History

The Shelby Street Bridge spans the Cumberland River in downtown Nashville, Tennessee. The original bridge was comprised of 48 spans, including three through pin connected Pratt trusses, one deck Pratt truss, two reinforced concrete truss spans, four steel girder spans and thirty-eight concrete T- beam spans.

The bridge was designed by Howard M. Jones and erected in 1907-1909 by the Foster-Creighton-Gould Company for Davidson County and is currently owned by the Metropolitan-Davidson County government. The approach spans provided a 12.2 M (40'-0") wide roadway with 2.67 M (8'-9") sidewalks on each side. The three river truss spans provided an 11.13 M (36'-6") wide roadway with 3.2 M (10'-6") sidewalks on each side. The bridge originally carried three traffic lanes within the trusses (the middle lane reversible at peak traffic hours), and four traffic lanes on the approach spans.

The bridge had a total length of approximately 695 M (2281'). The primary spans over the Cumberland River are three through high steel trusses, with one main span of 97.84 M (321'-0") and two equal side spans of 52.25 M (178'-0"). Each truss is a variation of a Pratt truss design. There is also a 30.89 M (100'-4") inverted deck Pratt truss span on the East approach. This span was enclosed within one of the buildings owned by the Nashville Bridge Company. The Nashville Bridge Company complex had grown and expanded around and under the East approach spans of the bridge.

The approach spans were comprised of concrete trestle bents with steel girder spans used over roadways and railroad tracks and closely spaced concrete T-beams with monolithic concrete decks elsewhere. The concrete bents were spaced at 9.14 M (30'-0") center-to-center. The steel girder and truss spans were supported on concrete piers founded on bedrock. (See fig. 1)

The most important and interesting feature of the bridge is the six reinforced concrete trusses that support the two West approach spans over the former freight yards of the Tennessee Central Railway. The spans are 29.72 M (97'-6") and 27.92 M (91'-7"), respectively and each span incorporates three trusses in its cross section. This area now serves as a paid parking lot. Mr. Jones notes in an Engineering News article published in November 1909 that the railroad company objected to the trestle approach being carried over their property, and agreed to give the right-of-way

¹ Civil Engineer Director, Structures, Tennessee DOT

² Principal, Lichtenstein Consulting Engineers, Inc. Paramus, NJ

necessary if only one pier was put in the yards. The designer considered several options including deck steel trusses, deck steel trusses encased in concrete, reinforced concrete arches, and concrete trusses. An exposed steel truss structure was quickly rejected, as the corrosive effect of sulfurous smoke from the coal fired steam engines would have severely affected the durability and the useful life of the bridge.



Figure 1: View Looking North

An encased steel truss was considered too dead load heavy and thus not cost effective. Concrete arches were dismissed due to their reduced headroom. The designer therefore settled on the concrete trusses as the structure of choice, even though there was no known American precedent at the time. The spans would be 29.9 M (98') each with one pier placed between the tracks. He decided to design a bowstring type truss omitting all diagonal members. The Engineering News article stated that, from a structural standpoint, the bottom chords acted as ties to take the horizontal component of the end thrusts of the arched top chords. The article further stated that one-tenth of the arch area was steel rods. Thus, these two spans are technically trusses and partially function as trusses, but they also distribute the forces within the spans as an arch does.

Mr. Jones' innovative use of reinforced concrete at a time when the material was barely beyond the experimental state is indeed noteworthy. The first bridge to be built with this technology was not finished until the late 1800's. Additionally most of the early examples of the use of reinforced concrete were seen in arch bridges where loads are carried primarily in compression. Mr. Jones' use of reinforced concrete in truss construction was criticized by prominent engineers, with the lack of accurate knowledge of the distribution of stresses under eccentric loading being the main point of attack. Not being satisfied with available theoretical solutions, Mr. Jones decided to make a reduced scale model of the longest truss and test it to destruction. A one tenth scale model was made using the same kind of concrete and was loaded until the truss was about to fall over. Mr. Jones wrote that the load at test termination was six times greater than the truss would ever be called on to sustain. Mr. Charles Cook in his manuscript titled "The Shelby Street Bridge: "Monument To Howard M. Jones" writes that only one other reinforced concrete truss bridge was known to have been built anywhere in North America. Completed in 1909 in Ontario, Canada, the Canadian bridge used similar techniques as the Nashville Bridge. The bridge is "one of a kind" with no other example built in the United States. Largely due to the concrete trusses, the bridge was placed in the National Register of Historic Places in 1986. (See fig's 2 & 3)

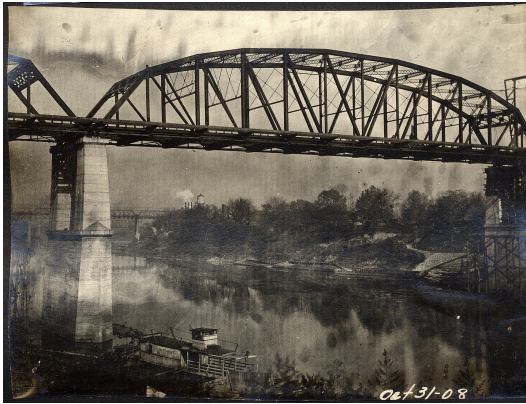


Figure 2: Metal Truss under construction



Figure 3: Concrete Truss under construction

The bridge experienced problems as far back as the early 1920's primarily with the concrete in the substructure and piers. In 1923, some deck slabs were replaced, pier columns encased and shotcrete repairs applied to some beams and to approach and main piers. In 1960, the condition of the concrete trusses worsened to the extent that additional shotcrete was applied at other beams and substructure elements. The steel fared better, with only minor repairs being required to the trusses. In 1990 all the steel truss spans were blast cleaned and painted.

The Tennessee DOT had been inspecting the bridge for the City for many years, and in 1992, reported that conditions had worsened since the last inspection and load posting of the bridge was needed. The city posted the bridge for M 9.5 (14 tons). In 1994, the concrete conditions, especially at the trusses, continued to deteriorate, resulting in the need to install protective netting around all the concrete trusses.

The need for major structural improvements to the ever-deteriorating concrete led the city to conduct a study for the replacement of the bridge. In 1993 the city hired the firm of Gresham Smith to conduct a corridor study and it concluded a new bridge downstream of Shelby Street should be constructed. The bridge was therefore slated for removal.

In 1995, an agreement was made with the Houston Oilers Football Team (now Tennessee Titans) to build a new stadium on the east side of the river adjacent to Shelby Street. This coupled with the new arena constructed on Broad Street led to a rethinking of the future of the Shelby Street Bridge. Historic Nashville, Inc. embraced the idea of preserving the bridge and eventually \$6m was allocated to rehabilitate the bridge and turn it into a pedestrian structure and linear park.

In early 1997, Lichtenstein Consulting Engineers, Inc. of Paramus, NJ was hired to conduct the study. The study would include an in-depth inspection, analysis and

determination of what portion of the bridge would have to be replaced or could be rehabilitated.

The conversion of the bridge to a pedestrian crossing would also require certain modifications to ensure safety and comfort of the users. Finally, street furniture, lookouts, lighting and other architectural enhancements would be addressed and the costs estimated. The results of the study would form the basis for the final design and construction of the rehabilitation.

Results of Study

The study concluded that the bridge could be rehabilitated, but that extensive work was needed. The concrete in both the superstructure and substructure had always been a problem; so long term solutions were necessary so as not to impose excessive maintenance costs on the city. The work would have to be carefully done to respect the historic integrity of the bridge. The important elements such as the piers and trusses would have to incorporate details that were acceptable to the State Historic Preservation Officer.

Approach Spans

Although the approach spans were of sufficient structural capacity and could be repaired, the work would be costly and would rival that of replacement. The decision was then made to replace the 396 M (1300') of east and west approach spans. The replacement would be composed of prestressed concrete beams placed on concrete bents. The design would clearly be new but it would not detract from the overall important historic portions of the bridge, that being the concrete and steel trusses.

Main Concrete Piers

The six concrete piers supporting the concrete trusses and overhead metal trusses were of major concern, as their replacement, if necessary, would be so costly as to exceed the budget for rehabilitation.

The piers were found to be in fair condition with heavy map cracking, spalling, scaling and efflorescence present. The strength ranged from 11.6 mpa (1,680 psi) to 20 mpa (2,900 psi.) As the sections were massive in nature and the applied stresses were low, it was felt that the piers could be rehabilitated.

Concrete Trusses

The gunite was in poor condition and would definitely need to be removed. The original concrete, where it was, visible exhibited spalls and delaminations. Compression testing resulted in strengths of 25 mpa (3,600 psi). Petrographic testing indicated the concrete to be in fair condition. Limestone, which was apparently used

instead of sand, contributed to the deteriorating condition of the concrete.

Remainder of Bridge

The concrete deck and sidewalks, although found to be in fair condition, were slated for replacement for long-term durability. The metal trusses, while needing repair, were in overall good condition and capable of supporting the pedestrian loads.

The concrete trusses were analyzed using a GTStrudl program. The entire bottom chord was in tension (4.9 mpa) (712 psi), while the vertical and upper chord experienced combined bending and axial compression, but with stresses lower than allowables based on the tested strength. It was determined that reinforcement of the bottom chord by the addition of a 102mm (4") shell of concrete with prestressing strands would remedy the situation.

Rehabilitation Plan

Rehabilitation of Metal and Concrete Trusses

The rehabilitation effort included the following bridge structures:

- Main river crossing two 52.25 M (178'-0") and one 97.84 M (321'-0") Pratt Overhead trusses.
- East approach one 30.89 M (101'-4") Pratt deck truss relocated from original position to a position adjacent to the overhead trusses.
- West approach one 29.72 M (97'-6") and one 27.92 M (91'-7") reinforced concrete bowstring deck truss.
- Substructure four river piers and two bents, all of unreinforced concrete.

The fundamental change to the configuration of the existing truss spans, aside from the deck span relocation, was removal of the original sidewalks. The root portion of the cantilever bracket connecting to the floorbeam was retained. The new cross section was to consist of a 4.57 M (15'-0") roadway and two 3.2 M (10'-6") sidewalks. The dead and live loads were significantly reduced and would largely eliminate any requirements for strengthening. The minimum design live loads were to be M13.5 (H15) or 4.07 KPA (85 psf), whichever controlled. The floor system framing for the steel trusses was to remain, while the concrete truss floor would be completely replaced. Scenic overlooks were to be placed at both main river piers. Conventional reinforced concrete deck slabs were to be utilized throughout. (See fig 4)



Figure 4: New Cross Section

The reconstructions of the four steel truss spans were all relatively similar. Minor repairs were needed for isolated main and bracing members, particularly the bottom connections of the overhead truss verticals in the 52.25 M (178'-0") spans. The eye bars in the bottom chords of these two spans also required strengthening. The bottom chords were each fitted with two high strength threadbars for their full length, held by clamping devices to the pins. This was the only strengthening needed in the steel trusses.

Minor repairs were also made to the floorbeams and stringers, as well as installation of shear studs for composite action. New brackets and stringers were placed at the two main river piers for the overlooks, which extended 5.49 M (18'-0") beyond the railings.

The bearings for the overhead trusses were rehabilitated, but the relocated deck span needed new bearing assemblies. Placing the new bearings to support the deck truss necessitated modification of the existing pier. Due to lack of flexural reinforcing, the bearing forces could not be supported by the pier cap. A concrete encased steel transfer beam, extending over the columns, provided the new seat.

The rehabilitation design for the concrete trusses included total replacement of the deck, floorbeams, spandrel columns, bracing struts, and bearings. The trusses required very extensive surface repairs, as the shotcrete facings were in poor condition. The original post-tensioned structural steel rods in the bottom chords were assumed to have lost



Figure 5: View of approach piers

all applied tensile forces, so new post-tensioning strands were included in the design. The existing river piers were comprised of massive unreinforced concrete sections. The total design stresses were low, but the surfaces of the columns and cap beams were in poor condition. The recommended rehabilitation was installation of fiber reinforced plastic jackets to completely encapsulate the concrete and protect it from weathering. The underwater portions were to receive corrugated PVC sheeting, mechanically fastened and sealed with concrete fill. The encapsulation work was subsequently removed from the rehabilitation plans for budgetary reasons, to be performed in a subsequent contract.

New Approaches

As mentioned above, the east and west approach spans comprised mostly of T-beam spans were to be replaced. The re-design for the replacement thirty-eight concrete deck girder and four rolled beam deck girder spans of the east and west approaches was executed by the Tennessee Department of Transportation under a separate design and construction project.



Figure 6: View of approach superstructure

As mentioned previously, selected concrete girder spans had, of necessity, been replaced in 1923 due to poor construction. By the time of the rehabilitation, many of the concrete deck girder and steel stringer spans had deteriorated to the point that rehabilitation was not practical. Additionally, the required new 4.6M (15') roadway and two 3.3 (10.75') sidewalks could not be configured from the existing cross-section furthermore the approaches were to be shortened several hundred feet on both ends, the approach grades would need to be steepened making the trestle bents unusable.

TDOT elected to replace the approach units with continuous precast, prestressed concrete box girders and composite concrete deck. The newly constructed bents for the approaches used a three column configuration with arched caps to complement and echo the style of the original piers for the truss spans, a feature not present in the tower trestle bents of the original approaches. (See fig's 5 & 6)

As previously mentioned, the 30.9 (100.33') inverted pratt truss span, originally located, near the center of the original east approach units, was removed, reconditioned and relocated westward to be adjacent to the overhead trusses of the river spans. Thus, all the portions of the original construction would be contiguously

located in the finished bridge.

The terminae for the final bridge, also designed by TDOT, consisted of a series of folded stairways and handicap ramps with form lined finished retaining walls, in accordance with the desires of the city's architect.

Adaptive Elements

A substantial amount of resources were put into the bridge to make the structure a significant addition to the beauty of the city. Outlooks at each pier finished with wood pavers, architectural lighting to illuminate the piers, ornamental bridge railings and street furniture were incorporated into the design.

Construction

The approaches were constructed first and were accomplished with no difficulty. The new spans provided access for the rehabilitation work of the trusses.

The construction of the rehabilitation for the historical portion of the bridge began after the new approach spans were completed under a separate contract. The concrete trusses were repaired first and work generally proceeded toward the center of the bridge, using completed spans for access.

Problems were encountered during the rehabilitation of the concrete trusses. The deck, floorbeams and spandrel columns had been removed, as they were scheduled for total replacement. Removal of the shotcrete cover on the bottom chord revealed that the core of the member, within the post-tensioning rods, was unsound. The concrete core was crumbling in some locations and delaminated in others. Apparently, during the 1960 bridge repairs, the shotcrete facing was installed over an unsound substrate. Complete replacement of the concrete in the bottom chord would be necessary, as well as additional shoring.

In lieu of completing the surface repairs, the contractor offered to replicate the concrete trusses for the same price as the rehabilitation. TDOT accepted this proposal and it was subsequently approved by the State Historic Preservation Officer.

A new design was prepared using the original bridge geometry. All member reinforcing and detailing conformed to current standards. In keeping with the historical design concept, post-tensioning of the bottom chord was utilized.

The contractor erected a plywood deck on shoring towers, set to the elevation of the bottom of the trusses. Formwork was then constructed for each truss and the members completed. After curing of the concrete, new spandrels, floorbeams and deck were formed and poured.

The deck truss that was to be relocated was on the ground adjacent to the east bank of the river when the work commenced. Cleaning, priming and structural repairs were completed there prior to lifting. The transfer beam and new expansion bearings were installed on the river pier and the span was hoisted into place with a single large crane.

The rehabilitation of the overhead trusses was very straightforward. The contractor commenced by installing a containment system above the deck, cleaning the steel and applying primer. Once the top of the bridge was completed, the deck was removed and the process repeated for the bottom chord and floor system.

The steel repairs and overlook framing additions were performed after deck removal. Needs for shoring of members were minimal. Stay-in-place metal forms were used and the concrete was placed by pumping.

The rehabilitation concluded with final painting of the steelwork, installation of the ornamental railings and provision of decorative lighting to accent the bridge structure. (See fig's 7 & 8)



Figure 7: Completed Bridge



Figure 8: Completed Bridge

Summary

The Shelby Street Bridge has had a remarkable history. When it was conceived and built by Howard Jones, it was a combination of already time-tested elements, such as the metal trusses and concrete T-beams, but it included a one-of-a-kind concrete truss. Throughout the years it served the people well, but the ravages of time nearly caused its ultimate demise. The people of Nashville, however, realized they had something special and with careful rehabilitation and replacement they now have a bridge that will not only serve a needed function, but also become another jewel in the cityscape of Nashville.