REPLACING THE SUSPENDER ROPES OF A TIED ARCH BRIDGE USING SUSPENSION BRIDGE METHODS

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ABSTRACT:

The Thaddeus Kosciuszko Bridge consists of twin through-arch structures which span the Mohawk River in the state of New York between the towns of Colonie in Albany County and Halfmoon in Saratoga County. Working with Modjeski and Masters, the contractor for this project proposed an alternative method for the replacement of all 168 suspenders for these bridges utilizing a modified technique previously applied to suspension bridges. One of the most significant benefits of the proposed method was that it allowed the work to be performed under full traffic. This alternative method saved the bridge owner approximately $5 million by eliminating the complex jacking system and traffic control requirements shown on the original Contract Plans.[1]

INTRODUCTION

The Thaddeus Kosciuszko Bridge consists of twin through-arch structures located in the State of New York which span the Mohawk River between the towns of Colonie in Albany County (on the South) and Halfmoon in Saratoga County (on the North). The bridges were built in 1959 and each carries three lanes of traffic in a single direction on the Northway (Interstate 87) – one bridge is for Northbound traffic and the other for Southbound. The bridges carry a high traffic volume of approximately 110,000 vehicles per day.

Figure 1 – Northway Twin Arch Bridges (Thaddeus Kosciuszko Bridge), Albany, NY

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In February 2008, a contract was awarded for the replacement of all 168 suspenders on the bridges. The nearly 50-year old suspenders, consisting of 50 mm diameter structural strands, had significant section losses as a result of corrosion caused by an aggressive upstate New York environment. The winning bid price submitted by Piasecki Steel Construction of just under $12 Million was over $4 Million less than the Engineer's Estimate. A Value Engineering Proposal submitted by the contractor subsequent to the award saved an additional $1 Million. Thus, the contractor's alternative method resulted in a combined savings of over $5 Million.

The cost savings were the result of an innovative approach to replacing the suspenders using an alternative method from that shown on the contract plans. This method substituted the complex jacking and shoring system shown on the plans with a simplified system similar to that used previously on suspender rope replacement projects for suspension bridges. Using this system, the contractor was able to remove and replace the suspenders under full live load. This was a significant improvement over the method shown on the contract plans which required closing the bridge during certain phases of the work resulting in a complex and costly traffic plan that involved a median cross-over to reroute traffic to the adjacent bridge.

BRIDGE DESCRIPTION

The Northway Twin Arch bridges are two-hinged steel arches with a span of 182.9 m between the bearing pins and a rise of 36.6 m relative to the spring line. Each bridge consists of two parallel rectangular arch ribs having a rectangular box cross-section approximately 1.2 m wide by 2.4 m tall, built up of riveted steel plates spaced 15 m center to center. Each bridge carries three 3.6 m lanes with two 1.0 m shoulders, for a total deck width of 12.8 m. The suspended portion of the span has a length of 167.6 m with three approach spans on each end for an overall length of 232.7 m per bridge.

The deck superstructure is suspended from the arches with 50 mm diameter structural strands – one pair of strands supports each end of the intermediate floorbeams. The superstructure of each bridge consists of 21 intermediate floorbeams spaced at 7.62 m on center (22 equal panels). The end floorbeams are connected either directly to the arch (at the fixed end) or attached with a pinned link (at the expansion end). Longitudinal stringers framing into the floorbeams support a reinforced concrete deck (designed as non-composite, although shear connectors were provided for added rigidity). Open steel grid deck is provided between the floorbeams in the shoulder areas to provide drainage.

There are a total of 84 suspenders – the longest of which is over 29.87 m long. The typical suspender has a Type 8 socket on each end – at the top, the socket bears on a transverse beam within the arch box (see Figure 5); and at the bottom, it bears on a stiffened seat angle attached to the web of the floorbeam. The connection is symmetrical about the webs of the transverse beam and floorbeam.

The suspender connection at the crown of the arch is unique. At this location, both suspenders share one large socket which in turn is supported by a pair of U-bolts that straddle a large pin (see Figure 8). The pin is a vestige of an original design feature of the bridge – it originally functioned as the crown pin for a three-hinged arch. As part of the original design, the bridge was constructed as a three-hinged arch for dead load. Once the deck superstructure was completed, the crown was locked by installing cover plates on the top and bottom of the box section to make this part of the arch continuous. Thus, the bridge was transformed into a two-hinged arch for live loads. Unfortunately, the design made no provision for future replacement of the suspender – the splice plates effectively blocked access to the suspender connection. This made for a more complicated repair at this location, as will be discussed later in this paper.

PROJECT BACKGROUND

In recent years, the condition of the suspender strands had rapidly degraded due to a combination of age and exposure. Salt spray from the adjacent roadway had run down the suspenders over the years, concentrating the damage at the area where the suspender connects to the floorbeam. The suspender strand in the vicinity of the seat angle began to suffer from corrosion related section loss, eventually leading to failure of the individual wires. As the wires began to break, they would splay outward, eventually resulting in a rather dramatic display of deterioration (see Figure 3). In the most extreme cases, section losses of up to 50% were reported. As a result, the decision was made to undertake an immediate replacement of all 168 suspenders on both bridges. Of these, a total of 22 suspenders were identified as requiring emergency replacement.

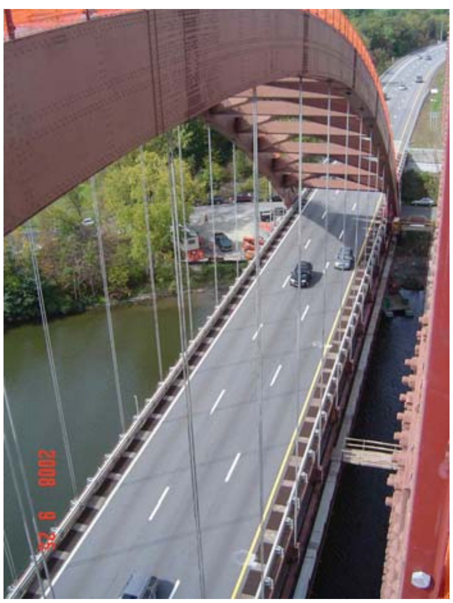

Figure 2 – View at Crown of Arch

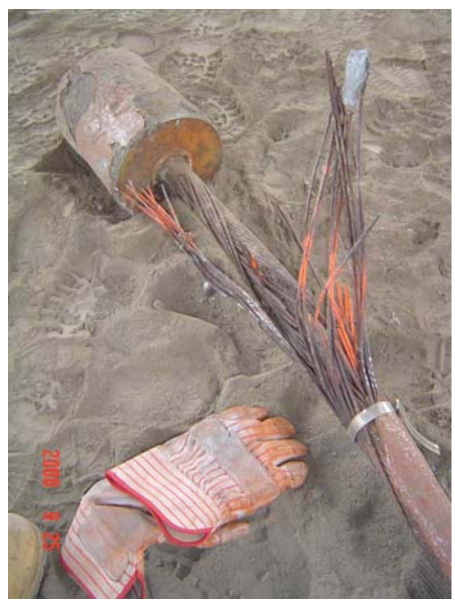

Figure 3 – Photo of Deteriorated Suspender Strand with Broken Wires (After Removal

The contract, awarded in February 2008, required the replacement of the 22 worst suspenders prior to the end of November 2008 and complete replacement of all suspenders by November 2009. The contract contained a penalty clause of $10,000 per day if the contractor did not meet the November 30, 2008 deadline.

Although a temporary support system for the replacement of the suspenders was fully designed and detailed on the contract plans, the contract documents allowed for an alternative lifting scheme to be submitted by the contractor. The contract stipulated that any alternative system would have to meet the specific requirements of the contract, such as load capacity and deflection criteria, and had to be designed and detailed by a licensed Professional Engineer. Furthermore, the alternate system would be subject to review and approval by the NYSDOT.

The winning contractor, Piasecki Steel, hired Modjeski and Masters to prepare the detailed design calculations and working drawings of the alternate structural lifting system. The design was completed in May and accepted by the NYSDOT in June 2008.

The contractor began replacing suspenders in September 2008. In October, as a result of the routine annual inspection of the bridge performed by the NYSDOT, some of the 22 yellow-flagged suspenders were upgraded to a red-flag condition – thus requiring repairs to be completed within 6 weeks. This forced a modification of the already advanced replacement sequence; however, the contractor was able to mobilize additional jacking systems to accommodate the accelerated schedule and the repairs were completed on time – with just 1 day to spare before the November 30th deadline!

DESCRIPTION OF THE ALTERNATIVE STRUCTURAL LIFTING SYSTEM

The structural lifting system developed for this project is very similar to those that have been used for the replacement of suspender ropes on suspension bridges. For these structures, the lifting system is designed to perform the following tasks:

1. Temporarily support the floorbeam to allow the suspender to be removed
2. De-tension the existing suspenders
3. Tension the new suspenders

Although similar in concept, some of the features of the suspender system for this bridge structure were quite different from the details found on typical suspension bridges. Due to the unique features of this structure, developing a structural lifting system to allow the completion of all the required repairs presented quite a challenge. Some of these features include:

- Each pair of suspenders supporting the floorbeams of the arch consists of two individual elements, anchored top and bottom. In this case, each suspender could be removed and replaced individually. On most suspension bridges, the suspenders are continuous over the top of the cable, such that both legs of the same rope must be replaced simultaneously. Therefore, when replacing a suspender rope, both legs of the suspender are typically de-tensioned and tensioned simultaneously.

- The suspenders of this bridge are attached directly to the web of the transverse floorbeams. Unlike suspension bridges, this bridge has no longitudinal stiffening element (truss or girder) that supports the floorbeams. On a suspension bridge, the presence of the stiffening truss typically allows for the installation of separate systems during rope replacement: one to temporarily support the panel point and another to de-tension/tension the suspender ropes. In this case, the structural lifting point had to be located directly on the floorbeam itself and allowed for little space for the attachment of a separate system for suspender removal and installation. Furthermore, the floorbeams required steel repairs, some of which could only be done once the floorbeam was off-loaded and the suspenders were removed.

- Due to the lack of a longitudinal stiffening element, the structure does not provide for a redundant load path to redistribute loads to adjacent panels during the removal of a suspender. Owing to the resulting low inherent stiffness, the ends of the floorbeams are relatively free to deflect during jacking operations. Therefore, the original design contract specified strict limits on the deflection of the floorbeam during the removal and replacement of the suspender: no more than 8 mm of differential downward deflection between any two adjacent floorbeams; and no more than 6 mm of upward deflection of any one floorbeam from its original position. The reasoning provided by the design engineer for the deflection limits was to prevent cracking of the concrete deck as a result of excessive movements of the floorbeam. However, due to the lack of longitudinal stiffness of the deck superstructure, the displacement of the floorbeam as a result of live load exceeds that allowed during jacking (particularly near mid-span where the elastic stretch of the suspenders under the design live load is on the order of 25 mm).

ADVANTAGES OF THE ALTERNATIVE SYSTEM

The method in the value engineering proposal has a number of advantages over the system shown on the original contract plans, such as:

- The system shown on the contract plans relied on transferring load to the adjacent floorbeams (and deteriorated suspenders) with a temporary support beam (see Figure 4). The alternative method uses a completely independent system to support the floorbeams during suspender rope replacement (see Figure 5).

- With the alternative method, there is no change in load path during the removal and replacement of the suspender. The jacking system is attached to both the arch and the floorbeam in a way that is structurally equivalent to the existing suspenders (see Figures 6 and 7).

- The alternative structural lifting system does not require modification of the existing arch cross-section to allow tensioning of the new suspenders. Tensioning of the new strands is accomplished by the same friction clamping system used to de-tension the strands. The stressing method shown on the original contract plans involved cutting a permanent hole in one of the plates comprising the rib cross section in order to tension the new suspender from within the arch using a special type of top socket.

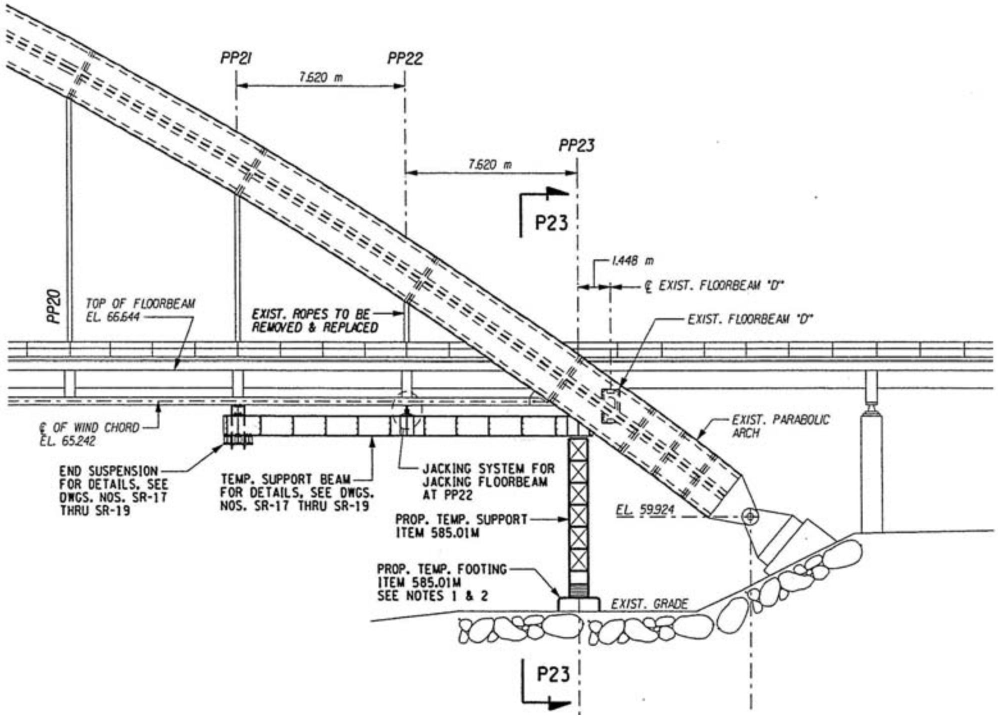

Figure 4 – Method of Replacing Suspenders in Original Contract Plans.

- The alternative method allows for suspender rope replacement under full live load. Furthermore, the contractor fabricated the new ropes using the measurements shown on the shop drawings from the original bridge construction, rather than attempting to measure the suspenders in place. This eliminated the complex and costly traffic control procedures required by the contract plans that involved shutting down one bridge at a time and installing cross-over's to re-route traffic to the adjacent bridge.

- The alternative system combines all the functions of the temporary support, de-tensioning of the existing suspenders and tensioning of the new suspenders in one system. This efficient system has a total weight of only 1.8 tonnes. The system shown on the contract plans utilized a separate means of temporary support, consisting of either beams supported by adjacent suspenders (for intermediate panels) or towers supported at ground level (at end panels). The temporary support beams alone consisted of double W36x300's with a weight of approximately 15.5 tonnes. The temporary support towers had a height of approximately 7.3 m, a capacity of 159 tonnes and required a temporary footing at the edge of the river.

- The contractor was able to complete the replacement of all the suspenders by fabricating 4 identical systems.

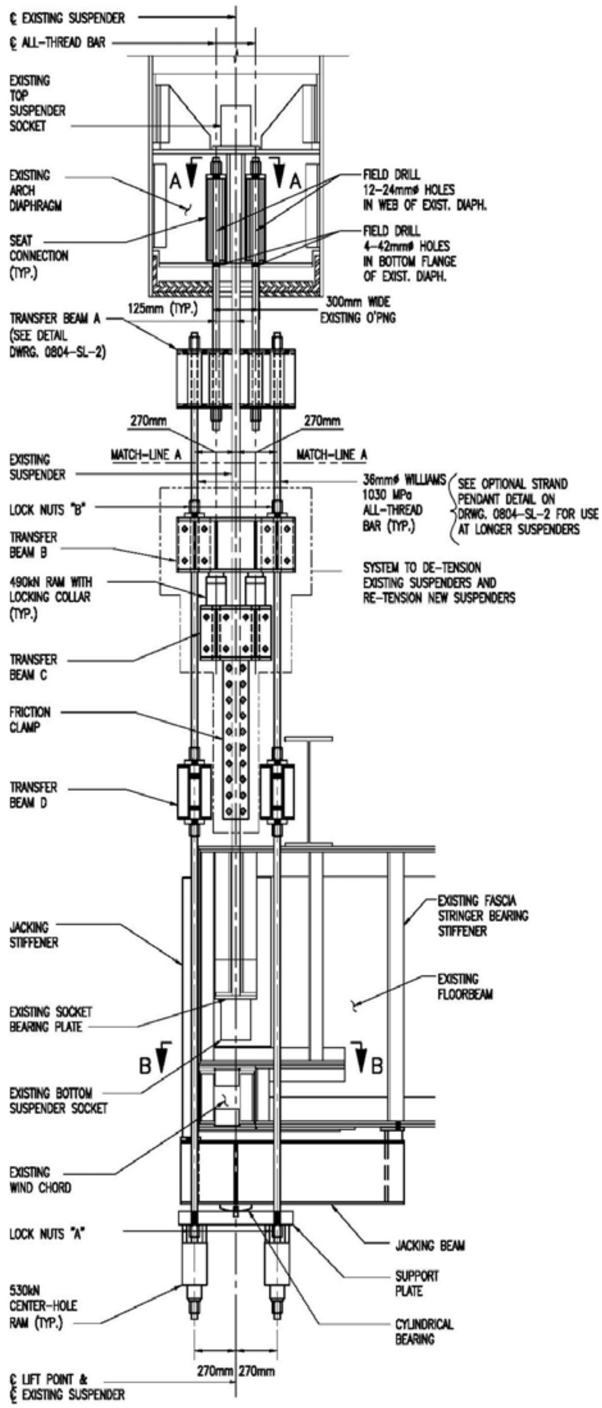

Figure 5 – Alternate Structural Lift System

Figure 6 – Connection at Transverse Beam Inside Arch Box

Figure 7 – Structural Lift System Installed at Panel Point 3

FEATURES OF THE ALTERNATIVE SYSTEM

A thorough description of the features and functions of each element of the alternative jacking system is beyond the length limits of this paper. The following section highlights the details of some of the more unique elements of the alternative system; these are: 1) the friction clamp, 2) the floorbeam steel repairs, and 3) the steel repairs at the arch crown (Panel Point 12).

FRICTION CLAMP – Rope removal and installation was performed using a friction clamp, similar to those used on previous suspension bridge suspender rope replacement projects. According to the contract specifications, the clamp had to be load tested to determine the friction factor of the suspender strands for use in the design of the clamp. Due to the proposal to use the friction clamp for the installation of the new ropes, the load test was also required to demonstrate that there would be no damage to the galvanized coating of the suspenders as a result of the applied clamping force.

For this project, it was elected not to use a zinc liner at the contact surface between the clamp and the suspender. Previous experience with installing clamps on wire rope suspenders indicated that there would be no damage to the surface of the ropes. The contractor pointed out that clamping devices are used during the manufacturing of both ropes and strands (as part of the stressing beds used to pretension the strands to remove the initial elastic stretch) which do not utilize zinc liners.

The contractor fabricated two friction clamps for the load test based on a preliminary design performed by Modjeski and Masters (see Figure 8). Assuming a friction coefficient of 0.15, the clamps were designed for the required structural lifting load of 445 kN (per suspender) with a safety factor of 1.5 against slip (ultimate capacity of 668 kN). This resulted in a clamp utilizing 20 – 25 mm diameter A325 bolts fully tensioned to a minimum load of 227 kN each (total clamping force of 4,536 kN, min.). For the initial test, the ram was operated to its maximum capacity (890 kN), but no slip occurred in either clamp. This proved the design was adequate; however, in order to determine the coefficient of friction, it was necessary to determine the load at which slip would occur. Therefore, the test was repeated, removing two bolts each time, until slip was achieved. Slip finally occurred at a load of 890 kNs after eight bolts had been removed (12 bolts remaining). Assuming an average bolt tension of 271kN per bolt (227 kN min., 316 kN, max.) with a total clamping force of 3,256 kN, the actual coefficient of friction coefficient was calculated to be 0.27. This meant that the actual capacity of the clamp was 1,223 kN (ultimate) vs. the required capacity of 445 kN, resulting in a safety factor of 2.75 for the design jacking load.

Figure 8 – Friction Clamp During Load Test

Upon the conclusion of the test, the clamps were opened and the rope was visually inspected by NYSDOT personnel. The load test demonstrated that the galvanized coating was in satisfactory condition – there was localized deformation of the coating due to the high bearing stress on the surface of the outer wires, but the integrity of the coating was not compromised.

FLOORBEAM STEEL REPAIRS – The original Contract Plans showed three types of steel repairs for the floorbeams: Type 1 involved replacement of the end stiffener angles and plate; Type 2 involved replacement of the vertical stiffener angles at the suspender connection; and Type 3 combined both the Type 1 and Type 2 repairs plus the replacement of an existing fill plate between the vertical stiffener angles and the web. The contract was later modified to include Type 2 repairs at all locations (adding approximately $700,000 to the cost of the contract). This was prudent given that the only time these repairs could be completed was when the suspenders were removed. An inspection of the existing stiffener angles also revealed that many were in poor condition and the outstanding legs were actually bowed outward (possible due to crevice corrosion at the top and bottom of the stiffener angles). Type 1 repairs could be performed independent of the suspender removal because no off-loading was required.

As a result, it was imperative that the jacking system design accommodate the need to perform steel repairs once the suspenders were removed. In order to accomplish this, the floorbeam would have to be lifted away from the existing suspender connection. However, the most logical location – the bottom flange – was blocked by the presence of the wind chord. Due to the detailing of the wind chord, as well as the deteriorated condition of this member, transferring the floorbeam reaction through this member was not deemed a viable option. Therefore, the decision was made to provide a temporary jacking beam that would effectively bridge over the wind chord by supporting the floorbeam at two points – at the end stiffeners and at the first interior stiffener. (see

Figure 4) A support plate connected to the hanger rods would react against the jacking beam through a simple rocker bearing to ensure equal distribution of the lifting loads to all four hangers. This system required that any Type 1 repairs be performed prior to the installation of the jacking system, as the beam utilized the end angles for support. In cases where no Type 1 repairs were required, the structural capacity of the existing riveted connection of the end angles was compared to the anticipated lifting loads. In fact, it was determined that the rivets were not sufficient and that either the rivets would need to be replaced with new high strength bolts or that additional bolts would need to be added between the existing rivets (the latter option was preferred by the Contractor).

At locations with Type 3 repairs, an additional step was required in the repair process as a result of utilizing the end angles for support of the jacking system. In order to replace the existing fill plate, it needed to be cut into two sections to allow the new end stiffener angles to remain in place while the remainder of the fill plate was removed along with the vertical stiffener angles. This cut had to be performed delicately in order to prevent damaging the existing web. The Contractor employed a core drill to make a series of adjacent holes along the cut line to remove the majority of the plate material. Then a grinder was used to remove any remaining material between the holes and to make a straight edge. A new narrow fill plate was installed along with the new end stiffener angles. Later, when the vertical stiffener angles were removed, the remainder of the fill plate was removed and replaced.

SUSPENDER REPLACEMENT AND STEEL REPAIRS AT CROWN OF ARCH (PANEL POINT 12) – The contract plans originally stipulated an extremely tight window for the contractor to remove and replace the suspender strands at Panel Point 12 (crown of arch). The work consisted not only of the replacement of the strand itself, but also involved substantial steel work – the bottom splice plates of the arch first had to be cut to re-establish the original access opening and allow the existing socket to be removed. Once the replacement of the existing suspenders and hardware was complete, the splice plates needed to be reinforced by installing new cover plates. Cutting the access hole involved removing a substantial amount of area from the existing splice plates which maintained the continuity of the arch for live loads. Therefore, the Contract Plans contained an involved procedure that restricted much of the work to take place while the two lanes adjacent to the arch could be closed – a condition that was only allowed during a 6-hour overnight window. The Contractor indicated to the DOT that it was not physically possible to perform all the required repairs in such a limited timeframe (not to mention the difficulty associated with attempting the work at night). Upon further discussion with Modjeski and Mastersn, the restrictions were modified to allow the suspenders to be removed and replaced during one - two-lane closure window and the steel repairs to be performed during a subsequent two-lane closure window. Actual cutting of the splice plates was allowed while maintaining only a single lane closure.

While these work restrictions were ostensibly designed to limit the loads on the arch to account for the reduced splice plate section, a careful review of the procedure on the contract plans showed that the restrictions would not have this effect. In fact, the procedure indicated that during certain times, lane closures were not required to be maintained at all while the access hole was opened. This fact was confirmed with the NYSDOT and the consultant responsible for the design. Their analysis indicated that the arch would effectively revert back to a two-hinged arch while the repairs were performed and would be adequate for the anticipated live loads. Once it was realized that the burdensome procedure shown on the Plans served no real purpose, it was abandoned in favor of a much simpler method of affecting the repairs.

A repair was developed that allowed all work to proceed without the need for lane closures, except for final torqueing of the bolts on one-half of the splice connection (approximately one hour's work, during which a two-lane closure would be required). The jacking system was similar in concept to the other panels on the bridge in that an independent hanger system was used to carry the floorbeam reaction while the existing strands were removed and replaced. The difference at this location was the connection at the arch due to the presence of the original pin in place of the typical transverse beam. In this case, saddle blocks were fabricated that sat on top of the pin which accepted the all-thread hanger rods and transferred the hanger reaction directly through bearing on the top surface of the pin (see Figure 9).

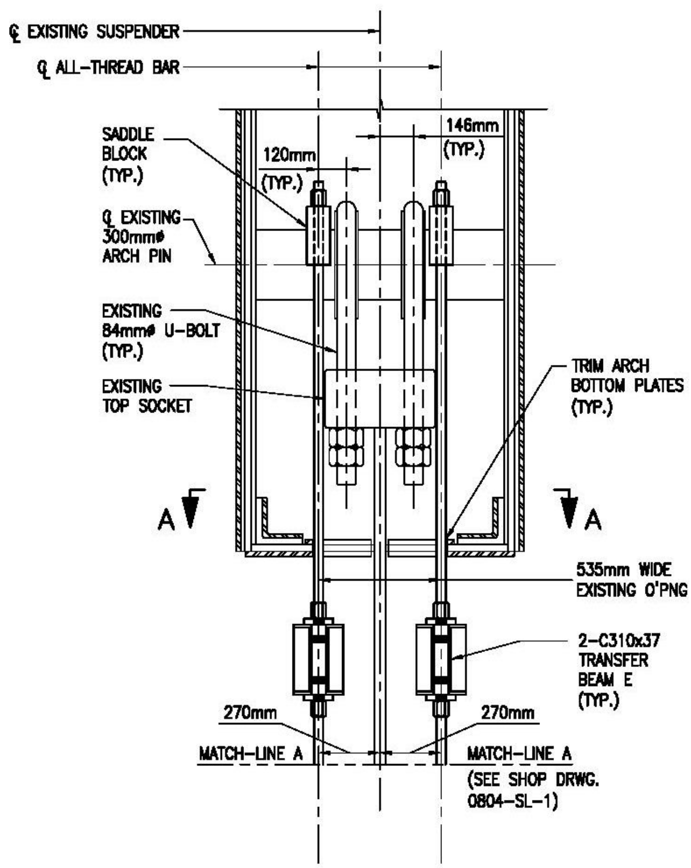

Figure 9 – Cross-Section at Crown of Arch (Panel Point 12)

The tight clearances necessitated some trimming of the edges of the access opening to provide clearance for the hanger rods. The resulting minimum clearance between the new top socket and the hanger rods in the final assembly was only 8 mm. This did not leave much room for error in the installation of the approximately 1.41 tonnes assembly (top socket with a pair of suspenders and bottom sockets). Once the new suspenders, socket and U-bolts were replaced, new cover plates were installed to close the access opening. The cover plates were installed with the bolts torqued on only one side of the splice – final torqueing of the remaining bolts was only performed under a two lane closure to minimize the live load stresses on the arch, which are transferred through the splice plates (see Figure 10).

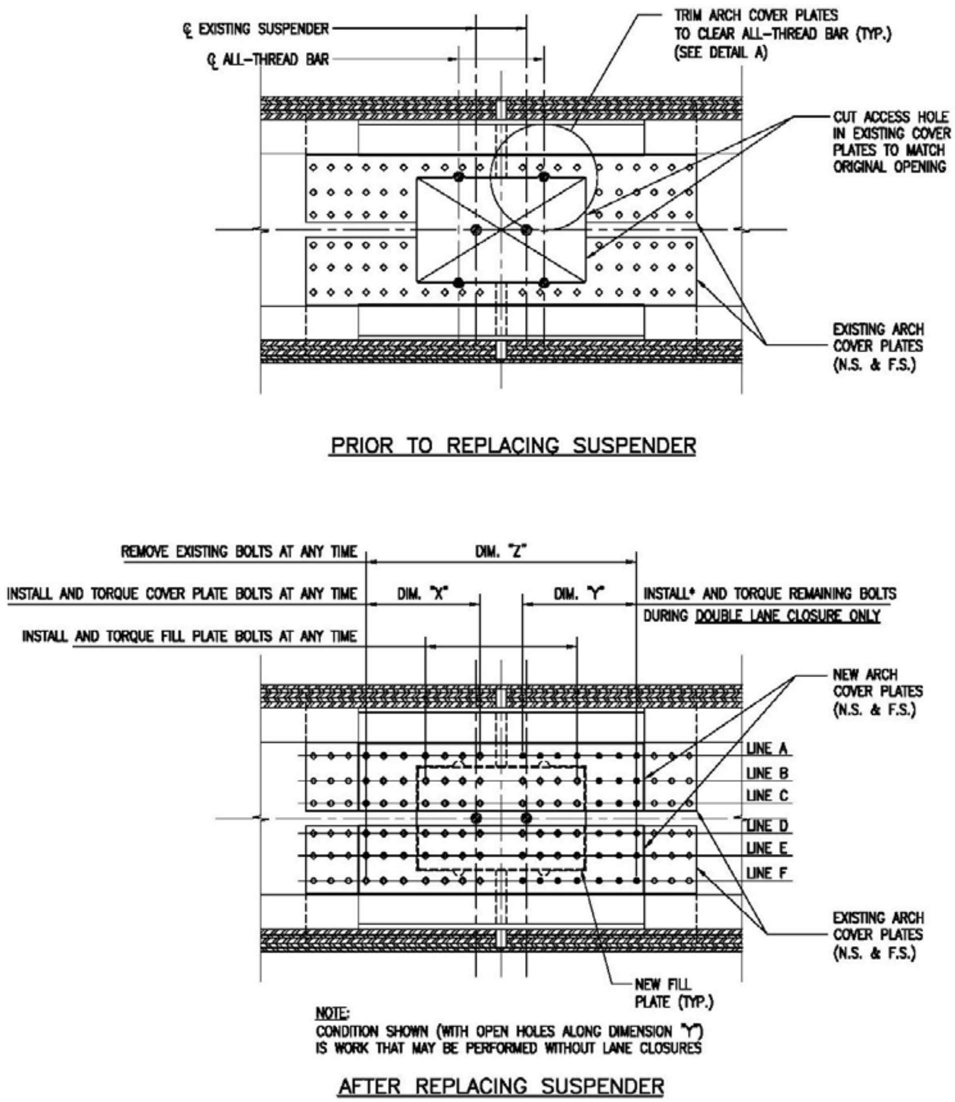

Figure 10 –Access Opening Repairs at Crown of Arch (Panel Point 12)

CONCLUSION

A modified method typically used in suspension bridges was proposed as an alternative method for the replacement of the suspenders for twin through-arch bridges which saved the owner, the NYSDOT, over $5 Million on a roughly $16 Million project. The alternative structural lifting system was not only less expensive and easier to install than the version shown on the contract plans, but also safer in that it did not impose additional loads on the existing deteriorated suspenders during the replacement process. The system also improved safety and decreased inconvenience to the traveling public by eliminating nightly closures of the individual bridges, which required crossing all traffic over to the adjacent bridge. Even though additional steel repairs have been added to the project, the contractor is on schedule to complete the replacement of all 168 suspenders of both bridges by November 2009.