HEAVY MOVABLE STRUCTURES, INC.
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Counterweight Trunnion Bearing Rehabilitation for a Strauss Heel Trunnion Bascule Bridge

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INTRODUCTION

CSX Bridge QDC 1.71 is a double track Strauss heel trunnion bascule bridge in Buffalo, NY constructed circa 1912. The length of the bascule span from the heel trunnion to the live load supports at the toe end of the span is 124 feet. The total weight of the counterweight is estimated to be 800 tons, producing a reaction at the counterweight trunnion bearings of approximately 1,400 tons total or 700 tons per bearing. The structure spans over the Buffalo River and is operated infrequently for marine traffic. Typically the span is operated mostly in the winter months to permit ice breaking operations on the Buffalo River in an effort to prevent ice jams and resultant flooding in the South Buffalo communities along the river. Openings are also required for periodic dredging operations on the river. The waterway is considered a federal navigation channel and is controlled by both the Coast Guard and the Army Corps of Engineers. Presently CSX operates a single track over the structure. QDC 1.71 is a critical link in the CSX system.

PROJECT BACKGROUND

The project team's involvement with this structure began in early July 2014. CSX contacted Stafford Bandlow Engineering, Inc. [SBE] to investigate an issue affecting operation of the bridge. The reported issue was that the north rack and pinion teeth were "skipping" which prevented the movable span from opening. While SBE personnel were able to diagnose the cause of the skipping and implement a temporary repair to resolve that issue, the limited mechanical inspection identified that the north counterweight trunnion assembly was in poor to critical condition.

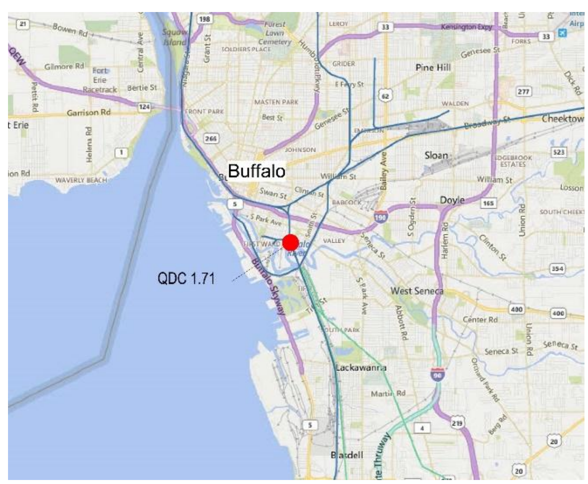

Figure 1: CSX System Map detail of Buffalo vicinity.

The counterweight trunnion bearings consist of a lower outer bushing which is made out of bronze and supported by a bearing base and a bearing cap which has a babbitt metal lining. The counterweight trunnion bearings are stationary and are supported by the tower structure. The counterweight trunnion bearings support a trunnion sleeve and pin. The trunnion sleeve and pin rotate with the counterweight truss. The trunnion sleeve has a 27 ½" outside diameter.

The trunnion sleeve is mounted between the gusset plates of the counterweight truss. The loads from the counterweight and balance link are transferred from the counterweight truss to the sleeve via a 13" diameter pin. The pin is threaded at each end and each end is provided with a 9" pin nut to secure the pin axially. In addition, (6) 1 7/8" turned studs are provided to prevent rotation of the trunnion sleeve relative to the gusset plates of the counterweight truss.

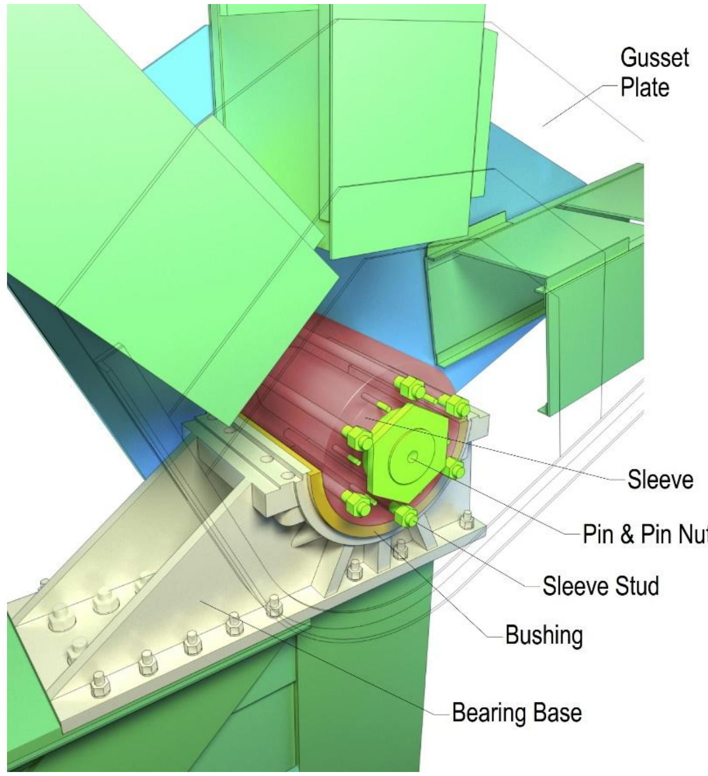

Figure 2: Rendering of Trunnion Bearing Assembly.

Figure 2 is a rendering of the trunnion bearing assembly. Figure 3 is taken from the American Bridge shop drawings dated 1912 and depicts the arrangement of the trunnion sleeve and pin.

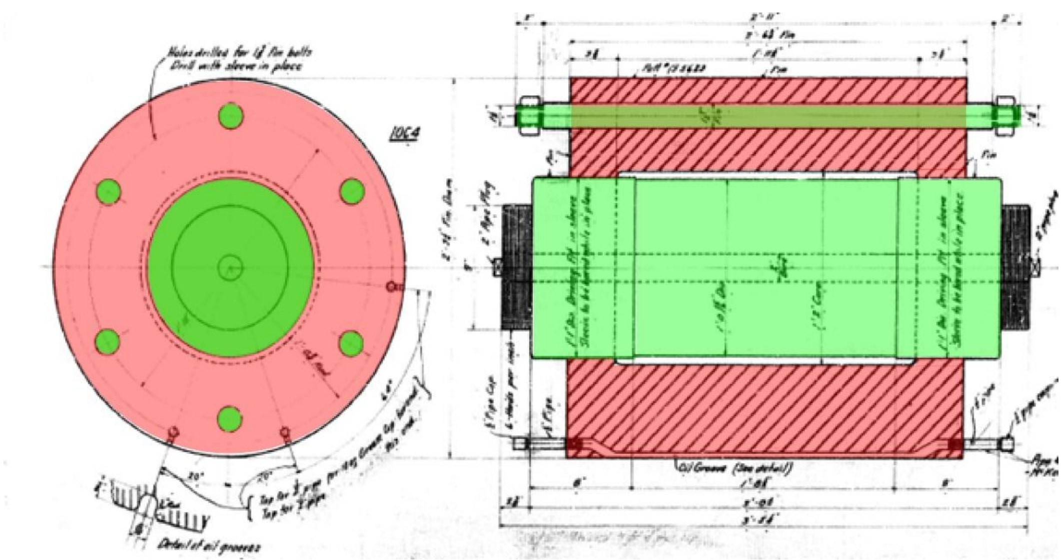

Figure 3: Original Shop Drawing

The north counterweight trunnion bearing was making loud banging noises during operation which is characteristic of stick-slip action between the trunnion sleeve and the outer bushings. This is typically a result of poor lubrication and may indicate degradation of the wearing surfaces of the trunnion. These noises prompted further investigation of the north counterweight trunnion assembly. This investigation identified the following issues:

- The north counterweight trunnion pin was missing the large nut at both ends and was restrained axially by the use of thin plates and threaded rods. The bearing pin had moved axially to the south about 1”. See Photos 4 and 5.
- The pin was intended to have a “driving fit” with the truss according to the American Bridge shop drawings dated 1912. It was clear that the movement of the pin had resulted in significant wear of the truss plates and/or pin as there were large gaps evident. See Photo 6.
- The north counterweight trunnion sleeve had sheared 5 of the 6 sleeve studs. See Photo 7. The sheared studs are an indication of high friction between the trunnion sleeve and the bearing and/or radial movement of the pin subjecting the studs to dead loads that they were not intended to carry.
- The north counterweight trunnion sleeve had rotated relative to the truss. See Photo 8. Ongoing, intermittent movement was confirmed at this location during operation. The sleeve was observed and felt to “jump” simultaneous with the banging noises. The amount of rotation observed suggests that all studs must had sheared to an extent that their integrity had been severely if not completely compromised.
- The operating loads, measured via dynamic strain gage testing, were found to be excessive. This was in part due to high system friction. Although the issues at the north counterweight trunnion assembly were not the only likely source of high friction identified as

Photo 4: North Counterweight Trunnion Bearing, Outboard. The pin nut is missing which has allowed the pin to move axially to the south.

Photo 5: North Counterweight Trunnion Bearing, Inboard. Close up of the bearing pin revealing axial movement 1” to the south.

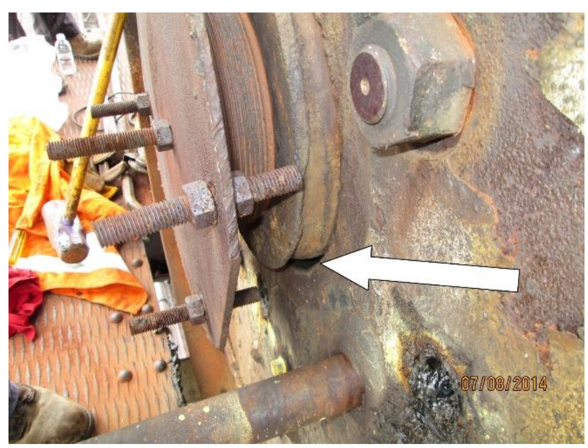

Photo 6: North Counterweight Trunnion Bearing, Inboard. View of a large gap between the pin and truss.

part of the limited investigation, they were expected to be a contributing factor.

- There are three grease grooves per trunnion sleeve: Two are symmetrically located on either side of bottom dead center and the third is just below the split line on the counterweight side of the bearing. Each groove had a lube port at each face of the sleeve that is tapped to accept a pipe through which grease can be introduced into the groove under pressure. There are six ports total. As a consequence of the sleeve rotating in the truss, the access holes in the truss no longer lined up with the lube ports at five of six locations such that a pipe could no longer be installed. The inability to properly grease the bearing was likely the root cause of the observed high friction and noise.

Photo 7: North Counterweight Trunnion Bearing. Five of six turned studs which secure the trunnion sleeve to the counterweight truss plates are sheared and are either missing (3 red circles, one not visible) or are protruding from the assembly (arrow).

Based on the evidence of high friction and concerns about damage, it was suggested that the north trunnion bearing cap be removed for inspection of the wearing surface of the trunnion sleeve. The bearing cap was removed both when the span was in the closed position and when the span was opened to about 50°. It is important to note that this only provided limited access to inspect the portion of the trunnion sleeve that is most heavily loaded.

- With the bearing cap removed and the span closed it was apparent that the sleeve had rotated to the extent that the upper grease groove was visible above the split line. As a result it was possible to verify that the piping installed at the outboard lube port was intact and that the grease being pumped in to the lube port was reaching the groove. Unfortunately, it was not possible to plug the port at the inboard end of the bearing. Although the upper grease groove introduces lubricant into the bearing it does not supply lubricant at the bottom of the bearing where loads are highest.
- The overall condition of the visible portion of the trunnion sleeve was fair with light

Photo 8: North Counterweight Trunnion Bearing, Outboard. The sleeve is visible through the stud hole. It is clear that it has rotated and there is ongoing movement.

circumferential scoring. There was light bronze embedment and corrosion where the trunnion sleeve is in contact with the lower bushing. See Photo 9.

- With the bearing cap removed it was apparent that there were gaps between the sleeve and the truss gusset plates at both ends. This indicated that the failure of the studs and the missing pin nuts had allowed the gusset plates to spread apart. At the outboard end of the sleeve, the gap was more than 0.100”. See Photo 10.
- After internal inspection of the sleeve was completed, grease was pumped into the functioning lube port during operation of the leaf. This action was effective at significantly reducing the banging noises emanating from the assembly.

There was concerned that the integrity of the north counterweight trunnion assembly had been compromised and that if no action was taken to address the conditions at the north counterweight trunnion assembly the risk of failure would increase.

CSX provided information regarding a prior trunnion repair design effort to address these concerns. The scope of this effort included replacement of both counterweight trunnion assemblies. The intent was to drive pile foundations and erect a large structure up from the foundations and over the counterweight trusses. The counterweight trusses would then be lifted up to unload the existing trunnion assemblies, allowing for their removal and replacement. CSX had bid the repair project but found it to be an uneconomical solution. In light of the ongoing deterioration, the decision to repair was revisited. SBE suggested to investigate the feasibility of performing a more limited rehabilitation which would not require construction of a temporary structure to support the counterweight in an effort to reduce cost. CSX agreed and Bergmann teamed with SBE to perform the feasibility study with SBE serving as the mechanical engineer and Bergmann serving as the structural engineer.

The feasibility study focused on two main issues:

1) Structurally was it feasible to jack the north counterweight truss using only the existing tower for support?

Photo 9: North Counterweight Trunnion Bearing, Span Open. There is light bronze embedment and corrosion where the trunnion sleeve makes contact with the lower half of the bearing.

Photo 10: North Counterweight Trunnion Bearing, Span Closed. When viewed from the counterweight side of the bearing, there are gaps between the sleeve and the truss plates. A scraper has been inserted in the gap between the outboard end of the sleeve and the truss (arrow).

2) Mechanically was it feasible to re-use the existing trunnion bearing housing, bushing and sleeve and limit the rehabilitation to replacement of the worn pin and failed studs?

A prior HMS paper *Repair of Counterweight Trunnions on Strauss Bascule Bridge* by Ulo S. Pessa identified the likely root cause of the deterioration of this type of trunnion bearing as a loose fit between trunnion pin, sleeve and truss gussets leading to radial movement and eventual degradation. This supported the conclusion for the Buffalo River bridge that an in-kind replacement was suitable provided the fits could be restored and improved from the as-built condition. The study concluded that this approach was feasible, albeit with risks that would need to be mitigated during the design phase.

CONTRACT DOCUMENT DEVELOPMENT

Throughout development of the trunnion replacement procedure, the primary design goal was to mitigate as many risks associated with unknowns as possible. This objective was revisited constantly throughout the design process as the full scope of the trunnion replacement work was developed.

The initial schedule of the project was to prepare the contract documents as rapidly as possible through the summer of 2016 in preparation for construction in the fall and substantial completion by late December 2016. The Plans were prepared in five weeks and provided details for the following scope of work:

1) Install jacking system
2) Structural lifting
3) Replace pin, Inspect sleeve
4) Contingency repairs to sleeve
5) De-jack and remove jacking system

Coordination with the Coast Guard and Army Corps of Engineers was done in parallel with the development of the plans. These discussions identified the criticality of operating the span for icebreaking operations over the winter. This raised a significant concern with regards to the project specified inspection and reuse of the existing trunnion sleeve and bushing as part of the “base scope”. If an unknown condition prevented reuse of the sleeve and/or bushing, the intent was to proceed to replacement as a contingency repair. If this were to occur, construction would be halted while new sleeve and/or bushing material was procured and fabricated thereby likely extending the project schedule into the spring. This scenario would leave the bridge structure inoperable for an extended period of time and potentially restrict ice breaking operations on the Buffalo River.

Additionally, questions regarding the magnitude of the trunnion rotations due to train load movements and thermal changes were raised by Contractors during the bid process.

After discussion and careful consideration of the risks involved, CSX decided to cancel the initial project in late July 2016 with two objectives in mind: First, include the replacement of the trunnion sleeve and bushing, further minimizing the risk of scope changes resulting in delays and second, shift the construction schedule from the fall to mid-summer to mitigate the impact of any delays on ice breaking operations.

Photo 11: Instrumentation installed on the counterweight trunnion bearing

With the additional time afforded by the change in schedule, a decision was made to perform an analysis of the movement of the structure under live loading and over time due to thermal loads. To best capture the magnitude of trunnion bearing rotations, the towers and counterweight trusses were instrumented. SBE installed linear variable differential transformers (LVDT) and accelerometers at multiple locations at both the east and west trunnion bearings. Acceleration and angular rotation data was obtained for five different (normal daily) train configurations ranging in size, length and speed. Tiltmeters were also installed and 3 weeks of tilt data was collected over a wide range of ambient temperatures. After post-processing the data, it was concluded that the trunnion rotations and the corresponding movements at the temporary support locations were small enough to be accommodated by the sliding interface originally detailed in the temporary support system.

The contract documents were revised through the fall of 2016 to include the bushing and sleeve replacement work as well as some minor modifications to the existing truss to facilitate removal and reinstallation of the trunnion sleeve. The revised bid package was reissued and three general contractors submitted bids in December 2016. Hohl Industrial was identified as the successful bidder.

TRUNNION REPLACEMENT PROCEDURE

Consideration of railroad operations became a critical component of the project workflow and schedule. The final contract documents required two rail outages to remove and replace the trunnion pin, sleeve and bushing and associated hardware. Hohl Industrial submitted a construction schedule showing 40 hours for the first outage and an additional 42 hours for the second. After further consideration by CSX, the project team and Hohl Industrial were asked to reevaluate and fit the replacement procedure to 24-hour work windows which would be scheduled by CSX to minimize disruption to rail service. The bridge was to remain open to rail traffic at all other times. Through close collaboration with Hohl Industrial, the procedure was revised to fit into three Sunday 24-hour work windows. Work window 1 was the removal of the existing pin, sleeve and bushing. Work window 2 included the installation of the proposed bushing and sleeve and finally work window 3 was the installation of the proposed pin.

TEMPORARY JACKING SYSTEM

Typically the temporary support details are left to the contractor to design as a function of their preferred means and methods. In this case however, it was decided early in the design process that a fully detailed temporary support and jacking procedure would be provided in the contract documents due to the sensitivity of the jacking operations and the associated complex structural behavior. Small deviations and modifications to the details by the Contractor would be considered but wholesale changes to the scheme would not be allowed.

The goal of the temporary support system design was to develop a scheme which did not impede upon the rail traffic envelope immediately below the 800 ton counterweight and counterweight trunnion. As discussed earlier, other externally supported systems straddling the counterweight and supported on temporary foundations had been investigated and found to be very costly. Rather, the design team focused on using the existing components of the counterweight tower truss structure to support the reaction from the counterweight. This would be achieved by providing an alternative load path from the counterweight truss to the tower truss excluding the trunnion bearing and pin. The temporary hardware, described in detail below, would be located entirely above the train operating envelope and therefore would accommodate train movements while installed.

Record drawings and balance sheets for the existing 1912 structure and counterweight were made available by CSX which aided in determining the magnitude of the theoretical trunnion reaction. However, significant changes to the leaf span (i.e. removal of one of two tracks) and prior counterweight

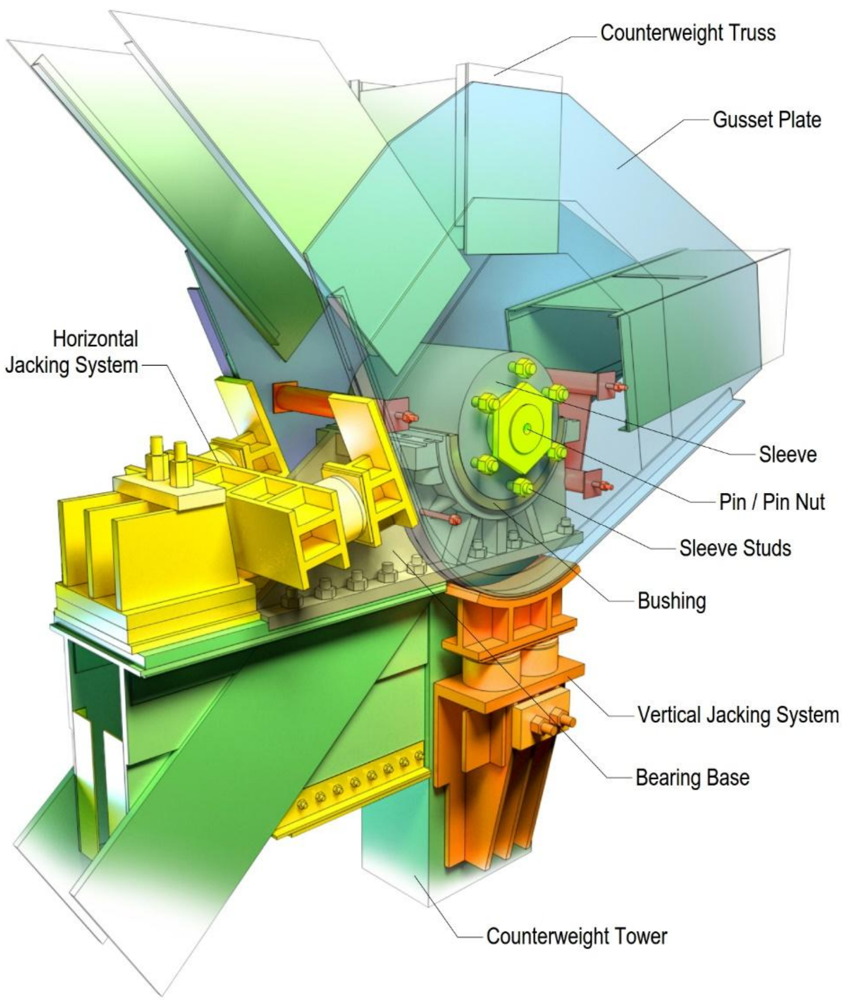

Figure 12: Rendering of Temporary Jacking System

shotcrete rehabilitation left some uncertainty as to what jacking force the trunnion would actually be unloaded at. A sensitivity analysis was completed introducing a number of variables (span weight, counterweight, center of gravity locations, etc.) and it was ultimately decided that a 40% increase in the theoretical reaction would be used for designing the temporary components. This increase would provide sufficient factor of safety against a variety of variables and unknowns.

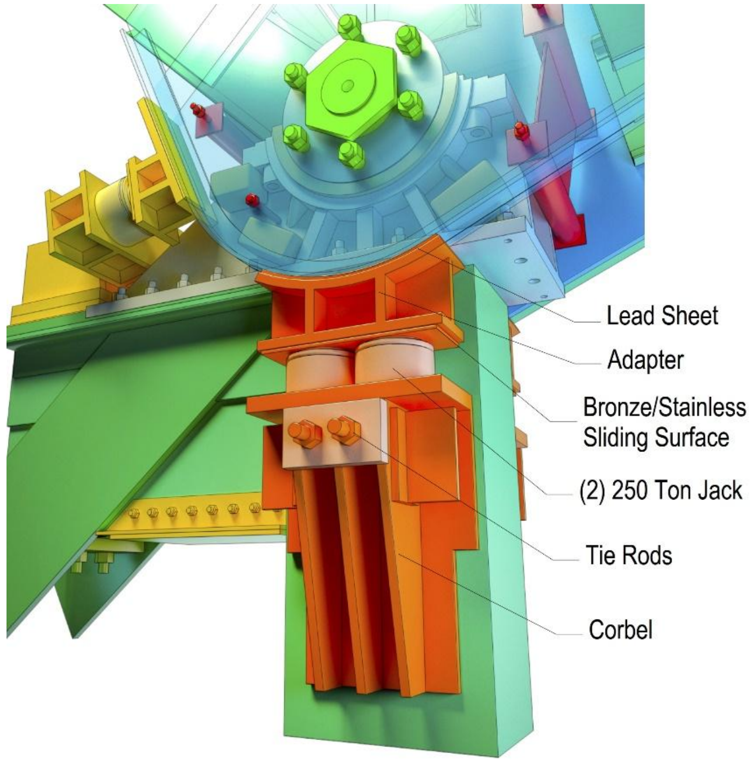

Figure 13: Rendering of Vertical Jacking System

The temporary system consisted of a vertical and horizontal support system anchored to the existing counterweight tower truss below and bearing directly on the free edges of the existing gusset plates straddling the trunnion bearing. A combined vertical and horizontal system was required to create an inclined jacking force resultant exactly matching the trunnion bearing resultant from above. The inclination of the resultant force was calculated to be approximately 20 degrees from vertical. The permanent load path for the reaction through the bearing pin, sleeve and bushing would be redirected through the temporary hardware and into the tower structure. The major difference in terms of the gusset plate behavior is the free or unsupported length nearly doubles when measured from the end of the counterweight truss members.

The vertical system is comprised of jacking corbels mounted externally to each face of the tower truss vertical column member. The corbel was connected to the tower column using A490 bolts that were exchanged one at a time with the existing rivets. Each corbel supports two 250 ton hydraulic locking collar jack cylinders pushing against a jacking adapter fabricated to match the gusset plate radius above. Stainless steel-to-bronze sliding surfaces were installed at the bearing interface between the hydraulic jacks and the adapter to accommodate the trunnion movements. A ½" thick lead sheet was installed between the jacking adapter and the gusset plate to help create a uniform bearing surface. The line of force from the gusset plates through the vertical jacking system into the corbel was eccentric to the existing truss column creating a moment attempting to "peal" the corbels away from each side of the column. To counteract this behavior, two 1 3/4" diameter high strength tie rods were installed at the top of the corbels to resist the tension forces and multiple pipe struts were installed in the existing built-up column at the bottom of the corbels to pass the compressive forces. The tie rods were prestressed prior to jacking to ensure proper engagement.

The horizontal jacking system included a grillage base and jacking beam designed to be installed at the top of the counterweight tower truss and connected directly to the (ten) 1 3/4" diameter bolts anchoring the trunnion bearing base. New A354 Gr. BD high strength bolts were exchanged one at a time with the existing bolts during installation of the grillage. Similar to the vertical system, two 250 ton hydraulic locking collar jacks were installed in-line with a stainless-to-bronze sliding surface, a jacking adapter and a lead bearing plate fit to bear against the free edge of the gussets. The line of force of the horizontal system was also eccentric to the counterweight tower truss, therefore a vertical tie rod system was installed and prestressed to anchor the jacking grillage to the tower. Supplemental stiffeners were installed on the free edges of the tower truss gusset plates to ensure stability while the load was supported on the alternative load path. The approximate weight of steel required for the temporary support system was only 9,000 lbs. equating to a super-efficient temporary steel-to-supported weight ratio of 1%.

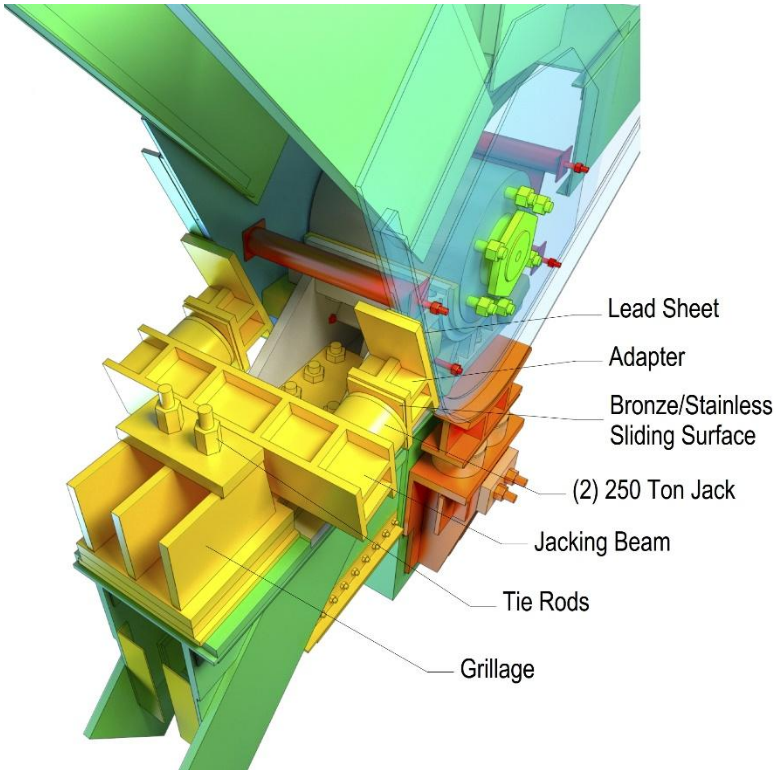

Figure 14: Rendering of Horizontal Jacking System

The contract documents required the independent vertical and horizontal jacking system to be operated simultaneously throughout the jacking procedure. Conventional hydraulic components including a high pressure manifold, shutoff valves and pressures gauges were installed in each system and mechanical locking collars were continuously engaged on each jack to safeguard against the loss of a hydraulic line. A 1.2 vertical-to-horizontal pressure ratio (2.4 force ratio) was specified to match the theoretical resultant force through the trunnion bearing. During the design process, it was decided not to require a computer synchronized jacking system due to the unknown of the actual jacking force and resultant direction. A conventional hydraulic system was thought to provide adequate accuracy and control while allowing some flexibility during field operations. During the actual field jacking operations, the sleeve, bearing and gusset plate alignment was monitored and minor adjustments were made to the jacking ratio to best match the actual trunnion bearing resultant. The structure lifted at approximately 20% over the theoretical jacking force and the vertical-to-horizontal ratio was reduced slightly to successfully lift the sleeve from the trunnion bearing base.

Once supported on the jacking hardware with the load bearing through the free edges of the gusset plates, the procedure focused on keeping the slender gusset plates stable while allowing the trunnion bearing pin and sleeve to be removed. In the permanent configuration, the gussets are connected to the sleeve via (six) turned studs effectively bracing the two gussets to each other. Prior to jacking, a variety of temporary braces were installed in close proximity to the sleeve to create alternative brace points between

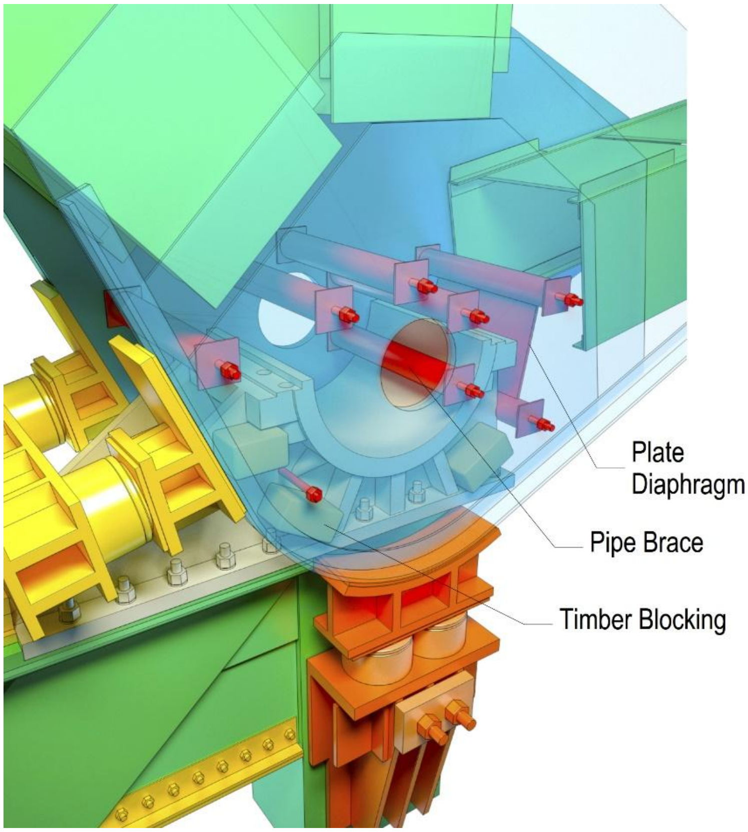

Figure 15: Rendering of Gusset Plate Bracing System

the gusset plates. Bracing types included pipe braces, a plate diaphragm, and timber blocking between the inner face of the gusset and outer face of the trunnion bearing base. Finite element modeling [FEM] of the gusset plates, accounting for initial out-of-plumbness and construction tolerances, was completed during design to ensure the factory of safety against buckling in the temporary configuration was adequate. Anticipating secondary jacking would be required in the field to spread the gussets for sleeve removal clearance, transverse jacking force limits were also determined at various locations along the gusset plates. Linear buckling and non-linear p-delta analysis were each run to confirm the resulting factor of safety. Furthermore, during the sleeve removal operations additional pipe sleeves were installed at the sleeve stud locations to further enhance the gusset plate resistance to buckling.

Given the fracture critical nature of the jacking operations and that the failure of any one component of the temporary jacking system would have significant implications on the bridge structure and the passage of train traffic, the design team strived to add levels of redundancy to the replacement procedure wherever possible. At least one of five available configurations of either existing, temporary or proposed pin or sleeve studs were required at all times to prevent splaying of the gussets. Additionally, a temporary trunnion pin undersized to easily fit through the gusset plate bore was installed at the end of each work window before the structure was reopened to train traffic. At the conclusion of work window 1 after the existing pin, sleeve and bushing were removed, an engineered plastic “quarter-sleeve” blocking system was installed in the bearing base leaving only an ⅛” gap between the temporary pin and the blocking. This provided an alternative load path should a relatively small deformation occur due to a jacking system malfunction. Similarly, the same temporary pin was reinstalled at the conclusion of work window 2 through the rough cut center bore of the newly installed sleeve again providing an alternative load path if needed.

In addition to the added structural redundancy, CSX permitted a slow order for all trains for the full duration while the counterweight was supported on the temporary system. Also, following the jacking operations a 48 hours and 5 train minimum waiting period was mandated to observe the overall behavior of the temporary support system under gravity, train and thermal loads prior to removing the existing pin.

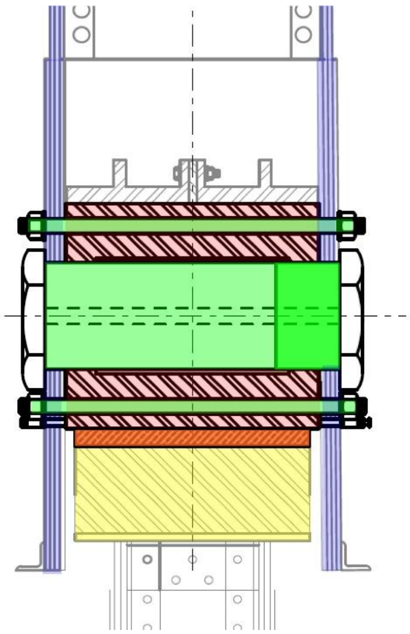

Figure 16: Section through trunnion assembly showing stepped pin.

MECHANICAL DESIGN

The mechanical scope included in-kind replacement of the existing sleeve and bushing. After installation and alignment of the sleeve, the new sleeve and existing truss gusset plates were line-bored to clean up to a uniform diameter and a larger pin was furnished to provide a driving fit with the bore. Rather than increase the size of the original turned studs, standard studs were used to clamp the assembly together and new dowel pins were installed between the studs to restrain the sleeve rotationally. New pin nuts were installed to restrain the pin axially in the bore.

Additional details for the individual components are as follows:

The original pin body was 36” long with a 13” diameter. The design called for a “driving fit” (i.e. an interference fit) with truss gussets and a short length of the cast steel sleeve adjacent to the truss. The center 20” long section of the sleeve was enlarged so there was clearance with the pin so that the length of the driving fit was 8” at each end. A critical objective of the project was to re-establish the driving fit to ensure that there would be no movement of the sleeve relative to the pin and truss as the dead load of the truss changed direction. There were several challenges to achieving this objective including the fact that the pin would be installed horizontally and that it would be difficult to heat the truss and sleeve to obtain the necessary clearance to install the pin. The final details of the pin and bore included a stepped diameter with the inboard end 1/16” larger than the outboard end. This would allow for insertion of the pin from the inboard side of the truss with only the final 8” of insertion engaging the fit. An ANSI FN1 fit was selected to ensure that sufficient clearance for installation could be achieved solely from cooling/shrinking the pin and therefore heating of the sleeve and truss would not be required. See Figure 16 for a section illustrating the stepped pin.

Another design consideration pertained to the length of the sleeve. It had been observed that the truss gussets had spread apart resulting in gaps at the ends of the existing sleeve. It had also been verified that the inboard gusset was no longer plumb and a variable gap was therefore expected at this end of the sleeve. The design team agreed that it would be very risky to attempt to displace the truss gussets and draw them tight to the end of the sleeve while the truss was supported on jacks. Rather, the

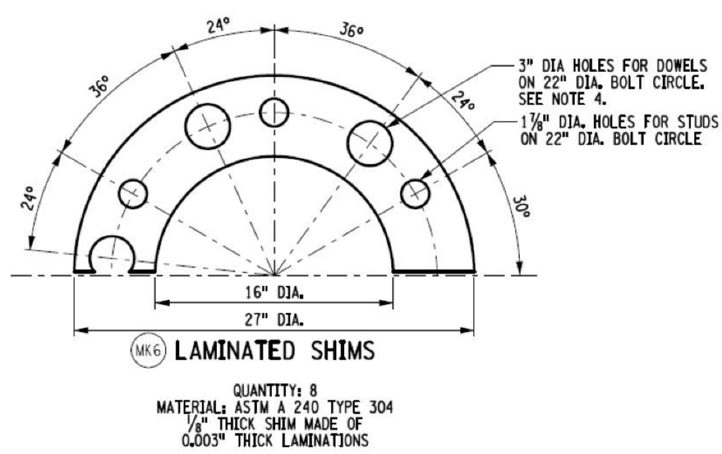

Figure 17: Laminated Shim Detail

design incorporated split laminated shims which would be installed between the sleeve and gussets to fill this gap. This would allow the studs to be tensioned, drawing the gussets tight to the sleeve, while minimizing the displacement of the gussets. During construction, the Contractor requested to reduce the length of the sleeve to facilitate installation and make up this length by increasing the thickness of the shims. This was done to great advantage as the removal of the existing sleeve was very difficult and time consuming as it travelled along its' path between the gussets and the installation of the new sleeve was relatively quick and unobstructed. See Figure 17 for the laminated shim detail.

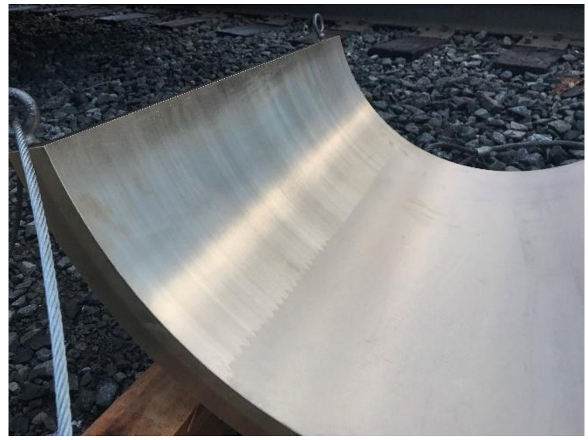

Photo 18: Close up view of the relief added to the counterweight side of the trunnion bearing bushing.

Given the fact that there were only short work windows available and that there was a small amount of movement between the truss and the tower/bearing housing, it was necessary to provide for clearance between the sleeve and bushing for the time period when the sleeve and truss were line bored and the pin installed. It was straightforward to provide for clearance at the bottom of the sleeve; the truss could simply be jacked vertically a bit further and the sleeve held in position with a small amount of clearance at bottom dead center. The issue was that due to the 27 1/2" outside diameter of the sleeve, it would be necessary to raise the sleeve substantially to produce clearance with the bushing at the sides of the sleeve. Since the load on the sleeve was not vertically down but rather 20 degrees from vertical towards the channel, a slight relief was added on the counterweight side of the bushing, the majority of which would be out of the load zone. This relief provided 0.035" clearance between the sleeve and bushing at the sides of the sleeve and concurrently 0.062" clearance between the sleeve and bushing at the bottom. See Photo 18.

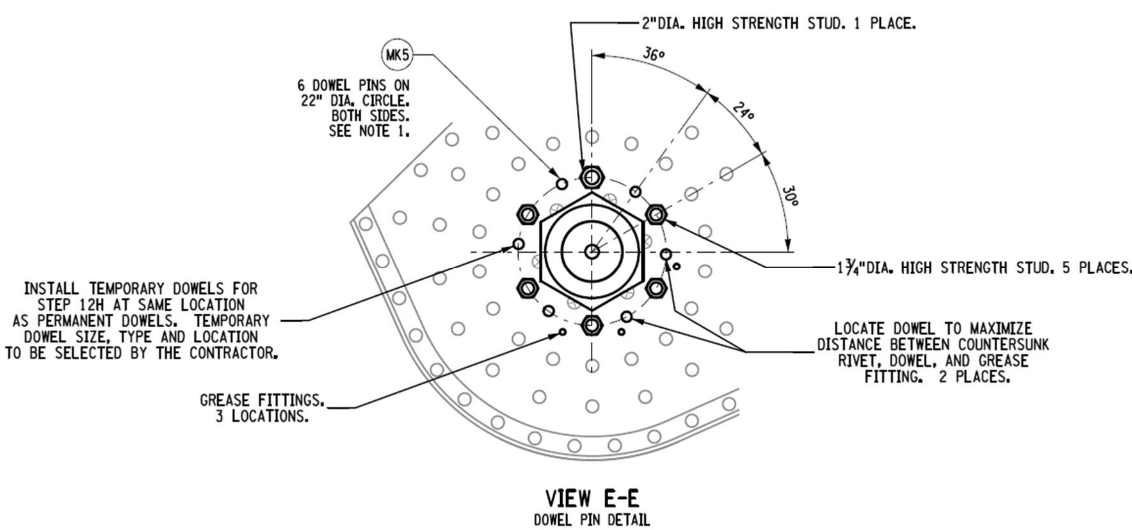

Figure 19: Dowel Pin Details

The original design provided for six turned studs with 1 3/4” diameter threads and 1 7/8” diameter body which provided a tight fit over 36” of length. There were several concerns with attempting to restore the tight body fit with the studs including the fact that it would be challenging to align all six holes in the sleeve with the existing holes in the truss and re-drill the holes without increasing the diameter substantially. The size and length of the holes also presented a challenge in terms of the time that would be needed to achieve a satisfactory hole size and finish. Instead, the design used standard 1 3/4” diameter studs with 1/8” clearance to the existing holes made from ASTM A913 Grade B7 rods. The studs would be tensioned to hold the truss gussets tight against the ends of the sleeve and six separate 1 1/2” dowel pins would be used to restrain the sleeve from rotation. The 6” long studs were specified to be installed with an ANSI FN1 fit with the truss and sleeve.

In addition to developing details for the new components, the mechanical design plans depicted a detailed sequence of work, illustrating what tasks could be completed under live load of train traffic and which items required a work window. There were two reasons for stipulating that work occur during a work window:

1) The work required temporary removal of components or bracing for the truss gussets and it was desirable to avoid live loading of the structure for that condition. This included the period where the existing sleeve and bushing were removed and when the new sleeve and bushing were installed.
2) During installation of the permanent pin which had an interference fit. Once the pin was removed from the cooling media there would be a critical working period to get the pin installed.

CONSTRUCTION

The construction contract was awarded to Hohl Industrial Services Inc. The effective date for starting work was February 17, 2017. The letter of permission allowed a marine closure of the navigation channel from May 29 through September 30, 2017. Hohl officially took the bridge out of marine service on June 20, 2017.

Structural Lifting

Once the marine outage was initiated, the vertical and horizontal jacking hardware was affixed to the existing counterweight tower structure. Hydraulic cylinders were installed and the vertical and horizontal hydraulic systems were pressurized simultaneously to create a combined jacking force equally opposing the trunnion bearing reaction in both magnitude and direction. All jacking operations were performed between train movements across the structure. See Photos 20 and 21.

Photo 20: Vertical jacking system installed.

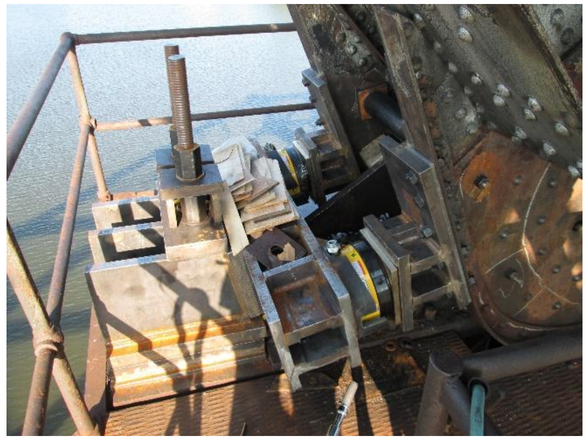

Photo 21: Horizontal jacking system installed.

24-Hour Work Window 1

With the trunnion assembly unloaded, the existing studs, pin, sleeve and bushing were removed. The existing bearing housing was cleaned and measured using a portable coordinate measuring machine (CMM). The engineered plastic "quarter-sleeve" blocking system was installed and the temporary pin was inserted and secured in position. All tasks were completed within the available work window. See Photos 22 through 28.

In the interim period between work windows 1 and 2, finish machine work was completed for the new bushing outside diameter and the new sleeve with the exception that finish stock was provided for the inside diameter. See Photos 29 and 30.

24-Hour Work Window 2

The temporary pin and blocking were removed, the new bushing was installed and seated in the bearing housing, and the new sleeve was installed and aligned in the bushing with gaps all around to allow for slight relative movement of the counterweight truss relative to the bearing housing. Shims were installed to fill the gaps between the end of the sleeve and the gussets of the counterweight truss. Temporary studs were installed and tensioned to secure the sleeve in position. All tasks were completed within the available work window. See Photos 31 through 33.

Photo 22: Close-up view of the existing counterweight trunnion pin where it interfaces with the counterweight truss during removal.

Photo 23: View inside the counterweight truss as the existing sleeve was lifted out of position. Temporary bracing installed as the sleeve moves along the removal path.

Photo 24: Close-up view of the wear/damage/corrosion on the inboard truss gusset plate where it bears on the pin.

Photo 25: View inside the counterweight truss with the bushing removed and the existing bearing housing cleaned for inspection and measurement.

Photo 26: View inside the counterweight truss with the engineered plastic “quarter-sleeve” blocking system installed prior to installing the temporary pin.

Photo 27: View inside the counterweight truss with the engineered plastic “quarter-sleeve” blocking system installed and the temporary pin in place.

Photo 28: Temporary pin secured, work window 1 complete.

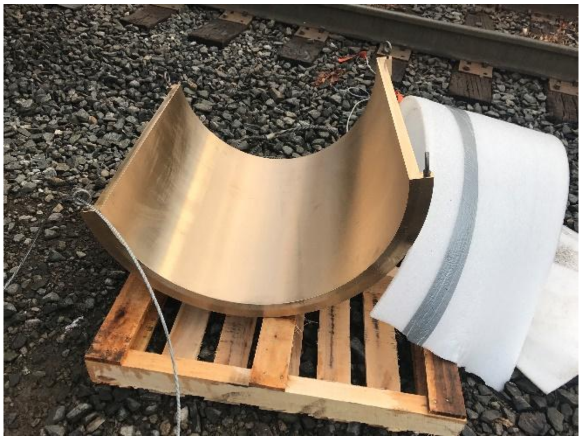

Photo 29: The new bushing finish machined and ready for installation.

Photo 30: The new sleeve finish machined except for the inside diameter and ready for installation.

Photo 31: The new bushing after installation in the existing bearing housing.

Photo 32: The new sleeve hung in place inside the counterweight truss, aligned to the bushing.

Photo 33: Temporary studs installed and tensioned to secure the new sleeve.

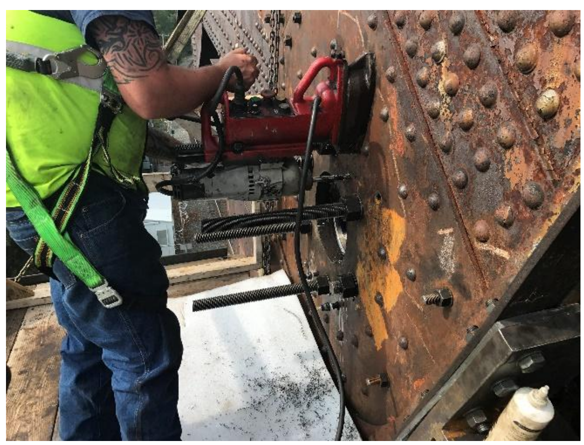

Photo 34: Drilling holes for alignment dowels.

Photo 35: Line boring equipment installed and boring underway.

Photo 36: Close up view of truss and sleeve after line boring.

In the interim period between work windows 2 and 3, small dowels were installed to lock the sleeve in position relative to the truss and the bore in the sleeve and truss was line bored to clean up. After line boring was complete, the finished inside diameter was documented and transmitted to the shop for finish machining of the permanent pin. The temporary pin was also installed for additional redundancy for the interim period after the line boring was complete and prior to work window 3. During this period, Hohl Industrial conducted numerous "practice runs" of the pin installation sequence to ensure the procedure could be completed in less than the anticipated 5-minute window in which the pin would be warming/expanding. See Photos 34 through 36.

24-Hour Work Window 3

The temporary pin was removed, the new pin was cooled, initially by dry ice and then in liquid nitrogen for installation into the bore. The elapsed time from removing the pin from the liquid nitrogen bath to installation through the sleeve was less than 3 minutes. Once the pin was installed and the temperatures normalized, pin nuts were secured. The temporary studs were removed one at a time and the permanent studs were installed and tensioned. All tasks were completed within the available 24-hour work window. See Photos 37 through 39.

Subsequent to work window 3, the structure was de-jacked to re-load the pin and bearing. Once this was complete, six dowel pin holes were drilled into the truss gusset plates and sleeve.

Photo 37: The permanent pin has been removed from the dry ice and transitioned to the liquid nitrogen for further cooling.

Photo 38: Permanent pin partially installed from inboard side of truss.

Photo 39: View of permanent pin from outboard side after it was fully inserted, prior to installation of the pin nut.

Operational Testing

All of the jacking components were removed and preparations were made for operating the span. A successful test opening was performed on September 13, 2017. Operating loads in the span drive machinery were monitored real time using dynamic strain gage measurements. A strip chart of the raw strain gage data and graphical results from the balance analysis is shown in Figures 40 and 41.

Span balance and system friction was derived from the strain gage data. The results showed that average friction decreased by 14% for the movable span compared to the testing results from 2014. The only known change to the bridge since the 2014 test is the counterweight trunnion bearing rehabilitation which indicates that the new bearing has less friction than the existing bearing it replaced. In addition to the reduction in friction there were no noises or vibration emanating from the counterweight trunnion assembly as there had been in the past.

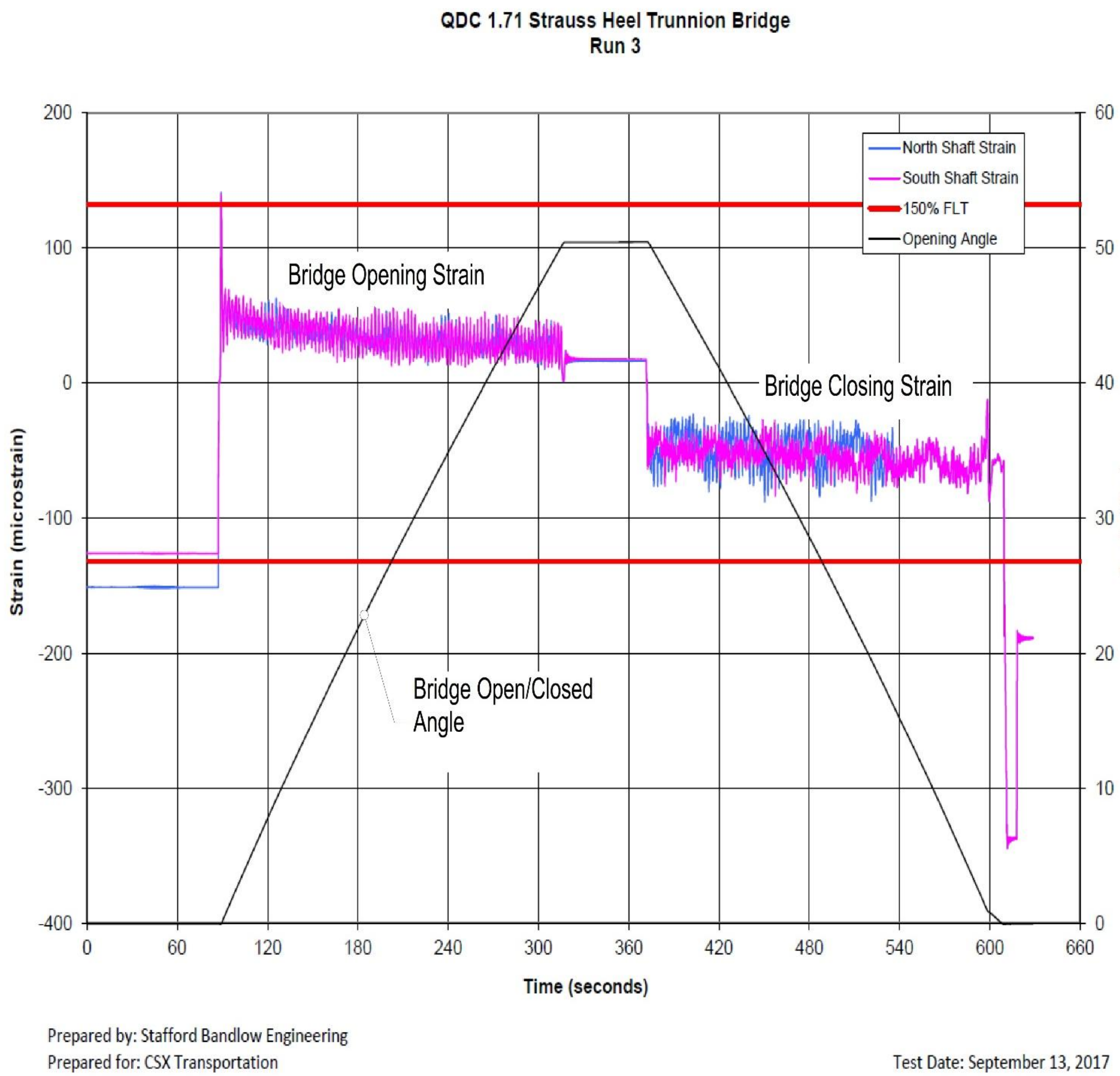

Figure 40: Strip chart of raw strain gage data and leaf opening angle vs. time.

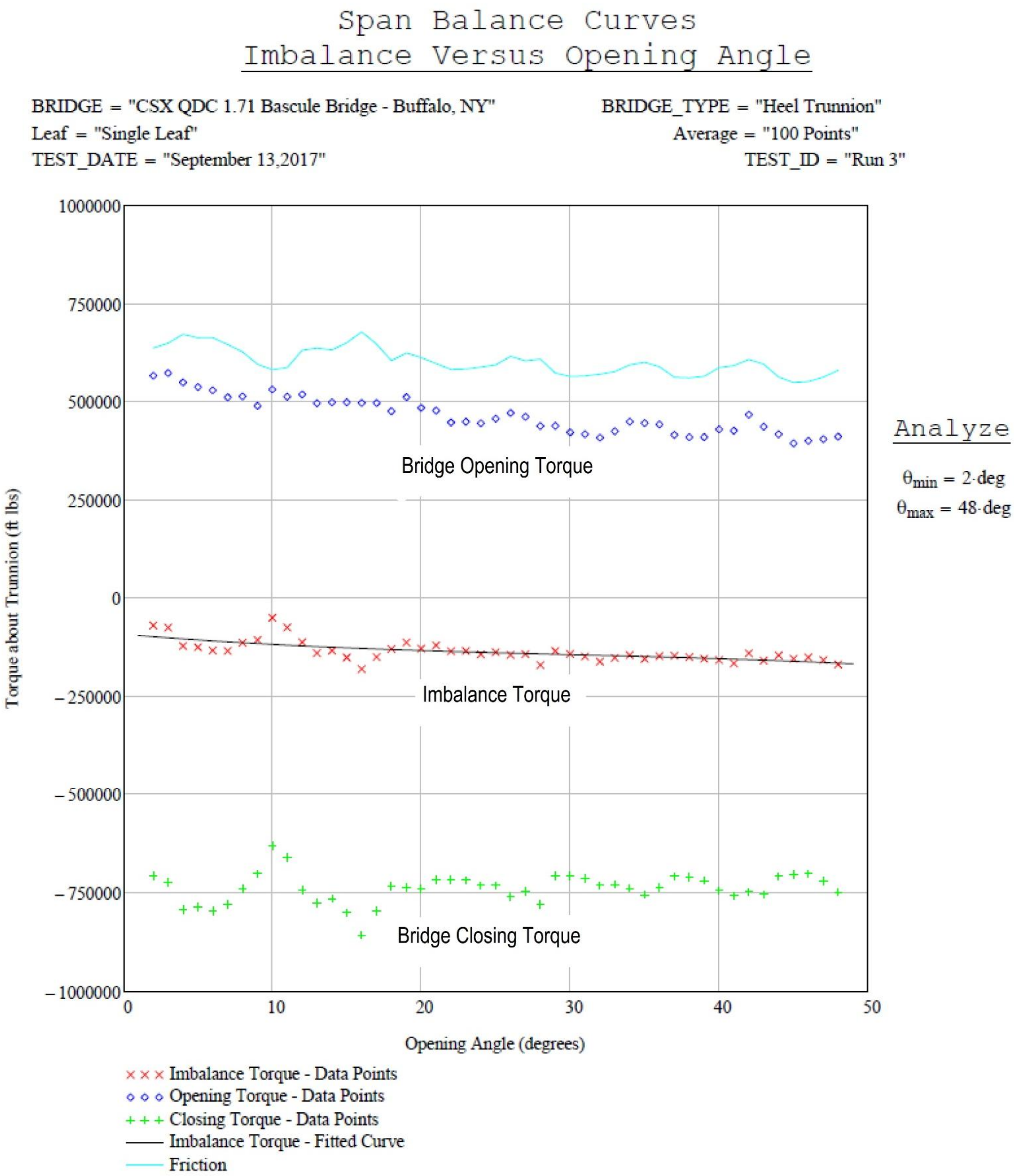

Figure 41: Graphical results from the balance analysis of the strain gage data.

SUMMARY

The counterweight trunnion bearing rehabilitation procedure for CSX's 1912 Strauss Bascule Bridge proved to be a complex and challenging project from both an engineering and construction perspective. Collectively Stafford Bandlow, Bergmann, CSX and Hohl Industrial collaborated to develop a highly constructible and cost effective solution that imposed minimal impacts to the rail traffic.

Bridge operation for marine traffic was restored on September 18, 2017 ending the duration of the marine outage at 13 weeks. Operation was restored within the permitted marine closure period. The bridge was closed to rail traffic for only three 24-hour work windows and supported on the temporary system for a total of 4 weeks. While each moveable bridge project is unique, our hope is that the details presented that attributed to the success of this unique repair project can be used on similar rehabilitation projects and for other owners, engineers and contractors to learn from.

Photo 42: View of completed repair from inboard side of the counterweight truss.