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Emergency Strauss Bascule Link Pin Repair - Seabrook Bascule Bridge

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Introduction

The Port of New Orleans (PONO) Seabrook Bridge is a Strauss Trunnion Bascule Bridge built circa 1919, and spans the Inner Harbor Navigation Canal in New Orleans, Louisiana. The bascule span is approximately 117’-0" long spanning an approximate 100’ clear channel which is open to marine traffic. For the purposes of this paper, directional coordinates are taken as lakeside (north), riverside (south), east and west. To the lakeside of the bridge is the Leon C. Simon Drive double leaf highway bascule span, and to the riverside is the U.S. Army Corp of Engineers surge gate. The bridge was originally constructed with two lanes of freight rail traffic, and two cantilevered roadways bracketed to the outboard side of both the lakeside and riverside trusses. The two cantilevered roadways had not been in service since the construction of the separate, adjacent highway bridge and were removed in 2013.

Late 2016, a project to replace and rehabilitate the bascule and tower span floor system and bottom chords was undertaken. Following the start of the floor system and bottom chords rehabilitation project, PONO personnel reported an unusual noise exhibited throughout the full operational range of the bridge. Additionally, retainer bolt failures and lubrication refusal was reported at the lakeside 2nd Link Pin Joint. In December 2016, PONO engaged Modjeski and Masters to investigate the trunnions and link pins with a special focus on the 2nd Link Pin Joint.

The lakeside 2nd Link Pin Joint was found to be in a state of partial failure. This resulted in the recommendation for immediate cessation of span operation and the need for an emergency repair. This paper presents the joint failure inspection findings, the repair design features, and construction challenges and solutions.

Overview of the Strauss Trunnion and Pin Details

The Strauss Trunnion Bascule utilizes four pin connected members arranged in a parallelogram (see Figure 1). The main trunnion, counterweight trunnion, 1st Link Pin, and 2nd Link Pin form the joints of the parallelogram. During bridge operations, the bascule span rotates about the main trunnion and the counterweight truss pivots about the counterweight trunnion. Balancing forces are transferred from the counterweight truss to the bascule leaf through the counterweight link. The 1st and 2nd Link Pins connect the counterweight link to the counterweight truss and bascule leaf, respectively. During operation, the parallelogram folds and elongates to raise the bridge. The span drive machinery powers the bridge movement through the operating strut. Main pinions engage rack teeth mounted to the bottom of the operating strut.

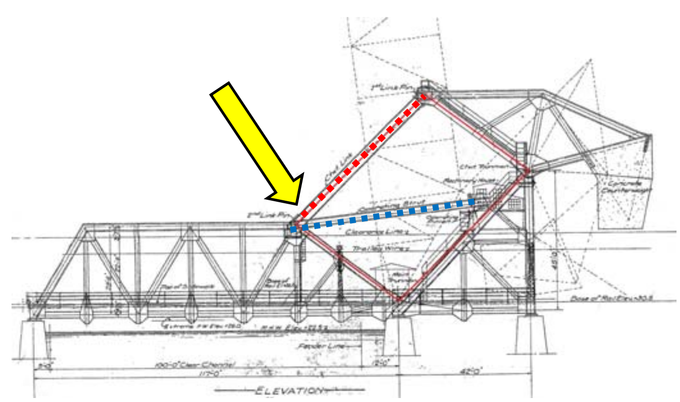


Figure 1 - Strauss Bascule Elevation. Note 2nd Link Pin (arrow), parallelogram (red lines), counterweight link centerline (red dashed line), operating strut centerline (blue dashed line)

The counterweight link forces in the original 2nd Link Pin assembly are resisted by a steel pin, steel sleeve, bronze bushing, and steel bearing housing (see Figure 2). The bascule truss gusset plates support the pin. Six retainer turned bolts secure the sleeve to the truss gusset plates to prevent rotation. The sleeve to bronze bushing interface provide the bearing surface for all relative movement between the

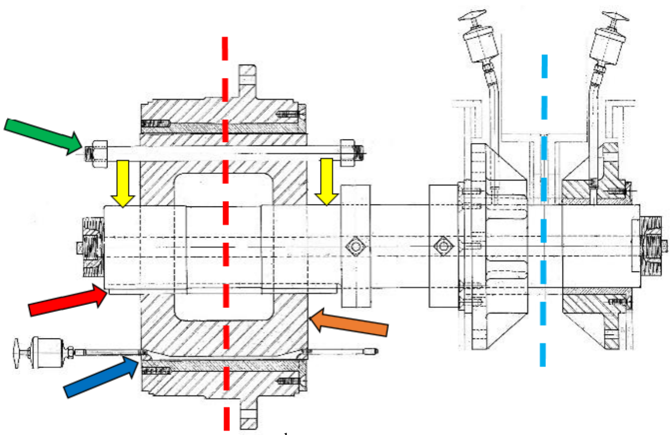


Figure 2 - Seabrook 2nd Link assembly cross section comprised of the counterweight link (red dashed line), main sleeve (orange arrow), bronze bushing (blue arrow) supported by the main pin and the span gusset plates (not shown at the yellow arrows), and the operating strut connection (blue dashed line). Note the grease grooves in the sleeves (blue arrow), the retainer bolts to resist main sleeve rotation (green arrow), and the pin key to restrict pin rotation (red arrow).

counterweight link and the bascule leaf. Grease lubrication of this surface is piped through passages in the gusset plates to grease grooves within the sleeve. These pipes serve as the only method to apply lubrication to the internal sliding surfaces.

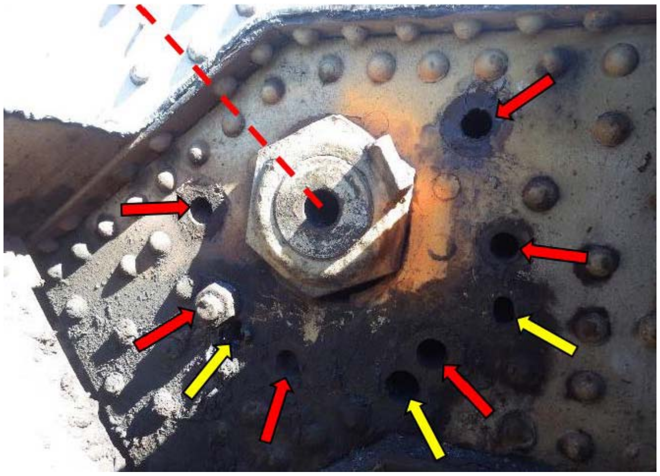
The 2nd Link Pin extends outboard for the operating strut connection to the bascule span. An outrigger on the bascule truss supports the pin at the center of this connection. Bearing housings are mounted to the operating strut webs and allowed the operating strut to rotate about the fixed pin. A key between the pin, main sleeve, and bascule truss gusset plates resists pin rotation from the operating strut bearing friction. Lomas nuts and pin collars secure the axial position of components on the pin.

Joint Failure Inspection Findings

Over many operations, it is common for Strauss bascule joints to experience wear between the pin and gusset plates. This wear causes unintended loading of the retainer turned bolts, leading to eventual bolt failure. Maintaining proper lubrication of the internal bearing surfaces also becomes problematic. Since the grease grooves are inside the joint, access is difficult to clean and maintain clear lubrication passages. Old grease tends to solidify in the grooves, blocking the passage for new fresh grease. Friction forces increase with inadequate lubrication further accelerating deterioration of the joint assembly.

Photograph 1 - General view of the lakeside 2nd Link Joint. Note the counterweight link centerline (red dashed line) and operating strut centerline (blue dashed line).

The Seabrook lakeside 2nd Link Pin was found to emit loud grinding noises constantly through bridge operations (see Photograph 1). The joint exhibited advanced deterioration and a partial assembly failure. It was reported that it was no longer possible to apply fresh grease between the main sleeve and bushing. All six of the retainer bolts were sheared at both ends of the internal sleeve (see Photograph 2). The original bearing surface between the sleeve and the bronze bushing appeared to be frozen causing all relative bearing rotation during bridge operation to occur either



Photograph 2 - Broken retainer bolts/holes (red arrows) and grease passages (yellow arrows) at the lakeside 2nd Link inboard gusset plate. Evidence of the 1" wear in the gusset plates can be observed by the gap at the 5 o'clock position. Note orientation of the counterweight link centerline in the seated position (red dashed line).

between the pin and the sleeve or the pin and the gusset plates (see Photograph 3). The original key at the interface of these surfaces had sheared in multiple places (refer to Photograph 3). Due to the reduced area, bearing stresses at these new locations of relative motion were over 6 times higher than the original sleeve to bronze bushing interface. Rapid wear was developing and pieces of the failed key were gouging into the adjacent components. The inboard gusset plate exhibited 1 inch of wear allowing the pin to shift radially from the original centerline (refer to Photograph 3). Internal damage between the pin and the sleeve could not be accurately assessed. Hard contact was present between the inboard lomas nut and the gusset plate and between the inboard face of the main sleeve and the gusset plate. Without the retaining bolts, the gusset plates lacked support to resist this side loading. In addition, the sleeve retainer bolt holes and grease grooves no longer aligned with holes in the gusset plates. Therefore, it was impossible to add lubrication to and restore movement at the original bushing interface.

The riverside 2nd Link Pin assembly was in similar but not as severe condition. All retainer bolts were present but only two of the six appeared to be sound. Several grease ports were leaking grease, indicating the potential of inadequate lubrication. Unsound retainer bolts were also found at each of the 1st Link joints.

Upon completion of the field inspection, Modjeski and Masters recommended complete cessation of span operations until the lakeside 2nd Link joint was repaired. Rehabilitation of the riverside 2nd Link Pin and replacement of the 1st Link retainer bolts were included in the repair scope.

Photograph 3 - Lakeside 2nd Link Pin failure. Note the pin rotation, sheared key and approximately 1" wear between the pin and the gusset plate bore.

Replacement Design Challenges and Features

The rotated position of the internal main sleeve relative to the original gusset plate alignment significantly increased the repair project scope. A common method to reinforce Strauss Bascule Bridge joints is to drill and ream the retainer bolt holes to install shear insert plugs. This fix can be accomplished in-place without unloading the joint; however, this was not feasible as it was impossible to correct the main sleeve's alignment while resisting the counterweight load. Therefore, complete unloading and disassembly of the joint was required to access and replace all necessary components. Unloading the joint required erecting temporary means to remove all counterweight loads from the bascule structure. It was decided that the bascule leaf at fully seated was the safest span position and most conducive for construction. Minimizing impact to rail traffic was a major focus in the design to support the 2.2 million pound counterweight. Reassembly and alignment of the new 2nd Link components required accurate positioning of the counterweight link arms. Therefore, the temporary structure and jacking mechanism needed not only support the weight of the counterweight but also provide for precise adjustments. Scott Bridge Company, Inc. (SBC) designed a temporary structure of piles and large overhead cross beams to hang the counterweight from above with Williams Rods through holes cored vertically in the concrete counterweight.

Complete disassembly and replacement of the joint components provided the opportunity to make design changes to improve installation and correct ongoing issues. Retainer bolt failures were a reoccurring issue at these joints. Shear insert plugs were incorporated to address this. While the original retainer bolts were designed only to resist the rotation of the inner sleeve due to friction, the new shear insert plugs were rated for the much larger counterweight link forces. Thru bolts were again used to hold the assembly together but were now protected from shear loads by the insert plugs.

Significant gusset plate wear in combination with the need to support the operating strut at the 2nd Link Pin created several design challenges. An in-kind replacement of the pin was not possible due to the wear. Boring out the gusset plates and using a larger pin diameter was also not possible since the pin was to be inserted from the outboard side through the operating strut bearings. A solution was found in the use of gusset sleeves to fit between the pin and new clean bores in the gusset plates.

The operating strut connection presented a second design challenge. Friction from the operating strut bearings causes rotational forces in the pin that must be resisted. Originally the pin was keyed to the span gusset plates for this purpose (refer to Figure 2); however, the new gusset sleeves were not thick enough for a keyway. Another method with similar anti-rotation capacity was required for the pin. The answer was found by adding flats at the interface between the end of the pin and the inboard gusset sleeve (see Figure 3). Ears were also added to the gusset sleeves, extending to two of the new shear insert plugs, to anchor the gusset sleeves from rotation.

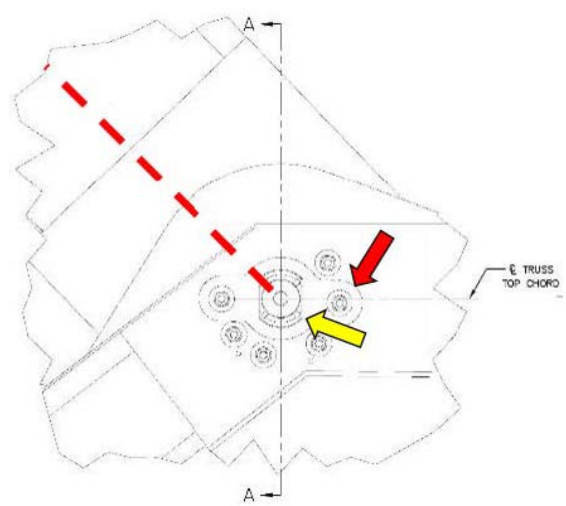


Figure 3 - Inboard 2nd Link gusset sleeve with pin flats to resist operating strut torque (yellow arrow) and sleeve ears extending to two of the shear insert plugs (red arrow).

Construction

Project Timeline

In January 2017, the PONO procured all raw materials for long lead items through an advance procurement contract. A pre-bid meeting was held onsite in February. By the end of March, the repair contract was awarded to Scott Bridge Company, Inc. (SBC). SBC's contract was to have the bridge fully operational within 75 consecutive calendar days from the notice to proceed in mid-April. All advance procurement material was delivered to SBC in April.

Photograph 4 - Temporary counterweight support structure. Note the pile structure on each side of the counterweight (yellow arrows), the four main double stacked W36x395 beams (red arrow), and the hydraulic jacks and Williams Rods (blue arrow)

Three major milestones were quickly identified and would need to be completed in succession in order to successfully complete the project within the deadline. The first major step required unloading and supporting the counterweight for disassembly and replacement of the 2nd Link assemblies. Secondly, after the counterweight was adequately supported, the pins would need to be removed and the counterweight link arms rotated up out of the joint. Difficulty of disassembly was a large unknown due to the uncertain internal damage and amount of wear on the pin and assembly components. The third and final critical milestone was installation of all new assembly components, culminating with the insertion of the main pins. All of these milestones needed to be completed with minimal impact to railroad traffic.

Photograph 5 - Lakeside 2nd Link main sleeve with grease grooves packed with solidified grease

Counterweight Support

SBC's temporary counterweight support structure consisted of 16 x 24" diameter steel piles, lateral bracing angles, framing beams, and four double stacked W36x395 beams. SBC cored eight 5" diameter holes through the entire depth of the counterweight to allow for the passage of 3" diameter Williams Rods. These 150 ksi rods, in combination with washers and threaded nuts, were used to support the counterweight from below, where only a few inches existed before fouling the track clearance envelope. Atop the framing beams, SBC installed four 500-ton jacks to engage the rods and raise the counterweight from its natural resting position. Effectively, four of the rods acted as jacking rods, while four rods were put in place for safety. See Photograph 4 for the general layout of the temporary counterweight support pile structure. The threaded rods enabled the jacking mechanism to make the precise position adjustment needed during disassembly and reassembly of the 2nd Link Joints.

While SBC was constructing the structure, and while loading the temporary structure, various locations on the bridge and structure itself were surveyed to monitor for any movement or settlement. Additionally, the rail car clearance needed to be monitored and maintained as train traffic did not cease throughout the counterweight jacking. To adequately track the reaction of the structure, SBC loaded the jacking system in increments of 250psi. Successful jacking was indicated by movement of the counterweight link at the

Photograph 6 - Lakeside 2nd Link Pin with wear steps up to 1/2" deep and severe abrasion

second link location. Once the counterweight was unloaded from the bridge structure and loaded onto the pile structure, no movement in the pile structure was recorded and a 3/8" increase in elevation was observed at the bridge tower truss leg. The track envelope was not fouled during the entire load transfer operation.

2nd Link Joint Disassembly

Disassembly began by cutting the existing 2nd Link pins and removing both operating struts and the support outriggers. The ability of SBC's counterweight support design to move the counterweight links in a measurable and controlled fashion ultimately lead to the success of milestone two, removal of the 2nd Link Pins. Once the jacking structure proved successful in unloading the counterweight forces, SBC had to accurately jack the counterweight and counterweight link arms to a position where the pins were free of all loads and could be removed. During the unloading, In-Place Machine (IPM) installed dial indicators and Modjeski and Masters installed strain gauges and string potentiometers to monitor movement at each 1st and 2nd Link Pin location. A portion of the lakeside 2nd Link sheared key and several intact riverside 2nd Link retainer bolts initially prevented fully unloading and removal of the 2nd Link Pins. Once these items were removed, extraction of the main pins was relatively easy with the aid of a small axial jacking device fabricated by SBC.

Removal of the main internal sleeve and bushing was only possible once the counterweight link arms were rotated up out of the bascule span gusset plates. Several truss top flange gusset plates had to be removed to provide a clear path for rotating the counterweight link arms, which remained pinned at the 1st Link Pin. M&M performed analysis to verify that live load traffic could continue across the bridge without these top flange sections.

Grease grooves in the lakeside 2nd Link main sleeve were discovered to be 100 percent filled with solidified grease (see Photograph 5). The lakeside 2nd link pin exhibited severe wear and abrasion with wear steps up to ½" deep (see Photograph 6). It was evident that most of the wear was occurring in the pin, thereby confirming the importance of ceasing bridge operations.

Photograph 7 - Disassembled 2nd Link joint with the counterweight link arms rotated out of the span gusset plates. Note counterweight link centerline (red dashed line) and original operating strut position (blue dashed line).

Photograph 8 - New bushing in the lakeside counterweight link bearing

Field Machining and Installation

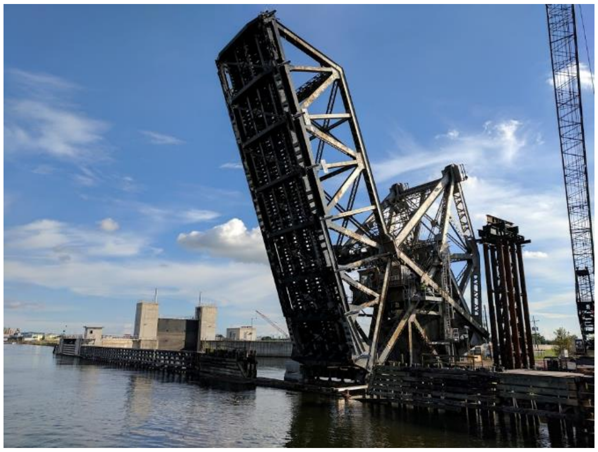
Prior to the unloading of the counterweight, In-Place Machining (IPM) performed a survey of the main trunnions, counterweight trunnions, 1st and 2nd Link Pins, and bascule truss centerlines to determine alignment of the existing pin and truss centerlines. This information along with the existing 2nd Link gusset plate geometry was used to establish a common centerline for the lakeside and riverside 2nd Link Pins to govern field machining. Temporarily supporting the counterweight links in a rotated position away from the bascule span gussets allowed field machining and installation efforts to commence simultaneously at both counterweight link bearings and both span 2nd Link joints (see Photograph 7). New bushings and main sleeves were installed at the counterweight link bearings after a few clean up line boring passes (see Photograph 8). Initial rough machining efforts at the span gusset plates removed the existing wear and old keyways. The gusset plates were also faced in the areas of the new gusset sleeve flanges (see Photograph 9).

Photograph 9 - 2nd Link truss gusset plates after initial machining. Note the original keyway removed from the bores and facing in the area of the new gusset sleeve flanges

The newly bushed counterweight links and main sleeves were then rotated back into the bascule span gusset plate joints. SBC adjusted the counterweight support structure and manipulated the counterweight links with ancillary jacks to position inner diameter of the main sleeves concentric with the gusset plate bores. Concentricity to within 0.030" T.I.R. was achieved. The main sleeve position was temporarily held in place by tapered undersized shear plugs then secured once most of the final shear insert plugs were installed after drilling, reaming, and honing. Installation of the gusset sleeves, operating strut bearings, operating strut outrigger, and main pin required several more line boring and installation sequences (see Photograph 10).

Photograph 10 - New gusset sleeves, shear insert plugs and thru bolts installed at the 2nd Link joint in preparation for installing the main pin.

The field machining and installation of new components was an incremental process requiring numerous steps and field machining setups. Final machining of most new components was held until


Photograph 11 - Bridge operation restored

machining of the existing mating structure was completed. Shop fabrication was closely coordinated with the field machining efforts and schedule with new components expedited to the site as they were needed. All the gusset plate retainer bolt holes were deformed or wallowed, often unevenly from one gusset plate to another. Templates guided field measurements to determine the required locations for new shear insert plugs to clean up the existing holes. These details were relayed back to the shop to finalize field machining guide plates and sub drill locations for the main sleeves.

CONCLUSION

Bridge operation was restored in July 2017 (see Photograph 11). Overall the emergency repair project was a great success. Long term reliability of the counterweight link joints was significantly improved. Post construction strain gage balance testing revealed that the total bridge friction was cut nearly in half with the new 2nd Link components.

ACKNOWLEDGEMENTS

Successful completion of this project was only made possible due to the excellent work accomplished by Scott Bridge Company and In-Place Machining Company along with teamwork and coordination of the all the stakeholders, including the Port of New Orleans, Norfolk Southern Railroad, and the United States Coast Guard.