HEAVY MOVABLE STRUCTURES, INC.
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Link Arm Repair and Counterweight Hanger Fatigue Strengthening for Long Island's South Shore Bascule Bridges

Ronald Kudla, P.E.
NYSDOT Director of Bridge Maintenance for Region 10

Dennis Biegel, P.E.
STV Incorporated

Alan Marchan, P.E.
STV Incorporated

CARIBE ROYALE HOTEL
ORLANDO, FLORIDA

Abstract

The New York State Department of Transportation operates and maintains five movable bridges in their Long Island Region. All five are bascule bridges. Two of these five are under-deck, articulating counterweight type bascule bridges designed and constructed in the early 1930's. The design details of these two bridges, Meadowbrook Parkway over Sloop Channel and Loop Parkway over Long Creek are slight variations of the original Joseph Strauss patent.

Some of the classic difficulties encountered on this bridge sub-type are exhibited on these two structures. In the case of the Loop Parkway Bridge, the hanger plates connecting the counterweight truss/counterweight assemblies to the counterweight trunnion pin had been documented as being at or near the end of their useful fatigue life. Recent Coast Guard regulation changes have allowed this bridge to reduce its annual number of navigation openings from roughly 7,000 to 5,000. This high operating frequency, coupled with the fatigue life assessment compelled the Region to embark on a project to retrofit the hanger plates, providing sufficient additional fatigue life until a more extensive rehabilitation or replacement of the bridge can be programmed.

In addition, the stabilizing links between the lower portion of the counterweight and the trunnion columns on these bridges is another common problem area. These links are fixed in length and require tight tolerancing of their overall lengths and end pin positions to function as intended and prevent high binding forces from being developed and transmitted to the structure. Both the Meadowbrook Parkway and Loop Parkway bridges had clear signs indicating a history of distress at their link end pin connections. This distress, combined with an inability to properly service the pin bearings, began to lead to operational problems on both bridges. The Region determined that best course of action was replacement of the end bearings of these members and their connections with the counterweight truss and trunnion columns.

Introduction

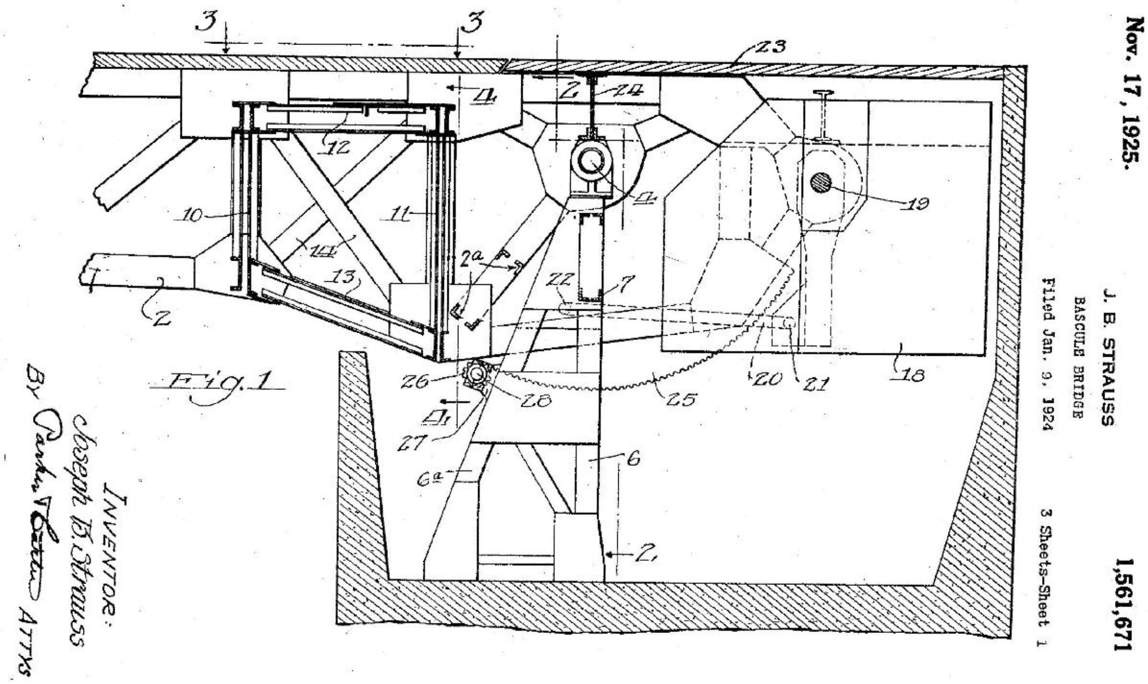
NYSDOT's Long Island Region

The New York State Department of Transportation is divided into eleven geographic regions. Region 10 encompasses the eastern portion of Long Island outside of New York City. Today, the Region is responsible for the maintenance of 546 bridges, serving almost three million local residents. The Region's infrastructure consequently has substantial demands placed on it. Nassau, one of the two state counties included in the Region, was the fastest growing county in the United States from the 1950's through the 1970's, with many of the residents commuting daily to New York City.

Of the 546 bridges owned and maintained by the Region, five are movable bridges – all of the bascule type. All of these are on Long Island's south shore carrying major regional parkways leading to the Jones Beach and Robert Moses state parks. The bridges carry large volumes of vehicular traffic during the summer months and have high demands for opening for seasonal recreational vessels. The area also has an active commercial fishing industry which places a year-round demand for opening on one of the five bridges, which carries Loop Parkway over Long Creek.

The Joseph B. Strauss Under-deck Articulating Counterweight Design

Two of the five bridges, Meadowbrook Parkway over Sloop Channel and Loop Parkway over Long Creek, are simple trunnion bascule bridges featuring an articulating counterweight, similar to that first patented by Joseph B. Strauss in 1925. This ingenious patent maximized span length while substantially lowering the substructure cost by separating the counterweight from the girder and transmitting the counterweight dead load through a rear counterweight trunnion bearing whose location could be moved to reduce length of the rear portion of the bascule girder while still keeping the forward and counterweight center of gravities aligned thru the center of rotation. This ability to position the rear center-of-gravity and to keep the line of action thru the main trunnion permitted the counterweight to be nested within the back end of the girder much closer to the center of rotation than could a fixed counterweight. The ability to reduce the rear portion of the bascule span allows for the elimination of closed pit piers in some cases and when closed pit piers are required, it reduces their size considerably. This made the patent very attractive as it allowed new structures to be closer to the waterline in keeping with the natural coastal and riverine geographies.



The patent did have its problems however. The design, under competition from other patented bascule bridges at the time, pushed the material stresses in the hanger plates to their limit. In some cases minimal allowance for moving impact were found in the stress sheets. Ultimately what caused the patent to fall out of favor was its failure to provide for bending stresses in the hangers due to the friction in the counterweight trunnion as it started and stopped. The hanger remained vertical while the span started moving until the starting friction was overcome, this induced bending in the hangers on top of the high axial forces. By the mid 1930's, about 10 years after the initiation of the patent, failed hangers on many bridges had suffered the loss of the counterweights bringing the patent's widespread use essentially to an end.

STV staff have been involved in the inspection, investigation and repair of numerous Strauss patented bridges and have actually designed a replica replacement of this patent type. This experience and familiarity with this unique bascule span type has provided significant insights on some of the issues we will address in this paper.

Project Background

STV Incorporated came to be involved with the Region's movable bridges as a result of its National Director of Bridges' long personal history with them, dating back to the 1970's. While working for another consultant, he was involved with numerous inspection and design projects involving all five bridges. He was also involved with the recent replacement of one of the bascule bridges, designed by Hardesty & Hanover. This historical knowledge and our in-house staff capabilities attracted the Region's Bridge Maintenance Department to directly engage STV to assist in troubleshooting isolated operational issues on several of their bridges. *(maybe edit this paragraph but in any case let's see what the whole thing looks like)*

During this initial involvement, the Region identified problems with the functioning of the link arms at the Meadowbrook Parkway and Loop Parkway bascules. Specifically, the link arm tower-end end bearings were producing loud noises as the bascules opened and closed. This condition appeared to be compounded by the absence of a means to regularly lubricate these bearings.

It was also noted during a site visit that the Loop Parkway bascule does not rotate open and closed perfectly vertically, resulting in rubbing contact at the flower boxes. This suggested the possibility of out-of-plane bending of the counterweight hanger plates, which are historically fatigue-prone elements. One uncovered nuance to the counterweight hanger bending stresses are that the bearings tend to go out of round as the bridge ages and the bridge develop a 'nested' position. This keeps the bending stresses in the hangers at their maximum load throughout travel instead of dropping off as soon as starting friction is overcome and the much lower running friction values dominate. This possibility prompted the Region to have strain gages installed on the hangers and record strain readings through a series of test operations. The results of this testing was compiled and analyzed by another consultant. Their conclusion was that the hangers had reached the end of their service life.

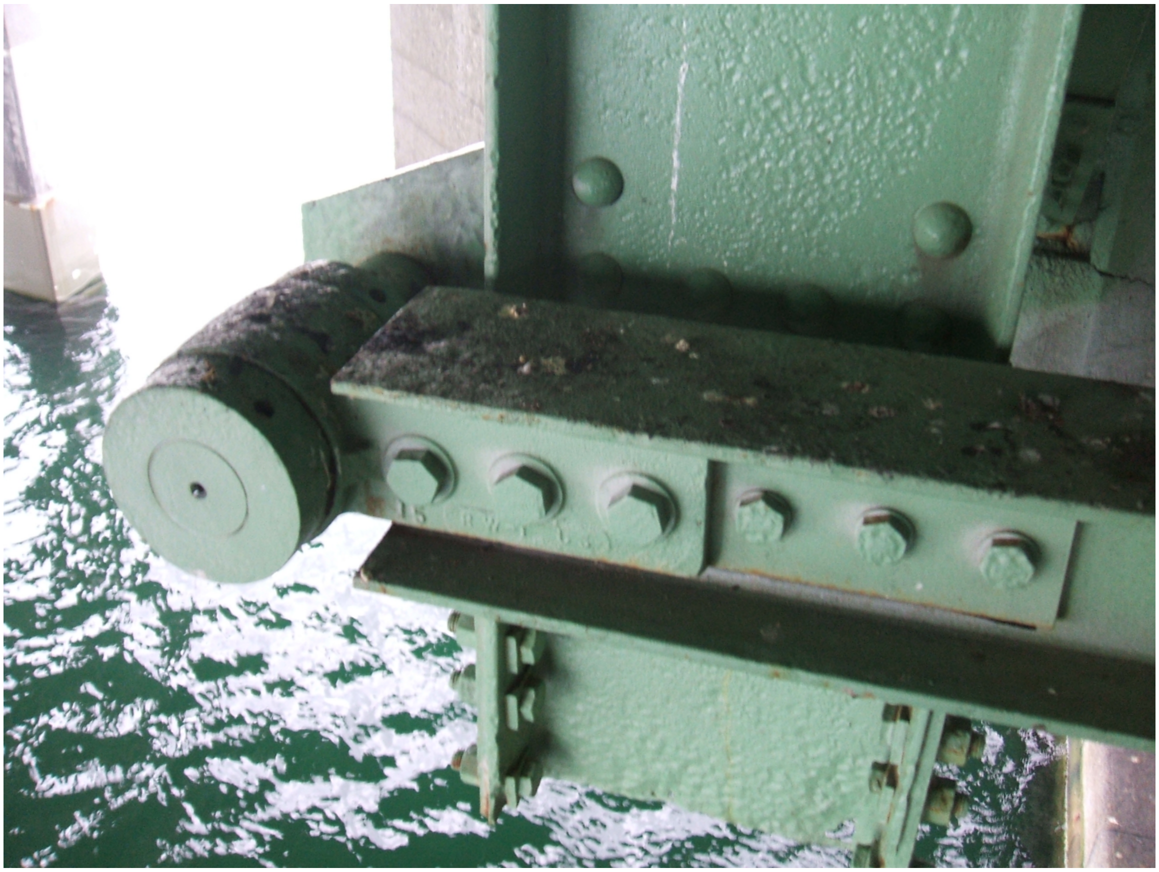
It was realized that addressing these issues would require significant engineering effort and that a formal advertisement was required. In the middle of 2008, the Region issued a request for proposals for an engineering consultant titled "Emergency Bridge Design for Repairs Affecting Public Safety" with the intent of including repairs to the Meadowbrook and Loop Parkway bascules under this contract. A team headed by STV was the successful respondent.

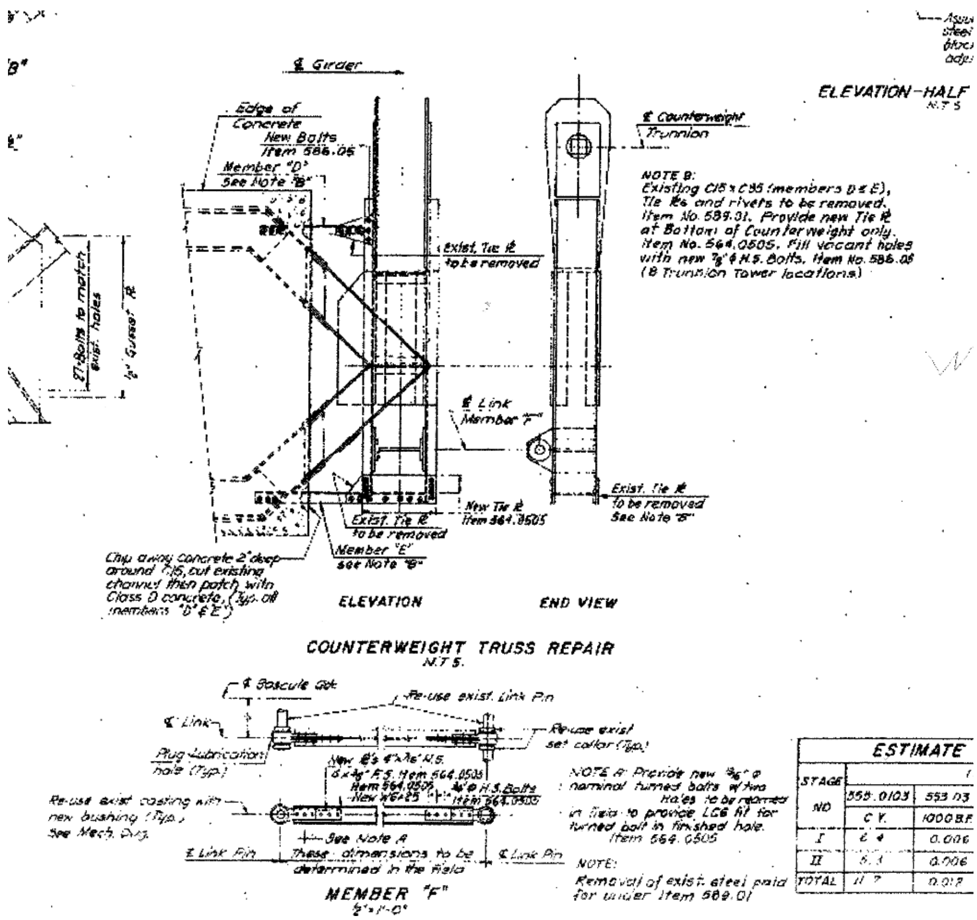
Meadowbrook Parkway over Sloop Channel

Both the Meadowbrook Parkway and Loop Parkway bridges were designed in 1933 and constructed between 1933 and 1934 by the Jones Beach State Parkway Authority, which was absorbed into the NYSDOT in the 1970's.

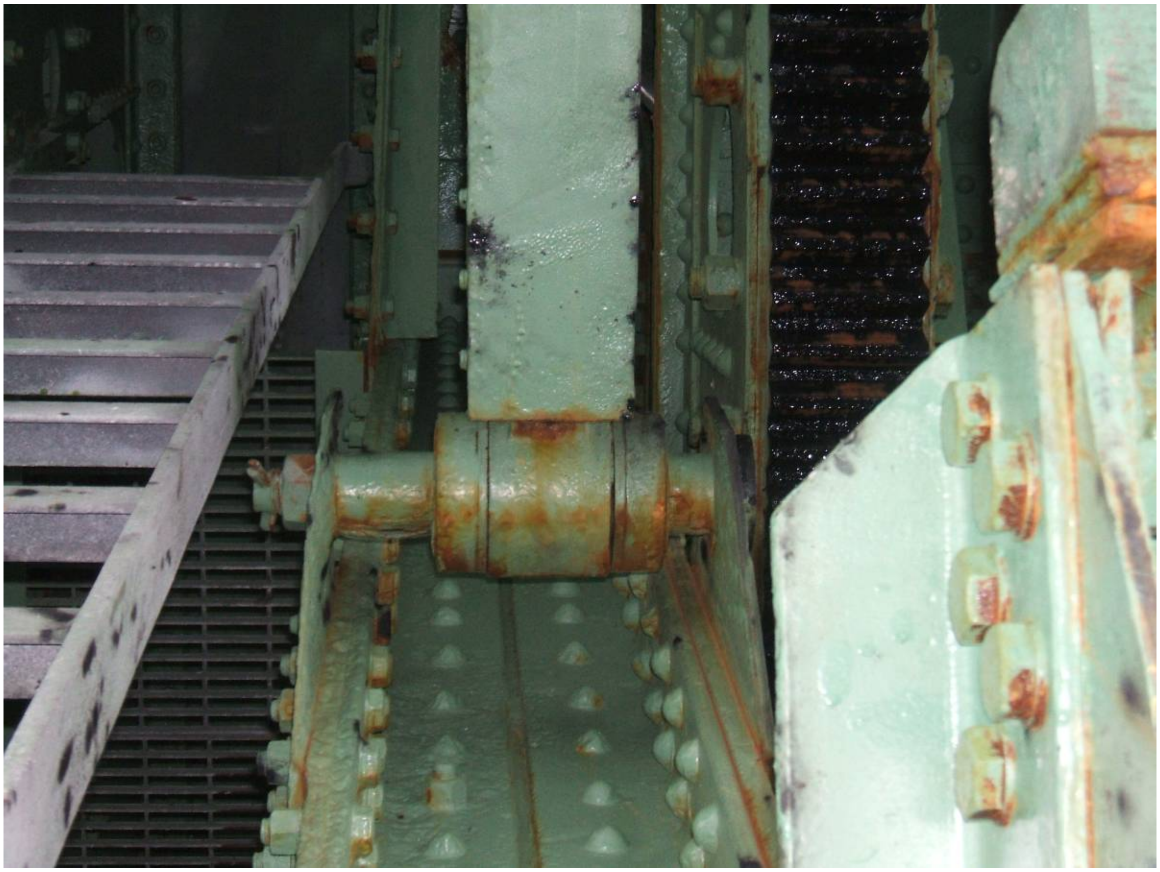
Meadowbrook Parkway over Sloop Channel is a twenty-five span, 1,480 foot long structure which includes an eighty-three foot long, six-lane (four leaf??) twin double-leaf, simple trunnion bascule span. The bascule girders are comprised of built-up sections riveted together. The centerlines of the inboard girders are six feet apart with no structural connections between them. However the bridge control system electrically links the operation of the twin bascule spans together, such that they cannot be independently operated.

The link arm assemblies originally consisted of 6-inch, 22.5-pound H-pile sections with cast steel, bronze bushed bearing assemblies fastened with turned bolts to each end of the H-pile. In the early 1990's, the H-pile sections were replaced with W6x25 sections as part of a major rehabilitation of the bridge. The cast bearing housings were retained, but had new bronze bushings installed. New turned bolts were provided to fasten the old castings to the new W-section to the AASHTO-standard ANSI LC6 class fit. New shaft collars were provided to retain the link arm ends axially on their shafts. What is significant to note is that the contract drawings do not dictate a tolerance on the overall length of the link arms, rather a note is provided indicating that the end-to-end dimensions should "be determined in the field". In addition, a note is provided directing that the lubrication holes be plugged.



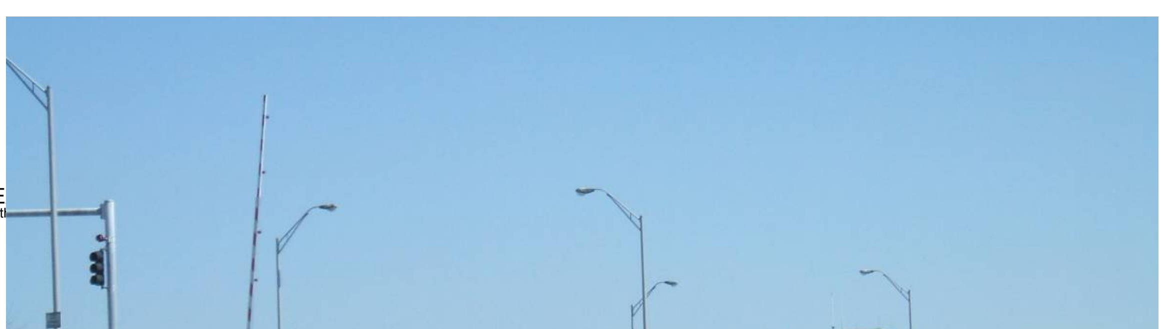


The link arm W-sections were in very good overall condition. The tower-end bearings and to a lesser extent, the counterweight-end bearings exhibited fretting corrosion and axial misalignment along their shafts. The link arm end shafts extend beyond the bearing bushings, passing through a pair of vertical plates. Each shaft has a smaller, square cross section near one end, which fits through one of the two vertical plates, and is intended to prevent rotation with respect to the trunnion towers and counterweight truss. Most of the vertical plates exhibited section loss with local plastic deformation around the square holes for the square ends of the link arm shafts.



Loop Parkway over Long Creek

Loop Parkway over Long Creek is a nineteen span, 680 foot long structure which includes a ninety-three foot long, four lane, double leaf, simple trunnion bascule span. The Loop Parkway structure was designed at the same time as the Meadowbrook Parkway structure and many of the design and construction details are identical.



The Loop Parkway bascule underwent a major rehabilitation in the early 1990's as well. The rehabilitation design was performed by the same consultant that provided the design for the Meadowbrook Parkway bascule. Again the link arm rolled sections were replaced, the end bearings re-bushed and the connecting turned bolts replaced. Also again, the contract drawings did not provide any tolerances on the end-to-end lengths of the link arms and the lubrication holes were required to be plugged.

The inspected conditions of the link arms and their end attachments was notably worse than that observed at the Meadowbrook Parkway bascule. This is likely because the Loop Parkway structure is more exposed to coastal storms and weather than is the Meadowbrook Parkway structure and because the Loop Parkway bascule has a significantly greater demand for navigation openings. Many of the vertical connecting plates exhibited section loss and warping or yielding. The fit of the link arm shafts in these plates was compromised with fretting corrosion clearly evident. The link arm end bearings were not centered axially on their shafts and in some cases the fit of the retaining shaft collars on the link arm shafts had failed.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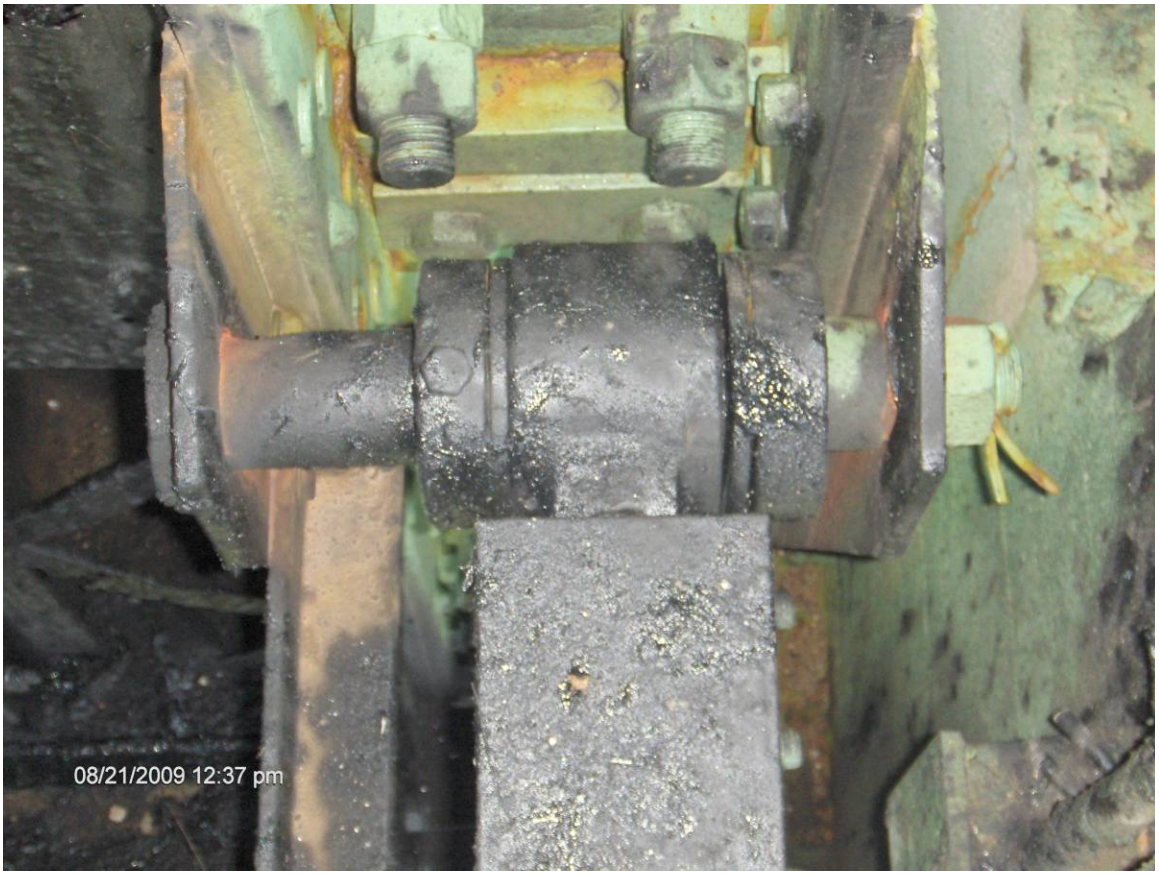
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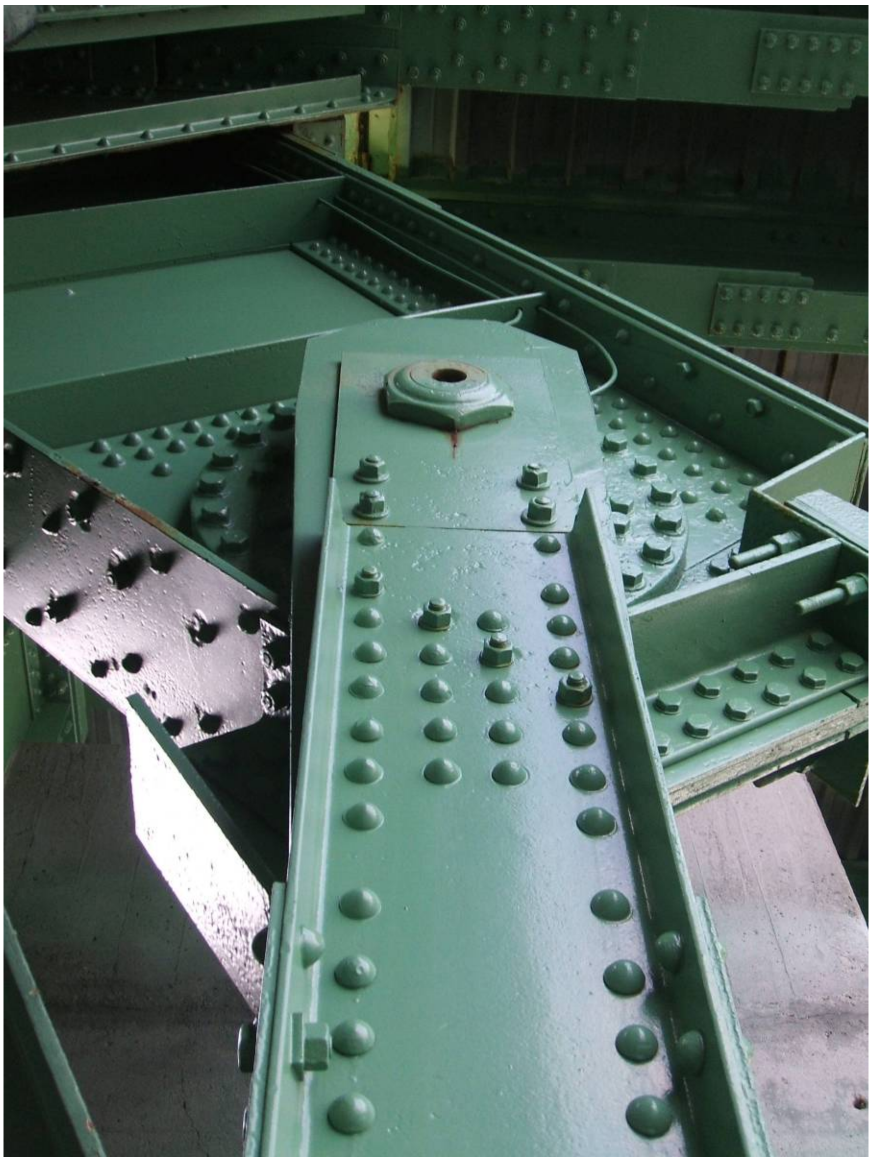
The Loop Parkway bascule also had the additional problem of bending stresses in the transverse plane developing in the counterweight link arms during opening and closing operations. The strain gage readings indicated the hanger plates were bending and twisting. The induced stresses were not momentary phenomena, but increased in magnitude as the bascule leafs opened. Upon closing, the stresses tended to switch from compression to tension, or vice versa, and reduce in magnitude as the leaves closed. The strain gage readings also indicated that bending in a longitudinal plane was occurring. Again, this was not a momentary phenomenon as one might expect from inertial forces. Rather the bending increased in magnitude as the leaves opened.



The strain gage results suggested that several things were happening to the bascule system as it was being operated. First was that the leaves also translated transversely as they opened and closed. Field surveys performed by a contractor hired by the Region to perform the STV team's recommended repair work suggested that at least the outboard faces of the main and counterweight trunnion shafts are misaligned by 0.12-inches for the west leaf and 0.11-inches for the east leaf. The inboard face of the trunnion shafts is not readily accessible for surveying purposes. Second, the link arms are of differing lengths with the centers of their end shafts not correctly located with respect to their theoretical locations. This again was confirmed later by surveys performed by the contractor. This condition caused high axial forces in the link arms and binding at the end bearings to develop during opening and closing operations. The high load condition was exacerbated by the lack of lubrication at the end bearings. High torques between the end bearing shafts and the vertical connecting plates were caused by steel-on-steel friction, which led to localized yielding of the plates. This may have actually relieved some of the binding in the short term, but the condition of the link arms remained a maintenance issue. The high forces developed through the link arms, combined with frictional resistance in the counterweight trunnion bearing assemblies are the cause of the longitudinal bending detected by the strain gages.

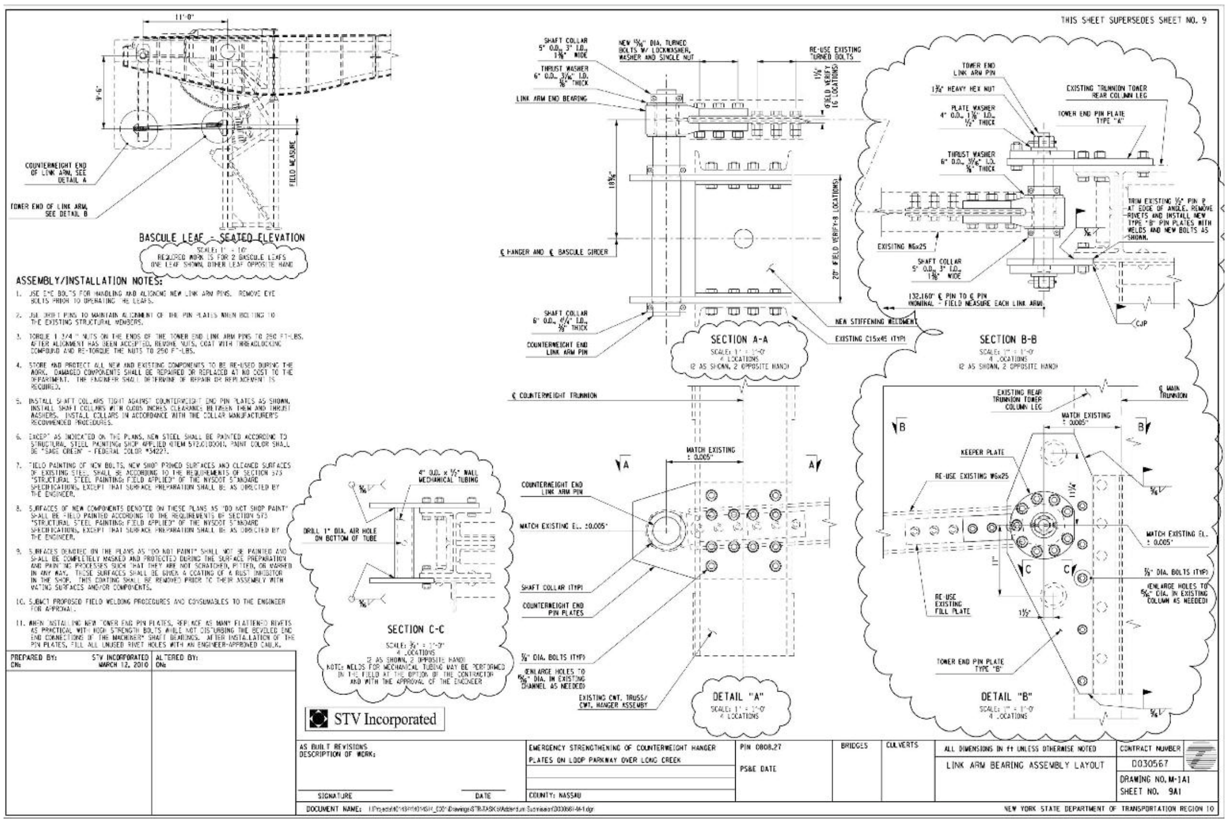
Repair Design

Link Arm Replacement

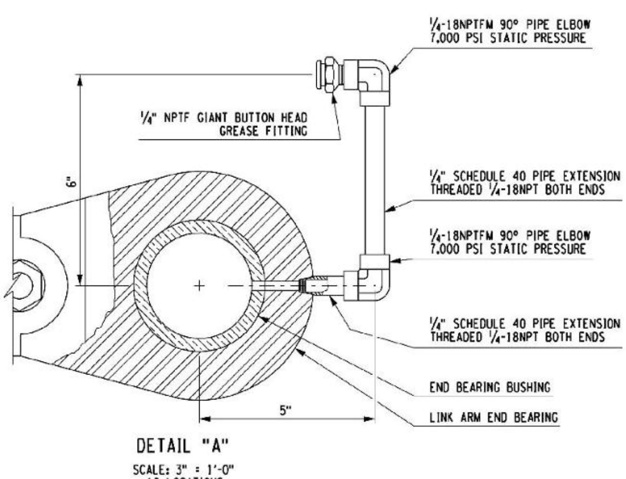
Based on the condition of the components, historic difficulties in correctly aligning link arms on similar bridges, and the operational issues NYSDOT had experienced, STV recommended and NYSDOT agreed that the link arm should be repaired. Later, when the contractor performed his field surveys, the improper location of the link arm end bearings was verified.

The intent at first was to simply replace the end bearing assemblies and connections to the trunnion towers and counterweight truss. Essentially this approach would have replaced everything except the rolled sections and fill plates attached to the rolled section web with turned bolts. In the interests of minimizing field time, it was decided to fabricate entire new link arm assemblies beforehand. The governing principal throughout the design was to select materials that were readily available. As an example, rather than have the end bearing housings made from cast steel, the design called for it to be machined from ASTM A36 plate. The new bronze bushings were stock size cast bronze units available from several providers. The new tower-end and counterweight-end link arm shaft materials were selected from typical supplier stock listings.

The rest of the steel members were ASTM A709 Grade 50 plate. Galvanizing the steel was considered, but abandoned, due to concerns about making sure tight tolerances were maintained.



The original design featured lubrication holes that were extremely difficult to access. The new design left these holes in the same location, but called for a lubrication piping arrangement that would provide easier access. While many of the lubrication fittings for the mechanical components are accessed at central manifolds, the Region requested this not be done for the new link arms – their preference was to access the new grease fittings as close to the surface requiring lubrication as practical. Should this preference change, it would be a relatively simple matter to remove the local fittings and install flexible hoses to new or even existing manifolds.



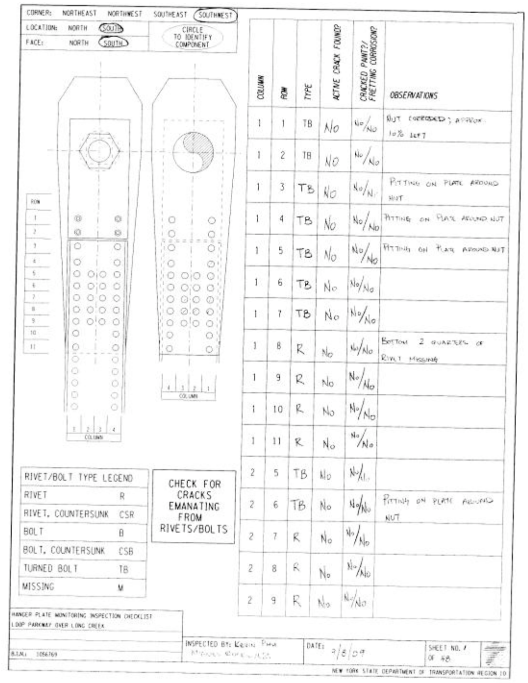
The contract documents include directions to the contractor on requirements for field measurements and on fabrication and installation tolerances for the new link arms. Initially, placement of the link arm end bearing centers was required to be accurate to ±0.005-inches. After subsequent discussions with the contractor, this has been relaxed to ±0.015-inches. The shaft center to shaft center lengths of each new link arm was to be individually determined based on survey made by the contractor. Per the theory behind Strauss' system, this length will match the distance from the center of the main trunnion shaft to the center of the counterweight trunnion shaft. The vertical and longitudinal offsets of the link arm shaft centers from the main and counterweight shaft centers are dictated on the contract plans.

The work in the field is planned to take place during a weekend channel and roadway closure. The channel closure was determined to be needed both the better facilitate the contractor's activities and because opening and closing the bascule span can cause excessive swinging of the counterweight as the operation starts and stops. Closing the channel during this period therefore helps to safeguard the safety of the contractor's personnel and equipment. Since the amount of swaying that could take place is not determinable from the information available, there is also a concern that a number of access ladders and walkways that the counterweights come in close proximity to could be damaged.

Counterweight Hanger Plate Strengthening

The earlier report issued by another consultant which concluded that the hanger plates had reached the end of their expected fatigue life dictated that some form of remedial action be taken. The extreme solution of replacing the hanger plates was not seriously considered. Overall, the Loop Parkway over Long Creek structure is nearing the end of its useful service life and the cost of replacing the hangers entirely was not viewed as a prudent investment. Under the assumption that this structure would be programmed by NYSDOT for replacement in a ten to twenty year time frame, a strengthening of the hangers was determined to be the preferred option.

In parallel with the repair design effort, the STV team developed a monitoring program for the hanger plates for use by the Region's maintenance personnel.



CORNER: NORTHEAST NORTHWEST SOUTHEAST SOUTHWEST
LOCATION: NORTH SOUTH
FACE: NORTH SOUTH
CIRCLE TO IDENTIFY COMPONENT

COLUMN	ROW	TYPE	ACTIVE CRACK FOUND?	CRACKED PAINT?/ FRETTING CORROSION?	OBSERVATIONS
1	1	TB	No	No/No	NUT CORRODED; APPROX. 10% LEFT
1	2	TB	No	No/No	
1	3	TB	No	No/No	PITTING ON PLATE AROUND NUT
1	4	TB	No	No/No	PITTING ON PLATE AROUND NUT
1	5	TB	No	No/No	PITTING ON PLATE AROUND NUT
1	6	TB	No	No/No	
1	7	TB	No	No/No	
1	8	R	No	No/No	BOTTOM 2 QUARTERS OF RIVET MISSING
1	9	R	No	No/No	
1	10	R	No	No/No	
1	11	R	No	No/No	
2	5	TB	No	No/No	
2	6	TB	No	No/No	PITTING ON PLATE AROUND NUT
2	7	R	No	No/No	
2	8	R	No	No/No	
2	9	R	No	No/No	

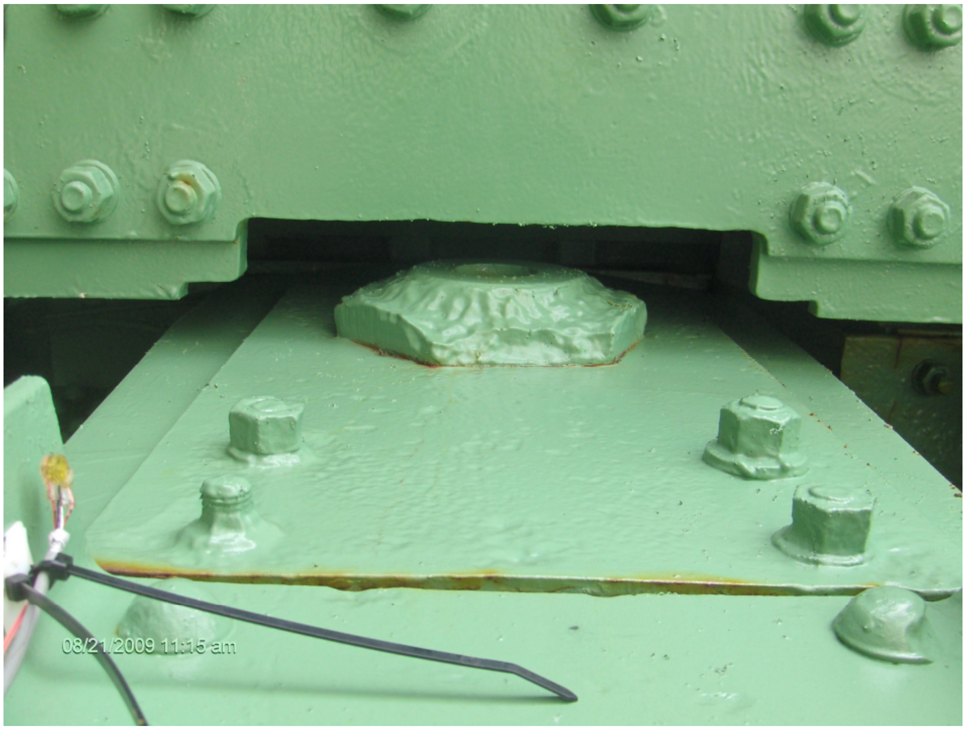
RIVET/BOLT TYPE LEGEND	
RIVET	R
RIVET, COUNTERSUNK	CSR
BOLT	B
BOLT, COUNTERSUNK	CSB
TURNED BOLT	TB
MISSING	M

CHECK FOR CRACKS EMANATING FROM RIVETS/BOLTS

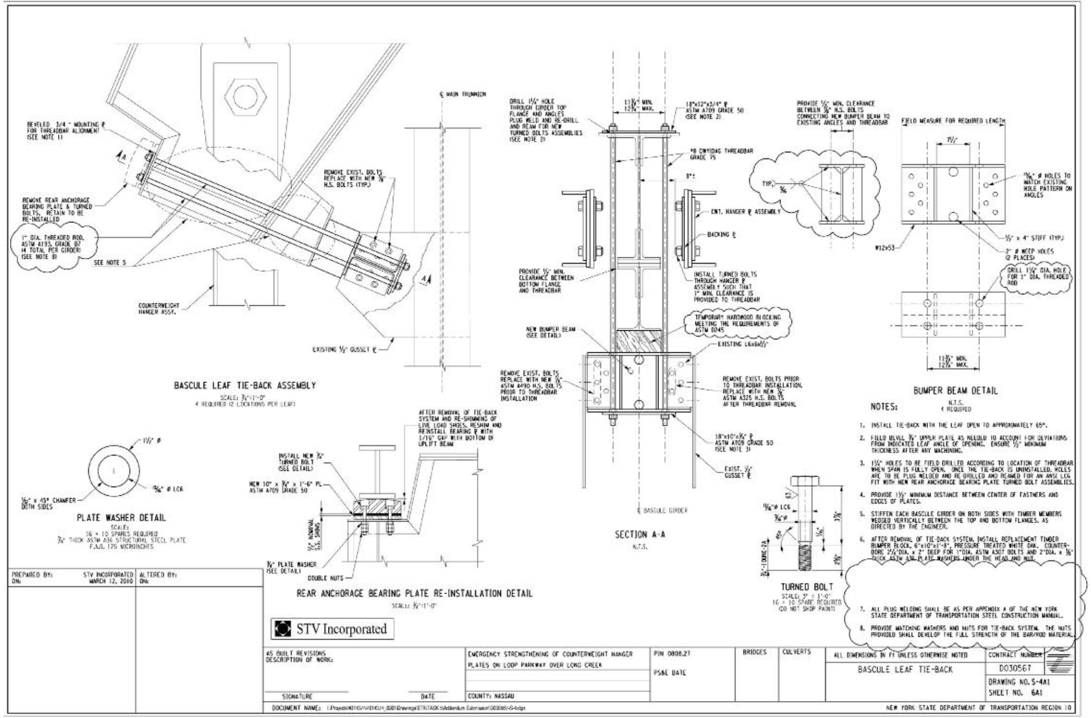
HANGER PLATE MONITORING INSPECTION CHECKLIST
LOOP PARKWAY OVER LONG CREEK
B.I.N.: 1056769
INSPECTED BY: KEVIN [illegible]
DATE: 9/8/09
SHEET NO. 1 OF 48
NEW YORK STATE DEPARTMENT OF TRANSPORTATION REGION 10

A requirement of any repair work was that roadway traffic be completely removed from the bridge during the work. This would facilitate the extensive field drilling and reaming operations that would be required as part of almost any repair option.

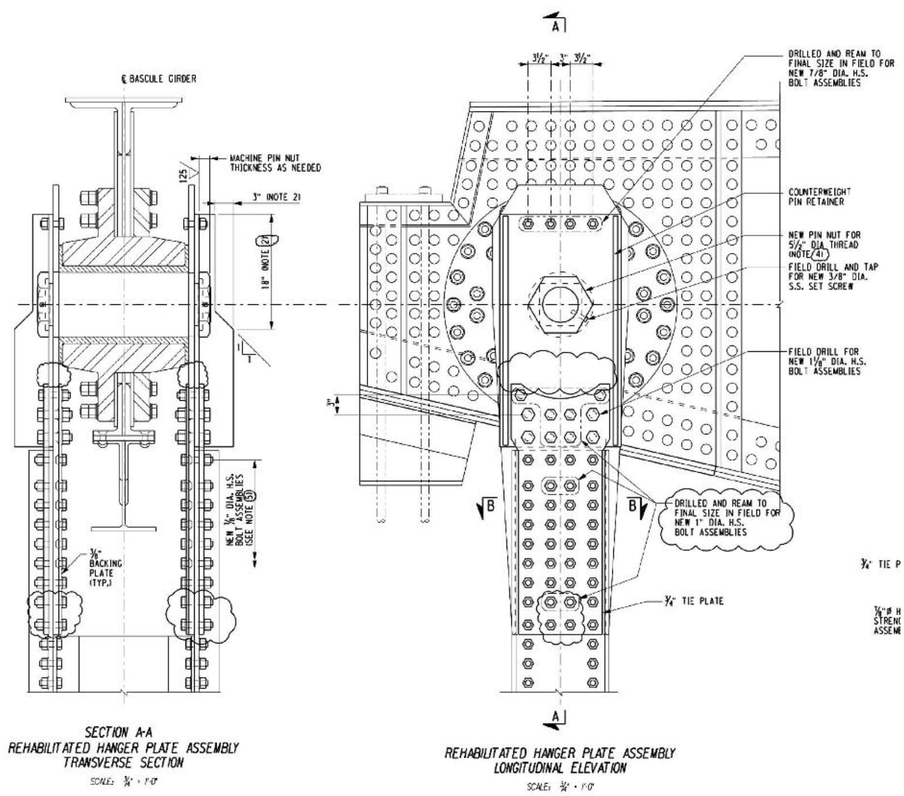
This bascule span does not have enclosed bascule pits and the counterweight hangs over water when the leaves are in their fully seated position. In this position, the top portion of the hangers are located inboard of the flanking span stringers, making full access impractical. Performing the work with the bascule leaves partially open was also not an option as that would restrict the channel for an unacceptable period of time. Consequently, it was decided the work needed to be performed with the leaves fully raised. After exploring an option for placing bracing between the toes of the leaves, a tie-back system using Dwidag rods at the bumper locations was selected. Part of the tie-back system will be left in place after the work as part of a rehabilitation of the bumpers.



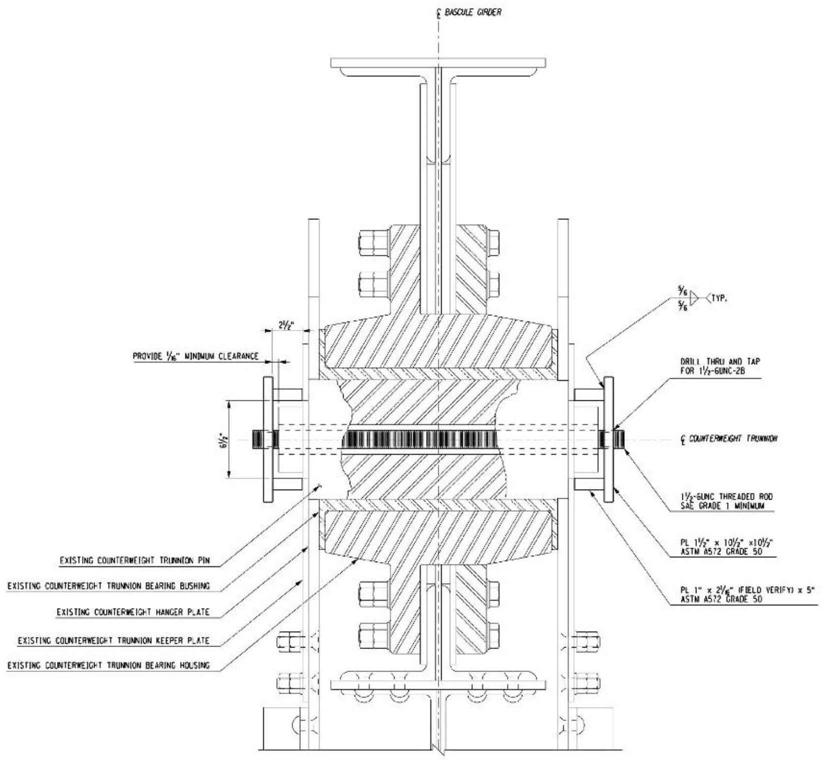
Perhaps the key question the design team faced early in the process was that of how much dead load the repair would relieve from the existing hangers. The STV team and the Region's staff initially investigated the possibility of having a repair almost completely support the weight of the counterweight with minimal contribution from the existing hanger plates. Such a system would entirely bypass fatigue sensitive areas of the existing hangers and would place the load through members with no cyclic loading history. This approach would restore much of the hanger system's original service life capacity. The method of support envisioned for the counterweight involved using a series of synchronized twenty ton jacks from the bascule pier. After considerable study, this proved to be extremely problematic. The issue was that under certain wind cases, uplift at the rear trunnion columns was possible. A number of solutions were considered, including parking a series of fully loaded cement trucks on the flanking spans during the work to replace the dead load from the counterweight.



This issue caused the design team to "take a step back" and take a fresh look at the strengthening. The result was a change to the philosophical approach to the problem. Given the anticipated remaining service life of the structure, there was no good justification for providing another half century or so of fatigue life for the hangers. Instead, the repair could transmit only a small, nominal amount of counterweight dead load and serve as a "back-up" to the existing hanger plates should they begin to develop fatigue cracks.



The repair of the hanger plates consists of first replacing the rivets of the built-up assemblies with new high strength bolts. To date, the contractor has done much of this replacement as part of his preparatory work. Use of bolted connection places compressive stresses on portions of the various plates and rolled shapes. On the upper portion of the hanger assemblies, rivets will be replaced one at a time with temporary drift pins placed to transfer loads and maintain position. The size and quantity of the drift pins were coordinated with the contractor and engineered to support the counterweight dead load plus twenty percent impact. The existing counterweight trunnion shaft retaining plates will be removed and temporary retaining clamps installed. The clamps will restrict any axial shifting of the trunnion shafts.



TEMPORARY HANGER PLATE CLAMP DETAIL

SECTION THRU VERTICAL PLANE PASSING THRU COUNTERWEIGHT TRUNNION CENTERLINE

Once the bascule leaves have been tied back, a jacking system will be installed and pressurized to support a small amount of the counterweight's dead load – a few thousand pounds at each location. Temporary supports will then be placed between the counterweight and the top of the bascule pier concrete to stabilize the counterweight in response to wind loads on the superstructure or construction loadings. A 3/8-inch inboard plate and a new counterweight trunnion shaft retaining assembly will then be installed. The new retaining assembly was designed to substantially increase the capacity of the hanger assembly to resist transverse bending loads. A 3/4-inch plate is then installed over the lower portion of the new retaining assembly and the upper portion of the existing hanger channel member. In this way the new 3/8-inch and 3/4-inch plates will transmit the weight of the counterweight to the counterweight trunnion assembly should the integrity of the hanger plate ever be compromised. These new plates will also share any load fluctuations that develop during operation of the bascule leaves. This will slow any crack initiation that may occur in the future. Correcting the lengths and locations of the link arms will add to this effect.

Quantifying the service life extension is really not practical at this time due to the uncertainties involved. The extent of the reduction in the operating stress fluctuations the strengthened hanger assemblies cannot feasibly be predicted. Follow-up strain gage readings could be performed after the completion of the work to validate the design and to update the fatigue life estimate.

An additional work item relating to the hanger assemblies will be the re-installation of counterweight truss bracing members that were removed in the early 1990's. These members are theoretically zero-force members and were badly deteriorated at the time. These members will, however, provide additional stiffening of the hanger assembly against transverse bending loads, further reducing operating stresses.