US 84 MISSISSIPPI RIVER BRIDGE – TRUSS PIN AND LINK REPLACEMENT

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BIOGRAPHY

James Gregg is the bridge department manager for HNTB Baton Rouge, LA office. He served as the project manager for US 84 Mississippi River Bridge Rehabilitation project as well as assisted with several NBIS inspections of the bridge. Mr. Gregg has over 10 years' experience with design and rehabilitation of complex structures, design-builds, and bridge construction inspections.

Justin Walker is the current state bridge engineer for Mississippi Department of Transportation with over 15 years of experience in bridge design. He currently serves as a member of AASHTO T17 Welding Subcommittee on Bridge structures and is a member of the Mississippi Engineering Society and the Structural Engineering Association of Mississippi.

Michael Xin is a principal bridge engineer in HNTB Chicago, IL office with more than 20 years' experience on complex bridges. Michael served as one of the lead designers of the for the US 84 Mississippi River Bridge Rehabilitation project.

SUMMARY

The US 84 Mississippi River Bridge is a 5 span cantilever truss bridge crossing the Mississippi River in Natchez, Mississippi. Two lower truss pins on the bridge shifted transversely and were flush with the outside gusset. The existing truss pins and links were removed and replaced. Temporary restraints were used to bypass the load in the truss pins and link and instrumentation used to evaluate stresses in the truss during removal.

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Introduction

The westbound US 84 Mississippi River Bridge is a 5 span cantilever truss with a 7 span approach that carries US 84 over the Mississippi River between Natchez, Mississippi and Vidalia, Louisiana (Figure 1). The Westbound Bridge was designed by HNTB in 1939 and opened to traffic in September 1940. The bridge was the third Mississippi River Bridge built south of Memphis, Tennessee and the first highway only Mississippi River Bridge south of St. Louis, Missouri. The bridge has one suspended span located between Piers 1 and 2 and eyebar links on Spans 2, 3, and 4. The Louisiana approaches, Spans 6 through 11, are plate girders. A twin structure located downstream was completed in July 1988 and the older bridge was restriped to two westbound lanes.

Figure 1 – Bridge Location Map

The westbound bridge has a 24’-0” clear roadway width, 2’-0¼” wide steel curb and rail, and a 7¼” thick deck (Figure 3). The deck is supported by crossbeams which are supported on 3 stringers. The stringers are framed into the floor beams that are spaced at either 39’-10½“or 43’-9”. Eyebar links (2’-0” x 10” x 7’-6½” long) are located at truss Joints U19, U29, U49, and U69. The westbound bridge was originally designed for a H15 vehicle (truck or lane).

A general elevation view is shown in Figure 2 and a section view is shown in Figure 3.

Figure 2 –General Elevation View

Figure 3 – Section View

As a border bridge between Louisiana and Mississippi, the bridge is maintained by Mississippi Department of Transportation (MDOT) but cost equally shared between MDOT and Louisiana Department of Transportation and Development (DOTD).

Pin and Link Details

Unlike other cantilever truss bridges in which eyebars supporting a suspended span are full length truss member, the pins and links on the US 84 Mississippi River Bridge are confined to the upper joint. The suspended span and quasi-suspended span loads pass through the suspended span or quasi-suspended span upper gusset and into the 7'-6½" long links via $10^1/_{16}$" diameter lower pins (Figure 4). The load is then transferred from the link into the cantilever span upper gusset via $10^1/_{16}$" upper pins. The pins and link also function as expansion joints for the bridge and were designed for up to 9" of movement between the two gussets.

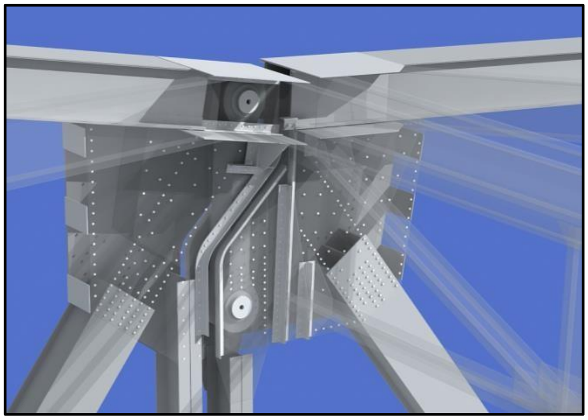

Figure 4 – Upper Joint

Pin Movement

U29 Pin Movement

In 1995, MDOT observed the tie rod that holds and restraints the pin from lateral movement was fractured and cover plates missing on the lower pin at U29 downstream truss. The weld that prevents the lower pin from rotating about the gusset was broken and the pin had rotated 2¾" from its installed position. The lower pin was also flush with the inside face exterior gusset on one side and extended 1" on the outside face exterior gusset (Figure 5 & 6).

MDOT contracted with HNTB which advised the outside ½" gusset supported the hanger and if the pin continued to move past the outside gusset, there would be an adverse effect to the factor of safety for the bridge, potentially resulting in closure of the bridge.

Figure 5 – U29 Lower Pin Downstream Truss Inside Face

Figure 6 – U29 Lower Pin Downstream Truss Outside Face

Pin Rehabilitation

In 1996, MDOT awarded a contract to temporarily remove the load off the pin and link via temporary restraints and push the lower pin back into place. Beneath one lane of traffic, HNTB proposed a vertical jacking assembly that would bypass the load on the link and pins via 4 post-tensioning bars (Figure 7).

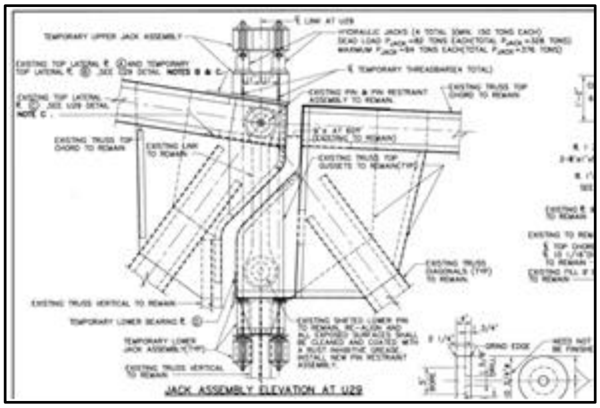

Figure 7 – Vertical Jacking Assembly

Prior to installing the vertical jacking assembly, the contractor attempted to reset the pin without removing the vertical load. The first attempt the contractor applied 675 kips of horizontal load in which his post-tensioning system failed resulting in post-tensioning bars passing traffic and into the river. The second attempt (Figure 8) the contractor redesigned the horizontal jacks and increased the horizontal load to 884 kips. The third attempt the contractor redesigned the horizontal jacks and increased the load to 1,325 kips, at which point no movement in the lower pin was recorded.

Figure 8 – Horizontal Jacks

The fourth attempt, the contractor redesigned the temporary restraints to include a vertical jacking assembly in which he applied 800 kips of vertical load to remove the theoretical dead load in the pin and link and then applied 727 kips of horizontal load to the pin, at which point no movement in the lower pin was recorded. Ultimately, MDOT and HNTB agreed any additional attempts would be futile, potentially cause damage to the bridge, and agreed to regularly monitor the pin for additional movement.

2010 In-Depth Inspection

In 2010 HNTB was contracted by MDOT to complete an in-depth inspection of the westbound US 84 Mississippi River Bridge in which non-destructive testing was completed on 8 of the 16 pins. The non-destructive testing revealed inter-component acoustic coupling (ICAC) between the lower pin at U29 downstream truss and the link which indicated the pin may have fused with the link. ICAC typically occurs when the ultrasonic wave from an ultrasonic examination is reflected from the transverse surface of an adjacent component, typically under high local bearing stress. The lower pin was still flush with the exterior gusset but an oblong hole in the gussets with a 3/8” gap between the bottom of the lower pin and the gusset was observed. The oblong hole was consistent with the assumption the lower pin was rotating about the gusset vs. the pin. It was the intention of the original designer that the pin would not rotate about the gusset and the bearing stress on the gusset from the pin be 0.56 F_y. (AASHTO allows 0.4 F_y for pins subject to rotation and 0.8 F_y for pins not subject to rotation)

The in-depth inspection also revealed the lower pin tie rod on U49 upstream truss had fractured, the cover plates missing, the pin was flush with the exterior gusset, and there was roughly ½” gap between the bottom of the lower pin (Figure 9).

Figure 9 – U49 Lower Pin

Pin and Link Replacement

Investigation

After the 2010 in-depth inspection, MDOT contracted with HNTB to investigate and make recommendations to address the lower pins at U29 downstream truss and U49 upstream truss. HNTB investigated four options:

1. Restrain and monitor
2. Rest pins
3. Replace lower pin
4. Replace lower and upper pins and link

Option 1 – Restrain and Monitor – This option is similar to the "no build" option in an environmental assessment and entails reinstalling the cover plates on the lower pins and continuing to monitor.

Option 2 – Reset Pins – This option would entail reusing the concept from 1996 and attempting to reset the lower pins

Option 3 – Replace Lower Pins – This option would entail using the vertical jacking assembly similar to figure 7, however, using destructive measures to remove the lower pin, boring a new hole in the gusset and link, and installing a new lower pin.

Option 4 – Replace Lower and Upper Pins and Link – This option would entail installing temporary restraints so that the upper and lower pins and link could be removed and replaced.

Risk Matrix

In order to review all four options, HNTB prepared a risk matrix for all four options listing the pros and cons to each option for MDOT and DOTD to complete. The risk matrix listed risk and probability/likelihood on a scale of 1 to 5 for the different options and components within each option.

Option 1 – Although MDOT had been monitoring U29 for over 15 years, this option represented the highest risk with moderate probability. With the bridge at its design life of 75 years, the pins could have shifted for several reasons such as wear or pier movement. Unfortunately, there was minimal information to support or dismiss theories. Ultimately, if the pin moved further within a 12 month period or became locked, there would be little to no warning signs outside of complete collapse. The probability was identified as moderate due to fact the lower pin at U29 downstream truss had not moved in 15 years, however, the pin at U49 upstream truss had. MDOT and DOTD decided this option was not preferred.

Option 2 – If successful, this option would represent the lowest risk; however, it was assigned a low probability of being successful. Based on the experience in 1996, the contractor was unsuccessful at resetting the lower pin at U29 and the non-destructive testing noted acoustic coupling between the lower pin and link which indicated potential fusing. If fused, the pin was not designed to rotate about the gusset which can be observed by the oblong hole in the gusset from the lower pin wear. The other lesson learned from the 1996 attempt was the fact the pin must be rotated prior to pushing back. It is anticipated the pin has grooves, and similar to a key in a lock, unless the pin is rotated while being pushed, any attempts would be futile. MDOT and DOTD decided this option was not preferred.

Option 3 - HNTB completed a comprehensive investigation of option 3 but the risk of damaging or finding damage on the existing link proved too high. Although the probability of damage on the existing link was low, the links are unable to be tested and are at their design life. Visual inspections have been limited due to special constraints and key sections would not be visible until the lower pin was removed. Contingency plans were contemplated in the event the links needed to be replaced; however, MDOT and DOTD decided this option was not preferred.

Option 4 – MDOT and DOTD unanimously agreed replacing the upper and lower pins and the link at U29 downstream truss and U49 upstream truss was the preferred option. This option had the highest probability of being successful with risk that could be mitigated through the design of HNTB's temporary restraints.

Pin and Link Replacement

In order to remove the pins and link, a temporary bypass that locks the joint from moving in all directions was developed. It was important the temporary bypass had internal redundancy plus alternate load paths to mitigate the risk of any one component compromising the bridge when the pins and link were removed. A series of bypasses were used to lock the joint and the Pier was expected to flex under thermal loads.

The temporary restraints were comprised of four main components; Upper Longitudinal Restraint, Diagonal Bypass, Lower Longitudinal Restraint, and Splice Plate (Figure 10).

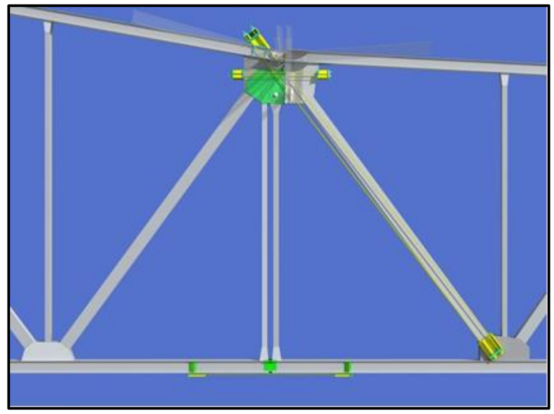

Figure 10 – Temporary Restraints

Upper Longitudinal Restraint (Figure 11) – Due to the fact U29 and U49 are expansion joints, the pins and link are free to rotate. When removing the link, the two gussets must be locked together. The upper longitudinal restraints use post-tensioning bars plus shim blocks to compress the two gussets together until the splice plate is installed. The upper longitudinal restraints are applied to both upstream and downstream trusses when removing the pins and links.

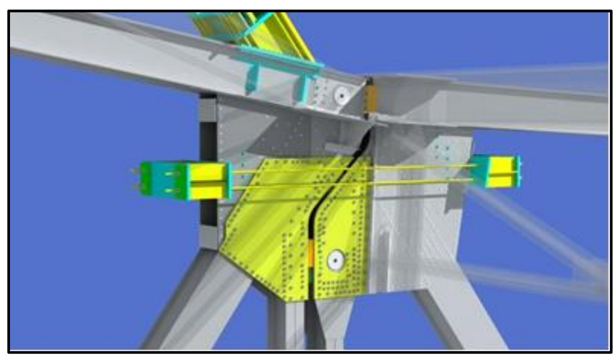

Figure 11 – Upper Longitudinal Restraints

Diagonal Bypass (Figure 12 & 13) –The majority of the load in the link is from the diagonal truss member on the suspended span (lower pin side of the gusset). The diagonal bypass was designed to unload the suspended span diagonal truss member and link. Once installed, the suspended span would bypass the lower pin and be transferred into the cantilever span gusset from above.

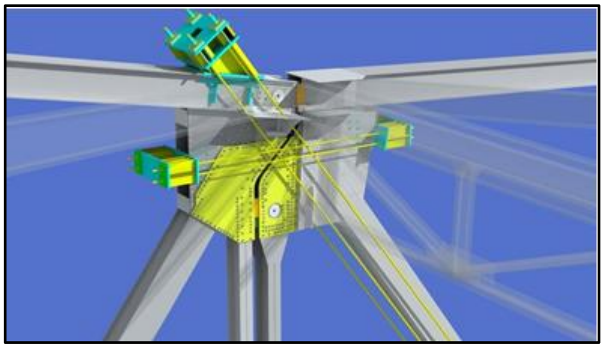

Figure 12 – Diagonal Bypass

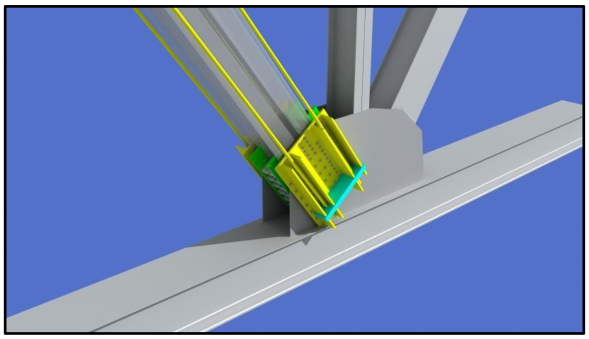

Figure 13 – Diagonal Bypass

Lower Longitudinal Restraint (Figure 14) – L29 and L49 bottom chord truss members currently are false chord members; however, they have similar properties to the other truss members. The Lower Longitudinal Restraint connects the two bottom chord members allowing them to act as an alternate load path. Shims were installed between the two members and post-tensioned to ensure they remained in compression.

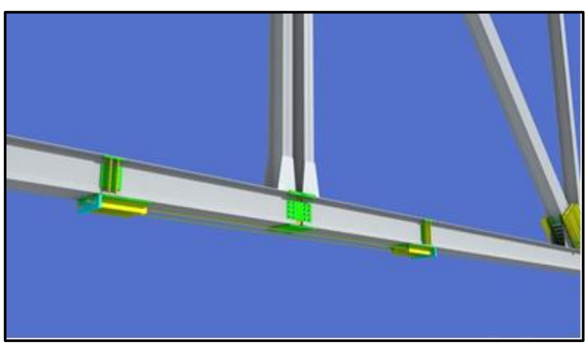

Figure 14 – Lower Longitudinal Restraints

Temporary Splice Plate (Figure 15) – As a means to control displacement and provide an alternate load path, a splice plate was designed to connect the suspended span gusset to the cantilever span gusset. The temporary splice plate required over 350 A490 bolts per truss which entailed removing existing rivets in the gusset or field drilling new holes. Because only one rivet could be removed at a time, each bolt was installed with a custom nut between the gusset and splice plate to ensure the splice plate bore uniformly on the middle nuts and middle nuts on the gussets. The force in the each bolt was calculated and bending in the bolt checked.

Cheek or shim plates were installed between the gussets and splice plate to provide additional friction force, however, the friction force was not included in the design of the splice plate or bolts.

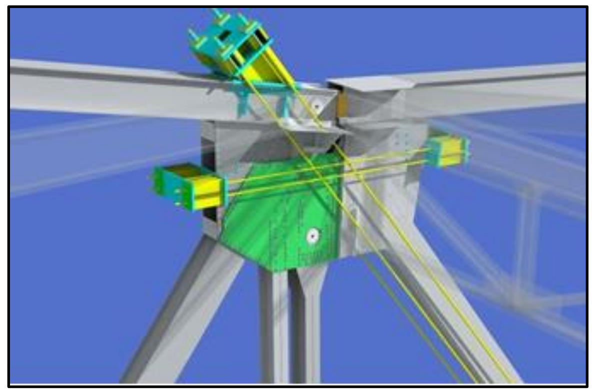

Figure 15 – Temporary Splice Plate

Redundant Load Path

In order to mitigate risk while the pin and link are removed, the temporary restraints were designed so that they had internal redundancy as well as additional load paths in the event one system is lost. Figure 16 and 17 & 18 illustrate the three load paths.

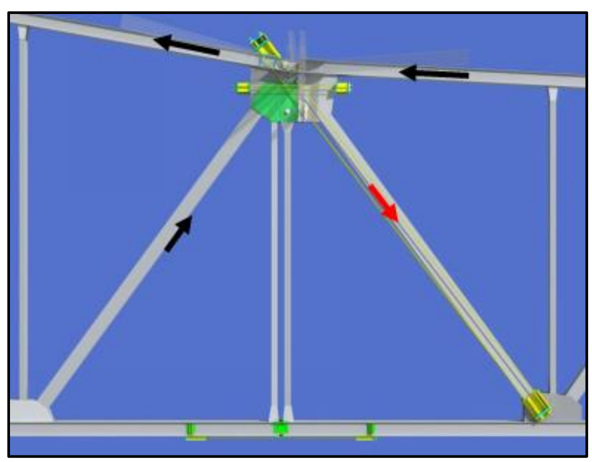

Figure 16 – Temporary Load Path A – Diagonal Bypass

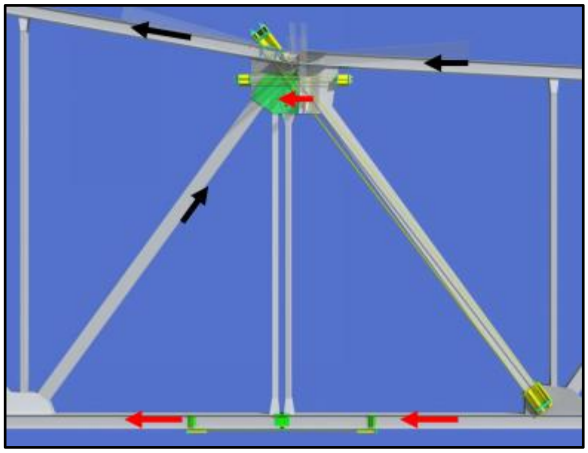

Figure 17 – Temporary Load Path B – Splice Plate and Lower Longitudinal Restraint

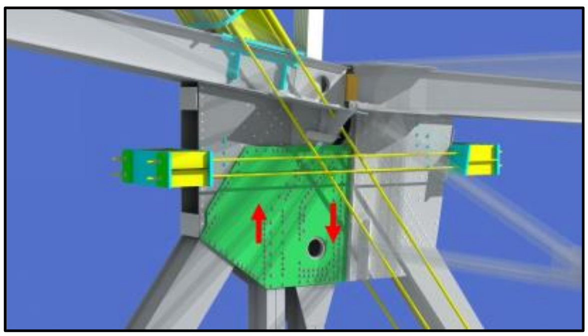

Figure 18 – Temporary Load Path C – Splice Plate

Construction

Overview

Typically MDOT projects are either design-bid-build or design-build. In the design-bid-build option, MDOT or its consultant prepares a set of plans and the project is advertised and any contractor may place a bid with the low bid winning. MDOT and FHWA agreed that due to unique nature of the work, plus the risk of a mistake or carelessness could result in collapse or severe damage to the bridge, MDOT decided to advertise a design-bid-build with a two-step process. Step one consisted of a request for qualification from contractors with a short list of qualified contractors. Two qualified contractors were shortlisted with both submitting bids based on plans developed by HNTB. C.E.C. out of Lafayette, Louisiana was the low bidder at $3.8 million and awarded the project.

Traffic Control

It was decided that because of the risk associated with removing the pin and link, the traveling public should not be on the bridge during the replacement. MDOT wisely decided to install crossovers and put traffic head to head on the eastbound bridge as well as re-synchronize traffic lights. Minimal to no queue was observed throughout the duration of the project.

U29 Misalignment

During installation of temporary restraints, it was observed that U29 upper pin gusset (cantilever span gusset) and lower pin gusset (suspended span gusset) near the lower pin were shifted inboard by 1.875" where they should have been centered with each other (Figure 19). The cantilever span gusset near the upper pin was shifted by ¾" and the cantilever span gusset appeared to have a slight rotation. Truss member U29-L30 also was kinked near the connection point at L30 (Figure 20). Based on review of the 1940 construction and erection records of the bridge, the suspended span from L22 was cantilevered out with the final tie-in between the suspended and the cantilever span at U29 (Figure 21). The misalignment was indicative of a geometric misalignment during erection of the bridge and the two spans were pulled together laterally in order to install the pins and link. It was speculated that U29 had locked-up lateral erection force which was being restrained by the existing pins and link.

In order to mitigate the locked-up erection forces, the anticipated load was calculated based on the observed deflection and checked against the top strut lateral restraints and found to be satisfactory. 200 plus additional A490 bolts were required at U29 splice plate to mitigate the additional bending plus an interior plate that engaged the entire bolt group installed. (Figure 22)

Figure 19 – U29 Offset

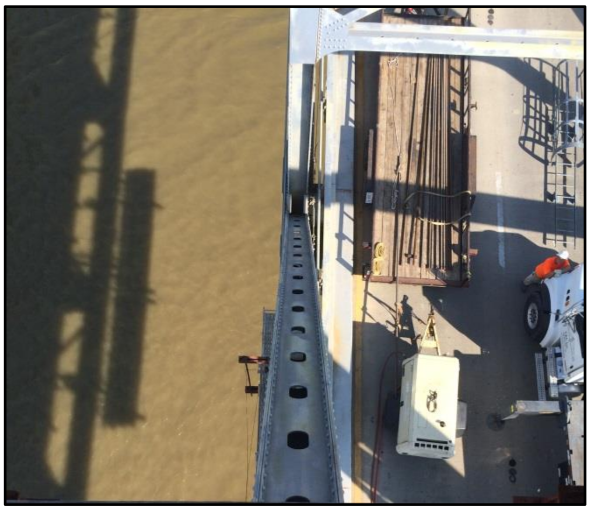

Figure 20 – U29-L30 Kink

Figure 21 – 1940 Construction

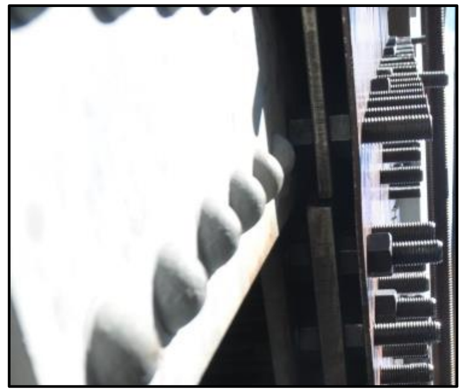

Figure 22 – U29 Middle Plate

Instrumentation

In order to ensure the temporary restraints were properly transferring the load off the pin and link as well as to evaluate any unforeseen losses in the restraints, strain gauges were installed on multiple truss members and the post-tensioning bars. The splice plates were also instrumented to evaluate stresses once the pins were removed.

Because the temporary restraints would change the boundary conditions of the bridge to fixed-fixed, adding additional load in the truss and forcing the Piers to flex, the Piers were inspected prior to and after locking each joint.

The initial inspection of the Piers revealed numerous cracks, as is expected for a mildly reinforced Pier at 75 years of age. No crack growth was observed in the post-inspection.

Based on the instrumentation output from the 8 links over a two week period it was obvious the bridge was behaving in a fixed-fixed condition. The existing link and pins would build up as much as 3.0 ksi of stress before breaking free and equalizing back to zero.

Sequence of Construction

As part of the contract plans, the contractor was required to submit a detailed sequence of construction demonstrating means and methods for removing the pin and link. The contract plans provided a suggested sequence of construction in which the contractor adopted with minor modifications. The contractor chose to remove the pins and link at U49 first, and based on lessons learned, some adjustments were made at U29. The following are the key steps to the sequence of construction with lessons learned from construction:

Step 1 – Tension Diagonal Bypass (Figure 23 and 24). L48 – U49 diagonal bypass was tensioned to remove the load in the existing truss diagonal member, link and pin. Stressing operation were conducted in increments and member stresses observed to ensure the bypass was functioning as anticipated. U49 existing link change in force was monitored and U49 diagonal bypass was tensioned to 10% over the anticipated force, resulting in the change in force in the link to be within 1% of the anticipated load (Table 1). Although the entire load would not be released until the pins were removed, it was preferred to minimize the load in the existing link to avoid the pins from binding and prevent sudden movement resulting from pin removal.

Figure 23 – Tensioning of Diagonal Bypass

Figure 24 – Tensioning of diagonal bypass

Table 1 – Diagonal Bypass

Member	Δ Load	Anticipated Load
U49 Diagonal Bypass	836 kips	760 kips
L48-U49	580 kips	761 kips
U49 Link	660 kips	655 kips
U29 Diagonal Bypass	782 kips	740 kips
L28-U29	699 kips	740 kips
U29 Link	634 kips	640 kips

Prior to tensioning U49 diagonal restraint, upper and lower shims were installed. The upper shims would transfer any horizontal force in the diagonal restraint. The lower shims would not be required until Step 2 but were chosen to be installed during Step 1 (Figure 25 and 26). During the stressing of the diagonal bypass, the lower shim shifted transversely by ¼". As the diagonal restraints became fully engaged, it became clear that one of the post-tensioning bars was conflicting with the truss lateral bracing, potentially causing the shift at the lower shims. The portion of truss lateral bracing that was in conflict was cut further allowing the diagonal post-tensioning bars to adjust; however, because the upper bypass was engaged, the horizontal load from the upper bypass did not allow the shims between the two gussets to shift back horizontally.

Once the existing pin was removed and the new one installed, it was observed that the inboard and outboard lower gusset had walked out by ½”. Fortunately the new lower pin was made longer and the pin bore directly on the gussets; however, the pin extension beyond the gusset was minimal. Although the gussets did not appear to walk when engaging the diagonal restraints, the existing pins may have been restraining them, and once removed, the gussets were free to walk.

For U29, the lower shims were not installed until after the diagonal bypass was engaged and prior to tensioning the upper longitudinal restraint. An additional stiffener plate was also installed and as a result, U29 outboard and inboard gusset did not walk.

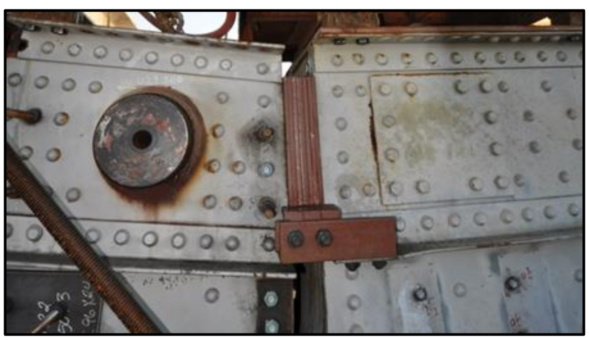

Figure 25 – Upper Shims

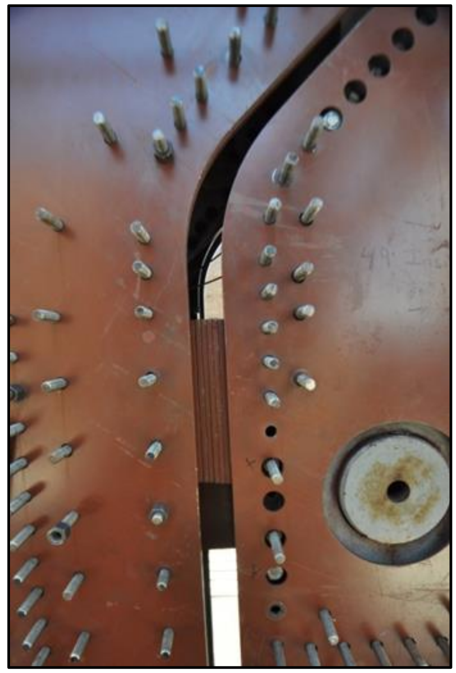

Figure 26 – Lower Shims

<u>Step 2 – Tension Upper Longitudinal Restraint</u> (Figure 27 and 28). Both upstream truss and downstream truss upper longitudinal restraints were tensioned to prevent the joint from moving longitudinally. The upper longitudinal restraints were designed for a 60 degree temperature drop but stressed to accommodate a 40 degree temperature drop based on the 10 day weather forecast.

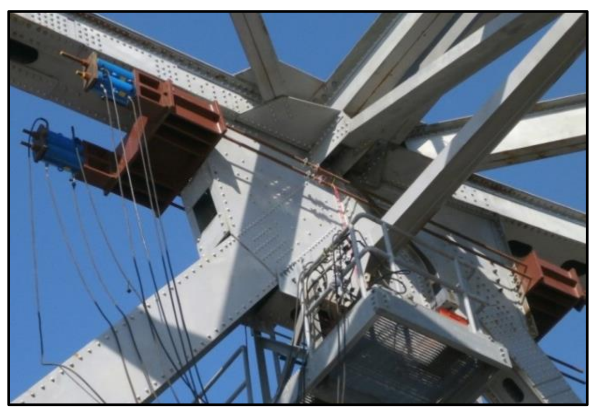

Figure 27- Upper Longitudinal Restraint

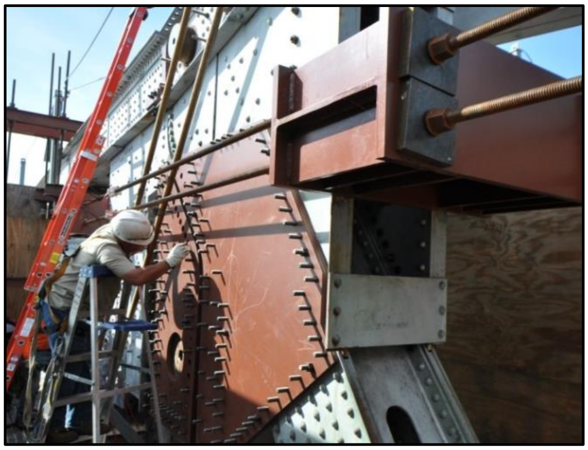

Figure 28- Upper Longitudinal Restraint

Step 3 – Weld Templates and Field Drill Splice Plate (Figure 29 and 30). Once the bridge was locked from moving, the splice plate templates were welded together and used to field drill the splice plates. Field drilling and installing the splice plates was challenging due to the 100 plus A490 bolts per face of gusset, but was completed with minimal to no incident.

Figure 29 – Splice Plate Template

Figure 30 – Field Drill Splice Plate

Step 4 – Install Top Strut Plates (Figure 31). Although there was a wind shear device at U29 and U49, the two top strut were connected together to provide lateral additional rigidity in the event there were any unexpected lateral forces when the link was removed.

Figure 31 – Top Strut Plate

Step 5 – Install Lower Longitudinal Restraints (Figure 32 and 33). Shims were installed between the two false chord members and post-tensioned together to ensure continuous bearing between members.

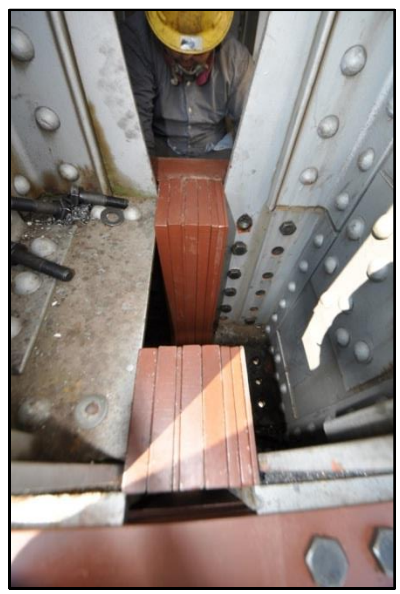

Figure 32 – Lower Longitudinal Restraint Shims

Figure 33 – Lower Longitudinal Restraints

Step 6 – Remove Pins (Figure 34 and 35). Because of the difficulty the previous contractor had with trying to reset the pins in 1997, the contractor elected to cut the pin with a diamond tipped wire saw. After cutting U49 upper pin, minimal change in force was observed in the link, and U49 and U29 splice plates saw about 1 ksi and 7.5 ksi of stress respectively (Table 2). It was speculated the higher stress in U29 was attributed to the misalignment of the truss. No movement was observed in either joint during removal of the pins.

The contractor attempted to push out U49 lower pin with hydraulics jacks after the upper pin was cut, but after applying 1,000 kips, minimal to no movement was observed. Ultimately, both faces of all pins required cutting and after the lower pins were removed, it became clear from the observed amount of grooving, the pins would not been able to be pushed out (Figure 36).

Figure 34 – Wire Saw

Figure 35 – Wire Saw Inside Truss

Figure 36 – U49 Lower Pin Drop Cut

Table 2 - U29 Splice Plate Maximum Stress

Inboard Gusset		
	Side 1 Stress, ksi	Side 2 Stress, ksi
Vertical Gage	0.472	-0.494
45 deg Gage	-4.614	4.264
Horizontal Gage	-0.985	-0.026
Outboard Gusset		
	Side 1 Stress, ksi	Side 2 Stress, ksi
Vertical Gage	3.09	-3.552
45 deg Gage	-2.066	4.117
Horizontal Gage	-5.631	7.535

Step 7 – Line Bore (Figure 37). The contractor line bored a 10½" to 10¾" hole through the existing gusset and new eyebars to ensure the new pins would bear properly and fit. With the existing link and pins removed, it was found that the existing upper pins at U29 and U49 were not plumb whereas the lower pins were. It is speculated this may have been part of the cause of the walking observed at the existing lower pins. It was also noted that U29 inboard and outboard gussets were not plumb and this was attributed to the locked-up erection forces in the gusset. New pins were bored plumb and in line with each other.

Figure 37 – Line Bore of Upper Pin

Step 8 – Install New Pins (Figure 38). Once the line bore was complete, the new pins were able to be installed with little difficulty. For the first location, U49, all four pins were machined and on site. However with the existing upper pin hole not being plumb and new hole required to be plumb, the existing upper original diameter of 10¼" was inadequate. The contractor sent U29 lower pin, which was 10¾" diameter, back to the machine shop to have it turned down to the needed diameter of 10½".

New pins were ordered for U29, however, they were not turned down until after the line boring was 50% complete.

Figure 38 – Installation of New Pins

Conclusion

After the new pins were installed, the temporary restraints were disengaged and load transferred to the new pins and eyebars. Table 3 includes the results from U29 and U49 eyebars. U49 eyebar loads appeared to be symmetric and behaved as a deep beam governed by Euler-Bernoulli. The inside eybar was 15% greater than the outside eyebar and it is thought that the inside gusset may carry more load due to the fact that the weight of roadway is transferred through the floor system which favors the inside gusset.

U29 loads were not as symmetric as U49 and heavily favor the outside gusset. The outboard eyebar was 44% greater than the inboard eyebar and it is thought that the misalignment in U29 was the primary culprit for the imbalance.

When comparing the total loads in Table 3, both U29 and U49 were within 3% of the dead loads shown on the 1940 contract plans.

Table 3 – U29 and U49 Eyebar loads

Location	U29	U49
Bar 1 (inboard)	70.9 kips	135.3 kips
Bar 2	105.4 kips	115.9 kips
Bar 3	119.9 kips	100.2 kips
Bar 4	115.6 kips	102.0 kips
Bar5	125.6 kips	104.1 kips
Bar 6 (outboard)	127.0 kips	115.7 kips
Total	656.5 kips	673 kips
DL in 1940 Plans	638 kips	655 kips

MDOT, HNTB and CEC all felt the project was a success and MDOT is anticipating replacing the remaining 12 pins and 6 links on a future project. The primary key to success was the partnership and determination between all the parties involved to make the project successful.