REHABILITATION AND STRENGTHENING OF BURLINGTON NORTHERN SANTA FE RAILWAY BRIDGE 482.1 OVER THE MISSISSIPPI RIVER MEMPHIS, TENNESSEE

by:

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ABSTRACT

Railroads are constantly looking for cost-effective ways and means of maintaining existing bridges and keeping them open to rail traffic due to the high capital cost of constructing new bridges.

This paper presents design and repair work done on the historic Burlington Northern and Santa Fe Railway Bridge over the Mississippi River in Memphis, Tennessee. The structural steel modifications and repair work allowed the BNSF to maintain rail traffic at this important location.

Bridge 482.1 is a National Historic Landmark, designated as such in 1987 by the National Park Service. It was designed by George Morison and constructed during 1888 to 1893. The single track, open-hearth steel truss bridge currently carries approximately 66,000,000 gross tons annually. The bridge has about 30 trains per day, mixed freight and unit coal and grain trains.

The areas of concern in the past few years have been the expansion panels in the suspended truss span and pin wear at the lower chord in the middle of the suspended span. HNTB and BNSF engineers, working in conjunction with BNSF field forces, inspected these locations and prepared design repair plans. The scope of the structural steel repair work has been to replace existing expansion joints, expansion stringer spans, transverse struts, floorbeam end connections, and bottom laterals and pin plates. Most recently, a lower truss pin joint was modified to restrain pin movement and ensure load transfer into the truss chords.

Key Words: bridge repair, truss bridge

INTRODUCTION

The purpose of this paper is to present the rehabilitation and repair schemes recently designed for the Burlington Northern Santa Fe's historic Bridge 482.1 over the Mississippi River at Memphis, Tennessee

DESCRIPTION OF BRIDGE

The Memphis Bridge is a unique structure and was designated a National Historic Landmark in 1987. This was the last major Mississippi River bridge designed by George Morison. This project was also his largest and most technologically ambitious structure. Design and construction of the bridge began in 1888, and the bridge was opened for train traffic in 1892. Completion of the approaches and other incidental work was completed in 1893. Two other notable engineers who worked on the project were Ralph Modjeski and Otis Hovey.

The Memphis bridge design was significant in that the bridge was one of the first crossings of the lower Mississippi River. The character of the Mississippi changed after joining with the Missouri River, taking on more of the characteristics of the Missouri, including more frequent and violent floods. The flood season also increased, leaving an effective working season of only five months.

Construction of the bridge was important because by the mid-1880s, ten rail lines entered Memphis and rail traffic over the lines was often congested at Memphis by the transfer steamer operation across the Mississippi. Memphis was also a point of increasing importance being situated in the increasing line of industrial traffic from the Southwest to the Gulf and Atlantic coasts.

George Morison's substructure design was long masonry piers founded on heavy timber caissons (George Morison, unpublished, The Memphis Bridge, A Report to George H. Nettleton, President of the Kansas

City and Memphis Railway and Bridge Company, by George S. Morison, Chief Engineer of the Memphis Bridge, 1894).

The Memphis Bridge was not founded on bedrock but on the alluvial clays below the riverbed sand. Mr. Morison designed the foundations to provide a reduced dead weight by specifying high quality masonry and using hollow construction in the bottom portion. Morison also designed the foundation base to distribute the bearing pressures over as large an area as possible. The foundations were also heavily protected from scour and sunk by the plenum caisson process.

The superstructure design featured the longest span length built to date in America. The long span of 790' was required to meet the Act of Congress authorizing construction that stipulated a 770' clear channel. The charter also required a solid deck to provide for the passage of trains, wagons, and vehicles of all kinds and for the passage of animals. The superstructure over the main channel was erected by cantilever method, which eliminated the falsework and allowed the use of slightly thinner piers than would normally be used. Thus, the increased superstructure design was slightly offset by the decreased substructure costs.

The bridge from north to south consists of a steel viaduct made up of deck plate girders on steel towers approximately 2334' long, a 338'-9" deck truss span, a 451'-8" suspended truss span, a 169'-4 1/2" cantilever truss arm, a 621'-0 1/2" central truss span, a 169'-4 1/2" cantilever truss arm, a 451'-8" suspended truss span, another 169'-4 1/2" cantilever truss arm, a 225'-10" anchorage arm and three approach girder spans at 28'-2 3/4" each, for an approximate total length of structure of 5015'. The bridge has an open timber deck with an inner guardrail. The expansion floor system panels are located adjacent to the suspended spans and the 169'-4 1/2" cantilever truss arms.

The bridge crosses the Mississippi River, lies in a general Northwest direction and has a single track. The bridge is situated between a Union Pacific Railroad bridge and the Interstate 55 bridge. The Union Pacific bridge is upstream of the BNSF bridge.

TRUSS FLOOR SYSTEM EXPANSION PANELS

The BNSF contacted HNTB in 1994 about inspecting and recommending repair or replacement options for the deteriorating truss system expansion joints.

There are three expansion joints in the truss spans located at the ends of the cantilevered spans (two in the south cantilever spans and one at the south end of the north cantilever span). See Figure 1 for the location of the joints. The original plans detail the expansion assembly as a link-pin arrangement framed to the expansion panel stringers. The three joints deteriorated due to corrosion and mechanical wear. The expansion stringer in the last panel of the cantilever arms of the truss spans and adjacent to the suspended spans was out of level with the stub brackets attached to the floorbeam. The stringer span was about 3/4 to 1 inch low at these locations.

A review was made of the original design, shop plans, and past correspondence. The pins were last replaced in 1952 and the field inspection led to the conclusion that the dropping of the stringer span adjacent to the joint was due to mechanical pin wear and deterioration of the top flange angles of the stub stringers and the expansion stringer. The plan files show that repairs were made to the expansion joint area during 1949 to 1952. The short expansion bars were replaced in 1949, floorbeam web repairs were made in 1951 and the casting at the bottom of the expansion stringer was replaced in 1952. The pins in the expansion joint were also replaced at the time other expansion joint repairs were made. The casting and short expansion bars were detailed with oil grooves. The location of the casting and expansion bars made routine maintenance a very difficult operation.

The field inspection in 1994 verified that the top rollers were rusted to the pin and stringer bearing plate and that the oil holes were plugged with dirt. The assemblies at the expansion joints shifted towards the centerline of track and the inside of the assembly were wearing into the stub bracket plate since the link-pin arrangement was not functioning as originally intended.

The following additional conditions were noted:

- The top angles of the stub brackets were very badly corroded and cracked.
- The top angles of the cross frame in the stringer span adjacent to the expansion joint were severely corroded.
- Holes in the floorbeam web on the backside of the expansion joint at the bottom of the stringer to floorbeam connection had developed. A reinforcing plate had been riveted to the floorbeam web on the expansion joint face to strengthen this area. This plate was added when the other expansion joint repairs were made.
- The floorbeam web below the bottom of the stringer was buckled locally due to a horizontal force induced into the web by a force couple from the stub stringer.
- The transverse strut connecting the lateral bracing member in the expansion panel to the bottom chords was also heavily corroded. The expansion joint struts had been repaired in the past by splicing angles and plates to the member. The original configuration of the transverse strut has contributed to the deterioration of the member as the original top member was fabricated of a 12" channel with the flanges turned up. By design, this detail retained debris and water. The pin connections at the lateral connections to the chord gusset plate were also heavily corroded.

The leaking of the fire protection waterline expansion joints had exacerbated the extensive deterioration at the expansion joint panels. Weep holes drilled into the 12" channel were not effective because of accumulated debris.

After meeting with the BNSF, it was decided to detail an assembly that would require minimal maintenance in the future. The following design concepts were adopted. See Figure 2 for a typical section at the expansion joint.

Expansion Joints

Based on results of the inspection and concerns of the BNSF, it was decided that the expansion joints in the floor system should be rehabilitated due to extensive corrosion and wear in the pins and bars of the expansion joints. The existing joints were last rehabilitated in 1951 by replacing pins, bars and castings. Because of the deteriorated condition of the stringers at the expansion joint, it was decided that the stringers would be replaced in conjunction with the expansion joint replacement. Repair schemes for the existing stringers were considered but complete replacement was determined to be more economical.

A rolled beam section fabricated to be installed as a complete unit replaced the expansion panel stringers.

Review of the existing plans indicated that a stringer saddle device similar to what has been used at other BNSF bridges could be designed to handle the anticipated magnitude of movement at the expansion joint. The saddle connection utilized existing rivet holes in the floorbeams. The use of the saddle would cause some increase in the eccentricity of stringer reaction to the floorbeam; however, details were developed to minimize eccentricities. Expansion in the truss floor system was accommodated through the use of a Teflon faced plate attached to a saddle bracket, allowing the stringer span to expand and contract. The saddle and bracket was designed to accommodate a total movement due to temperature and live load of 20 inches. The assembly was made up of plates welded to form the saddle. The saddle was designated fracture critical material and was stress relieved after fabrication.

Transverse Strut at Expansion Joints

It was decided that the existing struts at the expansion joints should be replaced because of extensive deterioration. The built up sections were replaced with a structural tube section that replaced the original area of the built-up strut sections. The tube shaped member was used to eliminate water and debris accumulation on the strut since the existing waterline on the bridge has a tendency to leak at the truss expansion joint.

Bottom Lateral Bracing

The pins, lateral braces, and pin plates riveted to the existing bottom chord gusset plate were also replaced. The pin plates that are riveted to the gusset were fabricated with full heads. This detail has lead to the formation of pack rust between the lateral bracing bars and the rivet heads. A temporary strut was utilized during the removal of the existing strut and installation of the new pin and transverse strut. The new pin was slightly increased in diameter and the existing hole rebored to permit reuse of the existing lateral gusset plates, and to minimize disruptions to the bottom truss chord.

REPAIR OF PINNED TRUSS JOINT

In October 1998, the Burlington Northern Santa Fe Railway Company contracted with HNTB to investigate truss pin wear on Bridge 482.1 over the Mississippi River in Memphis, Tennessee. The specific area of concern was the group of pin plates around the lower truss pin at joint L8 of the suspended truss span. A bridge inspector had noticed a 3/8” gap between the pin’s surface and the surrounding plates, 1/8” wear of the pin and excessive movement of the pin under live load. HNTB’s tasks were to design a scheme to repair the joint and reduce the pin movement and to develop shop fabrication plans and field erection details.

The lower truss joint at panel point L8 comprises the lower chord member, two opposing, box shaped, web diagonals and an 8” diameter pin with end caps (Figure 3). Since there is no vertical member framing into the joint, all vertical floorbeam loads are carried through the truss pin and into the truss diagonals. Any repair scheme would have to insure that the loads from the pin continue to be transferred into the diagonals as well as arrest the movement of the pin.

Selection of Joint Repair Scheme

The repair methods contemplated for the joint included: driving steel wedge-shaped shims between the pin and the pin plates; boring a new, larger diameter pin hole through the pin plates and installing a cylindrical steel bushing around the pin; and developing a method to wrap additional members around the pin and secure them to the truss diagonals. The option using steel shims was not pursued as a permanent solution since the result would likely have been uneven bearing pressures on the pin with no positive mechanism to stop the pin movement. More consideration was given to the option of boring an oversized pinhole through the joint so a steel sleeve bushing could be added. This scheme would develop a uniform and full bearing between the pin and the truss members. Preliminary details were created and a machine shop was contacted about developing a drill that could be used in the field to bore the hole. The drawback of this idea was that a large amount of falsework would be necessary to hold the geometry of the joint while drilling around the pin and inserting the sleeve. The cost of engineering and manufacturing the drill, the cost of the required falsework and the possible instability of the joint during construction combined to make this alternate less attractive.

The decision was made to design a system of tension ties that would encompass the pin and transfer the pin load entirely thorough this new system into the diagonal truss members. In effect, the proposed system would clamp around the pin and transfer the forces further up the diagonal, relieving the need for bearing between the pin and the pin plates.

Design and Detailing of Repair System

The system that was designed consists of two structural elements inside of and parallel to each diagonal truss member. One group of elements, the ties, transfers tensile forces between the pin the truss member. The tensile ties consist of hot rolled, epoxy coated, alloy steel post-tensioning rods that pass through a machined saddle block that fits around the underside of the pin (Figure 4). The ties are anchored further up the diagonal to a weldment frame that is bolted with high strength bolts to the web plates of the diagonal. The compressive forces are carried between the pin and the member with an element termed compression strut. Weldments also are used for the strut elements that have a semi-circular contour on one end to bear on the top of the pin surface. The struts are likewise bolted to the webs of the truss members.

The design forces for each portion of the retrofit system were based on the average of the capacity of the member that they were to reinforce and the design loads as indicated on Morison's original design stress sheet. The new design further specified that the tie rods receive enough tension during installation that they do not experience a stress range due to live load and impact forces.

Much effort was spent on the detailing of the individual pieces of the reinforcing system. The original shop drawings from 1890 were used to determine available clearances and rivet locations. Since the pin packing diagram on the shop drawings indicated the pin plates to be positioned tightly at the ends of the pin, the new system had to make use of the unoccupied area toward the center of the pin. At the same time, the retrofit could not increase the bending stresses in the pin. Therefore, the saddle blocks and their opposing compression struts were located in the same plane on opposite sides on the pin. The weldment pieces were sized to fit inside of the truss diagonals and to be manageable using a small hi-rail mounted boom. This required the weldments that secured the upper end of the tie rods to be fabricated in sections that could be field bolted together. Shim packs were provided to allow a more precise final alignment of the new material inside of the tightly packed joint. Shop fabrication details for all of the required material were provided in the design plans, which were issued in April 1999.

Fabrication and Installation

Roscoe Steel out of Billings, Montana fabricated the structural steel material for the job. Construction began in October of 1999 when a specialty contractor installed scaffolding under the truss joint to provide a safe working environment over the Mississippi River. The BNSF bridge gang performed the installation of the repair system. Working between trains, they temporarily removed lacing bars and batten plates from the truss members as indicated in the design plans. Prior to placing any new material against the pin, the workers cleaned the pin and coated it with a lubricant developed for open weather, high contact pressure applications. All of the material was installed inside the truss members without undue difficulty. Once the pieces had been bolted into their final location the tie rods were tensioned to transfer the forces into the new system. The design tension in the tie rods was obtained by jacking them to a specified elongation and locking off with double nuts.

CONCLUSION

To date the repairs and modifications to the expansion panels have performed well. BNSF regularly inspects the bridge with a snooper crane and no problems have been encountered. The repair scheme used at the pinned truss joint developed a new load path to eliminate concern involved with uneven bearing of the pin plates at the joint. The repair also significantly reduced the movement of the pin relative to the truss under live loading. The joint repair was inspected in June 2000 and continues to perform adequately. These modifications to the existing bridge have allowed BNSF to maintain traffic over this important and historic structure.

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Mr. Jeffery Johnson - Manager of Structures Design

Mr. Michael Hunt - Bridge Inspector

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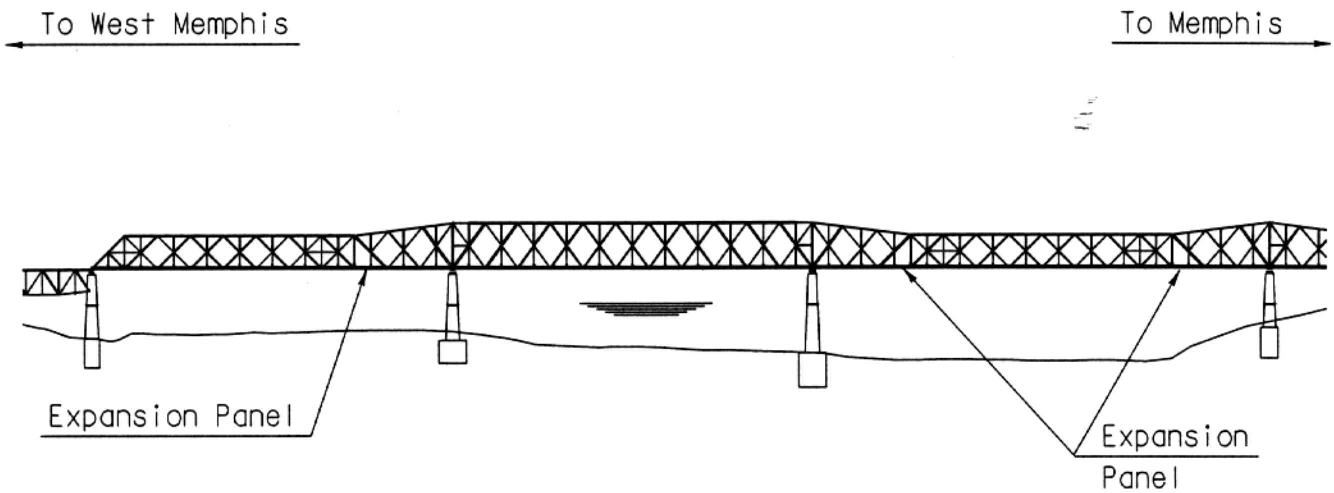

Figure 1. Elevation of Bridge 482.1

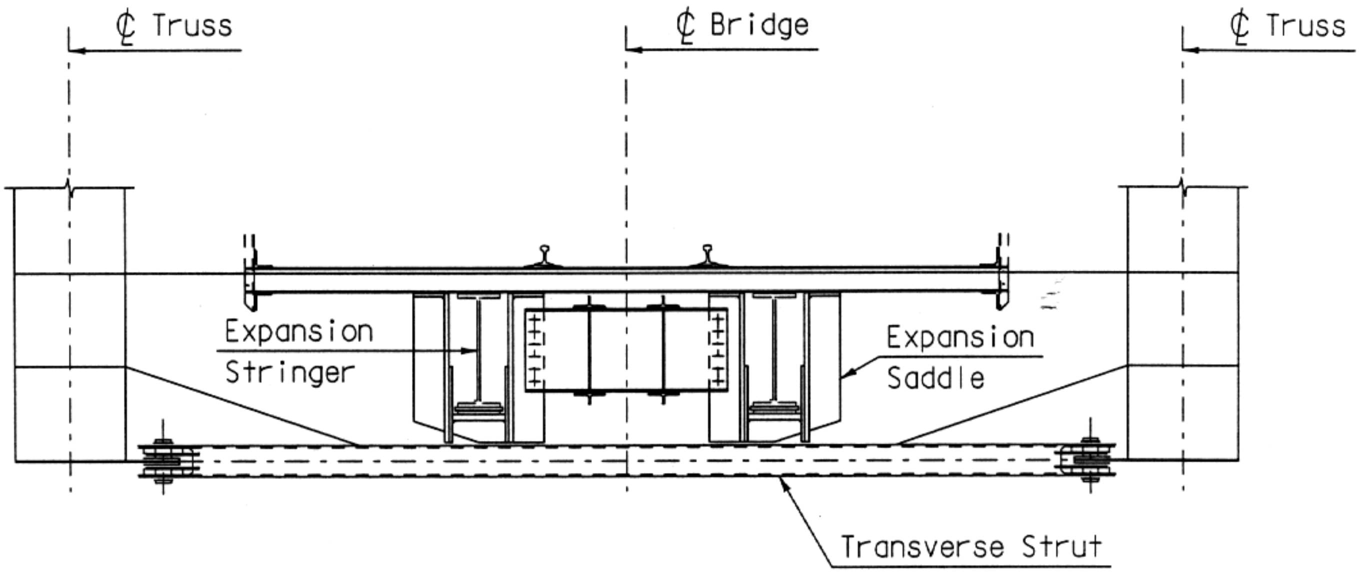

Figure 2. Typical Section - Expansion Joint

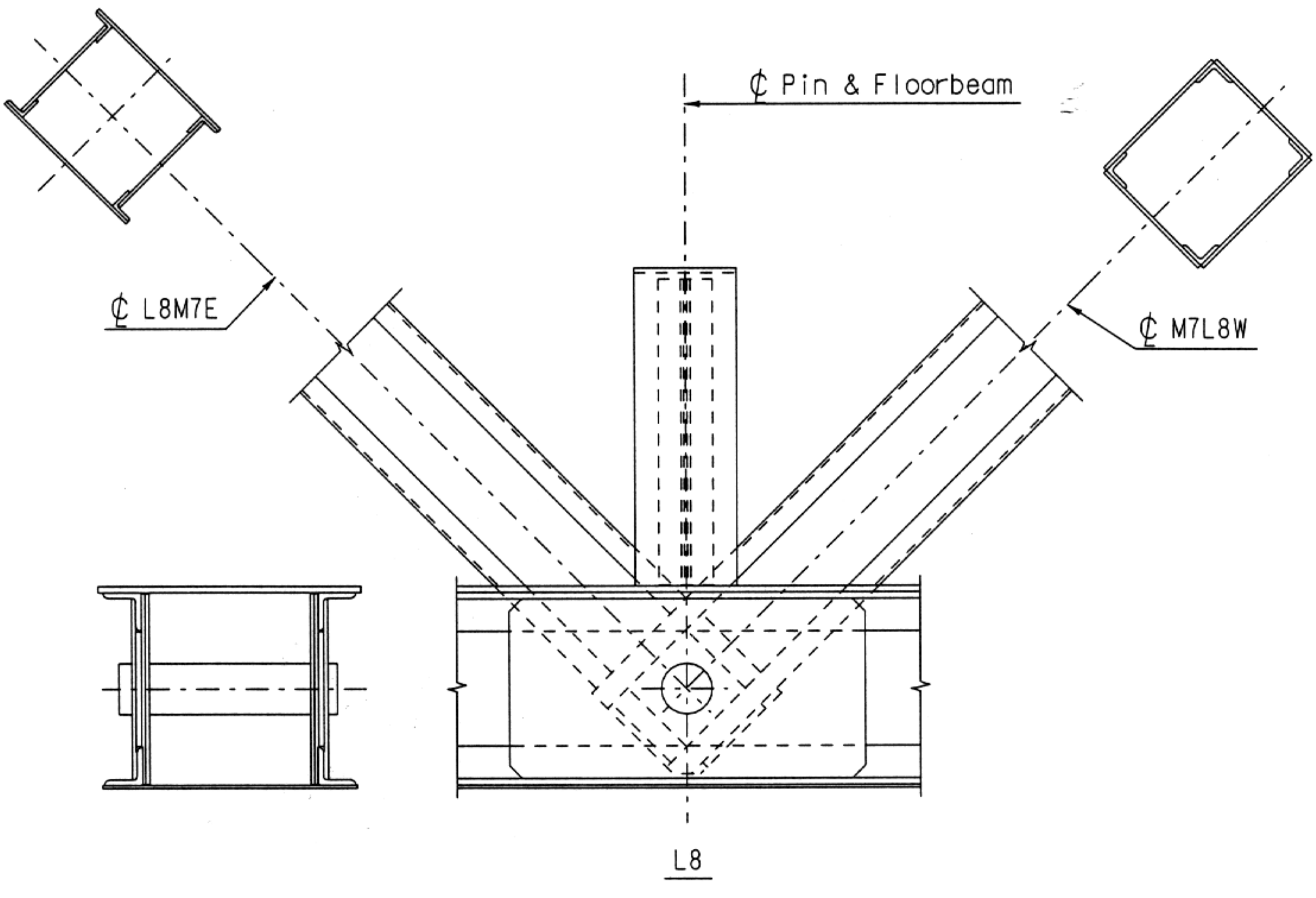

Figure 3. Truss Joint L8

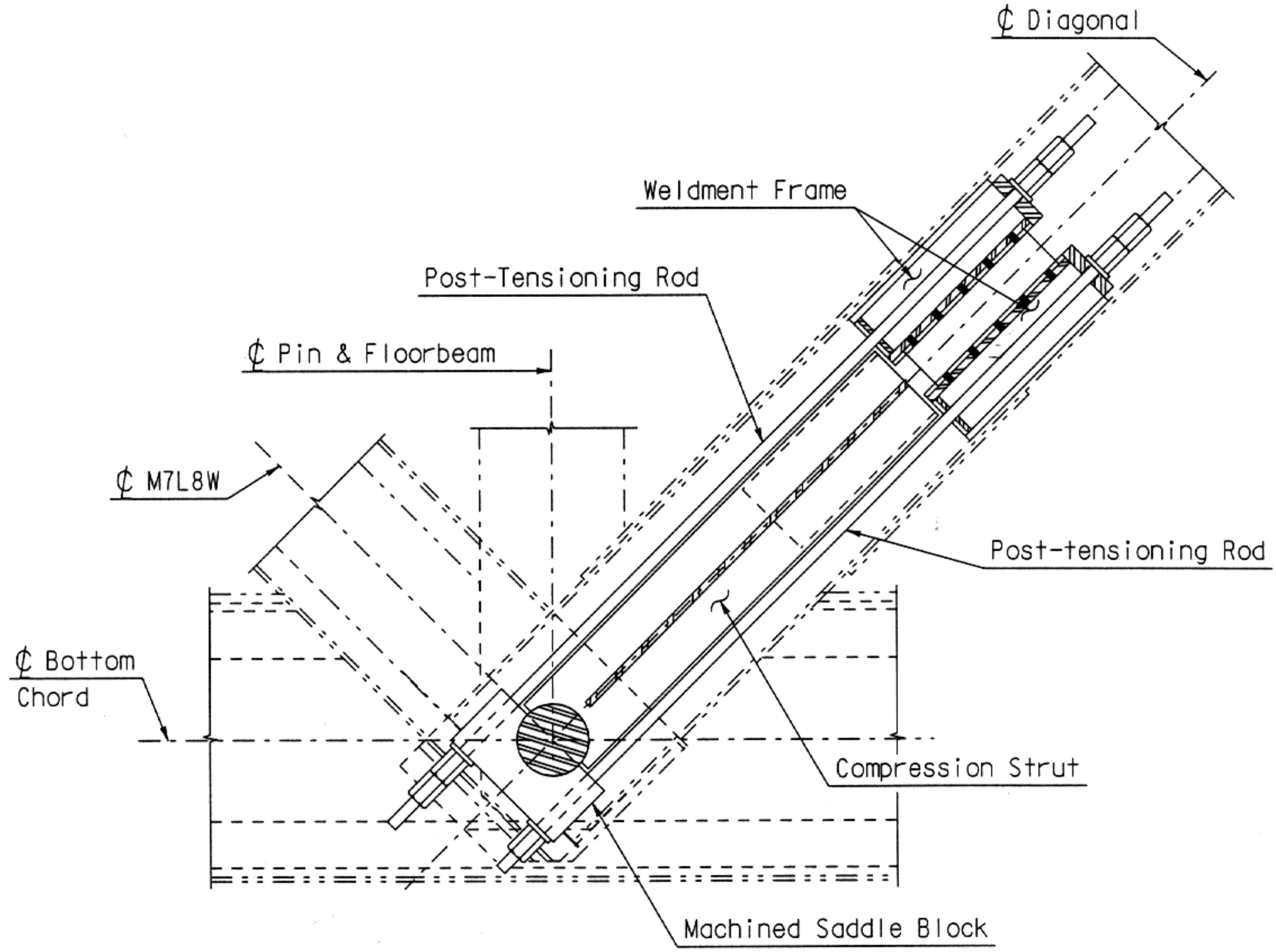

Figure 4. Repair System Inside Truss Diagonal