HEAVY MOVABLE STRUCTURES, INC.
SIXTEENTH BIENNIAL SYMPOSIUM

September 19 – 22, 2016

Three Mile Creek – Pivot Bearing Investigation, Design, and Replacement

Tyler J. Miller, P.E.

Modjeski and Masters, Inc.

TAMPA MARRIOTT WATERSIDE HOTEL AND MARINA
TAMPA, FLORIDA

Issues with a Three Disc Pivot Bearing

A three disc pivot bearing assembly, comprised of a double-convex bronze disc between two concave steel discs, is common on many center bearing swing spans built in the early 20th century. The pivot bearing location on a general swing span schematic and the typical components of a three disc pivot bearing are shown on Figures 1 and 2, respectively. The bearing discs rest on a lower casting anchored to the pier and support an upper casting mounted to the swing span. An oil box encloses the discs and is bolted to the lower casting with gasket material to prevent leakage of the bearing oil.

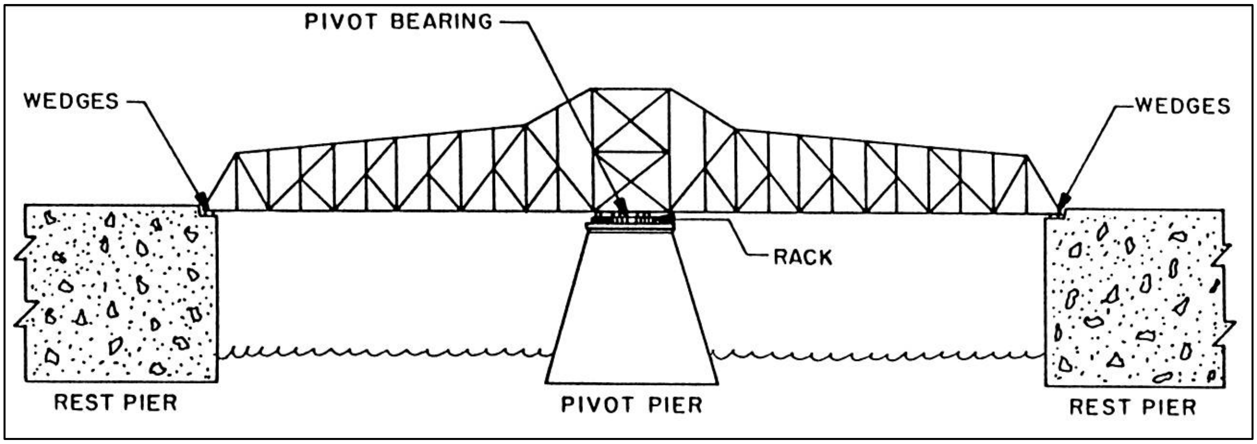

Figure 1. General swing span schematic

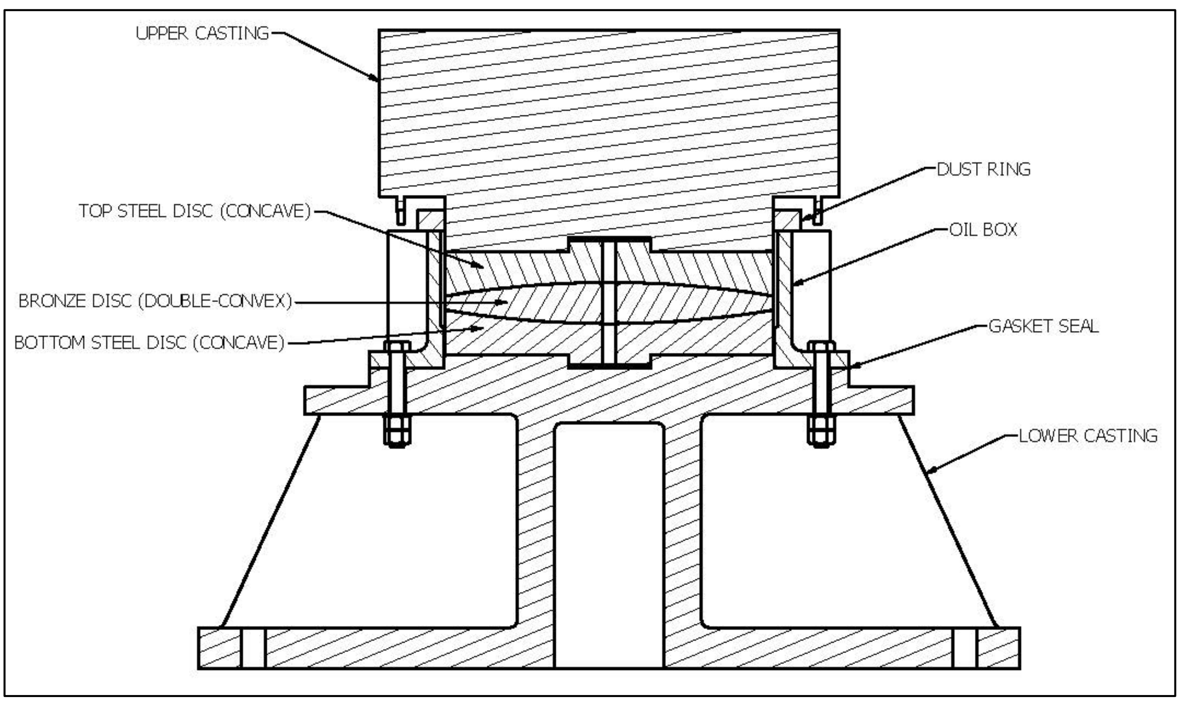

Figure 2. Common three disc pivot bearing assembly

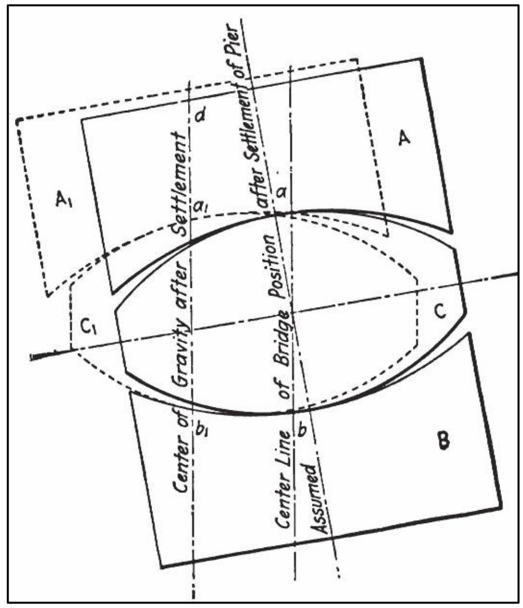

Figure 3. Exaggerated bearing disc position resulting from pier settlement. Retrieved from Movable Bridges Vol. 1, by Oits Ellis Hovey, 1926.

Although the three disc pivot bearing assembly is presently operational at many swing bridges, the design can become problematic due to its inherent unstable nature. Pier settlement or span imbalance will often intensify the issue. Any position adjustments are made by middle and upper discs relative to the fixed lower disc, creating a new center of rotation as shown in Figure 3. The double-convex middle disc and the downward concave upper disc are very sensitive to equilibrium changes and can become displaced. Once displacement occurs, there is no self-correcting tendency to return to an original position. The discs can protrude beyond the lower disc to the point where they apply force on the oil box. This unintended contact force on the oil box may loosen or break mounting bolts and damage the gasket seals, preventing the retention of bearing lubrication and accelerating wear. Displaced discs may also cause the swing span to lean more heavily to one side causing wedge operational issues or excessive wear in the balance wheel components. The pivot bearing discs are inaccessible due to the oil box enclosure. Therefore, diagnosis of a problem can be difficult and the shifted discs issue may be disguised as excessive span imbalance. The only potential solution to "reset" the existing bearing assembly is to jack the entire swing span and manually reposition the discs.

Case Study – Three Mile Creek Swing Bridge

The Three Mile Creek pivot bearing replacement project is an excellent case study of a problematic three disc pivot bearing disguised as other issues. The Three Mile Creek Bridge is a center bearing, deck girder swing span carrying two railroad tracks over the Three Mile Creek in Mobile, Alabama. The swing span is 152 feet long with shorter approach spans at each end. The operating drive system is comprised of a single pinion engaging the pier mounted rack, powered by hydraulic motors.

Many of the indications discussed above were present yet none of them initially pointed to a pivot bearing problem due to other issues at the bridge. Further investigations eventually revealed the pivot bearing as a major problem. An emergency pivot bearing replacement project was initiated after rapid deterioration of the bearing became evident through documented findings from site visits over a period of a year and a half. Rather than replace-in-kind, designs for the new pivot bearing assembly sought to improve stability with a two disc design as well as incorporate a pivot disc container.

The problematic bearing assumptions were confirmed once the oil box was removed during construction. It was discovered that the existing top steel disc had shifted ½" horizontally and was pressing against the oil box. Once the span was re-centered on the new bearing assembly, all of the related operational issues disappeared immediately. The following sections provide highlights of the Three Mile Creek pivot bearing replacement case study.

Inspection Findings and Pivot Bearing Investigation

The bridge appeared to have excessive transverse span imbalance. The east balance wheels displayed signs of high loading conditions. Deterioration of the balance wheel components was noted over the course of several site visits to the point where up to 1” of metal end flow was present at the outboard edge of each wheel. The east balance wheel shaft bushings had excess clearance due to wear. Figure 4 shows the 3/8” thick bronze bushing that was worn through, allowing the shaft to press into the steel housing.

Figure 4. East balance wheel shaft bushing deterioration from excessive loading conditions.

The balance wheel shaft was also shifting axially relative to the balance wheel with 2” of the shaft protruding inboard of the wheel housing. The east balance wheel track segments, in Figure 5, also displayed severe wear and plastic deformation between the radial segment stiffeners. Plastic deformation between stiffeners created peaks and valleys along the track riding surface. During operation, the span would tilt each time the balance wheels traversed a valley in the track. Increased loads in the turning machinery could be observed each time the balance wheels had to “climb” up to a peak in the balance wheel track.

Figure 5. Severe wear and plastic deformation of the east balance wheel track from excessive loading conditions. Note peaks (red arrows) and valleys (white arrows)

Figure 6. Hydraulic power unit room positioned outboard on the east side of the span.

At some point in the bridge's history, a large hydraulic power unit (HPU) room and platform was installed on the east side of the span, outboard of the superstructure, shown in Figure 6. This appeared to cause a significant transverse imbalance; however, balance calculations showed that appropriate transverse counterbalance weight was installed on the west side of the span. It was concluded that balance wheel and track damage was most likely a result of the pivot bearing deterioration, especially due to the noted problems associated with the three disc pivot bearing design discussed above.

In addition, the oil box gasket seal had failed and all of the pivot bearing oil box mounting bolts were loose, sheared, or missing. However, this was not a clear indication of pivot bearing issues, as described above, due to anchoring issues with the rack. The radial struts in Figure 7 had previously been installed to help secure the rack, which had only a few sound anchor bolts remaining. The struts were connected to the pivot bearing oil box and transferred torque to the box during each span operation. These conditions made efforts to retain oil in the pivot bearing futile. Improper contact between a potentially shifted pivot bearing disc and the oil box could have contributed to these issues, but the rack securing system was a major contributor.

Figure 7. Existing radial struts to secure the rack were connected to the pivot bearing oil box.

During initial visits, the east side of the pivot bearing upper casting was observed to briefly contact the top of the oil box during operations creating a periodic squealing noise. After period of a year and a half, the east side of upper casting had worn a ¼" deep groove into the top of the oil box stiffeners and the contact and squeal noises had become constant during operation. Figure 8 displays the increase in wear by comparing photos from those two site visits. Strain on the operating machinery was visually and audibly observed to be greater due to increased friction.

Figure 8. Change in unintended contact and wear between the east side of the upper casting and the oil box over a period of a year and a half.

Emergency Replacement Challenges and Design Features

The Three Mile Creek swing span supports significant rail traffic (located adjacent to a large rail yard) as well as navigation traffic. Minimizing outage time for the pivot bearing replacement was critical. A 12 hour outage on Thanksgiving Day, 2014 was selected as the target installation date. The project was initiated toward the end of August, 2014, leaving a little over three months for design and fabrication of new components.

Field inspections supported the assumption that the upper and lower castings could be reused and only the three bearing discs and oil box needed replaced. A two bearing disc design, shown in Figure 9, was chosen to replace the existing disc assembly to add stability and eliminate the tendency for disc displacement. Another major change in the replacement design was to use a pivot disc container instead of the existing oil box arrangement. Instead of the three discs resting directly on the lower casting, encircled by the oil box, the pivot container would have a solid base and sides to act as a housing bowl for the bearing discs and would mount on the top of the lower casting. The vertical height necessary to include the pivot container while maintaining the same span elevation was available with the removal of one disc in converting to the two disc assembly.

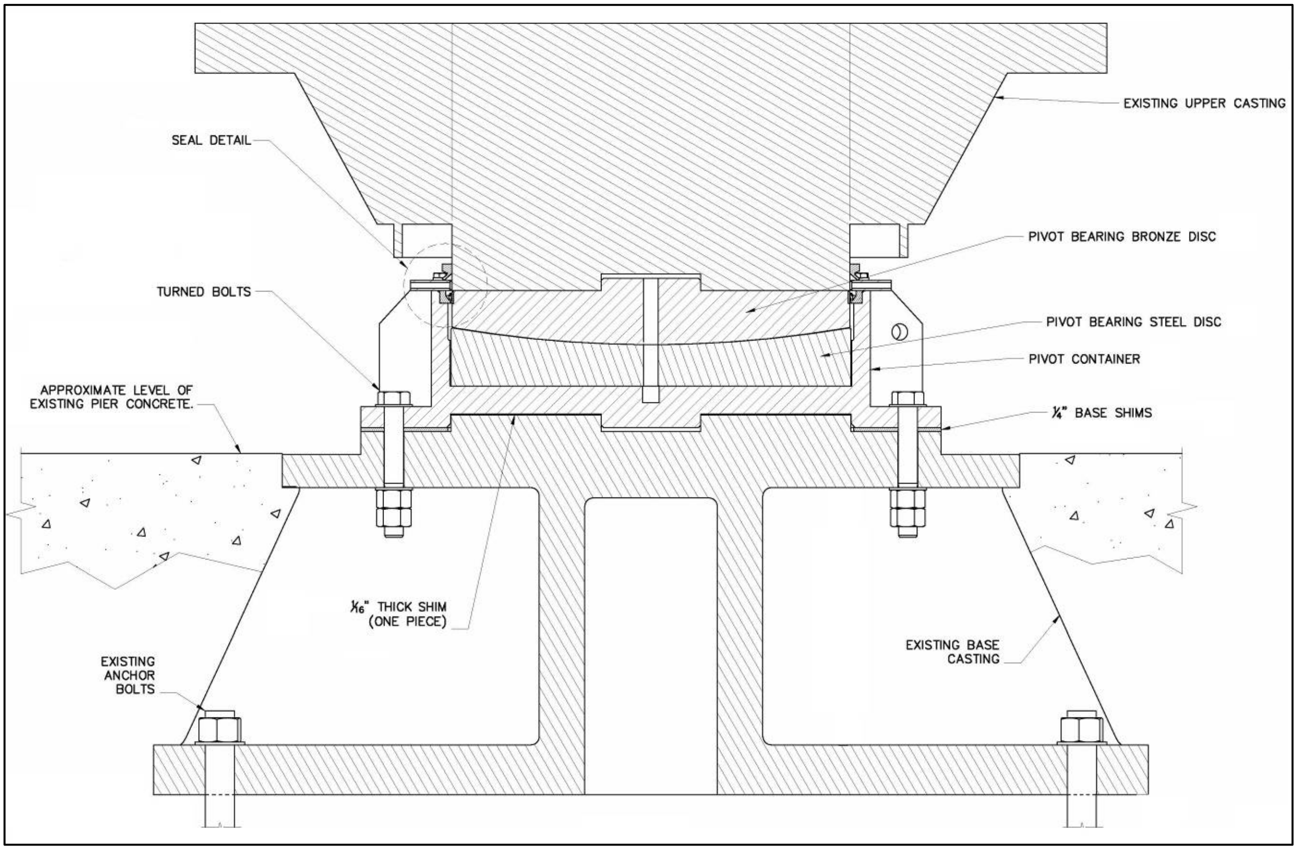

Figure 9. Proposed new two disc pivot bearing assembly.

The pivot container design has several pros and cons compared with the standard oil box configuration. Installation of the pivot container assembly is much easier and faster, which was a major benefit for this project. Pre-assembly of the pivot container and bearing discs allowed for a quick installation as one complete unit. Alternatively, an oil box design requires assembly of each part individually on-site with added time necessary to give care to achieving a satisfactory seal with the gasket material. Another major benefit of the pivot container design was the long term retention of bearing oil without the need to maintain the sealed oil box gasket. Due to the lack of joints or mating surfaces in the continuous bowl shaped design of the pivot container, the drain port is the only location where leakage could occur. However, because the oil box is one solid piece, one disadvantage is the inability to open up the sides to clean and inspect the bearing discs in service, as is possible with an oil box. This specific bridge had been known to have flood waters which would inundate the existing pivot bearing. The new pivot container design would not afford an easy method to clean the discs after such event other than an oil flush. It was decided that a seal arrangement would be included to prevent water and debris from entering the pivot container in the event of a flood.

The poor condition of the existing rack anchor bolts created a major construction sequencing challenge. Replacing the pivot bearing would require removal of the existing temporary rack stiffening struts. Once these struts were removed, it was clear that the rack anchor bolts could not solely support the rack gear during bridge operation. Therefore, re-securing the rack had to be included in the total pivot bearing replacement project. Since it was likely that the center of span rotation would be different once the new pivot bearing was installed, due to unknown shifts of the existing bearing discs, securing and aligning the rack could not happen until after the new center of rotation was established. It was decided that replacement of the pivot bearing followed by re-securing the rack would not all be possible in the allotted 12 hour outage. Therefore, an alternative means of operating the span was developed using a system of air winches and pulleys. This system temporarily powered span operation until the rack re-anchoring work was completed.

Pivot Bearing Replacement

Prep work prior to the outage included removing concrete around the lower casting to provide access to the existing oil box mounting holes. These would be reused for securing the new pivot container. Once the outage began, the span was stabilized and the existing oil box was removed. Figure 10 shows the ½" displaced position of the existing top steel disc that was discovered. The disc was pressing against the inside face of the oil box. This confirmed the assumption of a translated disc as the root cause of several problems. Wear marks on the bottom surface of the bottom steel disc indicated that rotation during operation was occurring at the lower casting interface. There were no keys or dowels in the existing design between the bottom disc and the lower casting to prevent this movement. The bottom disc also exhibited several significant cracks shown in Figure 11.

Figure 10. Opposite sides of the pivot bearing showing the ½" displaced position of the top steel disc (red arrow) relative to the bronze disc (green arrow) and bottom steel disc (blue arrow) discovered once the oil box was removed. Note signs of hard contact with the oil box on the top steel disc (yellow arrow)

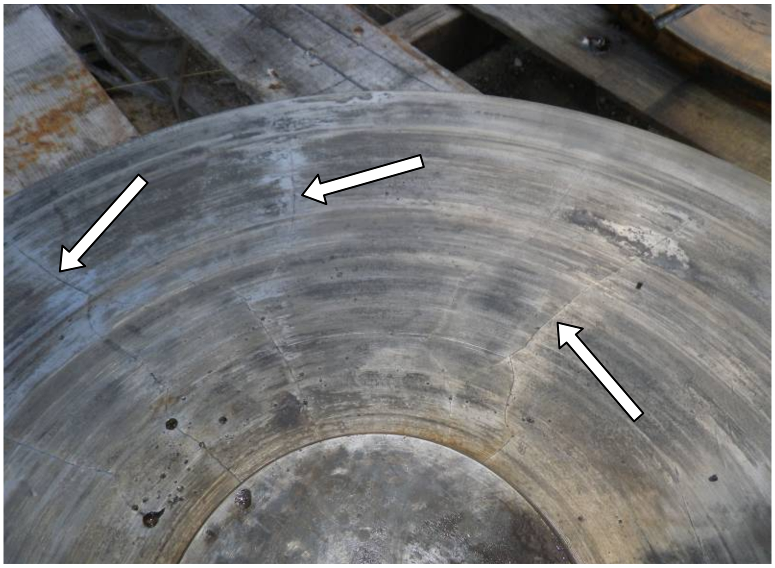

Figure 11. Bottom surface of the existing bottom steel disc with several significant cracks and signs of wear at the lower casting interface.

Hydraulic jacks lifted the span several inches to provide adequate clearance for the removal of all existing discs. The new complete pivot container and disc assembly was shifted into position on support rails as displayed in Figure 12. Raised buttons or bosses in the centers of the pivot container and upper disc matched existing voids in the lower and upper castings to center the assembly. The pivot container assembly was lifted and secured to the span while rollers were used at the jacking beams to re-center the span on the lower casting. This corrected the ½” displacement that had occurred. Once the span and lower casting were concentric, the span was lowered onto the new pivot bearing assembly. The bearing replacement was successfully completed during the planned 12 hour window.

The new rack securing system is shown in Figure 13. A new center anchoring plate was bolted to the existing lower pivot bearing casting. After the rack segments were re-aligned, new radial struts locked the rack in position, bolted to the rack segment joints and the center plate. Wherever possible, the existing rack anchors were reset. New stiffening angles were bolted between each radial strut with new concrete anchors to tie the whole system together.

Figure 12. Installation of the new pivot container and bearing disc assembly.

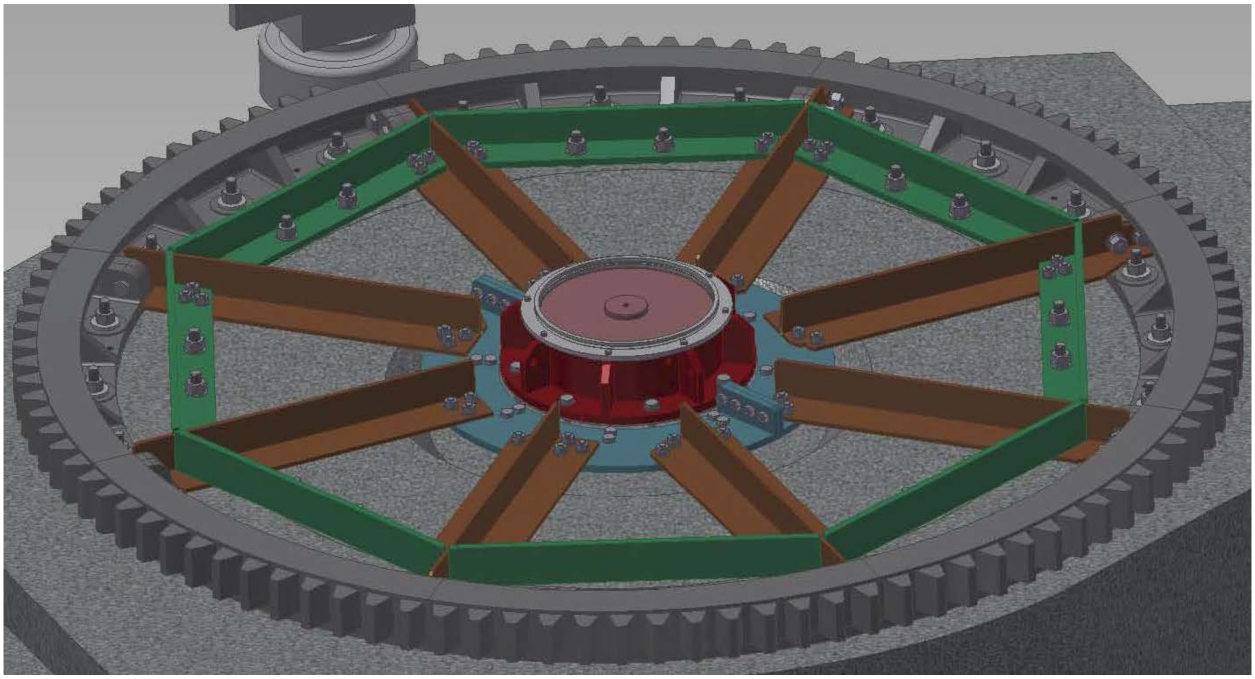

Figure 13. New rack securing system with a center anchor plate (light blue), radial struts (orange), and stiffening angles (green).

Conclusion

The pivot container design was instrumental in meeting the fast paced replacement timeline. Long term stability of the new pivot bearing will be enhanced by the change to the two bearing disc design. Improvements to span operation were immediate during the first test operation following the bearing replacement. Without any changes to span counterbalance weight, the span now appeared to be in proper balance and no longer tilted to one side. The east balance wheels hovered above the balance wheel track as the span rotated. Hydraulic pressure recorded for the primary hydraulic motors was drastically reduced, indicating a large reduction in friction. The pivot bearing was now silent during bridge operations.

Acknowledgements

Successful completion of this project was only made possible due to the great work accomplished by personnel in the CSX Engineering and Construction Departments.

References

[1] Hovey, O.E., 1926. Movable Bridges, Volume 1 Superstructure. New York, NY: John Wiley & Sons, Inc.