HEAVY MOVABLE STRUCTURES, INC.
NINETEENTH BIENNIAL SYMPOSIUM

October 16-20, 2022

Temporary Hydraulic Operating System: Installation Challenges and Construction Usage

Robert J. Tosolt, P.E.
Wiss, Janney, Elstner Associates, Inc.

RENAISSANCE ORLANDO AT SEAWORLD
ORLANDO, FLORIDA

ABSTRACT

This paper will present the design, fabrication, installation, testing and usage of a hydraulic temporary operating system to maintain this double leaf trunnion bascule bridge in full operation throughout the complete replacement of the existing electrical and mechanical operating systems. The paper will address the key challenges in optimizing the system capacity within the existing site constraints, installing the components, testing and commissioning. The paper will also touch on benefits afforded by the system during the installation of the new machinery.

INTRODUCTION

The Charles Berry Memorial Bridge is a double leaf trunnion bascule bridge that carries Erie Avenue over the Black River in Lorain, Ohio. The bascule leaves span 333'-0" between trunnion centerlines and carry two lanes of vehicular traffic in each direction with a pedestrian sidewalk outboard of the roadway on the outboard side of each truss. The bridge is oriented east-west with control houses located at the southwest and northeast corners of the movable span; both leaves are normally operated from the top level of the southwest control house.

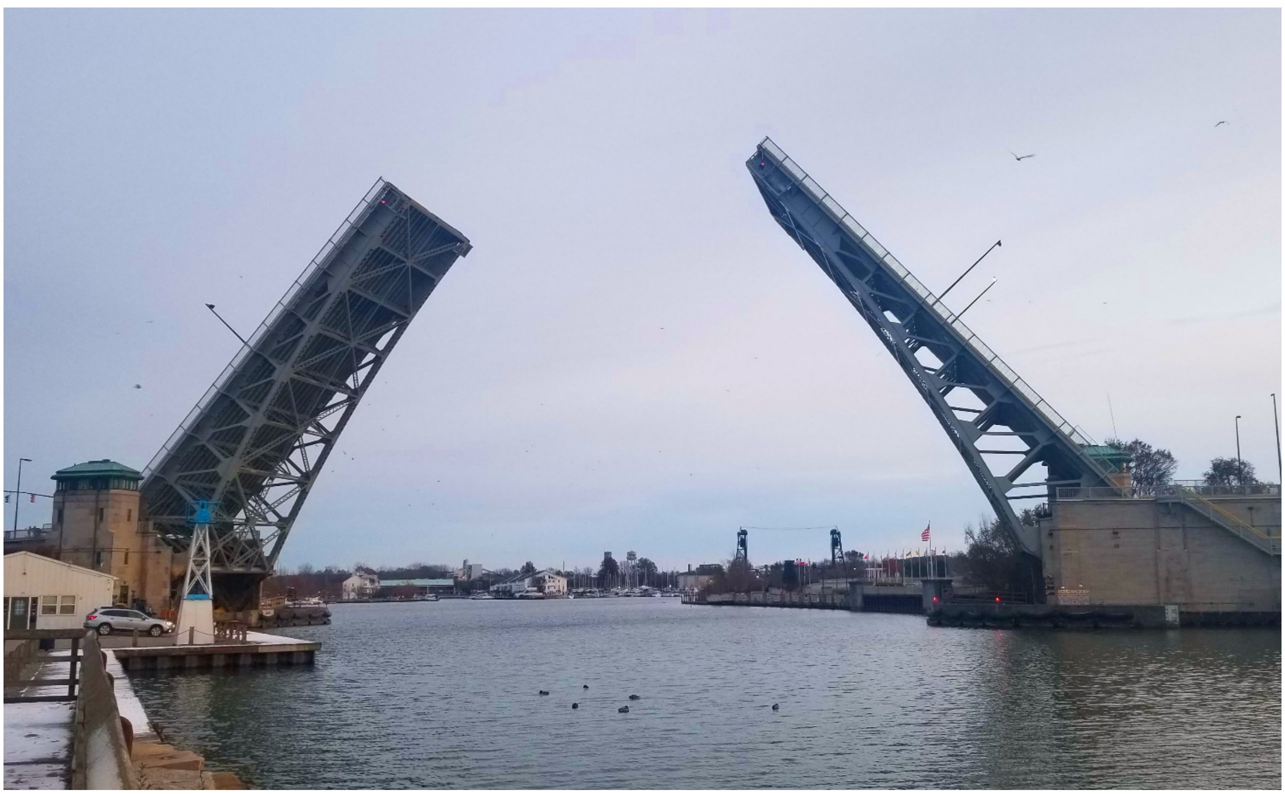


Figure 1 – Charles Berry Bascule Bridge No. LOR-06-0967, SFN 4700813 View from North.

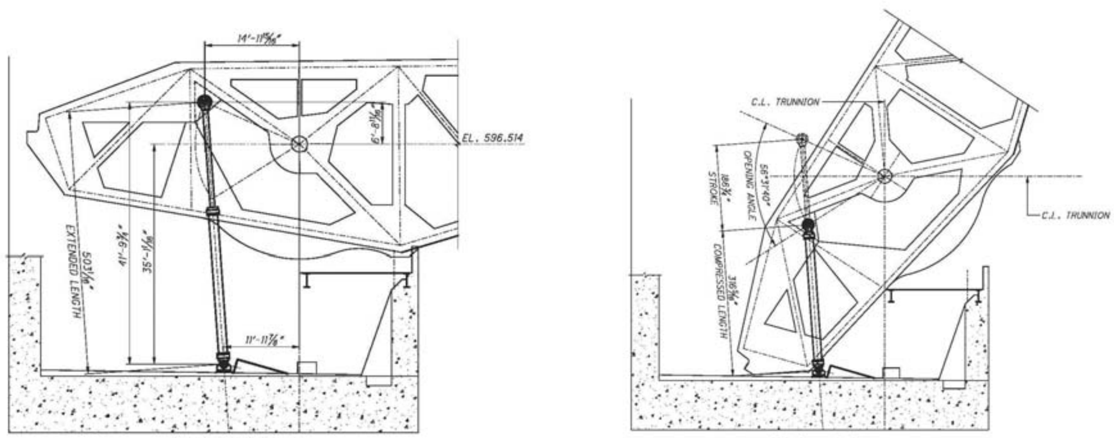
The movable leaves date to 1939 but underwent a comprehensive rehabilitation circa 2018-2020 including complete replacement of the electro-mechanical operating machinery and control systems. A temporary hydraulic operating system was used to maintain operation of the movable leaves while the machinery and controls were replaced. The focus of this paper is on the design and installation challenges to install the operating system as well as its usage throughout construction to facilitate project goals.

DESIGN CONSIDERATIONS

The design plans provided the concept, design parameters and general sizing for the temporary operating system and required that the contractor complete the design of the electrical-hydraulic-mechanical system components to conform to AASHTO and to verify integration of the system into the existing space as well as to integrate into the existing electrical controls while providing all required safety interlocks.

Each movable leaf utilizes a deck truss configuration and the entire dead load of each 3,700 kip leaf is supported by two trunnions with one trunnion mounted in each bascule truss and simply supported in a pair of bronze bushed pillow block housings. Each bascule pier is built up around and fully encloses the tail end of each leaf so that the counterweight rotates down into a cavernous pit during rotation. The trunnion centerline is over 35 feet above the pit floor.

The temporary operating system (TOS) concept proposed on the contract plans utilized two double acting hydraulic cylinders framed into each bascule leaf truss rear of the trunnion and anchored to the counterweight pit floor.



A) Leaf Closed B) Leaf Open

Figure 2 – Proposed Temporary Operating System Arrangement. Elevation View through Bascule Pier.

This arrangement complements the bridge construction as it makes use of the space afforded by the existing bridge design and is located so that it can be installed with minimal impact to bridge operation under the main operating machinery until it is connected to leaves. In order to realize this system, the contractor was commissioned with completing the design and detailing of the TOS system components to meet AASHTO requirements and to ensure seamless integration with the existing structure. To that end, the following critical tasks were performed:

Cylinder Loading

Calculations were performed to determine the cylinder operating loads through the full range of leaf operation based on AASHTO loading requirements. Calculations utilized the actual maximum leaf opening angles as established through strain gage load testing performed at the outset of this project. The cylinder operating loads were used to finalize cylinder sizing in conjunction with the hydraulics provider, as well as to evaluate the integrity of the connections to the leaf and pit floor. Our calculations corroborated the plan concept of requiring a cylinder with a 16” diameter bore / 9” diameter rod. The cylinders were designed based on an applied 3ksi design limit which generates a force of 603 kips (push)) or 412 kips (pull) per cylinder. The working pressure and relief limits of the hydraulic system were de-rated based on the limits of the end connections as will be discussed below.

Cylinder Geometry

Based on the proposed connection points at the pit floor and leaf gusset plates, the cylinder geometry and stroke necessary to achieve the required leaf opening angle was determined through field survey and calculation as documented in the following table.

Cylinder Dimensions	Location	Extended Length [in]	Collapsed Length [in]	Total Stroke [in]	Working Stroke [in]	Reserve Stroke [in]
Original Dimensions Contract Drawings	West Leaf	503 1/16	316 5/16	186 3/4	186 3/4	0
	East Leaf	504 11/16	317 7/8	186 3/4	186 3/4	0
Proposed Installation Dimensions	West Leaf East Leaf	503 7/8	317 1/8	188	186 3/4	1 1/4
Cylinder Fabrication Dimensions	N/A	504.5	316.5	188	N/A	N/A

Table 1. Field Measurements for Cylinder Length

As a slight deviation from the plan concept which had identified differing cylinder lengths for the two leaves, our analysis determine that all cylinders could be fabricated to one length and that differences between leaves could be accommodated through varying grout pad thickness at the anchorages. Additionally, the overall cylinder stroke was lengthened to provide a small amount of reserve stroke at each end of travel to allow flexibility in installation and adjustment of the leaves. See Table 1. Despite a normal cylinder stroke of 186 ¾” and an overall length just over 42 feet, reserve stroke was limited to 5/8” at each end of travel due to site space constraints. Therefore, dimensional location and control of the cylinder anchorage points during installation was critical to the proper performance of the cylinders.

Cylinder Connection to Leaf

For the cylinder connection to the movable leaf, the design concept employed the installation of a pin (the TOS trunnion) into the truss behind each main leaf trunnion. The concept called for the gusset plates on either face of the truss to be bored to accommodate the TOS trunnion which cantilevered outboard of the truss to connect the cylinder rod end. The concept provided for hubs at the outboard face of each gusset to support and distribute the trunnion load and indicated that the gussets should be otherwise strengthened as required.

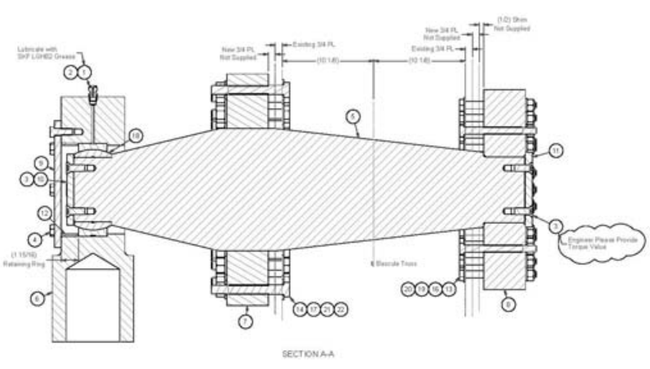


Figure 3 – Proposed TOS Trunnion Arrangement from Contract Plans.

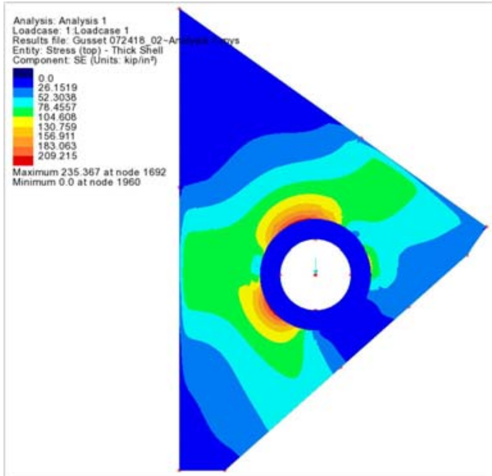


Figure 4 – FEA Analysis of Gusset Plate under Eccentric Loading (*Courtesy of Genesis Structures.*)

Based on the cylinder operating loads determined as part of the above analysis, structural evaluation of the gusset plates including a finite element model of the gussets was performed. As a result of the center of the hub being offset from the center of the gusset, the trunnion loading resulted in a moment on the gusset in addition to the direct load, creating undesirable and excessive stress of the gusset plates. See Figure 4. An alternative trunnion mounting arrangement was subsequently developed to eliminate the eccentricity; the mounting hubs were split and arranged to sandwich the gusset plates so that the loading on each gusset was symmetric. Analysis of the alternative arrangement identified that the symmetric loading decreased the stress on the gusset by a factor of 7 and the gusset plates could be strengthened as required for the design loading. The final design was progressed using the alternative trunnion mounting arrangement.

<u>Cylinder Connection to Pier</u>

The cylinder anchorage to the pier consisted of a simple clevis connection secured with anchor bolts. While the design concept for the clevis anchorage and anchor bolts had adequate capacity to resist the governing design loads, the anchor bolts did not engage a sufficient volume of concrete in the pit floor to resist rip out under the governing loads.

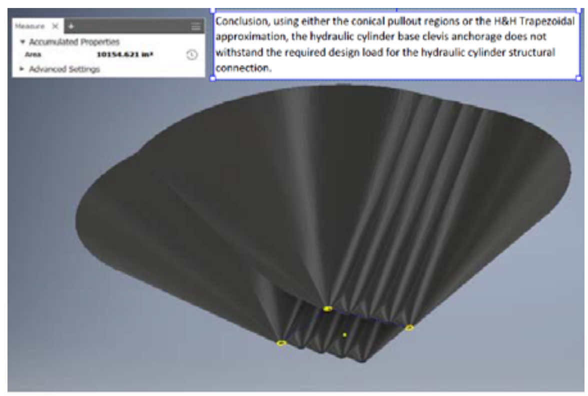


Figure 5 – Anchor Bolt Concrete Strength Evaluation Using either the conical pullout region or the Trapezoidal approximation, the anchorage does not withstand the required design load.

A challenge with any rehabilitation is meshing new equipment within the constraints of the existing structure. The available space around the perimeter of the leaf was adequate to accommodate the cylinders for the TOS, but little additional space was present. The cylinders were located on the outboard sides of the trusses and extended down to the pit floor just inside the pier wall. The clevis connection at the pit floor was bounded by the pit wall on one side and by the bumper block buttress on a second side. It was not possible to expand the clevis dimensions to include additional anchor bolts without compromising the pit wall or completely re-designing the clevis to accommodate an eccentric footprint.

As the clevis bolt configuration for the original design concept did have sufficient capacity to resist the force to open the leaves, and the limiting condition was resultant from the force required to hold the leaf in the full open position against the AASHTO specified wind holding condition, a waiver from the maximum wind holding requirement was requested and granted for this temporary operating system. To ensure that the concrete rip out capacity would not be exceeded during operation, the hydraulic pressure relief settings were adjusted to limit the maximum holding load within the anchorage capacity.

INSTALLATION

As discussed under design considerations, there was minimal clearance between interior wall of the bascule pier and the perimeter of the leaf to accommodate the TOS components. The tight space constraints necessitated the development of detailed installation procedures to ensure that the TOS system components would be installed without interference or damage and would not interfere with the movable leaves until they were ready to be attached.

The 41'long 16.5 kip hydraulic cylinders were too large and unwieldy to attempt handling other than in their upright position. The cylinders were lowered from roadway level via crane through a temporary access hole in the sidewalk above the clevis. The cylinders had minimal clearance between the pier wall and bascule truss so that care had to be taken as the load was lowered through the limiting clearance so as not to damage the cylinder body. Additionally, the design parameters for the cylinder resulted in an extended length of piston rod even when fully retracted, therefore, particular care had to be taken so as not to side load the piston during handling. Once lowered, the cylinder weight was maintained by the crane until the clevis pin was inserted through the floor mounted clevis. The cylinder then had to be rotated back on the clevis pin and secured with a strut in a reclined position so as not to interfere with the installation of the TOS trunnion assembly.

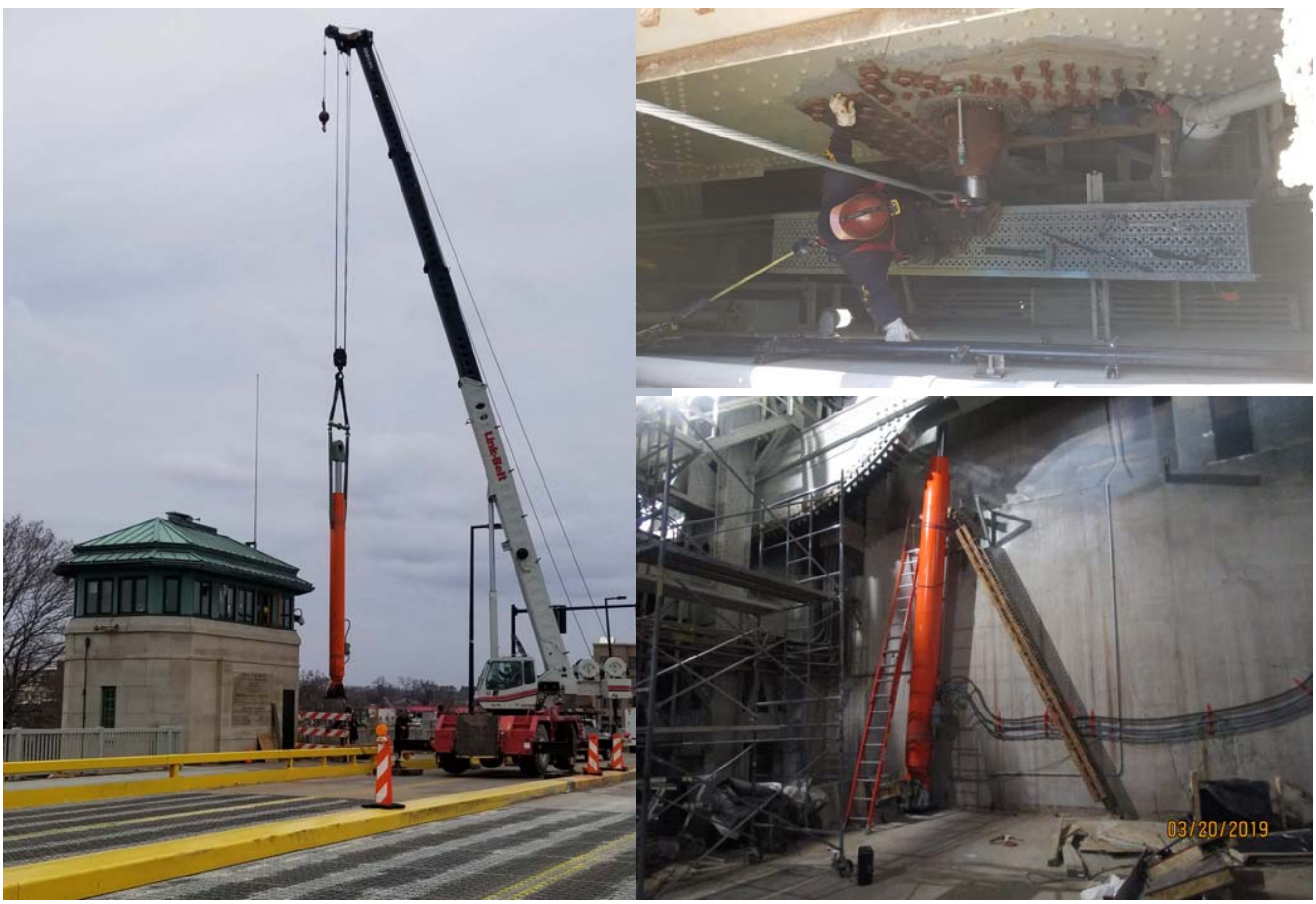


Figure 6 – TOS Hydraulic Cylinder Installation and Tie-Back.

A precision survey was conducted to locate each clevis foot at the pit level as well as the center of the bore through the gusset plates for the TOS trunnion to ensure that the system components were installed at their intended locations to meet the system geometry within the allowance of the reserve stroke and ensure proper operation of the system. Given that the clevis anchor bolts and gusset plates governed system loading, a pull test was conducted on the anchor bolts to ensure they met the minimum loading requirements while the gussets plates were strengthened via a design provided by Genesis Structures, Inc.

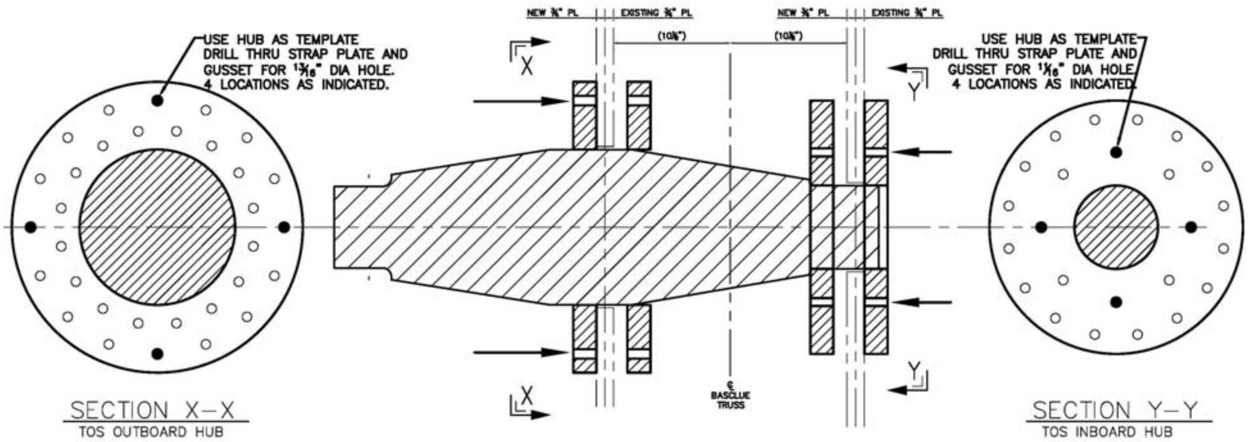


Figure 7 – As-Installed TOS Trunnion Arrangement, from Installation Procedure. Representative step for locating trunnion hubs and mounting bolts.

While the design modification to provide symmetric loading of the gusset plates solved the overstress issue, the split hubs required to realize this goal increased complexity during installation. To facilitate field installation, the hubs were machined in pairs to ensure uniformity of the LC1 fit between mating hubs and trunnion as well as to ensure proper clocking of the mounting bolts. An installation procedure was developed to provide a discrete step-wise breakdown for the trunnion insertion and how the outer hubs were to be located to ensure proper alignment of the trunnion.

Position and alignment were verified prior to installing the turned bolts to lock the hubs in position.

Figure 8 – Alignment Verification and Final Bolting of TOS assembly.

The final connection of the cylinder rod end to the TOS trunnion presented its own set of challenges:

- The TOS cylinder needed to be rotated forward from its stowed position to align the rod end with the trunnion. Due to the installation sequence, the cylinder also needed to be rotated outboard beyond the end of the TOS trunnion to fit-up the rod eye on the trunnion end. The close proximity of the pier wall limited the amount of outboard rotation, which was further constrained by the limited clearance at the clevis connection at the pit floor. While the spherical bearings in the rod eye could accommodate up to 6 degrees of rotation, the system constraints limited the rotation to 1.4 degrees, which provided a maximum of 1” clearance between the face of the rod eye and the end of the TOS trunnion.
- The fit between the rod end spherical bearing and the mating trunnion provided only 0.001” to 0.002” clearance. The manufacturer provided for limiting heating of the rod end to facilitate installation.
- The TOS system geometry required the piston rod to be at full extension (minus the reserve stroke) to mate with the TOS trunnion with the leaf seated. Therefore, the weight of the piston rod needed to be supported while precision alignment was performed to install the rod end bearing on the trunnion. The force applied to support the piston needed to be maintained in-line with the rod axis to ensure that no damage occurred due to side loading of the extended rod.

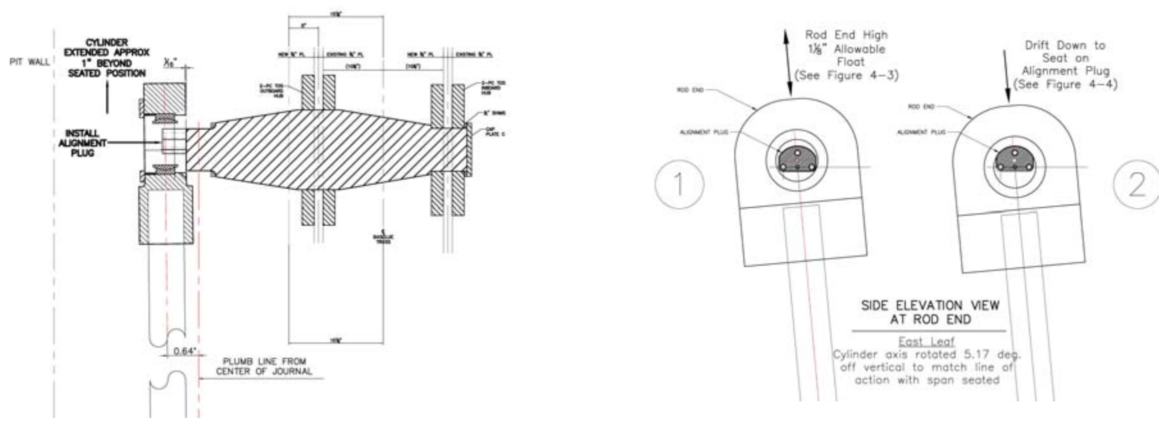


Figure 9 – Sequence for Mounting TOS Cylinder Rod End Spherical Bearing on Trunnion

To address the above concerns, a custom alignment plug was designed and incorporated into the installation procedure. The alignment plug was developed in conjunction with the shop drawings so that the necessary details could be reflected on the trunnion fabrication drawings. The top of the alignment plug was manufactured to the same radius and tolerance as the end of the trunnion, and was mounted to the end face of the trunnion with fitted bolts to ensure alignment of the top of the plug with the top of the trunnion. During installation, the plug was mounted to the end face of the trunnion and provided an initial contact point for the spherical bearing in the rod end that could be achieved independent of the radial fit, as the plug was only a segment and not a full diameter. Once the rod end rested on the alignment plug effectively establishing the proper elevation, the rod end was able to be axially shifted across the alignment plug onto the trunnion to complete the assembly. During this work, the alignment plug supported the weight of the piston rod and mitigated the side loading concern.

Figure 10 – Fit-up Rod End on TOS Cylinder using Alignment Plug and Final Connection.

Once the cylinder connection was made, the existing main drive machinery needed to be disconnected and the TOS operating system brought on-line so that the cylinders were not back driven. In conjunction with the installation of the mechanical components of the TOS system, the control system modifications were performed to accommodate the TOS system and the HPU was fabricated and installed at site to be prepared for cylinder connection. Due to the temporary nature of the installation and the need for timely installation and hook-up, the HPU for the TOS on each leaf was built into a shipping crate to provide for ease of handling and enable it to be located and/or re-located at site as necessary to suit construction needs. The TOS HPU was located at the approach side of the bascule pit and hydraulic lines were routed through the wall of the pit enclosure and along the sides of the pit wall to the manifolds at the cylinders.

Figure 11 – TOS Hydraulic Power Unit Arrangement and Routing to Cylinders.

PERFORMANCE

Following installation and connection of the TOS, the mechanical drive machinery was disengaged by de-coupling the cross shafts from the central machinery. Operating loads were recorded as part of the TOS start-up to verify the proper operation of the hydraulic controls as well as to document operational loading and balance. Test ports provided on the cylinder manifolds facilitated monitoring and recording of the blind end and rod end pressures via pressure transducers. From a review of the recorded pressures in Figure 12, it is clear that all operating pressures were well controlled throughout operation and remained well within the modified design pressures of 1700 psi at the rod end port and 1300 psi at the blind end port.

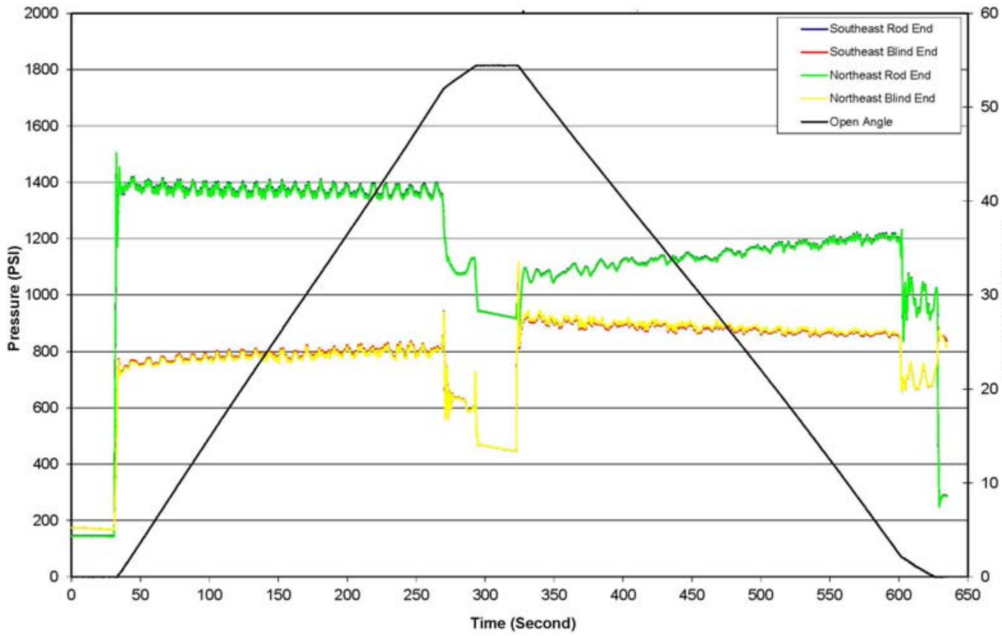


Figure 12 –Hydraulic Operating Loads, Blind End and Rod End Pressures

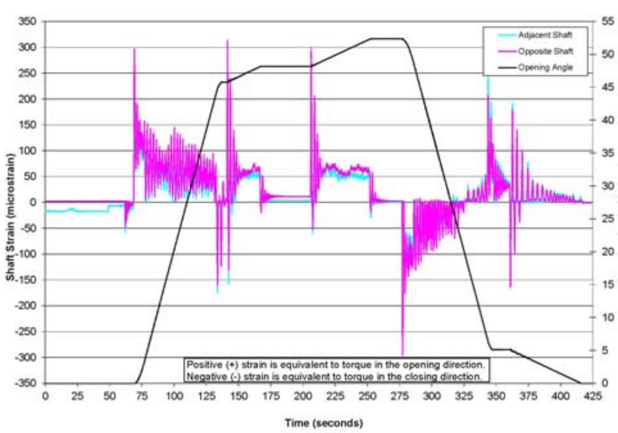


Figure 13a –Operating Loads via Existing Machinery

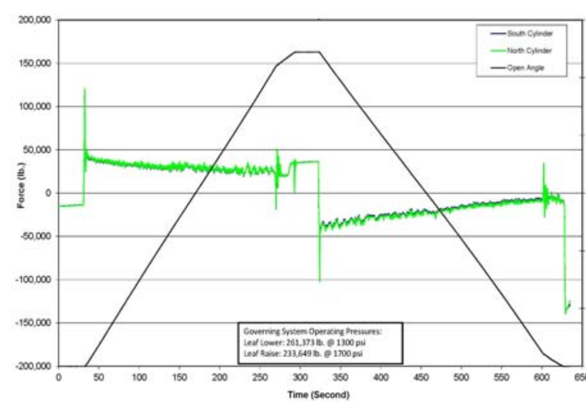


Figure 13b –Operating Loads via TOS Machinery

The total operating load under the TOS was also compared to the operating loads on the existing machinery determined via strain age testing of the existing machinery. From a review of Figures 13a and 13 b, it is clear that the TOS system produced far better and smoother control of the leaves than the existing open gear driven machinery which exhibit numerous load fluctuations and spikes that are not apparent under the hydraulic system.

The TOS system operated reliability over the duration of the project. The primary faults which did occur were attributed to the system being operated outside the prescribed operating sequence for which the system had been tuned.

OPERATIONAL BENEFITS

The TOS operated as intended to maintain leaf operation from the time that it was commissioned in September 2019 until the new drive systems were installed with start-up testing in March 2020 and commissioning in May 2020. While the design parameters for the TOS did require a restriction on operating conditions under maximum wind loading, no operating restrictions were ever required at site as the design wind threshold was not exceeded during any bridge operations on the TOS.

Aside from maintaining leaf operation for marine traffic, the TOS also provided an asset to the installation and alignment of the mechanical drive machinery. Leaf operation under the TOS was utilized to verify alignment of the new racks and rack pinions, as well as the fit-up of the secondary reducers and the functional performance of the span drive brakes. As a result, when the new electric drive was brought on-line, the alignment of the new drive machinery was fully vetted and accepted so that commissioning was focused solely on the electrical controls, sequencing and interlocks.

At the completion of its service life, the TOS was removed utilizing similar procedures as for installation.

ACKNOWLEDGEMENTS

Bridge Owner, Contract Administrator:
Lorain County, Ohio Department of Transportation

Engineer of Record:
Hardesty & Hanover, LLC

Prime Contractor:
The Ruhlin Company / Perram Electric

Machinery Fabricator:
G&G Steel Inc.

Hydraulics Provider:
Supreme Integrated Technologies Inc. (SIT)

Electrical Controls:
Dmytryka Jacobs Engineers (DJE)

TOS Gusset Structural Analysis:
Genesis Structures, Inc.

Movable Bridge Project Coordinator, TOS designer/coordinator:
Wiss, Janney, Elstner Associates, Inc. (as Stafford Bandlow Engineering, Inc.)