HEAVY MOVABLE STRUCTURES, INC.
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MBTA GLOUCESTER DRAWBRIDGE: CONSTRUCTION CHALLENGES DUE TO CHANGING CONSTRAINTS

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INTRODUCTION

Background and Project Team

The Massachusetts Bay Transportation Authority (MBTA) Gloucester Drawbridge carries the Rockport Line over the Annisquam River in Gloucester, MA. The existing bridge was built in 1911, reconstructed in 1932, and updated in 1984. The replacement of the existing double track bascule span began in 2019.

Select members of the project team and their roles are as follows:

Owner: Massachusetts Bay Transportation Authority (MBTA)
Engineer: Stantec (Structural) and Modjeski and Masters (Mechanical and Electrical)
General Contractor: J. F. White Contracting Co.
Steel and Machinery Fabricator: G&G Steel
Erecting Engineer: Genesis Structures
Movable Bridge Project Coordinator: Wiss, Janney, Elstner Associates, Inc.
Millwright: O'Connor Corporation Millwright Division

The new bridge has twin single leaf bascule spans, each with a single track and the new alignment has significant overlap with the existing alignment.

Project Constraints Included:

1. Long winter marine navigation height restriction only, channel must stay open with limited full channel closures
2. Daily tide range around 8 feet
3. Narrow channel
4. The replacement design required the work to be completed with no interruptions to rail traffic
5. A tight construction site due to the overlapping alignment and narrow right of way

Considering the last two constraints, the plans presented a staged construction scheme that envisioned splitting the existing bridge in half and removing the southern half to allow construction of half of the new structure.

After award the team proceeded with development of the means and methods to build the job as presented on the plans. The means and methods included the construction of a temporary trestle.

CONSTRUCTION STAGING CHALLENGES

The existing structure is comprised of a 90 foot steel approach span on the west with a 150 foot single leaf bascule over the navigation channel and a 125 foot ballasted wood trestle with a timber rest pier for landing the bascule toe on the east side of the channel.

Genesis Structures partnered with J. F. White to perform engineering evaluations of the construction staging and the structural analysis of the partially demolished bridge to support continued rail traffic.

Three issues posed significant problems for the existing structure to maintain commuter traffic.

1. Once the southern half was removed from the existing timber trestle, it would be an asymmetrical structure that would experience significant lateral movements if not braced externally, including the existing timber rest pier.
2. The existing steel bascule span, steel bascule span support towers and steel approach spans on the west side of the bridge were significantly deteriorated and would require significant strengthening and repairs to maintain traffic once split in half. See Figures 1 and 2.
3. Updated AREMA standards imposed additional demands on the structure that would require extra repairs and strengthening. This included longitudinal braking and acceleration forces as well as lateral forces due to nosing and wind forces where load paths thru the altered structure were compromised.

Figure 1: Deteriorated Bottom Flange

Figure 2: Bascule Girder Web Deterioration

Design of an external bracing system for the timber trestle progressed and a Timber Trestle Bracing System (TTBS) was installed to allow the trestle to be split in half while still allowing commuter traffic during construction of the southeastern portion of the new bridge. See Figure 3 and 4. The work on the new structure included construction of the new bascule support piers, precast box spans and support piers as well as the new operator control house. The TTBS allowed for a significant amount of the construction activities to be completed without disruption to commuter operations.

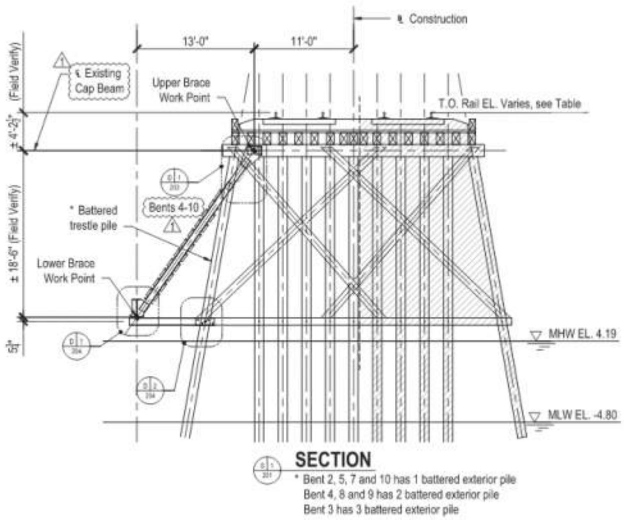

Figure 3: TTBS Plan Development

Figure 4: TTBS In Service

Further evaluation of the existing structure's deteriorated condition and the necessary strengthening to keep the bridge in service once split in half were performed and repair options were developed to keep the structure in service. It was evident that the scope of the required repairs and the time needed to install the repairs would cause the schedule to slip and the project to miss the navigation channel closing during the first winter marine navigation outage. Eventually, it was concluded that there was no alternative except to stop the trains, remove the existing bridge and then continue with construction of the new bridge.

Construction continued on the southeast portion of the site until work on the rest piers and west approach spans needed to commence. At that point, rail traffic on the existing bridge was halted and the existing bascule and west approach structures were demolished to allow construction of the new structures. Construction operations were accelerated to install the western portion of the support piers and approach spans as well as construction of the entire east abutment. The south precast approach spans were installed and ballasted, and the south bascule leaf was assembled and installed using the Construction Gantries.

Construction of the north half of the structure started once the south half was completed. This included demolition of the north half of the timber trestle and construction of the new foundation elements. The north bascule leaf was then installed using the Construction Gantries. The trestle components were removed in sequence working back towards the east abutment, removing components, and also setting the remaining new jump spans and precast box spans.

CONSTRUCTION TRESTLE

To gain access to the work area, a temporary construction trestle was built. The trestle consisted of large, double W36 girder lines along the extents of the south and north sides of the existing and new structures. The girder lines were designed to support the construction gantries that would ultimately install the bascule leaves into the bascule pier. The girder lines were supported by large diameter pipe piles. A third beam line was installed down the middle phase line. The third girder line supported steel crane mats within the appropriate construction phase to allow crane and drill rig access and operation. The third girder line was supported by large structural trusses that passed underneath the existing and new superstructure and sat on top of the pipe piles. See Figures 5, 6, and 7.

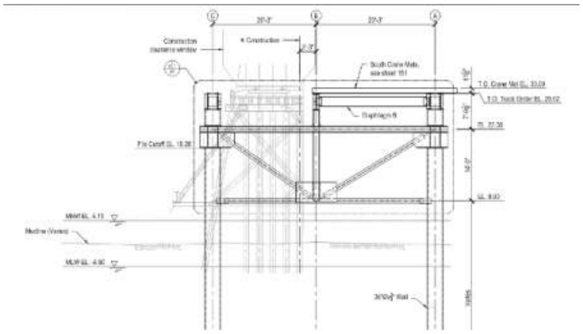

Figure 5: Construction and Timber Trestle

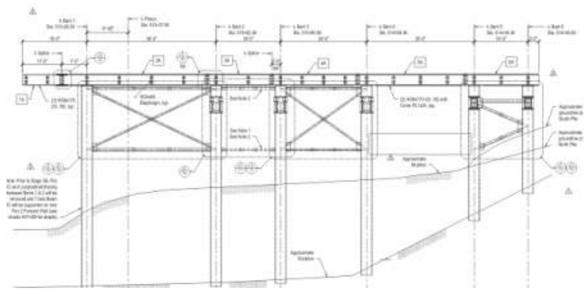

Figure 6: Construction Trestle Bents

Figure 7: Construction Trestle In-Service

Bascule Leaf Fabrication

G&G Steel fabricated the bascule leaves and the machinery. They assembled the heel section of each leaf upside down on their 10 meter gantry mill in Cordova, Alabama. The bascule girders were then machined in one setup for both the racks and trunnion bearing housings. The racks and trunnion bearing housings were then installed and redundant quality checks were performed using both the mill and a laser tracker.

All of this work occurred during Covid lockdowns which presented schedule and logistical challenges. The image in Figure 8 below is a screen capture from a ‘virtual shop inspection’ that was live streamed for the contractor team as well as the Engineer of Record and other representatives for the MBTA.

Figure 8: Screen capture during virtual shop inspection of the south bascule leaf

To check the rack, a pin was set in the teeth and the centerline of the pin was located by sweeping around the ends of the pin with a probe. The pin was sized such that the centerline of the pin was at the pitch line of the rack when it was set in the valley between two teeth. These QC checks identified some issues that required rework that were related back to thickness variations in the paint on the faying surfaces between the rack and girder, which demonstrated the value of the checks and also highlighted how tight the tolerances are for the alignment of the racks.

Full shop assembly of the bascule span is a typical requirement for many movable bridge projects and was required for this project as well. There is value in performing the shop assembly in a similar manner to the field assembly of the leaf. In addition to performing overall dimensional checks as required by the Contract, this is an opportunity to lay out and survey the as-built dimensions for bridge elements that will engage with temporary supports at the site.

The leaf was disassembled into four major elements for transport to the job site:

1. The heel section
2. The toe section
3. The two racks

The heel section was pre-assembled prior to machining on the mill to accept the racks. After completing the rack alignment checks on the mill, this assembly was then moved from the mill, flipped over, and set up on the shop floor right side up in a position where the toe section could be mated to it. Before making up the toe splice, dimensional checks were performed using a laser tracker to verify that the rack alignment relative to the trunnion had not been disturbed by flipping the heel over.

The toe section was completely assembled and brought into position at the splice. The toe and heel sections were adjusted to one another so that the splice plates would line up. The goal was to demonstrate that bolting up the splice plates would not alter the alignment of the rack.

Unfortunately, we learned that whenever the bolts were tightened in the flange splice, the rack would twist on the girder by an amount that was not tolerable. This issue was discovered at a critical point in the project, late in the spring when the team was trying to rush the leaf to the site and get it installed on the pier before the busiest part of the summer at which point the US Coast Guard would not permit any channel closures.

WJE partnered with G&G, the Engineer and other representatives for the MBTA to develop bolt on stiffeners that that allowed for adjustment of the rack, along with two channels running from girder to girder to stiffen the heel assembly. These added components are highlighted by the orange arrows in Figure 9 below. The splice was completed, and the stiffeners were successfully adjusted to maintain the rack runout both radially and transversely within .020" of an inch after the splice was complete.

Figure 9: Stiffeners bolted to the girder web (Right) and channels running from girder to girder (Left) indicated by orange arrows.

ACCELERATION

The project began with very challenging constraints to build two new bridges without stopping trains but taking advantage of lengthy marine restrictions. That plan changed when the scope of the repairs required on the existing bridge was identified. The team now pushed to accelerate the remaining work to minimize the duration that trains were out of service. This also meant having to push to install the first leaf before Memorial Day, 2021 – the start of summer and the busy boating season in Gloucester. As the project team worked together to develop ideas for accelerating the work, a big part of this was accommodating a new constraint – the Coast Guard would only allow weekday closures of the channel. Therefore, instead of having weeks to get the leaf open after installation, our team would have to install the leaf on a Monday and get it open by Thursday.

This short duration would place alignment of the machinery to operate the bascule leaves on the critical path, unless the leaves were operated by alternative means. A consultant for the MBTA developed two schemes for a temporary operating system to ensure that the bridge could open. The first scheme involved using large hydraulic cylinders to push the counterweight down and pull it back up. The second scheme proposed a winch mounted on the deck and a series of sheaves to pull the counterweight down. The winch concept was the favored concept and was developed by the MBTA far enough to demonstrate the technical feasibility of the approach. However, the contractor team didn't like the ideas: There was very little time to engineer these systems, get them fabricated, tested and delivered to the site. WJE was tasked with coming up with an alternative scheme to open the bascule leaves on a temporary basis.

The alternative that was developed took advantage of the hydraulic lifting gantries that were being used to install the leaves on the pier. The gantry would be attached to the counterweight using the same padeyes for leaf installation which would be relocated to a new position on the counterweight. The only extra work was the engineering for the balance staging, moving the padeyes, a couple of more days of gantry operation and installation of temporary ballast to make sure that the leaf was sufficiently counterweight-heavy that there would not be a loss of control with the leaf open under an established wind speed criteria. This concept was presented to MBTA and all agreed to proceed with this route as a simpler plan. Most importantly, the engineering could be completed faster thereby eliminating delays to the project.

MACHINERY INSTALLATION PLAN

The development of the machinery installation plan can be divided into phases:

1. Constructability review and development of shop details.
2. Development of means and methods for alignment and securing the machinery.
3. Development of the sequence of work and the construction schedule.

Constructability Review and Development of Shop Details

The machinery for the new bascule leaf was fairly conventional. The main area where the machinery details were revised to improve constructability was the fixed trunnion support assemblies. The plans depicted an arrangement that permitted field adjustment of the trunnion location by using vertical and horizontal shims.

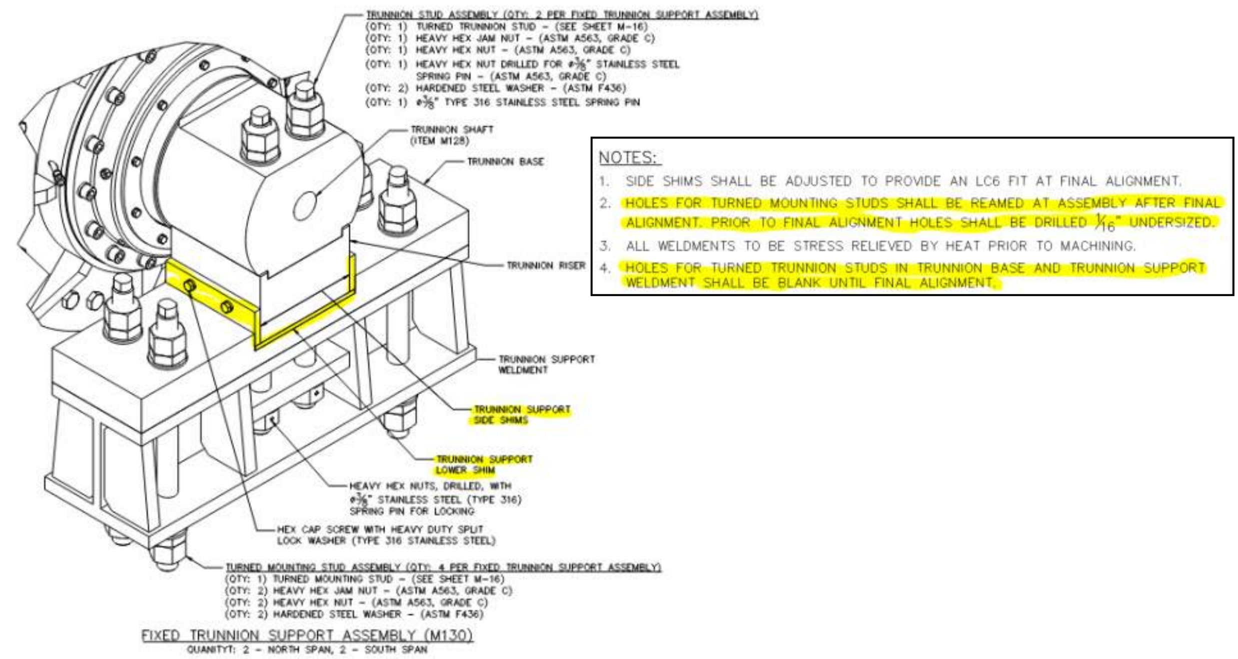

Figure 10: Original details for the fixed trunnion support assemblies.

Figure 10 is an isometric view of the original design of the fixed trunnion support assemblies with the lower and side shim locations highlighted. The location of the shims in the assembly was less than ideal for two reasons:

1. Making adjustments required jacking the leaf. Not only would this require time, but the operation would be risky due to the tight side clearances. We were concerned about our ability to execute these adjustments.

2. Because of the potential for transverse adjustments, the two long turned stud holes through the trunnion shaft, riser, lower shims and support weldment could not be drilled and reamed until after field adjustment and you had to leave the holes in the support blank. This would be a significant operation in and of itself.

Figure 11 presents the revised details. The side shims were eliminated, and a fill plate was added between the top of the tower and the support weldment. The long, turned studs through the trunnion were installed in the shop so that all of the alignment work would take place at the interface of the tower. The trunnion support lower shims were left there just in case but were not planned to be used.

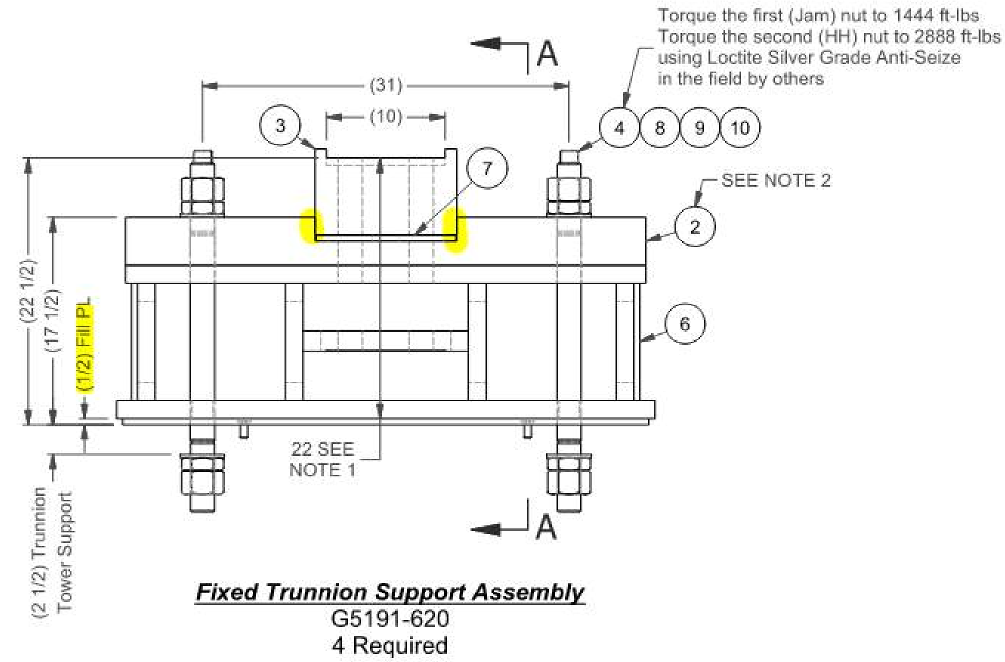

Figure 11: Revised details for the fixed trunnion support assemblies

Means and Methods for Alignment & Securing Machinery

The dimensional control plan was as follows:

1. J. F. White's survey crew would have primary responsibility for global dimensional control. A precision total station unit was used to establish baselines and provide benchmarks within the pier for the millwrights to pick up from and use for local control of all machinery elements.
2. As part of the machinery installation plan, we developed steel templates to facilitate installation of the cast-in-place anchor bolts for the trunnion support towers and the span drive anchors. The tower templates were located by J. F. White via total station.
3. Once installed over the anchor bolts, the trunnion support towers were adjusted by the millwrights using a laser tracker.
4. Once the tower was anchored and grouted. The as-built locations of the mounting bolt holes and the elevation of the corners of the tower top plate were documented with a laser tracker.
5. Both the laser tracker and optical levels were used to establish and verify elevations for machinery support sole plates that were grouted to the pier.

Sequence of Work and Construction Highlights

Starting with the installation of the towers on the pier by the ironworkers, the sequence of work was as follows:

1. Millwrights were responsible for fine adjustment of column elevation and location. The top plate of each column has two sub-drilled holes which are the controlling features that will match up to the trunnion support weldments. See Figure 12 below.

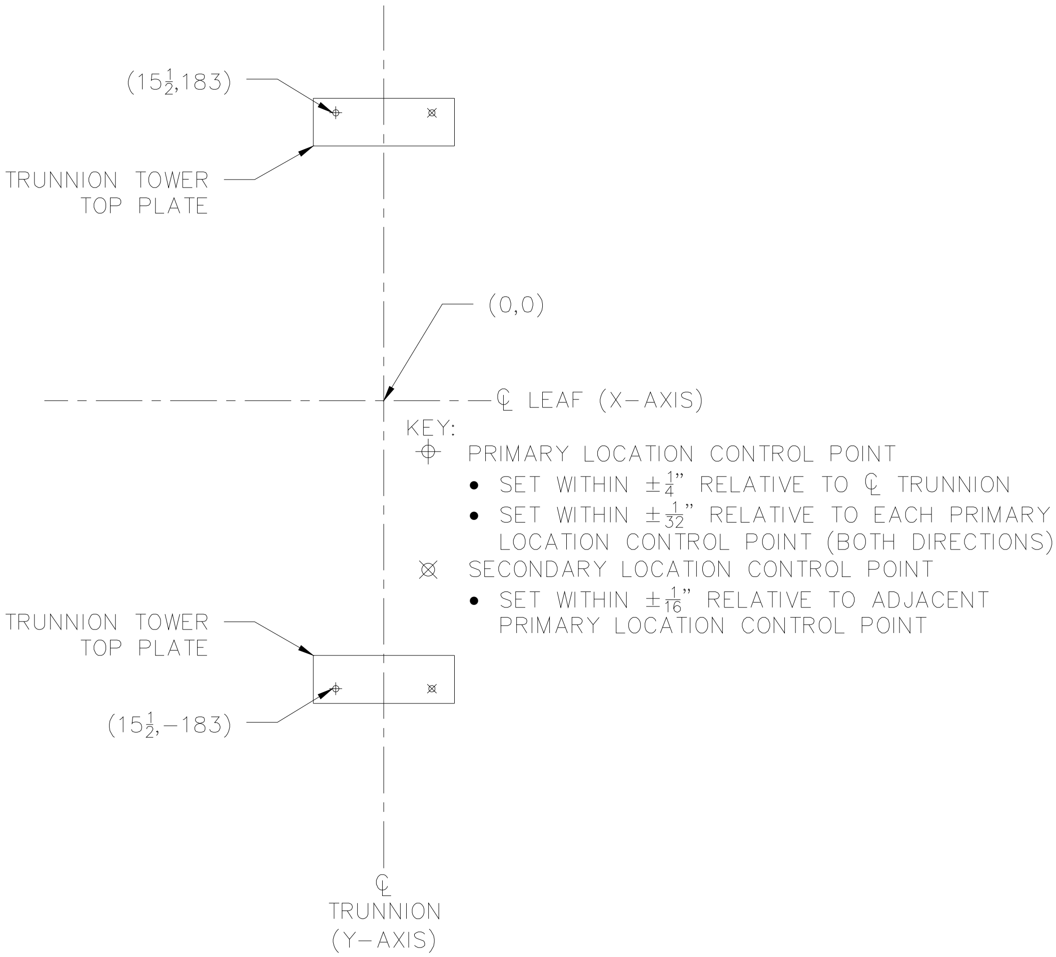

Figure 12: Trunnion Tower Dimensional Control

2. After the anchoring the columns, a precision as-built survey (via laser tracker) was performed of the top of columns to verify elevation and slope in the longitudinal and transverse directions. Using the as-built elevation, the thickness of the fill plate at the tower centerline was calculated with the top of fill plate set 0.073" high to account for dead load deflection of the trunnion and the tower. The fill plate was also tapered so that the top of the fill plate is to the correct elevation within 0.020" and set to level within +0/-0.010"/foot
3. The fill plate was drilled with holes so that once it was installed on the tower in the field, two additional subdrilled holes for the trunnion support weldment could be drilled.
4. A one-piece steel template was fabricated which has holes cut into it to locate the anchor bolts for the pinion supports and primary machinery support. There were also features to locate other elements to be used during the installation process (sole plates, alignment brackets, etc.). During the process of aligning the trunnion towers, a laser tracker was used to survey, align and secure the template into place on the pier within 1/16". See Figure 13 below. Once the template was aligned and secured, all of the anchor bolt holes were drilled, the anchors were set, and sole plates were grouted to the pier.

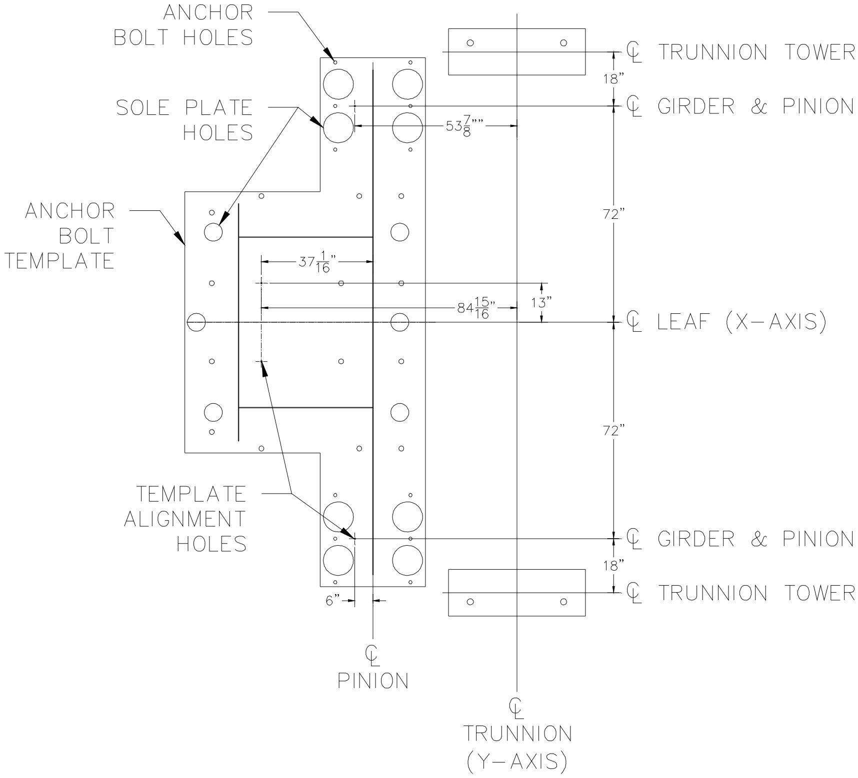

Figure 13: Span Drive Template Dimensional Control

5. The span drive machinery was comprised of three individual weldments: A primary support weldment with the motors, brakes, primary and secondary reducers and two pinion support weldments with the pinions and the pinion shaft bearings. All three weldments were landed on the sole plates over the anchor bolts and verified to be at the correct elevation. Because the initial operation of the leaf would be via the hydraulic lifting gantry, only rough alignment of the machinery was performed prior to leaf installation.
6. The leaf was delivered to the site. Assembly of the leaf was performed a few hundred yards from the pier along the right of way. The heel section and toe section were spliced, and the racks were bolted to the bascule girders. See Figure 14. A laser tracker was used to recheck the rack alignment and adjustments were made as needed to obtain acceptable rack runout both radially and transversely.

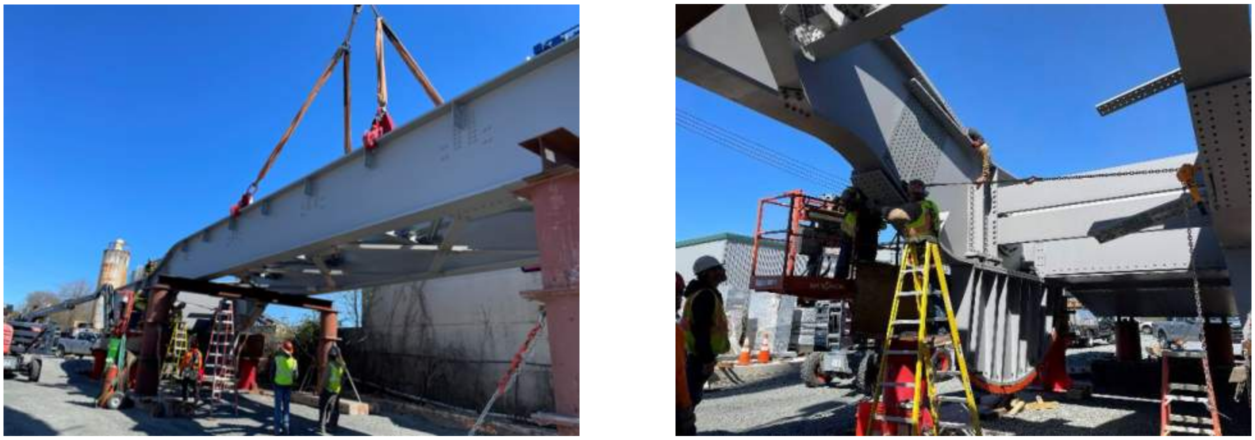

Figure 14: Leaf Assembly on the right of way. Setting the toe section (Left) and making the toe splice (Right)

7. The construction of the leaf proceeded according to the plan for "Phase 1" balance. This located the leaf center of gravity around 10 feet forward of the trunnion to be centered between the pick points to be used by the gantry. Phase 1 balance included:
    a. installation of all ties and the running rail, but not the guard rail.
    b. The concrete floor and back wall of the adjustment pocket were also formed and poured and a portion of the lead ballast plates were installed.
8. The Enerpac hydraulic lifting gantries with side shifting header beams were brought to site and installed on the construction trestle.
9. A self-propelled modular transporter (SPMT) was driven under the leaf. The SPMT then raised up to lift the span off of its supports. The SPMT was used to drive the bascule leaf down the approach and into position underneath the hydraulic lifting gantries. See Figure 15.

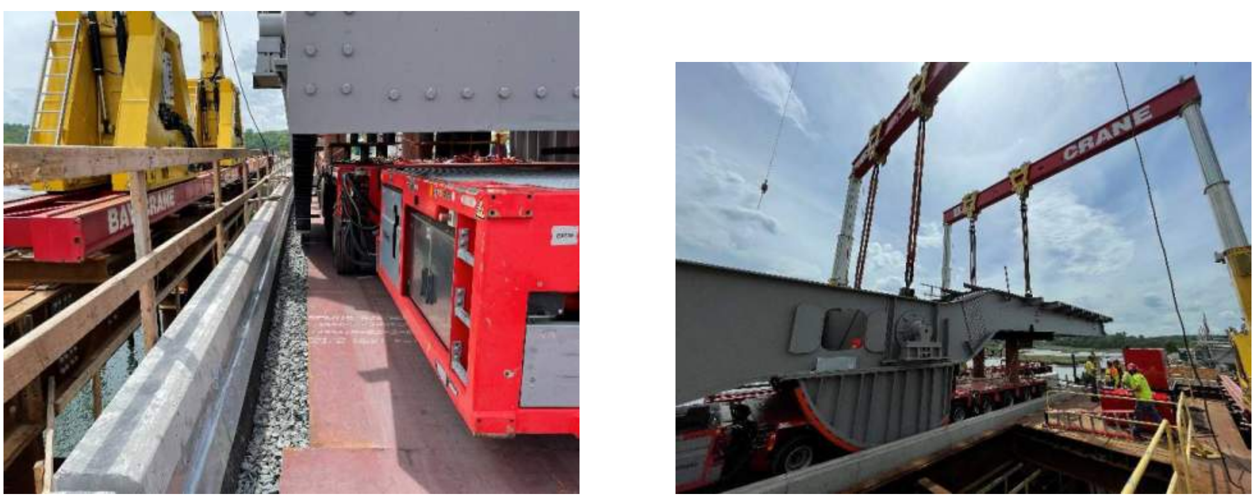

Figure 15: The leaf being moved under the hydraulic lifting gantries via a self-propelled modular transporter (Left) and rigged to be lifted by the hydraulic gantries (Right).

10. The leaf was lifted off the SPMT by the hydraulic lifting gantries. The hydraulic lifting gantries were then used to position the leaf over the pier. See Figure 16.

Figure 16: The leaf being moved over the pier via the hydraulic lifting gantries.

11. The leaf was lowered onto the towers. As this was done, a tapered alignment pin was used to line up the fixed trunnion support on each tower. See Figure 17. Once the leaf landed, survey checks were performed to ensure that no adjustments to the leaf location were needed.

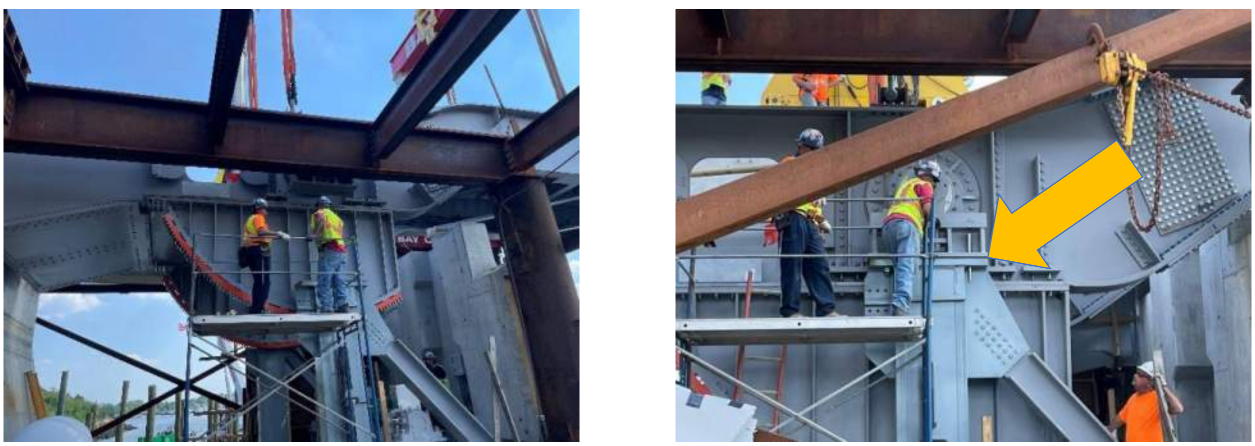
Figure 17: The leaf being lowered onto the tower (Left). The arrow indicates the alignment pin used to locate the leaf (Right).

12. The counterweight was filled for the "Stage 2" balance condition. The goal for the stage 2 balance was to make the leaf counterweight heavy to ensure that the leaf would remain in control when being operated via the gantry for the range of movement even if the wind direction was such that it would cause the leaf to close. The design wind pressure was 3 psf, which equates roughly to a 25 mph wind speed.
    a. The remaining lead plates were installed. Stage 1 balance had 26 plates and stage 2 had an additional 102 plates. Each lead plate weighs 1,600 lbs.
    b. Once the leaf plates were installed, a preliminary balance test was performed by jacking the toe of the leaf to measure the reaction. At this point it was determined that the actual imbalance was higher than the theoretical imbalance, likely due to variations in density of the timber ties. Some additional lead plates were installed to account for this variation.

c. Concrete was poured to fill the rear compartment of the counterweight and the cover was installed.
d. Shoring posts were installed under the counterweight to support the leaf when it was made counterweight heavy temporarily for the gantry operation.
e. A timber crane mat was placed on top of the counterweight, along with some large steel plates that had been placed on the railroad ballast for the SPMT to drive on.

13. A gantry was positioned over the counterweight, the pad eyes were installed, and the gantry was hooked up and lifted to take the load off of the shoring posts under the counterweight. The gantry then lowered the counterweight, raising the leaf to the open position.

Figure 18: Two views of the leaf being raised via the gantry. The view on the left shows the temporary ballast for stage 2 balance.

14. Once in the open position, the leaf was positioned against the bumper blocks and the gantry was disconnected and removed. Since the leaf would remain in the open position for an extended period, pipe restraints were added between the counterweight and the pier wall to secure the leaf against high winds. See Figure 19. The Contractor met the deadline to have the leaf open for the weekend boaters.

Figure 19: Restraints installed to secure the leaf in the open position.

15. The alignment of the span drive machinery was completed over the weekend with the leaf in the open position.
16. On the following Monday, the leaf was lowered with the gantry and the shoring posts were installed under the counterweight. The gantry was removed at this point. The counterweight was adjusted for the “stage 3” balance condition. The goal for the stage 3 balance was to make the leaf span heavy within the prescribed limits for operation via the machinery. To meet this stage, the only work to be done was to remove the temporary ballast.
17. The initial operation of the leaf was performed. During this operation the following checks were done:
    a. The operating loads were monitored real-time via dynamic strain gage measurements to verify that balance and friction were acceptable.
    b. As the leaf opened it was stopped incrementally to measure rack and pinion alignment and evaluate gear tooth contact.
18. Using the data from the initial opening, adjustments to the rack and pinion alignment as well as the balance were made in conjunction with the installation of the guard rail. Once that was complete, another test was performed. Testing and adjustments were repeated until both the gear alignment and the balance met the requirements of the Contract.
19. The machinery bases were grouted and the anchors fully tensioned. At this point the structural and mechanical construction of the bascule leaf was complete and leaf was handed over to the electrical team for completion of the control system.

Conclusions

The changing constraints for rail and marine outages necessitated the development of a very aggressive plan to install a bascule span on an accelerated schedule. The means and methods developed by the project team were very successful in mitigating the risks inherent with this plan so that the work was completed without sacrificing quality. While the overall rail outage was very lengthy, approximately two years, the acceleration of the installation of the south leaf during the navigation season likely reduced the duration of the outage by months.

The primary key to success was discussing field installation as a team early on in the project with all players involved. This was critical to the planning, development of shop drawings, material orders and assembly plans prior to the start of fabrication.

The value of shop assembly and precision dimensional measurements as part of quality control cannot be understated as this is where significant issues were identified and corrected. Without the modifications that were made to stiffen the structure after the initial attempt at shop assembly it is unlikely that a satisfactory final result would have been achieved.

There were some minor details that were changed to improve constructability, and these were ultimately key to ensuring both schedule and quality considerations were met.