HEAVY MOVABLE STRUCTURES, INC.
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Rehabilitation of the FEC MP260.93 Single Track Railroad Bridge St. Lucie River Stuart, FL

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SHERATON HOTEL
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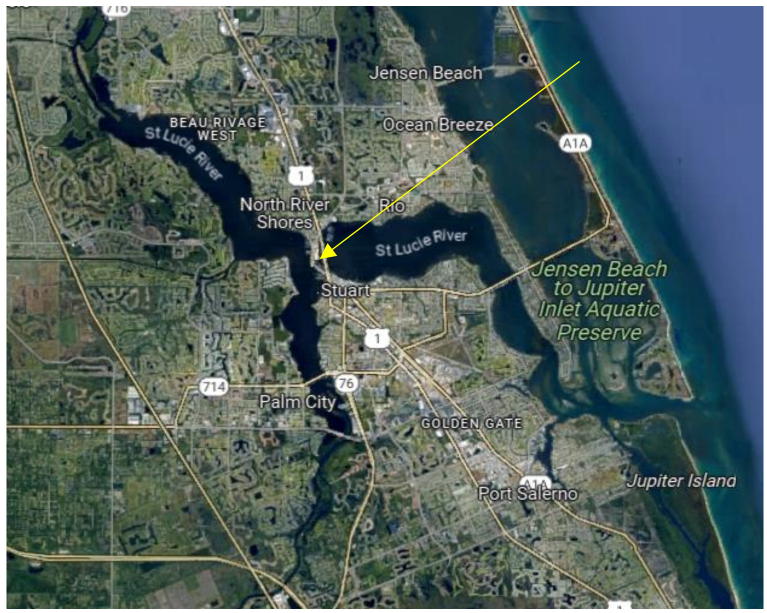
Introduction:

From Miami to Jacksonville, FL, the railway, owned and operated by Florida East Coast Railway (FEC), has several bascule bridges that span the waterways emptying into the Atlantic Ocean. Up until just recently, the railway was used only for transporting freight and included approximately 10-15 rail crossings of these waterways each day. As part of a contract with Brightline, FEC was looking to shore up these bascule spans to ensure their reliability as Brightline planned to operate a high-speed passenger rail service along the coast that would add an additional 30+ crossings per day. The bascule spans were evaluated, and plans were developed to refurbish their operations.

One such bascule bridge is in Stuart, FL, and spans the St. Lucie River. This bridge is a single-track, single-leaf bascule bridge that was built in the 1920's. With the planned volume of traffic, the long-term plan for this bridge is that of replacement as this marine crossing will require a dual-track design to mitigate the level of interruptions the new rail traffic will impose on the marine traffic. Design plans for a new dual-track are underway and is scheduled to be built adjacent to this single-track span at some point in the future. In the meantime, the existing single-track 100-year-old bridge span was to receive a short-term refurbishment.



St. Lucie River *- https://www.google.com/maps/@27.2272674,-80.2201746,30275m/data=!3m1!1e3?hl=en&entry=ttu*

This is where we came in.

In the following pages we will discuss some of the solutions the team developed to the known and anticipated challenges we expected to encounter as we refurbished the span. The first challenge was to determine where new would meet old within a given budget. Then the basic design challenges for the project included the following:

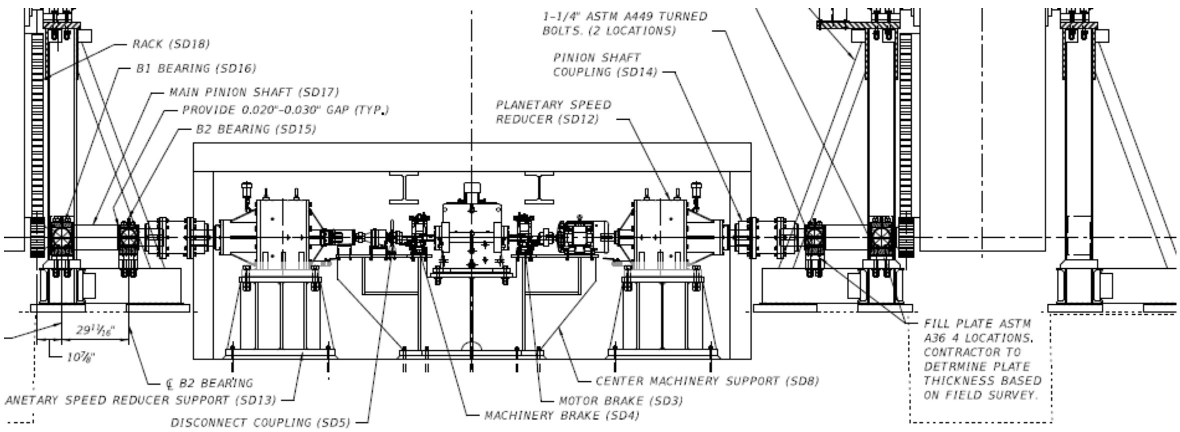
1) Fitting a new AREMA compliant drive system in the existing machinery room.
2) Fabricating and installing equipment within the construction window without interruption to rail traffic and with a 21-day marine closure.
3) Mating and aligning new equipment with the existing structure.

Meanwhile, all efforts needed to maintain the current Center of Rotation (COR). Afterall the bridge was working well prior to refurbishment and better remain that way.

Where will the new meet the old?

Aside from updates needed to bring the site up to date on electrical, plumbing, and access, the mechanical refurbishment would eventually include new machinery, new trunnion towers, and refurbishment of the worn trunnion journals. The "New" would meet the "Old" at the trunnion journals and at the mounting location for the new gear rack. The existing leaf would remain as found.

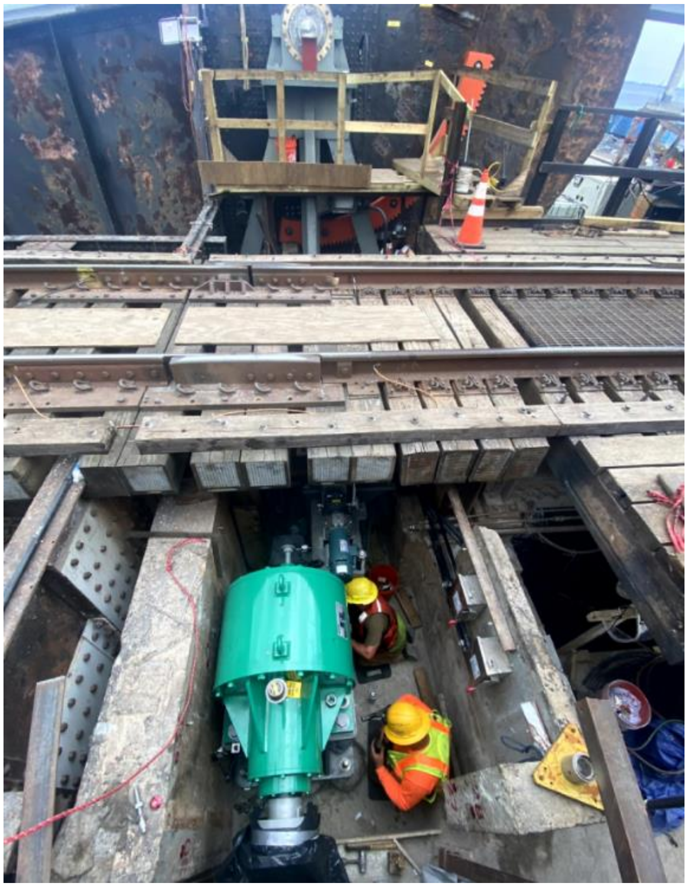
In the beginning however, the remaining budget for the St. Lucie Bridge did not include replacing the (4) trunnion towers. Our design efforts started with fitting a new AREMA compliant drive system in the existing machinery room with the goal of reusing the existing trunnion towers. With this plan, the new meeting the old would also include mounting the new trunnion bearing housings to the top of the old tower and mounting the new pinion shaft bearing housings to the lower framework of the old tower.



To comply with the current AREMA code, the new main drive machinery is much larger than the original equipment. Overall, the layout of the new drive system is traditional with a main motor driving a primary differential gearbox splitting torque to two secondary gearboxes that drive rack-and-pinion sets. The one item to note is that, in order to reduce the overall sizes of the gearboxes, the secondary reductions are planetary gearboxes instead of traditional parallel shaft gearboxes. Planetary gears allowed for a large gear reduction in a smaller space. Parallel shaft gearboxes would have been much too large. While planetary gearboxes are found on movable bridges, they are not in widespread use.

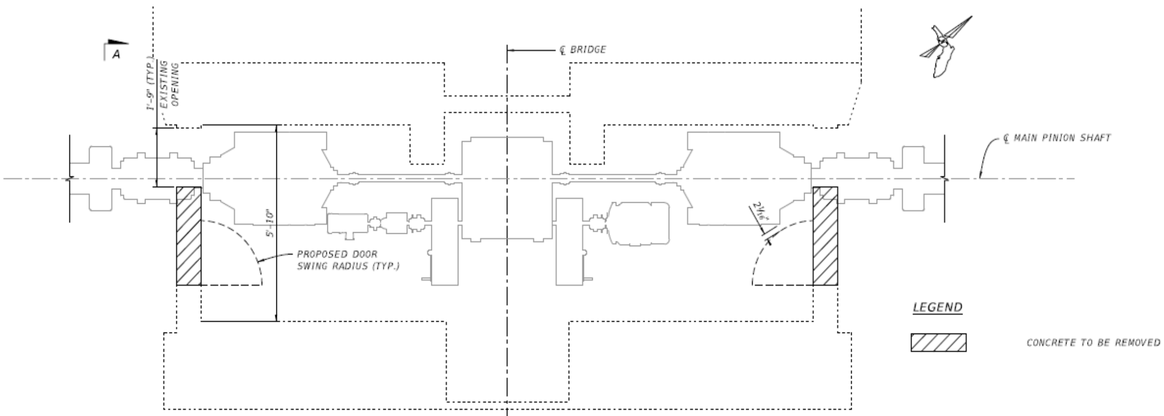
Fitting into machinery room was going to be tight.

Old Drive Machinery



New Drive Machinery

To fit this compact drive system into the existing machinery room, the pinion shaft would need to move toward the channel side of the pier by about 30″. Additionally, the concrete end walls of the machinery room would need to be removed as shown.

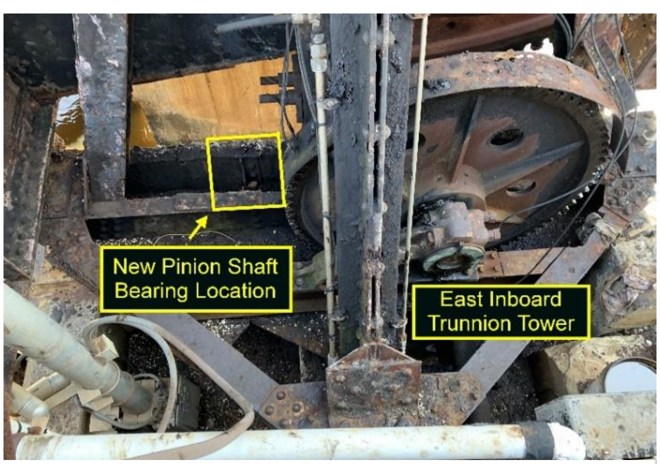


BASCULE PIER MACHINERY ENCLOSURE PLAN
(RAILS, TIES, AND SUPERSTRUCTURE GIRDERS NOT SHOWN FOR CLARITY)

With the position of the of the new pinion gear defined, designers proceeded to analyze options for mounting the pinion shaft bearing blocks to the old Trunnion Towers. A second field survey was conducted to determine the means and methods of attaching the pinion shaft bearings onto the lower portion of the trunnion tower and to attach the new trunnion bearing housing to the tops of the (4) towers.

Line of Sight for New Pinnion Shaft

Ideas were discussed for adding reinforcement plates to shore up the weathered framework and the feasibility of machining turned bolt holes accurately within the given work envelope. To install the pinion shaft bearing housings to the old towers, the means to rough locate, temporarily clamp them into position, kick them around to establish the blue fit with the rack and pinion mesh, and still allow enough head room to machine the Turned-Bolt hole pattern was required.



New Pinion Bearing Location

Replacing the trunnion bearing housings to the tops of the towers would not be a problem, but accomplishing this task would need to occur during the outage. At that time, after the weight of the leaf was transferred from the trunnion towers to the false work, the process to replace the bearing housings would look something like the following:

1. Remove the old bearing housing.
2. Machine the OD of the worn trunnion journals, correcting the geometry and surface finish requirements.
3. Add a sole plate to the top of the tower to provide a landing zone for the new larger bearing housing.
4. Machine the sole plate to be flat and level.
5. Land the new bearing housing with a new bearing onto the sole plate.
6. Align to the given COR.
7. Temporarily clamp the housing to the tower.
8. Machine the bolt hole pattern through the sole plate using the new bearing housing as a template.
9. Install the turned bolts and verify alignment.


New Tower and Bearing Housing

Considering the existing bearing must remain active until the outage, the only time this work could occur would be during the outage. A cost benefit analysis was performed to determine if the risks related to machining and installing the new equipment to the old tower would out way the cost of replacing the tower. With the risk related to the work being performed during the critical path time frame, it was determined that replacing the towers would be the best option. With new construction, the trunnion bearing and both pinion shaft bearings could be mounted and rough aligned during the build process and the entire tower could be installed as an assembly.

Side Note - The materials for this project were being procured and fabricated towards the end of the COVID 19 pandemic. Numerous design decisions were impacted by the availability of materials and the need to meet the construction schedule. One such decision involved the material for the trunnion bearing housings. Traditionally, these housing would be fabricated from cast steel or maybe a forging. In this case, cast and forged steel was not available within the necessary timeframe. Due to the long lead times for forgings or castings, the raw material chosen to fabricate the (4) trunnion bearing housings for this project was solid 14″ thick steel plate.

The entire shape shown here was whittled from solid plate.


New Trunnion Bearing Housing

Leave it "As Found"

The alignment of the span was not the problem. Noises created during operation were not terrible for a 100-year-old bridge. Nothing that would indicate the span was being forced through an unknown obstruction as it rotated on the trunnion journals. The toe of the span aligned well with the North approach track and the heel aligned well with the south approach track. No abnormal amount of wear was evident. There was significant wear to the (4) trunnion journals and both the rack and pinion teeth, but because the bridge operated well, the edict from the start was to leave the alignment "As Found."

As Found Trunnion Journal

As Found Rack Teeth

Laser Tracker Survey

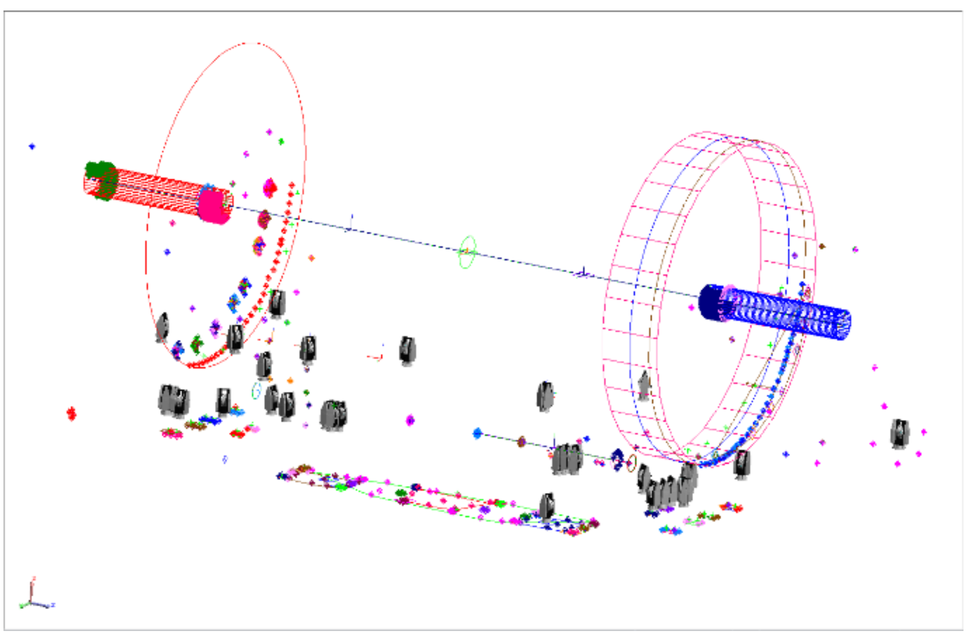
The Centerline of Rotation (COR) is the theoretical line that passes through the midpoint of the (4) trunnion journals. In January of 2021, IPM performed a laser tracker inspection of the span with the intent to define the actual COR in space. During this survey, the assumed work envelope as defined by the detailed drawings from the 1920's would be checked as well as the symmetry of the space with respect to the span. This would include verifying the pier elevations, both in the machinery room as well as at the (4) tower locations and checking how closely the span was centered within this space.

The inspection was to occur over a weekend while rail traffic was to be at a minimum. Many solid monuments were installed around the bascule and rest piers. These locations needed to be solid and unmoving, while also being visible from many locations. The goal was to find as many spots connected to Earth as possible and preferably concrete construction. This was a not a simple task. The size of this bascule pier was small, and it was an island located out in the middle of the St. Lucie River. One ideal location that could be seen from many locations was on the monitor house. This stood on wood piles adjacent to and connected to the railway structure. Unfortunately, this monument proved to move around during the inspection process by more than ¼″, rendering its location useless. Multiple monuments must be visible from each laser tracker location to accurately triangulate the data into a fine network or "cloud" of points in space. By placing about 20 monuments around the two piers we hoped to find at least 5 or 6 to be visible at each inspection location. This would ensure the resulting spatial analysis of the merged data to be accurate within thousandths of an inch.

To measure the COR, visibility of the (4) trunnion journals was required. The initial plan included removing the center plugs and looking through the center of each trunnion, like a piano wire test. Unfortunately, this was not going to be possible. The location of the existing limit switch used to signal the system of the leaf's location, was in the direct line of site. And because of its age and the risk of damage, moving the switch was not possible.

Line of Site Obstructions

Analyzing the COR reverted to measuring the outside diameter of the (4) trunnion journals. By removing the bearing caps, the top half of each journal was exposed allowing direct measurements to be taken in a grid format over the length of each journal. Using this grid of points collected from these half cylinders, a best fit cylinder was defined by the software. The inboard journals were measured from the center of the track while the outboard journals were measured directly outboard of the trunnion from underneath. This location was not ideal but was the only solid location we could find and still be able to tie back into the cloud.



Initial laser Tracker Results

A significant amount of data was obtained during this first survey and the analysis of the data revealed the centerlines of the East and West trunnion shafts did not point at each other. They were each pointing downward and a bit south. Over the 100-year life span it was obvious that the two inboard journals had settled more than the outboard journals and were leaning toward the shore at an angle approximately 180º from the fully open position of the span.

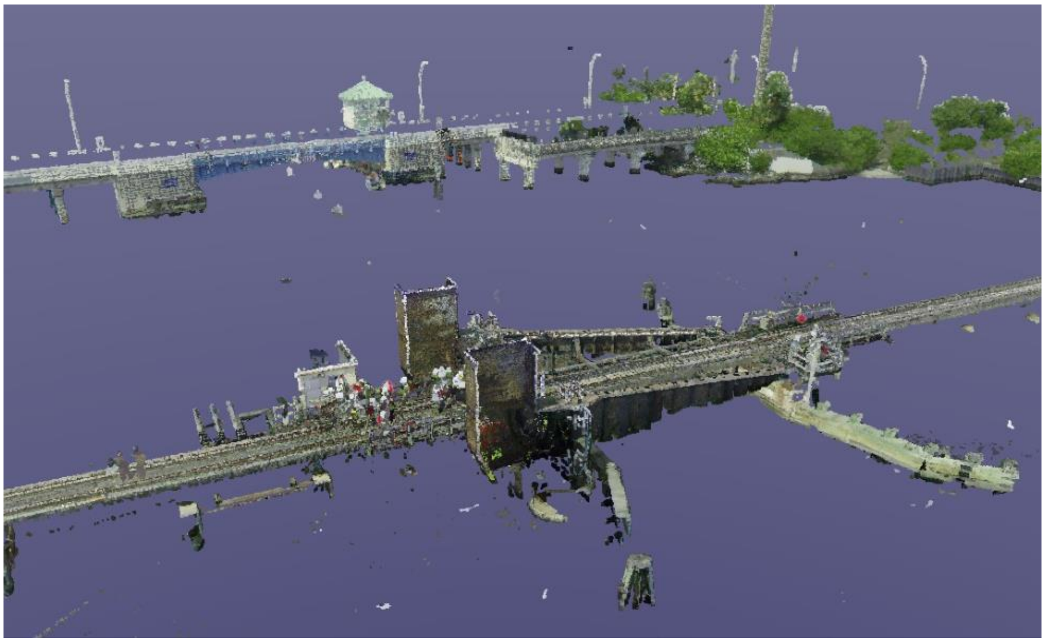
As Found Tilt of COR

Unfortunately, the angles of the East and West CORs created by the independent trunnion shafts were not square to the span. This was a concerning issue as the parallelism between the two interior girder webs were significantly out of parallel. Tying the mesh of two sets of rack & pinion gears together in a straight line through the machinery was going to be an issue. The decision to leave these (2) independent CORs in the “as found” condition or to try to correct this issue would require more data.

The initial survey data would continue to be analyzed over time, as the design phase progressed and as the means and methods to execute the rehabilitation of the bridge were being developed. During the summer of 2021, a list of missing information was developed and a return trip to site was scheduled for further survey analysis of the work area.

Reverse Engineer Using Scan Data

This second laser tracker survey was arranged to verify missing dimensions and to double check some of the previous inspection points. It was decided that this survey would also include a laser scanning event. The use of the laser scanning tool would help the design team generate an accurate solid model of the entire structure. The scan would include millions of data points taken with the on-board software utilizing the Global Navigation Satellite Systems (GNSS) to position the data with global alignment in real time.

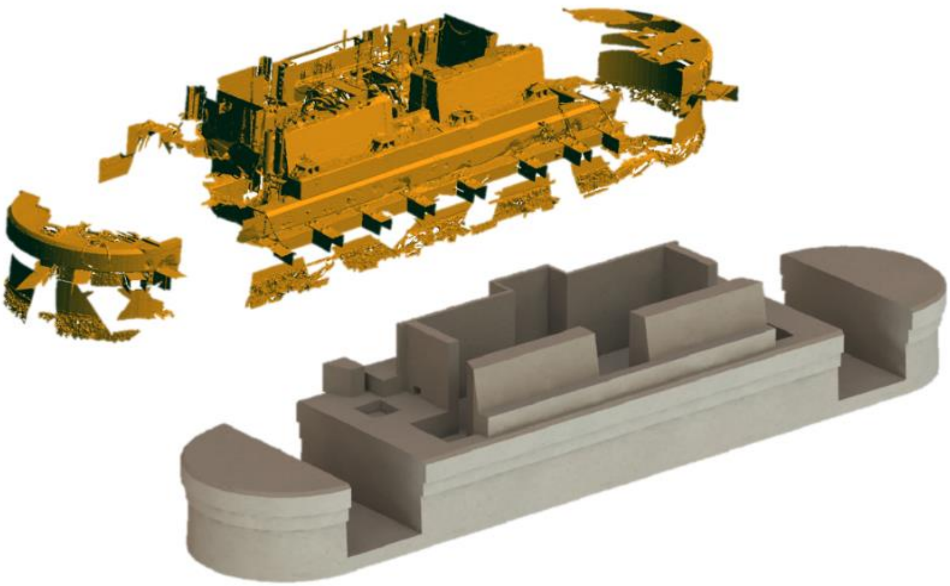


Scanned Data Cloud

Three dimensional scans were completed from a total of 41 setups which generated nearly 800 million data points. Some scans were taken with the span in the raised position while others were taken in the down position. From this data, a design engineer scrubbed the data to create a solid model of the entire area. This included the bascule span, the bascule pier, the machinery room, the rest pier, the inboard towers, and the approach spans.

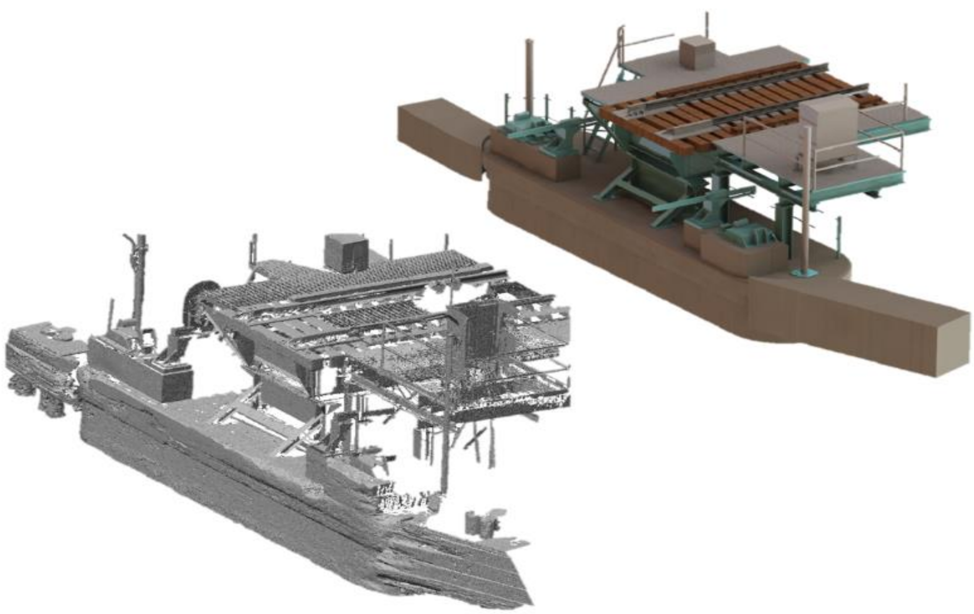
Translating the scanning data into a solid model was not a trivial task. Out of the 800 million data points, the relevant data needed to be selected from frivolous data, like seagulls or sailboats. Approximately 60 engineering hours were spent scrubbing the data and making the model. On the following pages, the scan data is illustrated along with the 3D model generated from this data.

Comparing the scanned data with the laser tracker data and the 1920’s drawings, the generated model was found to be quite accurate. The desired data that was checked for validity was found to be well within 1/16″ of actual verifiable data. Without verifying all 800 million data points, the design team used a conservative estimate of the scan’s accuracy of within 1/4″ for decision making purposes.



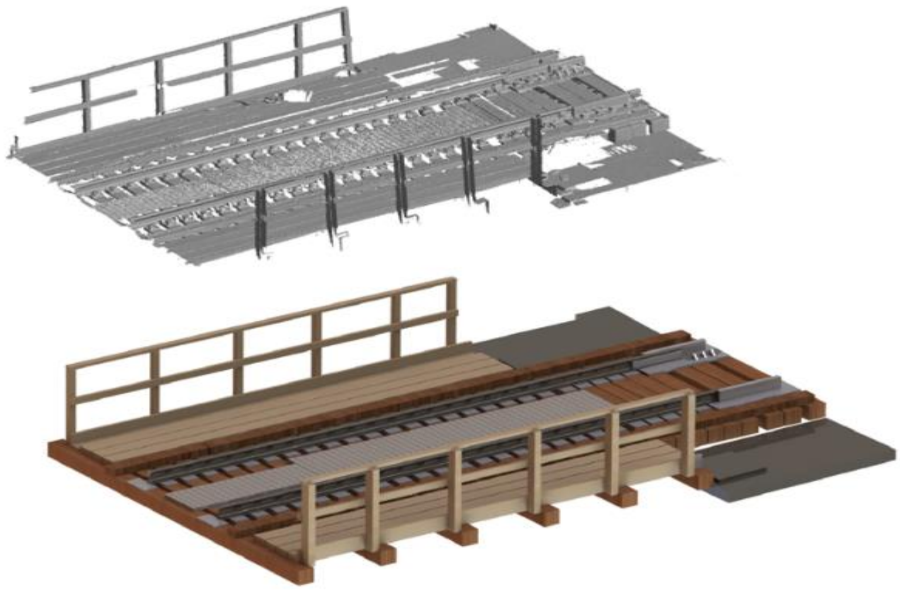
Modeling the Bascule Pier

Conversion of the Bascule pier data into a model included the interior & exterior of the machinery room.



Modeling the Rest Pier

The model of the Rest pier included the North Approach, Span Locks, and Live Load Shoes.

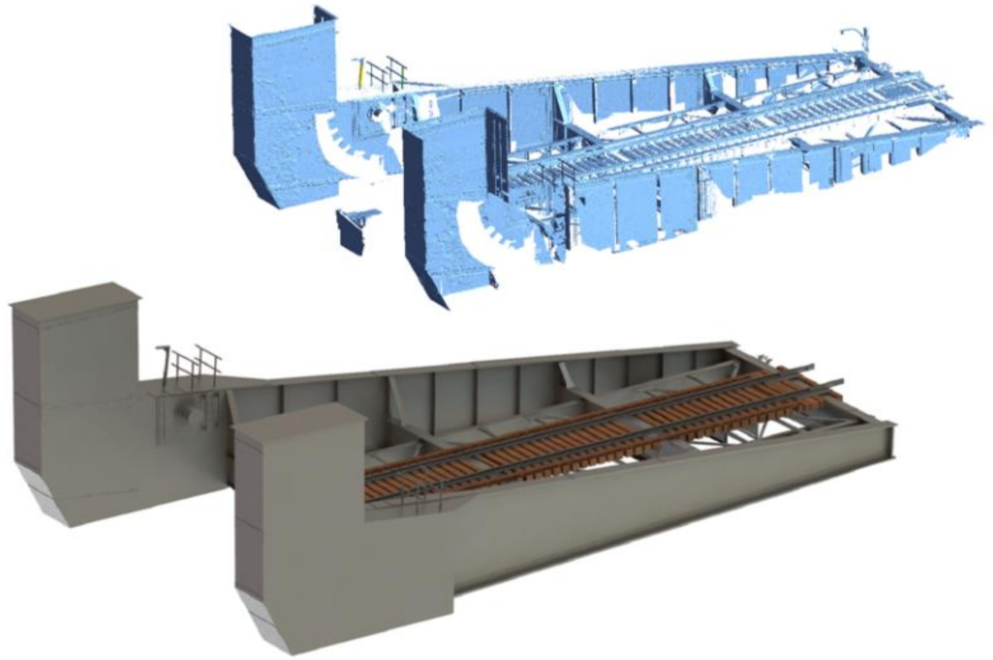


Modeling the South Approach Span

The South Approach Span was pulled out separately to assist with analysis of the machinery room.

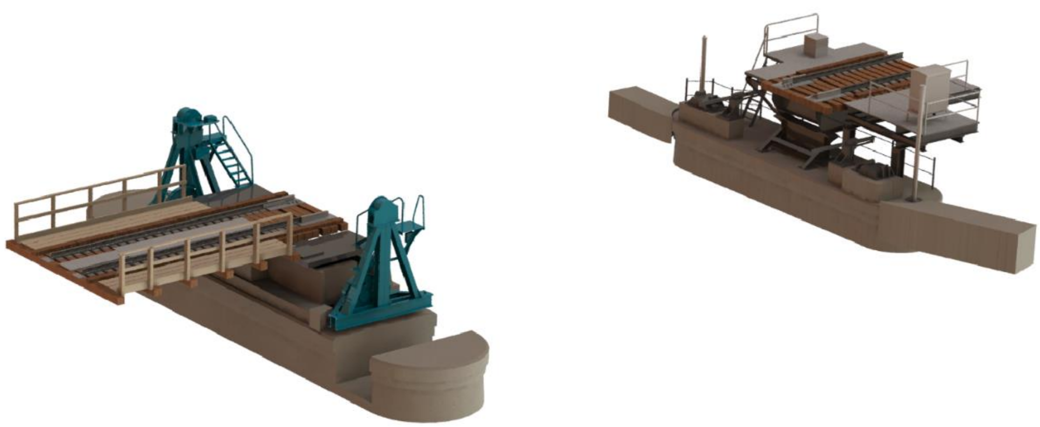
Modeling the In-Board Trunnion Tower

Inboard Trunnion Towers were developed to verify clearances.
We chose to ignore the data for the outboard trunnion towers.



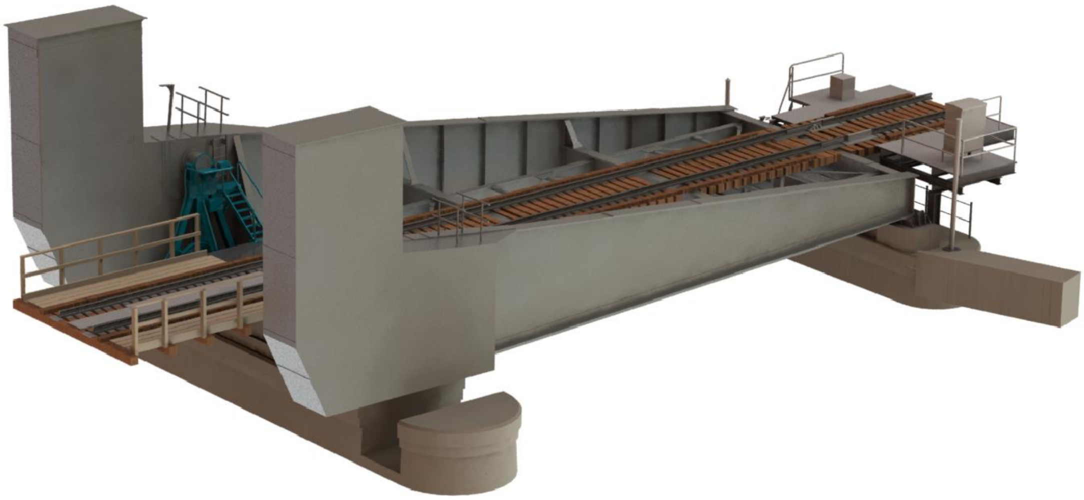
Modeling the Bascule Lift Span

The Bascule Lift Span was modeled with attention given to the Girder details.



Pier and Approach Assembly

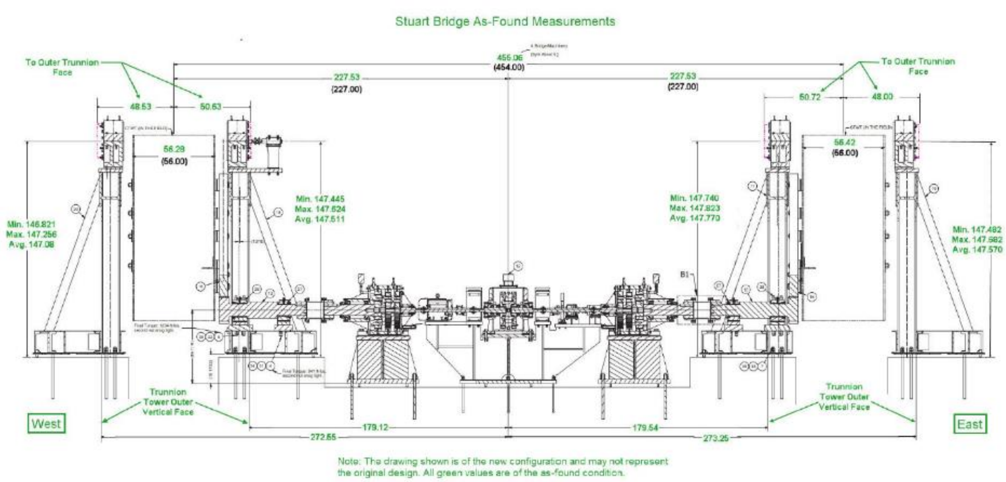
Assembling the models while verifying their spatial relationship with scan data, the laser tracker data, and the as built drawings.



Model of the MP260.93 Bascule Bridge over the St. Lucie River

The creation of this solid model proved to be an invaluable tool through different phases of the project. The girder web parallelism was analyzed and used to develop a plan to generate a plane perpendicular to the COR for mounting the rack. The dimensions of the counterweight wells were used to develop the false work needed to support the span while the towers were replaced. These are just two of the many examples where the solid model of the "As Found" structure was used to verify plans.

Validation of Plans



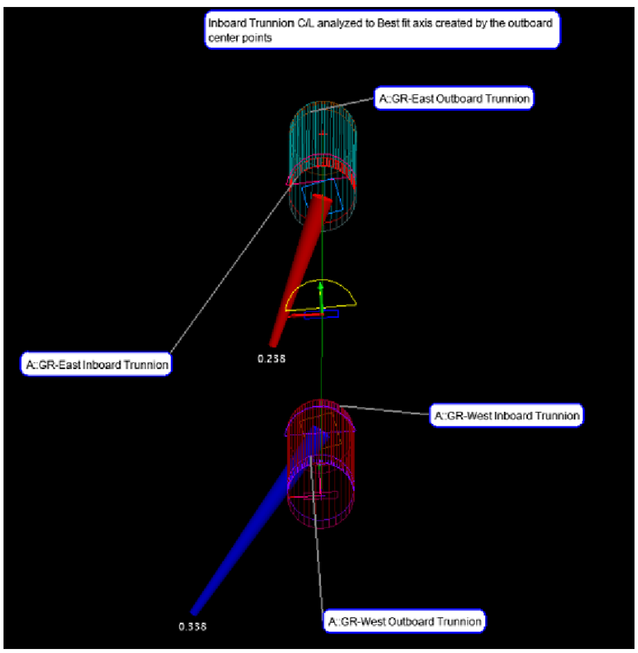
The scan and tracker data were used to verify the design criteria to ensure the new machinery would fit.

Old Meets New – Trunnion Journals

The trunnion journals had been damaged due to a lack of lubrication over the years and needed to be machined back to the AREMA specification of 8 µin Ra surface finish for trunnion journals. The predicted amount of stock removal needed to reach 100% cleanup was less than 0.15″ per side. To be safe, new bearings were manufactured to be 3/16″ per side smaller than the original Ø20″ nominal trunnion size.

To machine the journals, the alignment plan included referencing the adjacent undamaged surfaces of each existing journal. By aligning the machine's centerline to be concentric to these surfaces, the new journal diameter could be cut ensuring the COR would remain "As Found".

During the outage, however, when full access to the four journals was had, the COR for the (2) trunnion shafts were confirmed to be pitched at different angles. As measured previously, they were both tilted with the outboard journals higher than the inboard journals and the inboard journals closure to the shoreline than the outboard journals.



Through 3D modeling software, the misalignment of these (2) independent COR's proved the resultant angle of interface with the (2) pinion shafts would exceed the allowable angular misalignment provided by the new shaft couplings.

To fix or not to fix was discussed and it was determined that an attempt to manipulate the span must be made to ensure both the East Rack & Pinion mesh and West Rack & Pinion mesh would be achievable while connecting them in a straight line through the machinery room.

Mesh Inspection

May 1, 2023

Day 1 of the 21-day outage, task #1 was to take the load of the span away from the (4) trunnion towers and transfer it to the SBC designed and built false work shown here. It would be through the cribbing of the span on this false work that the adjustments could be made.

Scott Bridge Designed False Work

Execution of this event included close monitoring of the (4) trunnion journal locations to ensure the span's positioning was controlled without inducing any dramatic forces. Through this monitoring, analysis were made of any changes to the span's framework and the joints between the span's lift rails and the North and South approach rails. The span was jacked evenly at first until all four trunnions lifted about 0.04″. Then the inboard edges of the span's girder webs were jacked a bit higher. Jacking in very small increments, we lifted the inboard sides until the lift rail became even with the approach rails. This was visually reported to be an elevation change of less than ¼″ at the rail. At this point the slope of the (2) trunnion shafts had improved by approximately 50% toward being level but the toe end of the span started to move. The descision to stop was made and the load was fully transferred over to the False Work.

With the span in this slightly modified location, a new set of dimensions were taken and a new 3D model was created and analyzed. ***The results were good.*** The approximate 0.6º of misalignment had fallen to under 0.3º. This level of missalignment was now within the allowable range listed in the specifications for the pinion shaft couplings.

The (4) towers were then destructively removed exposing the (4) trunnion journals for the refurbishment work.

Span Alignment Through Cribbing.

Machining the Trunnions

It was now time to machine all (4) trunnions to the Ø19.625″ RC6 fit specified.
Train Traffic was to remain uninterrupted throughout the machining.

Trains kept A' Rollin'

With (4) machines running simultaneously we successfully achieved the fit and finish required and within the budgeted time frame.

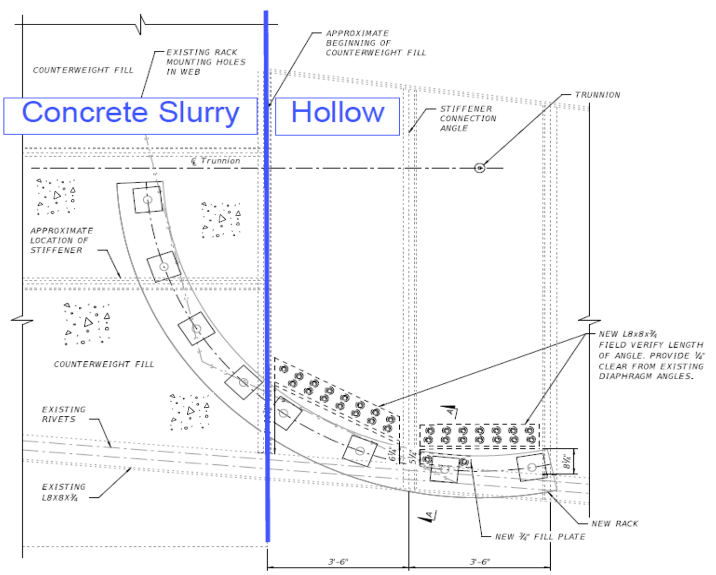
Inboard East Trunnion - Completed

Old Meets New – Rack

The development of the means and methods to attach the rack to the 100-year-old weathered girder web had several complicated factors.

1. Total outage time was to be limited to 21 days.
2. The existing rack was in the way.
3. The girder webs were not parallel.
4. The weather damage was significant.
5. Half of the landing zone was hollow, and the other half was filled with a slurry of concrete and steel punchings.

The new rack was to be fastened to the girder web using compressive forces generated through turned studs. Half of these studs were to be located over the concrete filled section of the counterweight box while the other half were located over the hollow section of the girder box. Holes through the counterweight needed to be machined through the interior girder web, then through the 55″ of concrete/steel slurry, and then through the outer girder web. The holes needed in the hollow girder box only needed to go through the interior web. The rack would then get bolted to each girder box with (4) approximately 65″ long studs passing all the way through the counterweight section and (4) approximately 12″ long studs passing through to the inside of the box girder. Additionally, all holes needed to avoid hitting the stiffeners of the originally built box.



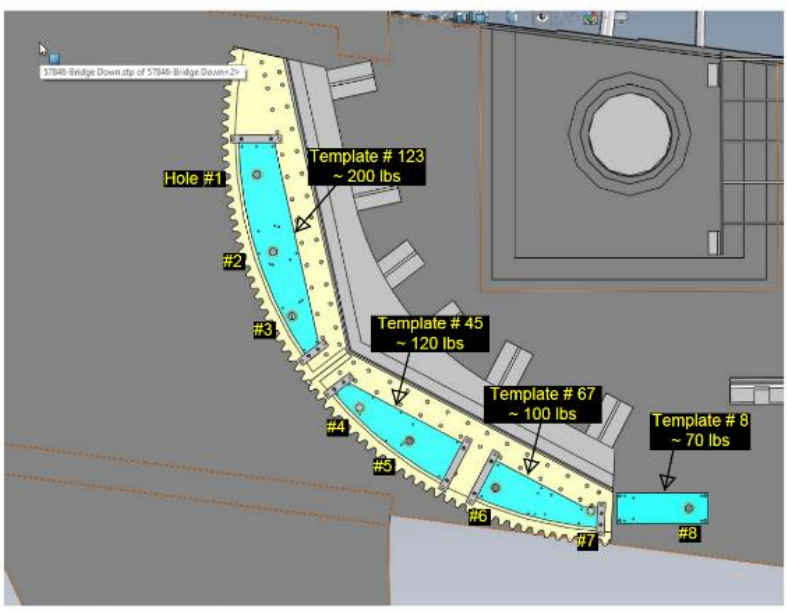
Sample of concrete and steel slurry

From the onset it was understood the timing would not allow for rack adjustments and that the placement of the actual girder hole locations would be critical to ensuring a good mesh between the rack and pinion gear teeth. The holes in both the racks and the girder needed to be precisely located. Then the RC5 fit between the rack hole, girder hole, and the turned stud would dictate the mesh of the gears.

Through the experience obtained on the Loxahatchee bridge, it was known that machining through the Concrete Slurry section of the counterweight box would be a lengthy process and one that would not fit into the outage time allowed. For the plan to work, the machining of rack mounting holes must be performed prior to the outage. And to do this, the existing rack must remain in place to keep the bridge operational.

Overcoming this challenge was accomplished by drilling through the existing rack and then through the girder webs. Together with the design team, mounting hole locations were developed and a clearance hole size was chosen. The locations allowed for machining through the existing rack without compromising the rack's integrity. They also provided spacing that would avoid the existing interior box stiffeners. The locations of these stiffeners were laid out using the as built drawings and then verified using scan data. The hole sizes would provide clearance for the fasteners and tools were ordered.

With this design, the means and methods were developed to add the holes. Prior to the main outage, 12 consecutive nighttime outages were arranged. During this "pre-outage" outage, the clearance holes needed for the rack mounting could be drilled. The execution began by mounting ground plates to the existing racks with low profile mounting hardware. Keeping everything low profile was necessary to allow the new plates to remain in place during bridge operations. These ground plates incorporated jack screws into the design that allowed the ground surface to be trammed onto the correct geometric plane of being perpendicular to the COR.

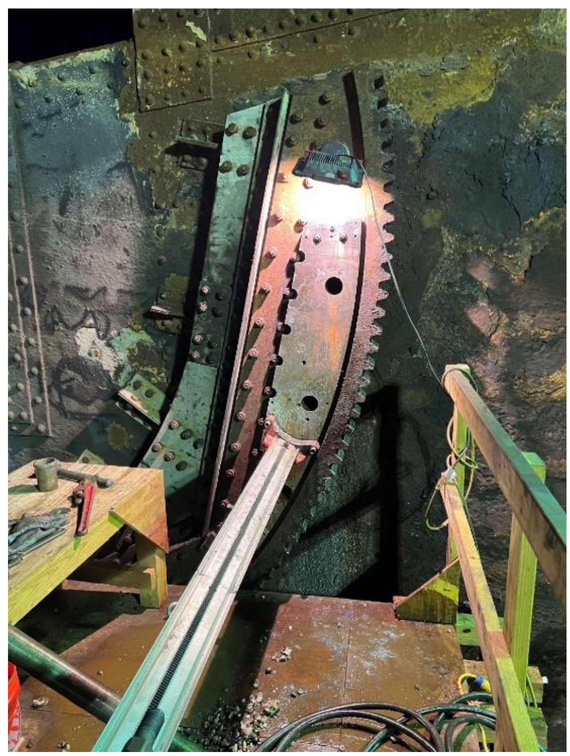


The ground plates provided a flat plane to locate the machining equipment to such that their centerlines would be parallel to the bridge's COR. By drilling through the existing rack, these low-profile templates became part of the rack during its last few weeks of life and allowed the bridge to remain operational during the day while also allowing machining of precise holes underneath the surface of the existing racks at night.

After mounting the plates, machining of the clearance holes through the girder web averaged a little less than (1) hole per night.

Drill templates mounted on plane.

Core drilling Hole #1 - East Girder.

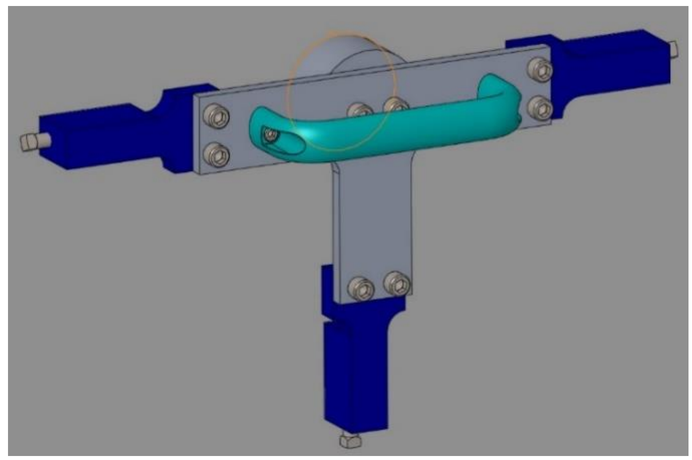


Holes #1 and #2 Completed – East Girder

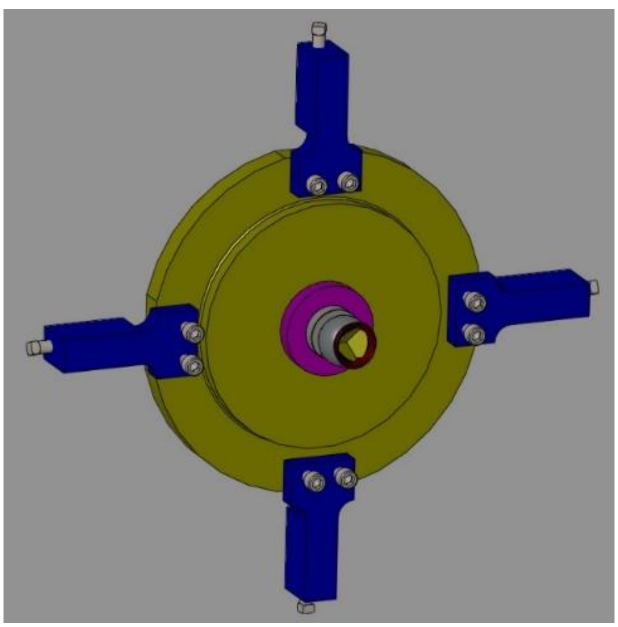
Adding the Puck

To address the challenges stemming from the out of parallelism issue and the extremely weathered condition of the girder web, it was determined in the design that adding a web reinforcement plate of some kind could be employed. The reinforcement plate designs discussed went from complete "gorilla sized" sections to a small plate at each hole location. After a material analysis was performed on a coupon of the 1920's web material, it was determined that a weld connection would work for adding this reinforcement plate.

From there, the team developed a web reinforcement plate, referred to as a "**Puck**". The Pucks would help solve a long list of challenges. They could be made long so that a precise facing operation could be performed to put the rack mounting face on the correct geometric plane. It also incorporated a bolt pattern that would allow for shimming to the proper elevation needed. The design also provided a landing surface for the machine tool that allowed for setup reduction.



Installation of the Pucks was performed in steps. Using the "T" shaped tool shown here, (3) kickers were temporarily welded to the girder in a precise radial relationship to the clearance holes previously machined into the girder web. Then the Puck slid in behind the kickers and a 4th kicker was added.



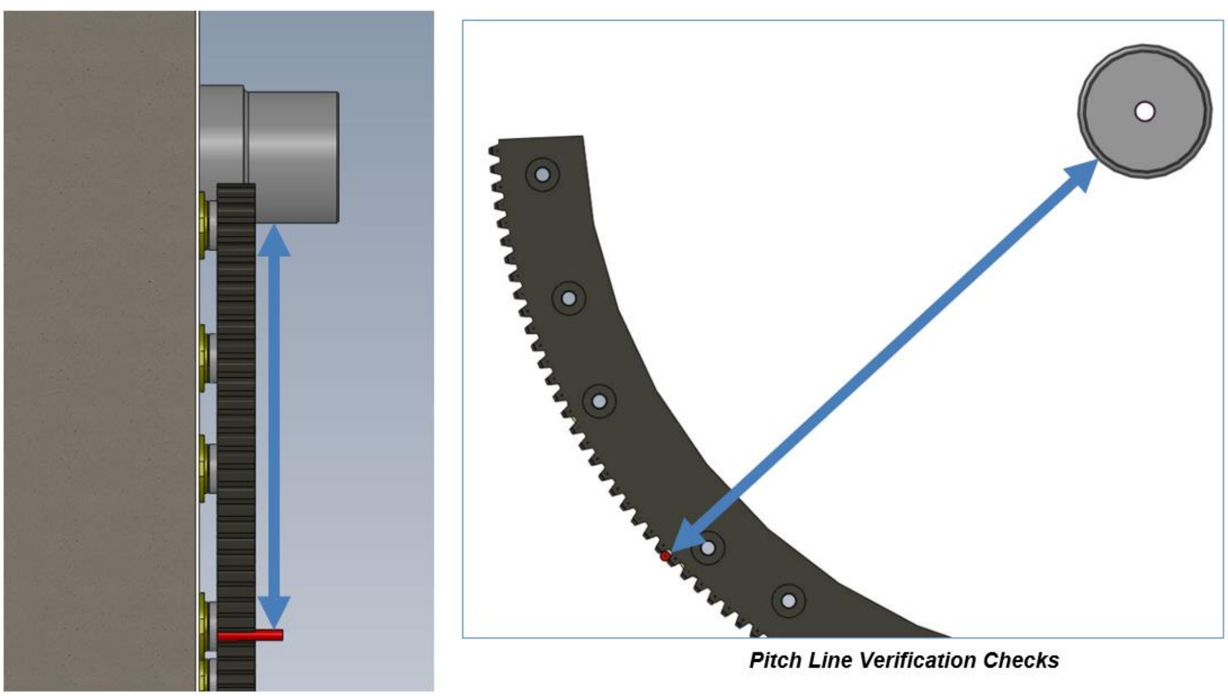
These kickers were used to move the puck around on the skin of the web to place the center hole at precisely the pitch line radius needed for the rack. Alignment through the laser tracker was quickly performed along with a specially designed monument carrier placed in the center of the Puck as shown here. The puck was then welded to the web and the kickers were removed.

Locating the Pucks

Face Machining of the Pucks

Each puck was provided with a setup ring for mounting the facing machine. This ring bolted onto the Puck using the bolt pattern outside of the rack mounting face. Using the laser tracker, we quickly shimmed the face of this ring to be parallel to the final rack mounting plane desired. Then the machine would bolt onto this ring and cut a face parallel to this surface. With all the planning and design development of the Puck, along with performing a mockup in the shop, we were able to machine the puck faces on our desired plane in record time.

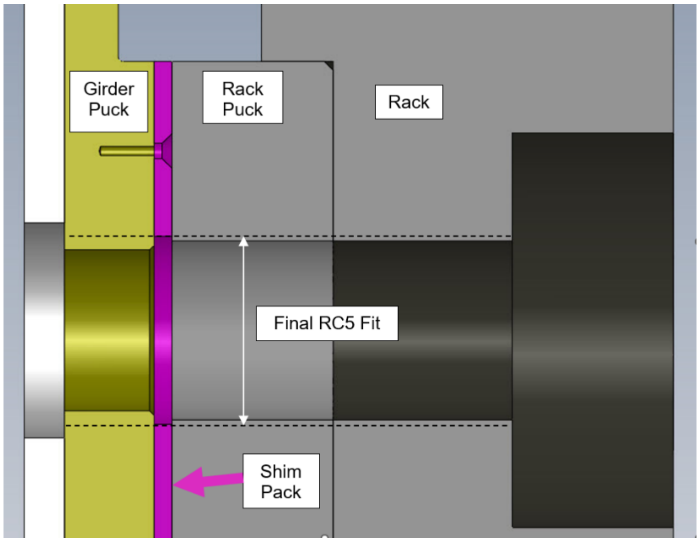
With the faces machined and the subdrilled holes accurately located, we assembled the Rack using temporary fasteners. The pitch line runout was inspected with the laser tracker and, for a sanity check, confirmed using the mechanical means of a pitch pin and a direct measurement to the trunnion journal as shown below. With ground pitch pins clamped into the teeth of the rack, tangent to the pitch line, a direct measurement of the distance to the trunnion journal was taken. The results confirmed that the subdrilled mounting holes accurately located the rack.



Pitch Line Verification Checks

From there, we removed one temporary fastener at a time, finished the subdrilled holes to the RC5 fit, and installed the final hardware.

Final hole size finished at assembly.



Hole #s 1, 2, & 3 completed with final fasteners torqued.
Working on Hole #4.

Machining RC5 Fit on Hole # 4

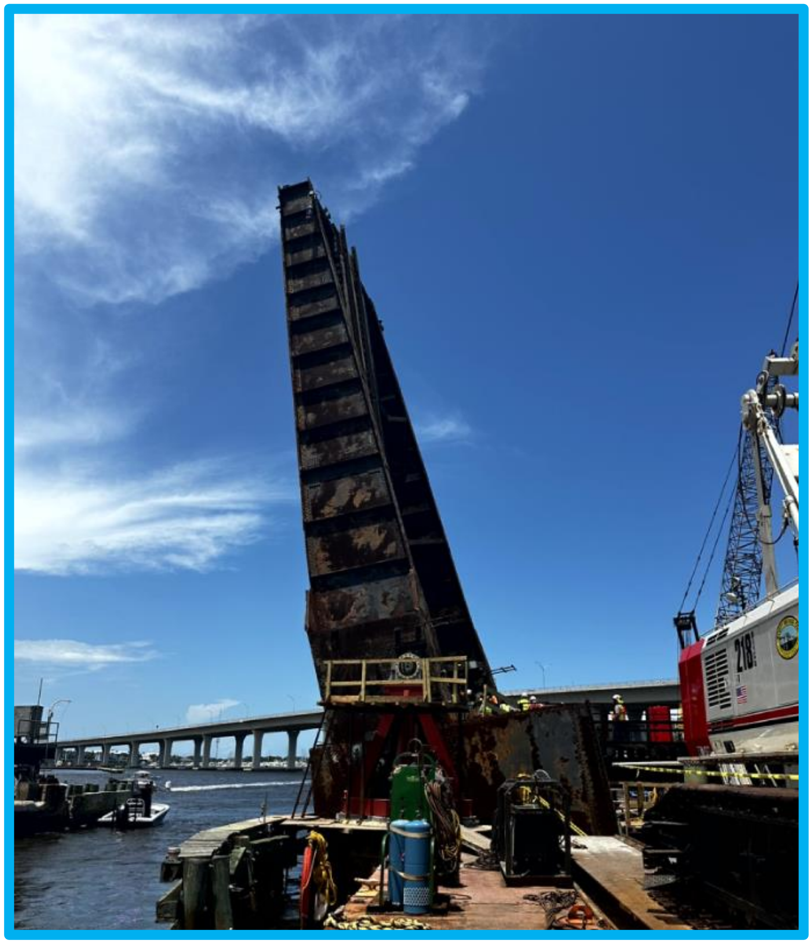
Conclusions

In retrospect, the biggest lesson learned was the need for redundancies. For each task, a Plan A was developed. Then depending on the level of risk inherent to the task, a Plan B and sometimes a Plan C was developed.

The "False Work" developed to carry the load of the span is a great example. This needed to carry the Dead and Live load with a safety factor. This design could have stopped there but because this task also represented the work bench needed to hold the span while we worked, the design incorporated a means to adjust the elevation. This ability to adjust became the tool used early in the outage to tweak the alignment of the span and correct the East and West girder alignment on the fly.

Having a surplus of machines on site is another example. With (4) trunnion journal machines running simultaneously, we were able to complete the journal machining ahead of schedule. A portable machine shop was brought to sight and used frequently for unplanned machining needs.

The upfront planning that went into this project was huge. Weekly meetings were set at routine intervals for about 18 months. All parties involved would get together and discuss the relationship that one team's production had to another team's needs. Many adjustments were made that did not impact the producer but greatly improved the user's chances of success.

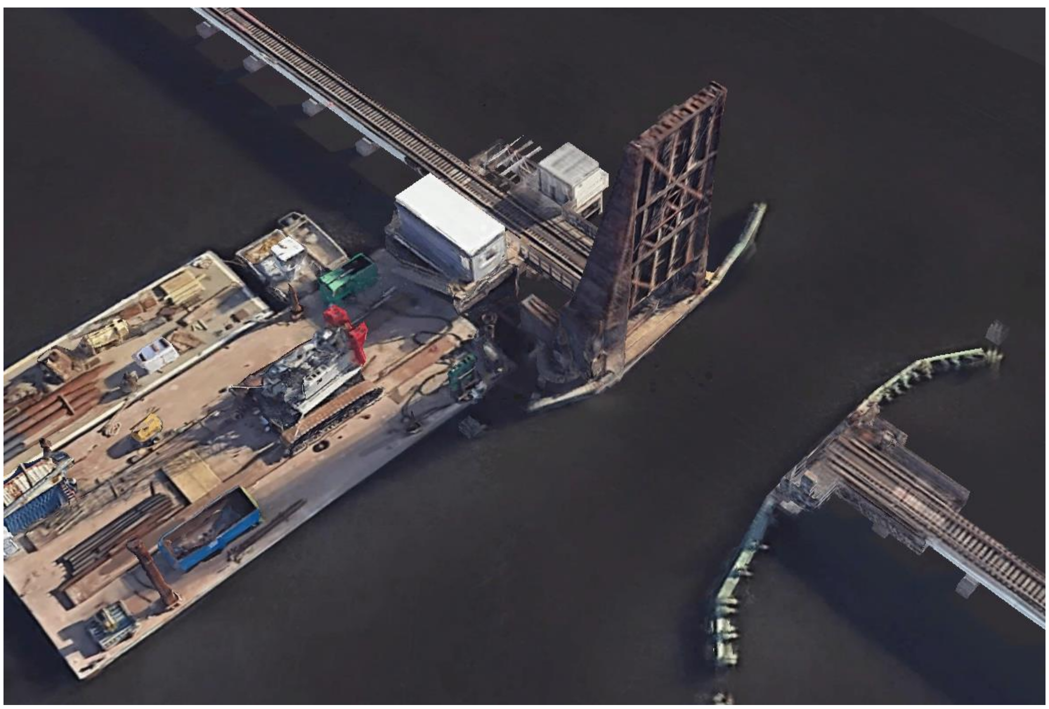


Successful Maiden Lift - May 20, 2023

Ultimately the project was hugely successful. The quality of the refurbishment was at the top of the scale, the outage finished (1) day ahead of schedule and the price tag was only slightly over the budget.

Acknowledgements:

Role:	Company:
Owner:	Florida East Coast Railway (FEC)
Operator:	Brightline
General Contractor:	Scott Bridge Company
Engineer– Mechanical & Electrical:	TranSystems
Steel & Machinery Fabricator:	G&G Steel, Inc.
Contractor's Engineer:	Wiss, Janney, Elstner Associates
Field Machining:	In-Place Machining Company
Electrical	Edwards Electric Corporation
Controls	Champion Controls



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