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Amtrak's Thames River Movable Bridge Replacement

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Abstract

Amtrak completed the replacement of the Thames River movable bridge span in 2009. The bridge crosses the Thames River between Groton and New London Conn., and carries 38 daily Amtrak passenger trains between New York and Boston, and 2 daily freight trains. The drawbridge opens over 1600 times per year for marine traffic including US Navy submarines, US Coast Guard, commercial, and recreational vessels. The Strauss heel trunnion bascule drawspan was put into service in 1919 and had been operationally problematic for the last 25 years. The bascule span was replaced with a span driven vertical lift bridge on the same footprint while keeping the drawspan in operation.

This paper will discuss the various engineering features unique to this 3 year construction project, as well as obstacles that were overcome, including mitigation of unanticipated pier settlement with extensive foundation grouting, pier modifications including drilled piles and post tensioning, fabrication and erection of 5 million pounds of structural steel, machinery fabrication and installation, erection of lift towers over electrified catenary, lift span truss erection on barge, removal of existing 4 million pound counterweight, span change out using float out/float in method during 4 day rail shutdown, and restoration of operations for both rail and marine traffic.

Introduction

The Thames River Bridge carries Amtrak's Northeast Corridor at Milepost 124.09, midway between New York City and Boston, across the Thames River between New London and Groton Connecticut near its confluence with Long Island Sound. Located upriver from the bridge is the US Navy Groton Submarine Base, the US Coast Guard Academy, a coal-fired power plant, a chemical manufacturing facility, and various shipyards. Downriver is New London Harbor with marine piers for intermodal shipping and the Electric Boat Division of General Dynamics submarine assembly and launching facility. Amtrak operates 38 passenger trains across the bridge daily, carrying more than 2 million annual passengers, and the Providence and Worcester Railroad operates 2 daily freight trains. The movable bridge span has 1600 to 2000 openings annually for marine traffic.

Figure 1 - Location Map

History

The first railroad bridge across the Thames River at New London was completed in 1889, consisting of a double track swing span, 503 ft in length and the longest such span in the world at that time. Shortly after it was built, the bridge piers began to settle. The settlement of the piers progressed to the point that in

1908, traffic was restricted in weight and reduced to a single track while plans were underway to replace it. Upon completion of the 1919 structure, the 1889 bridge was converted for highway use.

The 1919 Thames River Bridge was constructed for The New York, New Haven, and Hartford Railroad approximately 150 ft north of the 1889 swing bridge. This two track bridge has a total length of 1389 ft and consists of 4 through-truss approach spans; Span A at 185 ft and Span B at 328 ft on the west approach, Span D at 327 ft and Span E at 324 ft on the east approach. Span C was a heel trunnion bascule designed by the Strauss Bascule Bridge Company and was a through-truss of 188 ft span length and provided for a clear channel width of 150 ft. The bascule span's 4 million pound counterweight rotated about a pair of 2 ft diameter trunnion bearings which were nested between the top chords of Span B. The masonry and concrete piers and abutments were constructed to accommodate 4 tracks, but the bridge was never widened beyond the original double track configuration. The substructure was completed in 1918, and the superstructure was completed by The American Bridge Company in 1919. A unique feature of the bascule span is how it was supported by the adjacent approach spans which cantilever from the piers towards the channel, which reduced the length of the bascule span for the required channel width.

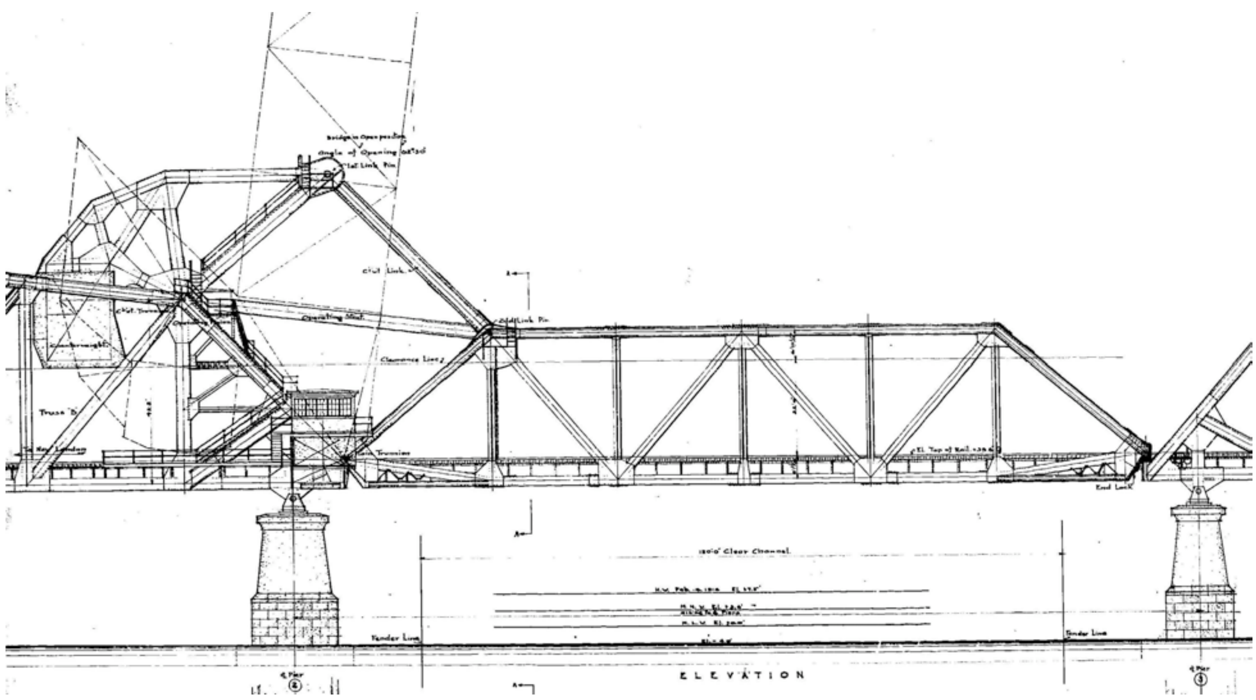

Figure 2 – Strauss Bascule Span (Span C)

Over its 89 years of operation, the bridge was upgraded and partially rehabilitated a number of times. In the early 1980's portions of the bridge were rehabbed under the Northeast Corridor Improvement Project, including replacement of broken counterweight trunnion retainer bolts. These retainer bolts, which were 2 ¼ in. diameter by 56 in. long, held the counterweight trunnion bearing assemblies together, with 8 bolts per assembly. In 1982, 10 of the 16 retainer bolts in both of the trunnion assemblies were found to be broken. These were replaced, but bolts continued to break during the next several years in spite of various methods of repair, none of which offered any long term remedy.

Planning and Design

In 1996, Amtrak commissioned a study to determine the long term solution to the trunnion bearing problem. This study looked at the consequence of a complete trunnion failure and concluded that the risk was significant for the bridge to be stuck in a partially opened position which would block the crossing for both rail and marine traffic. Emergency repairs could take months which was deemed intolerable. Options investigated to prevent such a catastrophe included replacement of counterweight trunnions, replacement of the bascule span, and replacement with a vertical lift span. All options retained the existing substructure and approach spans. Consideration was given to initial cost, life cycle costs, constructability, impact to rail and marine traffic, and the environment.

The vertical lift span option was deemed to be the most feasible. After submittal and review of the Environmental Assessment and discussions with local governments, US Coast Guard, US Navy, and Connecticut Department of Environmental Protection, Amtrak chose to proceed with design of a new vertical lift span. After requesting and evaluating proposals from several engineering design firms, HNTB was selected to perform the design for replacement of the bascule span with a new vertical lift span.

Design was done in accordance with AREMA Recommended Practice and Amtrak requirements, and was completed in 1998. The design plans included the following features:

- Suggested construction sequence including a method of temporarily supporting the existing 4 million pound counterweight, removal of existing bascule span, and installation of new vertical lift span, within a 10 day marine outage and 4 day rail outage.
- Enlarging 2 existing channel piers to support the lift towers. Utilize existing approach spans, modifying existing lift span bearing supports for the new lift span.
- A two track through truss span driven vertical lift with twin 75 HP DC SCR Drive electric motors, twin 40 HP auxiliary drive motors, and an emergency back up generator.
- 222 ft high lift towers providing 135 ft maximum vertical clearance over the water.
- Four 16 ft diameter tower sheaves with roller bearings; 64 each 2 ¼ in. diameter steel wire counterweight ropes; 8 uphaul and downhaul ropes.

Figure 3 - Rendering of New Lift Span

Preconstruction

In 1999 Amtrak requested proposals for construction. Bids came in higher than expected and due to Amtrak's financial situation, the project was placed on hold. The existing bascule bridge continued to cause grave concerns due to loud metallic banging noises emitted from the counterweight trunnions and the increasingly frequent breaking of main and counterweight trunnion retainer bolts during operation.

Renewed efforts to budget for the bridge replacement were successful in 2003. Amtrak solicited proposals from several construction management firms to perform a constructability review, assist with construction proposals, and help manage the construction. Washington Group International (WGI), which has since become a Division of URS Corp., was selected in 2004.

WGI performed a constructability review of the contract plans and specifications and forwarded their comments to Amtrak and HNTB for review. Several meetings were held to review comments and determine changes to plans and specifications. Revisions were made by HNTB while the prequalification process took place for prospective construction contractors. Additional input was received by the prospective contractors and some items were the basis for additional revisions to plans and specifications. The construction contract was developed in accordance with Amtrak requirements and AREMA Recommended Practice. Two additional scope items were added to the construction contract; installation of C&S submarine cables, and fender system replacement using material manufactured from recycled plastic, designed by Hardesty and Hanover.

Amtrak received technical and financial proposals from five pre-qualified contractors. Among the key issues addressed in technical proposals were methods for demolition and removal of existing counterweight, removal of existing bascule span, fabrication and erection of structural steel towers and new lift span. Each contractor's technical and financial proposals were analyzed with greatest weight based on the merits of the technical proposal. Five proposals were received, and the one which scored the highest was submitted by Cianbro Corporation, Inc. They were awarded the Contract with a Notice to Proceed date of November 15, 2005.

Formula for Success: $P+C^3=T$

A partnering session was held in March 2006 with key project team members from Amtrak, HNTB, WGI, and Cianbro to establish project expectations, participant roles and responsibilities, and define success with the formula "Purpose + Commitment, Communication, and Collaboration = Teamwork", or $P+C^3=T$. Monthly meetings were held throughout the project to discuss design issues and resolve engineering problems. Weekly and daily meetings were held as the project progressed, and as challenges were faced, $P+C^3=T$ was consistently practiced among the team members.

Mobilization

Fortunately there was property available for lease a short distance away from the bridge that had formerly been a steel fabrication facility with direct access to rail and the Thames River. Cianbro began mobilization to this property in January 2006 and a steady flow of equipment and materials commenced.

Substructure Construction

Unconfined in-water work was restricted by the project environmental permit to the period between October 1 and March 31. In January 2006, Cianbro began the excavation of the riverbed required to install the submarine cable necessary to complete the C&S improvements that had been added to the project scope.

Shortly after the Notice to Proceed, Cianbro submitted a value engineering proposal to alter the construction method for the pier extension support. The original specifications called for sheet pile cofferdams driven into a layer of organic silt and muck to elevation -22 from the water surface, with pipe piles spun to bedrock followed by 10 foot deep drilled rock sockets. Cianbro noted that the elevation of the mud line in the substructure extension area would probably conform to the navigable channel depth of -40 rather than -22 and would thus afford less stability at the toe of the sheeting. Combined with the reduced sheet pile toe, the organic sediment layer would likely be insufficient to adequately support the proposed tremie concrete and crushed stone and concrete layer. Instead, Cianbro proposed to use temporary cofferdams and 48 in. diameter steel pipe piles as casing shells around 36 in. diameter steel pipe piles drilled to rock rather than the permanent cofferdams and 36 in. pipe piles driven to rock. This approach eliminated both the crushed stone and tremie concrete; the cost savings for which were applied to the longer required sheet piling. The pier extension foundation work commenced with the construction of the temporary cofferdams and the pile template, which were completed in March 2006.

Cianbro subcontracted Case Foundations to install the 48 inch diameter casings and 36 inch diameter pipe piles spun to rock and proofed with a 30,000 lb hammer. The casings were installed to elevation - 82 and the piles to elevation – 180. During proofing of the piles, it became evident that Pier 2, which supported the bascule span and counterweight, was settling to the south (downriver). This movement resulted in track misalignment, reaching the point where the span locks at the toe end of the bascule would not engage the receivers. Pile operations were halted with 7 of the 8 pipe piles completed and proofed. Span D, upon which the misaligned span lock receivers and centering device socket were attached, had to be horizontally re-aligned to meet the new position of the bascule span.

Mueser Rutledge Consulting Engineers (MRCE) was retained to study and assess the movement of the piers and provide recommendations for stabilization. As recommended by MRCE, Amtrak directed Cianbro to perform exploratory borings to better determine the subsurface conditions. Clarence Welti and Associates performed the boring work and MRCE installed inclinometers through the substructure caissons to ascertain the cause of the settlement. Based on this investigation, MRCE recommended an extensive program of grouting the sand and gravel river bed to stabilize the piers. The execution of this additional work was a major impact to the complexity, schedule, and cost of the project. Several papers and articles have been published that fully describe this effort, and are referenced at the end of this paper.

The original design for extension of Piers 2 and 3 consisted of drilling and epoxy grouting reinforcing dowels and bars and placement of 4000 psi concrete. During review of conditions of the existing substructure, MRCE raised concerns about the capacity of the existing piers to accommodate the forces and loads that would be applied by the new lift bridge given the original design parameters and the behavior of grouted soils. MRCE recommended modifications to the original design to include a significant increase in the reinforcing steel and adding lateral and longitudinal post tensioning, with a hoop system embedded in the pier extension concrete. Additionally, the concrete strength requirements were increased to 4500 psi. Preparatory work consisted of roughening the surfaces of the existing piers to obtain a surface profile with amplitude of ¼ inch. Cianbro subcontracted Concrete Cutting Services to core drill holes through the existing piers for installation of post tensioning ducts and the new tower anchor bolts. To address interferences between reinforcing steel and the post tensioning components, an HNTB representative was onsite to provide direction. Cianbro installed the reinforcing steel and post tensioning components, and placed concrete concurrently with the performance of the grouting program.

Fabrication and Delivery

Fabrication commenced in May of 2006 of the tower structural steel by Oregon Iron Works in Oregon and the lift span structural steel by G&G Steel in Alabama. Cianbro secured a number of storage yards adjacent to the bridge site for storage of the structural steel as it was delivered to the site. The new end floorbeams for Spans B and D, the new counterweight boxes, miscellaneous steel for stairs, platforms, and ladders were fabricated by Cianbro Fabrication and Coating Corporation at their facilities in Maryland and Maine. Cianbro faced some challenges in shipping portions of the main tower legs by rail from Oregon to the project site, as the member dimensions exceeded the limitations of a railway tunnel in Lisbon, CT. Cianbro was ultimately successful in procuring an alternate route.

G&G Steel provided the majority of the main machinery components including the tower sheaves, reducers, line and cross shafts, and operating drums. G&G Steel procured the reducers from Steward Machine. To transport sheaves via rail, Cianbro fabricated a cradle that was mounted to a drop-center rail car. Each sheave was shipped separately, with a round trip for the car and cradle taking approximately 5 weeks. The 64 main counterweight ropes and the 8 uphaul and downhaul ropes were fabricated at The Wire Rope Corporation of America in Missouri. Cianbro contracted with Panatrol to fabricate and assemble the bridge operation and control system. WGI handled fabrication inspection.

Cianbro contracted with Kobyluck Concrete to mix and deliver the heavyweight concrete, utilizing heavyweight aggregate from Canada. The approved mix design had a density goal of 235 pounds per cubic foot.

Erection

During erection of towers and counterweights it was anticipated that a small amount additional pier movement would continue to occur during the grouting program so Cianbro set the tower anchor bolts in sleeves to allow for horizontal adjustment. Cianbro also placed shim packs and jacking systems under the tower bases to allow for tilt adjustment. Cianbro commenced erection of the tower at Pier 3 on August 2, 2007, while the grouting program continued at Pier 2. Tower erection at Pier 2 commenced on November 7, 2007 utilizing their Manitowoc 4100 ringer crane (with boom lengths varying between 240 and 280 feet) mounted on a barge. Cianbro set up areas to pre-assemble a number of larger structural components such as sheave hoods, counterweights, lifting girders, and portions of the tower framing, as well as platforms, stairways, and ladder assemblies. Cianbro assembled the lift span on a flexi-float barge positioned along the shoreline adjacent to their staging area utilizing a Manitowoc 4000 crane mounted on a concrete pad.

Figure 4 - Lift Span Erection

Figure 5 - Tower Steel Erection

As erection of the new tower steel progressed, Cianbro expressed concern over potential wind loads and eccentric loading from the new counterweights that the piers may experience during construction prior to float in of the new lift span. The existing piers below the new pier extensions are composed of five rows of granite block in the tidal zone between Elevation +4.75 and -5.25 and unreinforced concrete with a width of 12 feet between Elevation -5.25 and -20.00. WGI contracted with Ocean and Coastal Consultants of Trumbull, Conn., to perform an underwater inspection of Pier 3. The inspection found no indications of tensile cracking in the dimension stone or unreinforced concrete. To lower the potential wind loads, Cianbro opted to defer erection of the sheave hoods until after float in and connection of the lift span to the counterweight ropes. As Cianbro completed assembly of the lift span, their preliminary weight calculations indicated that the lift span weighed significantly more than had been anticipated. Additionally, the heavyweight concrete was not as dense as anticipated in the mix design. Cianbro placed a significant amount of steel billets in the counterweight to overcome these differences.

The original contract included replacement of the end floorbeam assemblies at both Spans B and D. Field investigations revealed that other approach span members exhibited significant section loss and warranted replacement. Of concern regarding repair of existing steel was that most of the work had to be performed during the 96 hour rail outage, subsequent to removal of existing trackwork, but prior to float in of the new lift span. Cianbro removed all rivets that were accessible and replaced them with temporary high strength bolts to reduce the amount of work required during the outage.

Track Alignment

The original intent of the contract was for the contractor to perform track work on the new lift span to best match the alignment of the existing approach spans. However, movement of Pier 2 necessitated revisions to the plan, with the lift span trackwork becoming fixed, and with jacking of Spans B and D to the north to match. Span B became misaligned due to Pier 2 settlement, and Span D was intentionally misaligned to line up with the bascule Span C during the Pier 2 settlement to keep the bascule span operable. Vertical jacking of both Spans B and D was also required to achieve the proper top of rail elevation. Additional vertical adjustments were anticipated in Span B trackwork to compensate for rebound in Span B after removal of the existing counterweight.

Counterweight Removal

Although the issue of pier settlement was satisfactorily mitigated with the grouting program, there was some concern that the suggested temporary counterweight support pile methodology depicted in the original contract drawings could aggravate the stability of Pier 2. As an alternative, Cianbro proposed to use diamond wire saws to cut the counterweight in place into five sections weighing approximately 300 tons each, and remove them with a 1000 ton capacity fixed boom barge crane, named the Chesapeake 1000, which was the largest crane available on the East Coast. This would be done prior to the rail outage and change out of the movable span, but required that the bascule span be inoperable for an additional ten days, so an extension of the original ten day channel restriction was submitted to the Coast Guard and approved. Removal of the existing bascule span would also be performed with the Chesapeake 1000. Upon acceptance by the Coast Guard of the revised channel restrictions of twenty days, the four day rail outage schedule was finalized for June 14-17, 2008. Although planned from the project's beginning, a four day rail outage was unprecedented at Amtrak and it required significant effort to publicize to the traveling public that no Amtrak service would be provided between Boston, Mass. and New Haven, Conn. during the bridge change out. Plans were also made to piggyback an Amtrak maintenance blitz between Boston and New Haven to take advantage of the rail outage.

On June 1, 2008, the channel restriction began and bascule span was made inoperable. Cianbro erected a waterproof platform over the catenary to support the wire sawing operation. The wire sawing contractor began saw cutting on June 6 and immediately encountered problems. The counterweight contained an area consisting of heavyweight concrete comprised of steel punchings in a cement matrix. This heavyweight concrete proved not to be a homogenous mass but consisted of concentrations of steel punchings not fully consolidated within the cement. As the wire saw passed through this area, the steel punchings became loose, causing the saw to jam. By June 8, Cianbro abandoned the wire sawcutting operation in favor of hoe ram demolition. The original schedule was abandoned and the scheduled rail outage was postponed, much to the dismay of Amtrak.

Now began the fast tracking of an alternate method to separate the counterweight from the bascule span so that the span could be removed and the new lift span erected as quickly as possible. The change in demolition method required Cianbro to rapidly develop plans for temporary support of the counterweight onto Span B. It was determined that approximately 60 percent of the counterweight could be supported by the existing Span B truss, requiring removal of 285 cubic yards of concrete and steel weighing about 1.4 million pounds. Initially the hoe ram demolition rate was too slow to afford a span change out much before early July. Given that the navigation channel was now height restricted, impacting commercial marine traffic, US Navy vessels, and recreational craft, a July 4th weekend float-in was out of the question. Cianbro would have to step up their demolition and debris removal methods. Employing a larger hoe ram and devising a chute large enough to convey extracted material to a barge below, Cianbro doubled the demolition rate. At the same time, Cianbro engineers completed design and procurement of necessary support beams to affix to the top chord of Span B to support the counterweight remnant and allow the bascule span to be disconnected and removed.

By the morning of June 14, over 25% of the targeted amount of concrete had been removed and the production rate was rising. By June 18, 70% of the targeted concrete had been removed and on that day a meeting was held with the Thames Harbor Safety Working Group to discuss the progress of the job. In attendance were representatives of Amtrak, WGI, and Cianbro to present to the Coast Guard, US Navy, marine users and the public the latest information and to obtain concurrence on a revised marine and rail outage schedule. A new rail outage schedule of June 24-27 was established. Amtrak immediately contacted those rail passengers with reservations affected by the change. Amtrak was able to offer some alternate service during the outage between New York and Boston via Springfield, but most rail service would be stopped.

By June 19, 90 percent of the targeted concrete had been removed and Cianbro began installing counterweight support beams on the top chords of Span B. Installation of the temporary supports was completed on June 21. That Saturday evening, using four 430 ton hydraulic jacks, Cianbro began the load transfer of the counterweight from the counterweight link to the Span B support frame. This process was carried out with meticulous precision, with careful monitoring of the dial indicators to ensure that the anticipated loads were properly removed from the link between the counterweight and the bascule span. Within two hours, the counterweight load had been transferred. On June 22 the counterweight link and upper portions of the counterweight frame were removed in preparation for the start of the four day rail outage on June 24.

Figure 6 - Temporary Support of Existing Counterweight

Span Change Out

The US Coast Guard issued a temporary deviation from the regulations governing operation of the Thames River Bridge, allowing it to remain in the closed position from June 28 through June 30 and to operate on a restricted schedule from July 1 through July 9. Provisions were made within the revised schedule after the removal of the old bascule span and before the installation of the new lift span for navigation windows to allow high priority marine traffic through the channel. On June 23, at 11:25 PM, Amtrak Train #67 was the last train to cross the old bascule bridge. When #67 cleared the block, the four day rail outage began.

The Chesapeake 1000 was mobilized in the channel and after top truss bracing was removed from the bascule span, shackles weighing 600 pounds attached to a 4 part sling were lowered onto the deck level and attached to lifting eyes that had been previously installed into the floor system. As the crane picked up the 1.2 million lb bascule span, the main trunnion bearing cap bolts were removed with a thermic lance, and slowly the span was freed up from its home for the last 89 years. A barge was positioned so that the span could be lowered onto it. By 4:00 PM on June 24th, the channel was cleared for several marine vessels that had been impacted by the delayed outage.

Figure 7 - Removal of Bascule Span C

Replacement of end floorbeams on approach Spans B and D commenced immediately after the span was removed. Span B had end panel stringers replaced as well. Modifications to support bearings for the new lift span followed. Span D was brought into proper alignment, but Span B could not due to the existing counterweight still in place, so the new centering device for the lift span had to be installed in a temporary alignment on the new end floorbeam of Span B to line up with the new lift span, which was being installed in the correct permanent alignment. Cianbro also installed the Pier 2 tower portal strut and cross bracings, which could not be performed prior to removal of the existing bascule span due to operating interferences.

With the existing bascule span removed, channel users were provided with a period during which the channel was open and they were able to pass on June 25th. The new lift span was floated from its erection site into the channel after the last marine vessel passed at 5:00 PM June 25th. In consideration of the small swing in the tides at the site and to provide vertical adjustment, Cianbro designed and constructed a vertical jacking system with four towers and 1000 ton strand jacks that were used to raise the lift span about 30 ft from the deck of the flexi float barge to clear float-in interferences, and then lower the span onto its bearing supports.

Figure 8 - Float-In of New Lift Span

Cianbro utilized wire rope winches mounted on two spudded crane barges located on both ends of the lift span barge to maneuver the new lift span into position. At 6:00 PM June 26th, the new lift span landed on its bearings. Work began immediately to install the rail lock assemblies, and connect Track 1, including installation of miter rails, with catenary and signal system work being done by Amtrak forces. Cianbro focused on completion of droop cable connections and alignment of the track on Spans B and D, completion of the remaining tower and approach span structural connections, as well as begin hooking up the main counterweight ropes to the new span lifting girders.

At 5:15 AM on June 28th, Track 1 was put into service and a locomotive ran across the new span four times. Amtrak Train #66 was the first train to cross the bridge at 5:59 AM, which began normal weekend rail service.

After initial span balancing by removal of several counterweight balance blocks during a night time rail outage, Cianbro was successful in making several test lifts using the auxiliary drive. The lift span was put into limited operation for scheduled openings using the main drive system on July 1. The bridge operated with no significant problems during the July 4th weekend, and was put into normal operation on July 10th. Additional fine tuning with balance blocks was done prior to the first full lift for 135 ft clearance on July 15th.

Figure 9 - Lift Span Partially Opened

Post Change Out

Work completed after span change-out included realignment of Span B, restoration of Track 2, installation of sheave hoods, demolition and removal of the old counterweight, completion of fender system, refurbishing the operator's house, commissioning of mechanical, electrical, and control systems, training of Amtrak operators and maintenance personnel, and project closeout.

Figure 10 – Completed Bridge

Conclusions

The replacement of the Thames River movable bridge proved to be a challenging and complex construction project. By practicing "Purpose + Commitment, Communication, and Collaboration = Teamwork ", or $P+C^3=T$, the project team overcame many significant issues and obstacles, pulled together, and successfully completed the project. Given the hazards of heavy bridge construction, at elevated heights and on the water, busy railway operation with catenary, active movable span operation, and significant marine traffic, the project had only one reportable injury during the three years of construction. There was excellent quality control practiced during the project, and given a good design, the result for Amtrak is an extremely reliable bridge.

Some Lessons Learned

As with most major projects of this magnitude, there are lessons that can be learned from the experience. Some lessons gained from this project are:

1. If the substructure of an existing bridge is to be retained, research should be conducted on the original construction to discover any problems when it was built. A thorough geotechnical investigation should be performed early in the design phase to better understand behavior of foundations that do not bear on bedrock.
2. Do a complete baseline survey of existing conditions if portions of superstructure and substructure will remain. This will show any deviations and misalignments from original design drawings.
3. Beware of counterweights filled with concrete. Recognize that wire sawing may not work for demolition when encountering heavy weight concrete containing steel punchings.
4. Develop a contingency plan for critical outages.
5. Practice good quality control and maintain a safe working environment.
6. Hire a good construction manager who has had similar project experience.
7. Hire an experienced contractor with a good in house engineering staff.
8. Don't hesitate to call on specialized experts to help solve major problems.
9. As an owner, practice strong leadership and foster a climate of teamwork with the designer, construction manager, contractor, railroad operations, and outside interests. Practice the formula for success: $P+C^3=T$.

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