INTRODUCTION

The Bayonne Bridge is an iconic steel arch structure with a suspended roadway deck spanning the Kill Van Kull channel. Erected in 1932 the main arch spans 1675ft, at the time the longest bridge of its kind in the world.

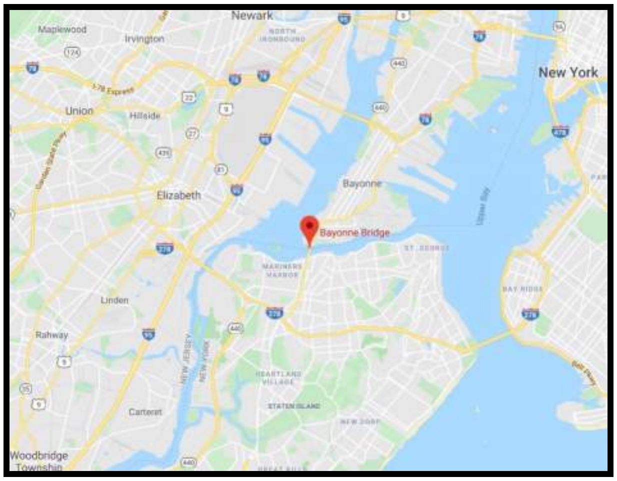

Figure 1 – Bridge Location Across Kill Van Kull

In 2016, the $5.4 billion Panama Canal expansion increased the size of container ships allowed to pass through its gates. The Bayonne Bridge is the gateway to the largest ports serving the northeast coast. However, at only 151ft above the waterway the current bridge would restrict access to new Panamax ships to these critical ports.

The Port Authority of New York and New Jersey (PANYNJ) initiated an innovative and cost effective plan to raise the Bayonne Bridge roadway 65ft thus allowing the new container ships to pass underneath safely. The plan included building new approach roadway structures to the north and south of the main span and building a new main span roadway above the existing utilizing the existing arch structure. Using this method, traffic was maintained on the existing structure through all phases of construction.

The construction of the main span raising can be divided into 4 major phases: partial demolition of the exisitng roadway and strengthening of the arch, erection of the new roadway steel and the Northbound half of the concrete deck, demolition of the existing roadway, and the construction of the Southbound concrete deck to complete the new roadway.

Figure 2 – Existing Bayonne Bridge Main Span

The contract for this work was awarded to Skanska Koch-Kiewit Joint Venture (SKK) in 2013. SKK hired Siefert Associates, LLC (SALLC) as a subcontractor to provide lift planning, structural analysis, demolition & erection planning, and other construction engineering tasks as required.

This paper reviews the challenges encountered during erection and demolition operations of the new and existing main span superstructure. Namely, due to the constricting geometry from the presence of the superstructure above and the waterway traffic below.

EXISTING MAIN SPAN STRUCTURE

The existing main span roadway consisted of 40 panel points starting at PP0 at the abutment tower and proceeding to PP20 at the center of the bridge about which the bridge is symmetric. The typical roadway structure is made of a 40’-0” wide concrete deck on 14’-0” roadway beams at 5’-3” on center spanning over four 41’-4” longitudinal stringers connecting to 74’-0” riveted steel floorbeams at each panel point supported by cables hung from the arch. In total, the bridge supported two lanes of traffic in each Southbound and Northbound direction.

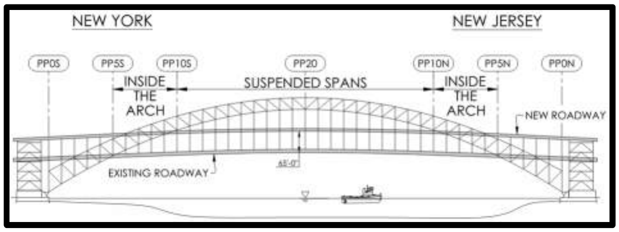

Figure 3 – Bridge Elevation Illustrating Panel Points

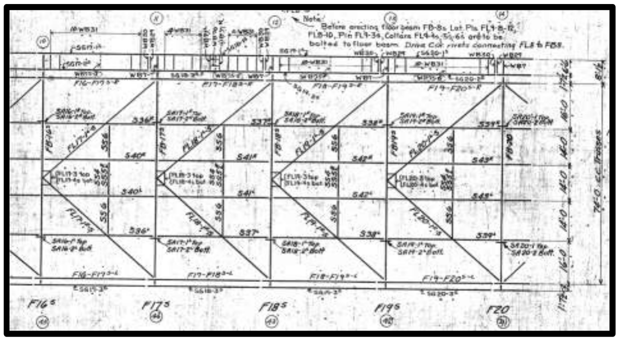

Figure 4 – Typical Existing Framing Plan

In an effort to conserve material in the 1930's several of the main span floorbeams were utilized as temporary falsework for the erection of the main span arch[1].

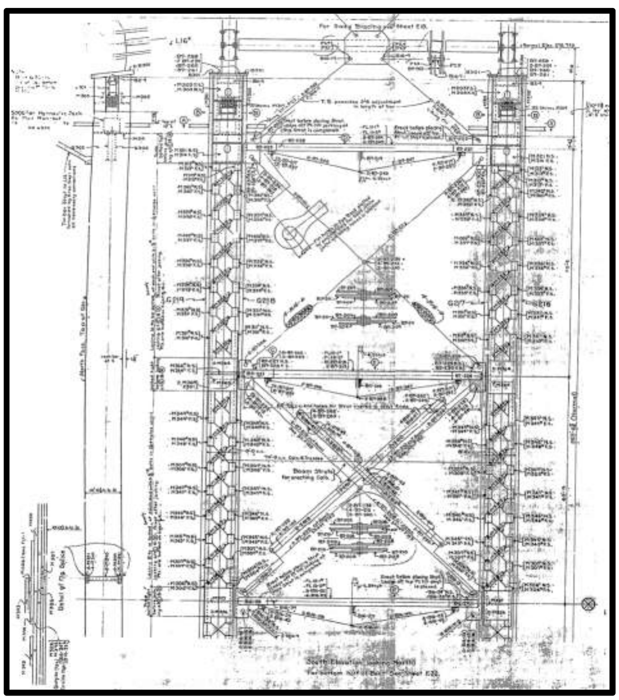

Figure 5 – Floorbeam Steel Used as Temporary Bent for Main Span Arch Construction

Consequently, these girders had existing steel components that were slightly modified compared to the published shop drawings - which lead to an increase in girder self-weight.

SELECTIVE STEEL DEMOLITION

Part of the innovative design of raising the roadway was keeping the existing arch structure; however, the arch was not designed to carry two roadway structures, live traffic, and construction loads. This was solved with two methods first the arch was strengthened at critical points to ensure a safe support and second anything that was not essential on the existing roadway had to go. The elements removed mainly consisting of the sidewalk and East third of the roadway deck, thereby reducing traffic to one lane in each direction and limiting the amount of room for construction.

SALLC was hired by the demolition subcontractor to analyze the existing structure for various types of construction equipment including excavators weighing up to 80,000 lbs and cranes with lifting capacity up to 55 tons as well as providing all engineered lift plans.

Figure 6 – Deck Demolition Operations

MAIN SPAN STEEL ERECTION

With the selective demolition and critical portions of the arch strengthened, the erection of the new main span steel could begin. The main span steel span presented numerous engineering challenges. The presence of the existing arch located just above and the heavily traveled waterway below led to unique operations for erection.

As mentioned previously the main span was broken up into panel points, the new bridge would keep the same naming convention. As illustrated in **Figure 3**, from PP0 to PP5 the new roadway is just an extension of the existing and would be supported by columns at each panel point. From PP5 to PP10, the roadway travels through the inside of the arch structure, and from PP10 (South) to PP10 (North) the roadway is suspended with cables from the arch.

The case studies of the unusual erection techniques in this paper will focus on the latter two locations of the bridge, namely, inside the arch and the suspended spans.

EQUIPMENT

SALLC put careful thought into selecting the proper crane to perform work on the main span. The crane choice was crucial due to the loads and pick radii required, geometry of the existing framing, and special restrictions.

The crane chosen was the Liebherr LTM 1130-5.1 hydraulic crane. This crane fit the profile perfectly in that the size was enough to pick our heaviest steel (170t), the boom was about 200ft long so it could reach up and over structures where other cranes could not. It was able to travel with half its counterweight making setup very quick allowing workers to perform their duty at night and reopen the bridge to traffic in the morning. SALLC took advantage of the outrigger geometry and used specially designed dunnage to transfer the loads safely into the existing structure. SALLC analyzed the existing roadway structure provisions of AASHTO's Manual for Bridge Evaluation First Edition[3] to confirm the structure's capacity during construction operations.

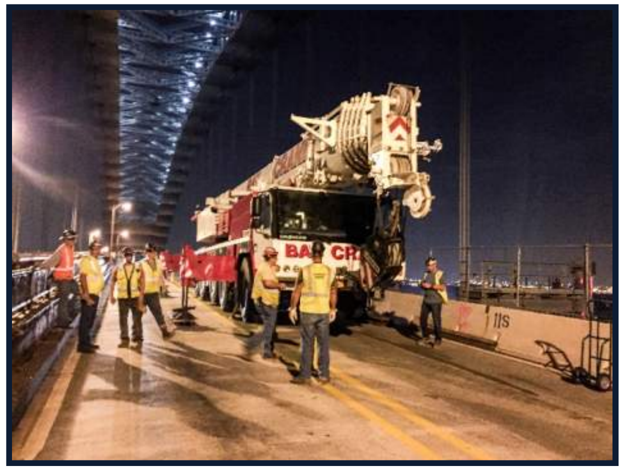

Figure 7 – LTM 1130 Setup on the Main Span

INSIDE THE ARCH – PP7-PP8 FLOORBEAM ERECTION CASE STUDY

The first floorbeams of the new roadway to be erected were those between PP7-8. These were a priority because, not only did they support the new roadway but, they were used as struts for the existing archway and were therefore critical for the strengthening schedule. These floorbeams were about 70ft long and were erected in 3 parts – two 10ft sections that connected to the existing arch and the 50ft center section that was spliced to the two ends. This case study focuses on the center portion of the floorbeam erection.

Figure 8 – Inside the Arch

The spider web of existing steel the new steel would have to be erected through presented its own set of challenges. However, the addition of safe span shield, in place for the painting of the bridge, took the challenge to a new level.

The safe span could only be opened enough to provide an approximately 4ft wide hole to fit the crane boom and floorbeam up through; thereby eliminating the crane from swinging.

The safe span height above the roadway also hindered the crane setup. The available head room did not allow for the crane to set its counterweight. To overcome this obstacle, the crane was positioned at PP12 to install its counterweight, then walked down to PP7/8 where it would erect the new steel.

To fit the floorbeam through the hole in the safe span SALLC devised a plan to trip the floorbeam up to a vertical position off of the delivery truck and pull it up past the shield.

Figure 9 – Opening in Safe Span Shield with Crane Boom

The floorbeam then had to be suspended from temporary hoists hanging from the existing arch steel while the crane boom reset so that the floorbeam could be rotated to be aligned with its final position transversely to the roadway.

Once the floorbeam was rotated, it was then transferred to a final set of hoists that would raise it to its final location and hold it steady so the final splices could be made.

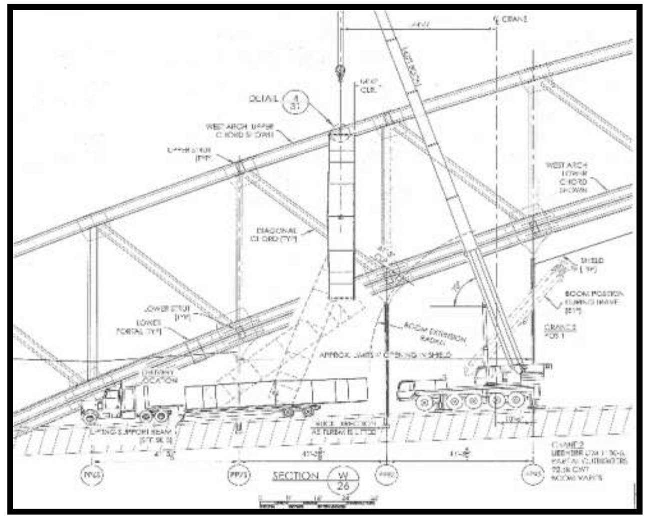

Figure 10 – Initial Trip Up of PP7 Floorbeam

ERECTION OF SUSPENDED SPANS PP10S-PP10N

The new suspended portion of the main span began at panel point 10S and ended at panel point 10N. PP10 was a pin and hanger connection to the bottom cord of the existing arch and new cable suspension ropes were installed between PP11S to 11N.

Figure 11 – Transfer Truss at PP20

The proposed method of installation of the new floor beam required the existing suspender rope to be removed and the new floor beam installed with new suspenders from the bottom cord of the arch. Finally, a temporary suspender installed from the bottom of the new floor beam to the existing floor beam completed the floor beam erection at a panel point. The temporary suspenders were approximately 60ft long, the raising height of the bridge.

Removal of the existing suspender cables required the design of a transfer truss. The truss span was two panel points, roughly 80ft, and would temporarily support the existing floor beam below the new floor beam that would be installed.

There was a total of four transfer trusses installed on the bridge during the installation of the floor beams with the designed maximum mid span reaction of 150 kips. Winches, mounted at the ends of the truss, pulled it from floor beam to floor beam during the installation.

The day shift was responsible for moving the truss and bolt up of all members. The night shift was tasked with hanging all steel members and installation of the permanent and temporary suspenders. The transfer truss schedule was a priority and could not be delayed.

PP11-11 SUSUPENDER BOX REPLACEMENT

Figure 12 – Existing Suspender Removal

In order for the new suspender rope installation, the entire rib section of the existing suspender box had to be replaced. The existing gussets, or elephant ears, from the bottom cord remained. Strengthening plate installation on PP10 through 12 on the underside of the bottom cord was also necessary. All four existing 3-1/4" diameter suspender cables were rigged out together with the rib section intact utilizing the chain falls and custom rigging.

The first step was to replace all the rivets in the elephant ears with bolts. Trunnion mounted on the faces of the bottom cord hung four chain falls, two up station and two down station. Beams attached to the underside of the rib section, the sled, were attached to these four chain falls.

With all rigging in place the next task was to unbolt the rib section from the elephant ears and lower the sled with the four chain falls. The sled only had to be lowered ten feet where a mobile crane on deck had a hook positioned for transfer and disposal.

The four point rigging hitch presented cross cornering issues and had to be monitored closely during the lowering. The mobile crane used both blocks to take up the slack cable and sled simultaneously for easier disposal. The operation was reversed for the installation of the new rib section and shorter suspension ropes.

CUSTOM RIGGING DESIGNS

From the start of the project, SALLC had a good idea that some unique rigging solutions would be required for a lot of the installation as well as the demo. As mentioned earlier the triangular lift link provided some clever ingenuity for daunting task, as did the rigging sled for the suspension ropes.

Several different variations of lifting lugs or lifting points and trunnion were designed. These tools were universal and installed on all faces the both the top and bottom cords of the arch by removing rivets or mounted through bolt patterns on strengthening plates.

No other design was more in demand than the hangman. This rigging point was specifically constructed for worker access and design for 6kip vertical working load. Spider baskets or two men scaffolds were hung from the hangman for the ironworkers to bolt up members and install rigging if needed. The beauty of this design is that it was capable of adjusting to the pitch of the top chord of the arch.

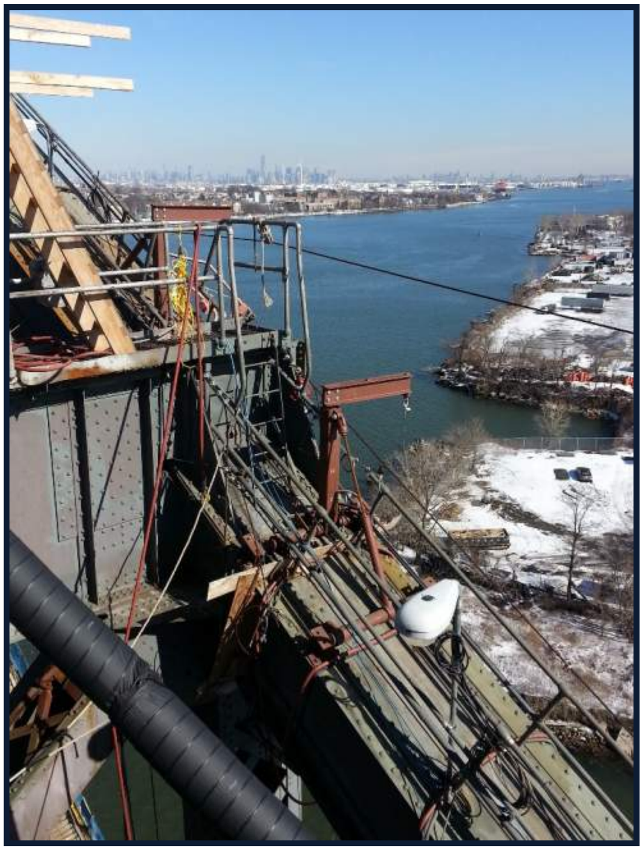

Figure 13 – The Hangman

TYPICAL FLOOR BEAM AND EDGE GIRDER ERECTION PP11S TO 11N

After the arch rib section was replaced and the new suspender rope installed, floor beam erection was the next step. The floor beams in PP11S-11N were all identical with a weight of approximately 67kip and 86ft long, they were dog bone shaped with 8.5-foot sections of edge girders attached to their ends.

The challenge of these lifts was the lack of real estate on the existing bridge for placement of the crane and delivery of the floor beam. The crane that fit the task was the one and only Liebherr LTM 1130.

First, a stretch trailer carrying a floor beam was brought in a parked tight against the Jersey barrier to the east directly under the panel point being erected. Next, the crane fully dressed would travel and park inside the stretch trailer bed and set up on half outrigger spread. Typical deck dunnage spanning between transvers roadway beams were used.

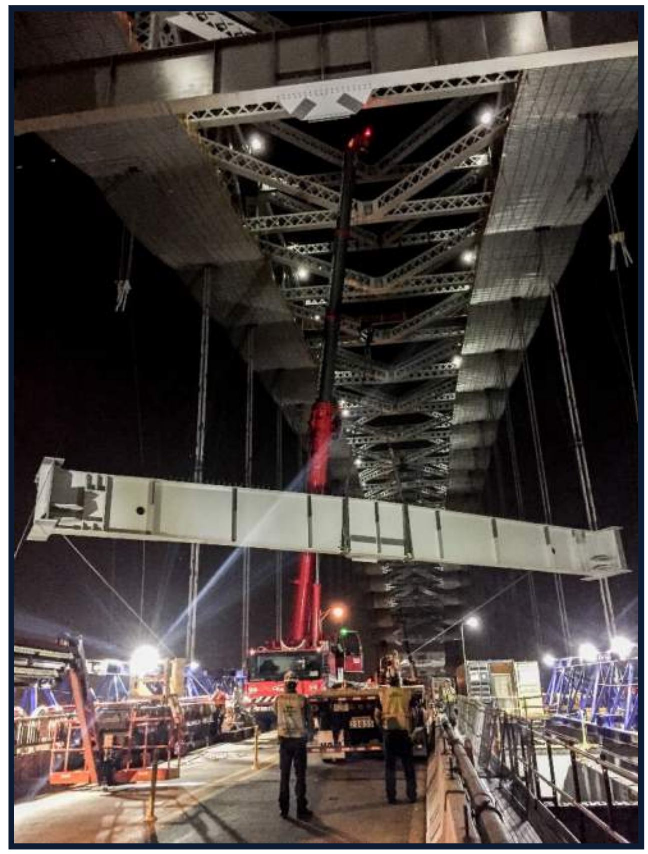

Figure 14 – Floor Beam PP12S

This setup took advantage of the crane footprint and capacities to simplify the lift. The procedure went like this: pick the floor beam straight up off the trailer at 26ft radius, spin the floor beam 90°, swing slightly and attach to the new suspenders hanging from the bottom cord of the arch.

After the floor beam was hung, the temporary suspender cables were installed to the bottom of the new floor beam and to the top of the existing floor beam directly below. The permanent suspenders are four 2-3/8 inch diameter ropes varying in length and the temporary suspenders were four 1-5/8 inch diameter ropes.

With the new floor beam into place connected to the existing floor beam below the transfer truss could then move on to the next panel point and the process could start all over again.

Figure 15 –PP11 and 12 with Permanent and Temporary Suspenders

In some cases up to four floor beams were installed prior to any edge girder, wind brace, or stringer steel erection. This was mostly a result of the transfer truss schedule. The edge girder erection was typical using the LTM 1130 on short outriggers, taking delivery over the rear and setting into place both east and west members. The spliced edge girders were approximately 23kip and 33ft in length.

The only deviation from this plan was between PP 10-11. The crane boom tip did not have enough clearance under the bottom cord of the arch so the edge girder had to be transferred to a rigging point mounted on the bottom cord and rigged into place.

WIND BRACE & STRINGER ERECTION PP 11 TO 11

The final elements of the framing plan were the seven stringers (41ft - 7 kip), and two diagonal wind braces (60ft - 8kip). It was not weight nor crane capacity that made this installation difficult, but rather the clearances with the crane boom.

Several crane positions were necessary for completion of a bay of steel, especially between PP10-13. The lack of headroom and bound boom on new and existing steel required crane placement within the bay, up a bay and down a bay to install all the members of a span.

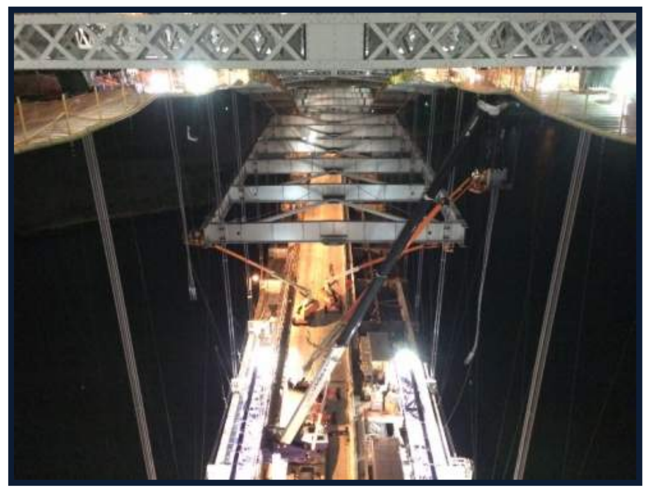

Figure 16 –PP10-16 Floor Beam, Edge Girder and Wind Bracing

After PP13 the arch head room became a non-issue and the erection became much easier. The crane used for these lift plans was a Tadano GR1000 based on its ease of set up and scoping capacities.

MAIN SPAN DEMOLITION

With the erection of the main span steel complete, the contractor poured the first half of the concrete deck using lightweight concrete to limit the dead load and traffic was shifted to the new structure. Demolition could now begin.

With the demolition along came the same challenges as the erection, low headroom from the existing arch and not being able to foul the shipping channel below. There were also some new challenges, namely, the new roadway above caused headroom issues along the entire length of the main span and the construction schedule needed to keep the launching gantry erecting the precast concrete approaches so the demolition of the main span had to occur simultaneously with the demolition of the approaches. This essentially led to the main span demolition operations to be conducted on an island 150ft in the air.

DEMOLITION WITH WINCHES

The contract specified a limited number of 12 hour shipping channel closures that could be used by the contractor for demolition operations. The shipping channel was located approximately between PP11S to 11N, almost all of the existing suspended spans.

Using the limited shipping channel closures, SALLC designed a three winch rigging assembly that could lower two existing panel points weighing over 150 tons down to a barge in the water below[3]. The winches were mounted on beams supported by the new roadway floorbeams above.

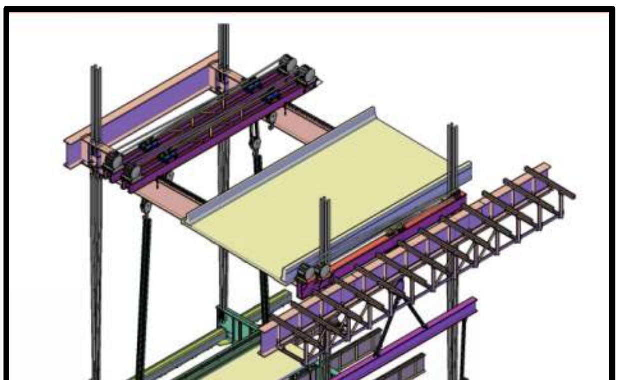

Figure 17 – Isometric View of Winch System Lowering Existing Roadway

Using winches to lower sections of the roadway into the water presented some risk in that if something was to breakdown during operations it would stop shipping to one of the busiest ports in the country and repair would be very difficult being suspending over 150ft in the air. The system needed to have redundancy and it was incorporated by adding "auxiliary" winches so in an event of a malfunction a back up hook could be lowered down and connected to the roadway section to continue the demolition. SALLC had to design a tri-pin plate to smoothly transfer load from one hook to the other if required.

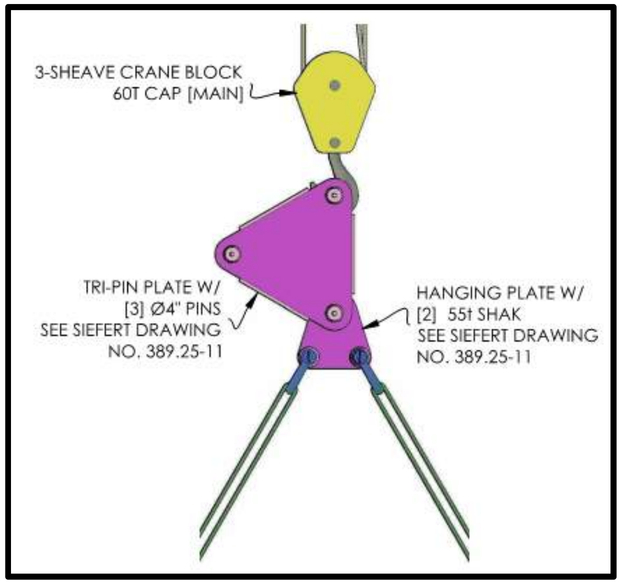

Figure 18 – Tri-Pin Plate Detail

Ultimately, this demolition scheme was abandoned due to cost of the required six winches and supporting assemblies and the shipping channel closures proved to be too difficult to coordinate between all parties and the risk that weather could continuously postpone all operations.

DEMOLITION WITH CRANES

SALLC also offered the concept to demolish the existing roadway using cranes positioned on the existing structure. The plan would use the same workhorse crane from the erection the Liebherr LTM 1130 and scoping techniques developed during the erection of the new steel to demolish the existing steel without lowering it into the shipping channel. The use of a crane could also have the contractor work with two crews starting at the middle of the bridge and working out. This idea saved the contractor a lot of time, money, and risk.

Figure 19 – Crane about to Remove First Floorbeam at PP20

The crane option also came with its fair share of challenges. The first being if the roadway was to be cut at the center and equipment was to be used on the structure the existing expansion joints at PP8N and 8S had to be "locked" so that the suspended bridge would not detach and be free to sway in the wind. The design engineers at HDR ran a non-linear analysis of the existing structure with the construction equipment and wind loads and SALLC designed a splice on the wind chords at PP8 to resist the required forces to keep the bridge together during demolition.

The second major obstacle was due to the approach demolition taking place simultaneously with the main span therefore, there was no means of driving equipment and demolition material on and off the bridge. This led to the use of a "transfer" crane just off the main span that would raise and lower equipment and demolition material from the existing bridge to the ground below. This also included SALLC providing lift plans to remove the transfer crane itself off of the bridge once the demolition was complete.

The third major obstacle was the lack of space to work and general congestion on the existing roadway. The contractor had to be very organized with all equipment and operations and SALLC designed a temporary deck unit for the East side of the bridge to safely support manlifts and other equipment.

DEMOLITION OF THE ABUTMENT TOWERS

The final portion of the bridge to be demolished was the existing main span abutment towers. Utility portions of the towers were demolished previously to allow for the erection of the new abutment towers that was built around the existing towers.

This led to many challenges as the existing tower was completely surrounded by the new tower, over 100ft tall, and on a concrete pedestal surrounded by water on three sides.

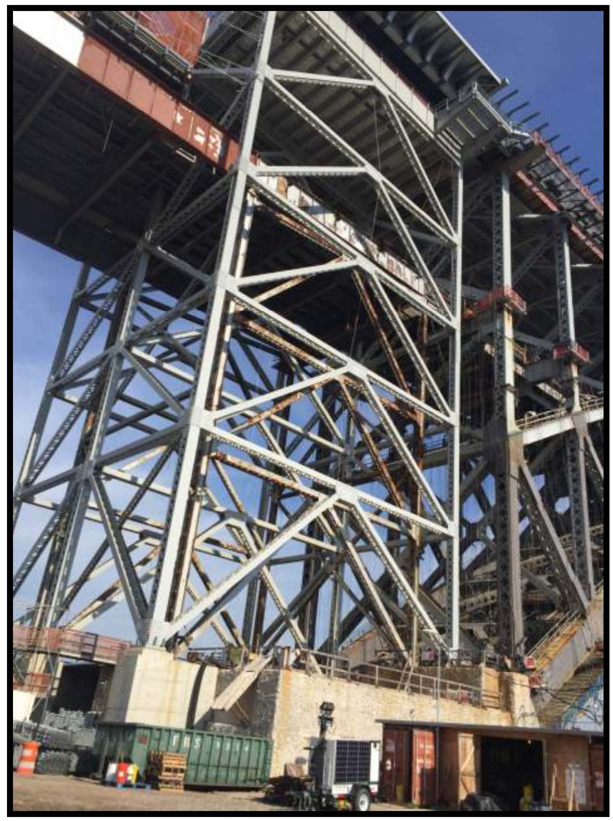

Figure 20 – Existing Abutment Tower Surrounded by New Abutment Tower

Several solutions were put forth including intricate winch and chain fall systems but the most economical and easiest was to place a crane inside the both towers and use it as a mobile winch to lower pieces onto the concrete pedestal then use auxiliary equipment to load the pieces out onto demolition trucks. SALLC created a 3D model of the existing and new steel to check adequage clearances and crane capacities for every pick.

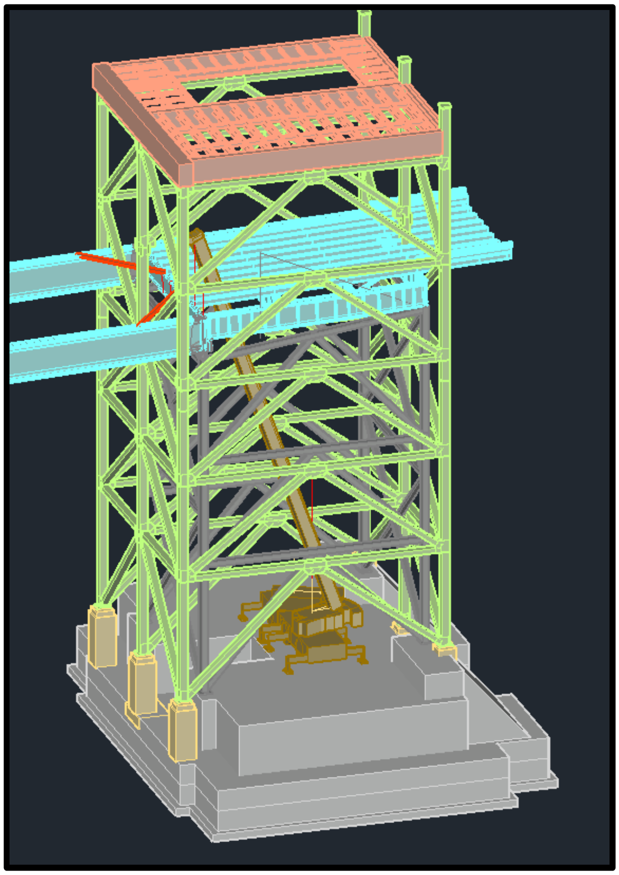

Figure 21 – 3D Model Used to Check Crane Clearances

SUMMARY & CONCLUSIONS

Demolition and erection may not be as glamorous as other construction operations, but any errors made during these operations can have very impactful consequences. It is imperative that the engineers and contractors take the stability of the structure as the highest priority. Great care should be taken when considering the order of operations for removal of a structure. It is imperative that the demolition team check the structural stability of the structure during all stages of the operations. Clear and open lines of communication between the engineer of record, the contractor, and their subcontractors, are required to ensure a safe and efficient jobsite.

Working on an iconic and challenging bridge structure can be a memorable experience for all those involved in the project. Success is only achieved through a team first approach in all aspects of the planning and construction process.

ACKNOWLEDGEMENTS

The authors, and SALLC, would like to thank the hard working individuals from Skanska-Koch Kiewit who made this project a reality. SALLC would also like to recognize the efforts of the permanent designers, HDR, for their constructible design.

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