HEAVY MOVABLE STRUCTURES, INC.
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Innovative Temporary Systems for Florida Vertical Lift Rehabilitations

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Introduction

The recent rehabilitation of two vertical lift bridges in the State of Florida required application of innovative temporary systems to maintain vehicular and/or navigation traffic during construction.

This paper will discuss how innovative temporary systems that were utilized on the Main Street and Hillsborough Bridge rehabilitation projects to meet challenging conditions.

Main Street Vertical Lift

FIGURE 1: Main Street Vertical Lift Bridge

Main Street Vertical Lift Introduction

The Main Street Vertical Lift Bridge, officially the John T. Alsop Jr. Bridge, is an aesthetic constant of the downtown Jacksonville skyline. Averaging daily traffic of 18,300 vehicles, Main St. Bridge is a direct link over the St. Johns River between the southern San Marco area and the downtown area to the north. A total of 16 bridges span over the St. Johns River encompassing Jacksonville's river city culture: ten fixed bridges, five movable bascule bridges, and the Main Street bridge (the only vertical lift bridge in the city). The vertical lift bridge is owned by the Florida Department of Transportation.

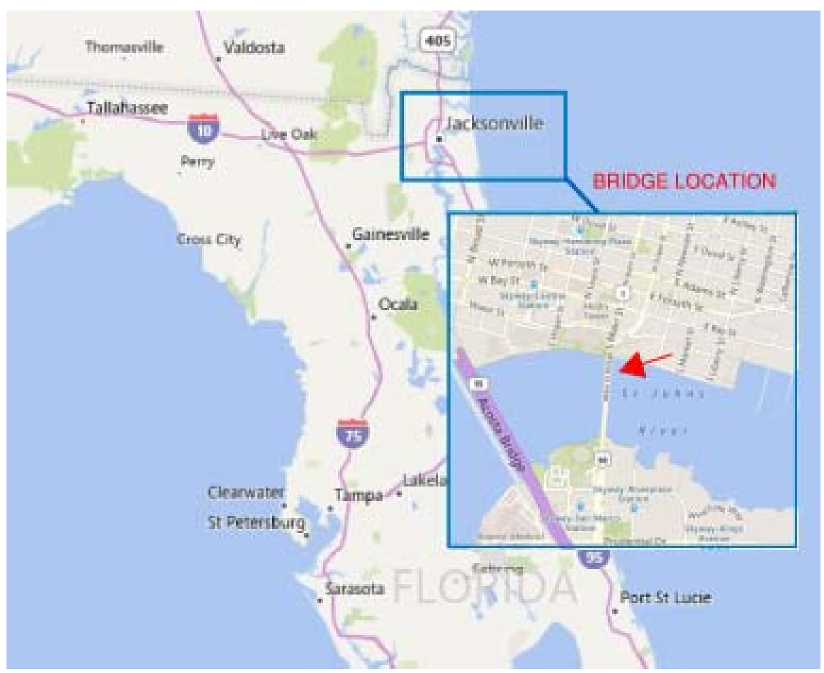

FIGURE 2: Bridge Location

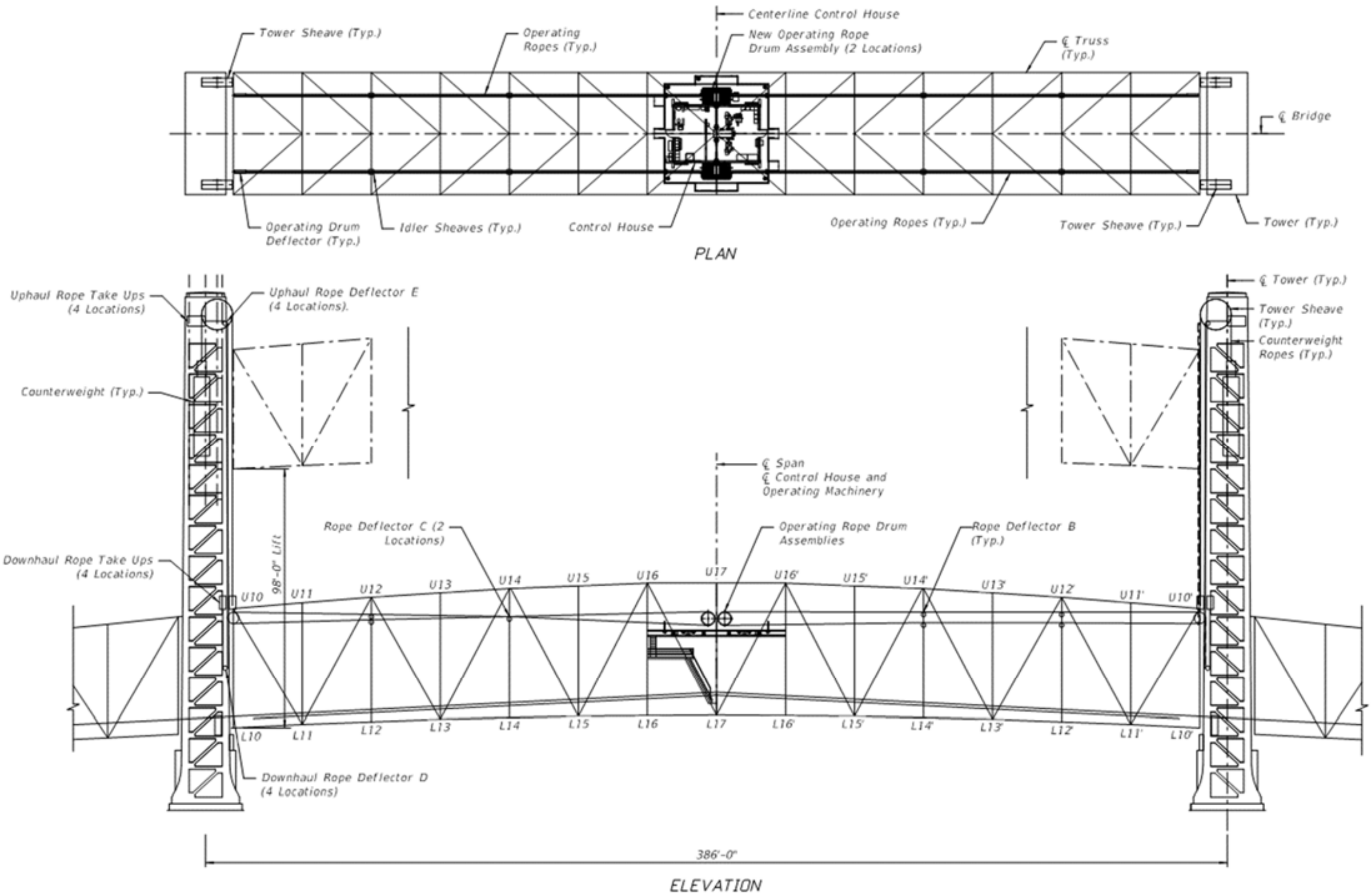

FIGURE 3: Main Street Vertical Lift Bridge Plan and Elevation

Constructed in 1941, the Main Street Bridge is a 3,000 kip through-truss, Waddell-type bridge, with a 365-foot span and 46-foot truss-to-truss width. It carries four general purpose lanes and two sidewalks with a vertical clearance of 138 feet when opened and 40 feet when closed.

The span drive bridge operates utilizing machinery mounted on the vertical lift span and supported by the through truss, with the main gear train housed in the machinery room located above the roadway. The main gear train machinery consists of a redundant pair of 200-HP electric motors that provide input to a centrally-located, parallel-shafted, non-differential speed reducer. The primary reducer drives a pair of open gear sets located outside the machinery room via floating shafts press, fitted with gear-type couplings. Each input shaft of the speed reducer is coupled to a drum-type motor brake and each intermediate input shaft is splined to a hydraulic disc brake. The main drive integral pinion shaft is coupled to the transverse running floating shaft, which drives a pair of ring gears that are mounted on corresponding operating drums and supported by pillow block sleeve bearings.

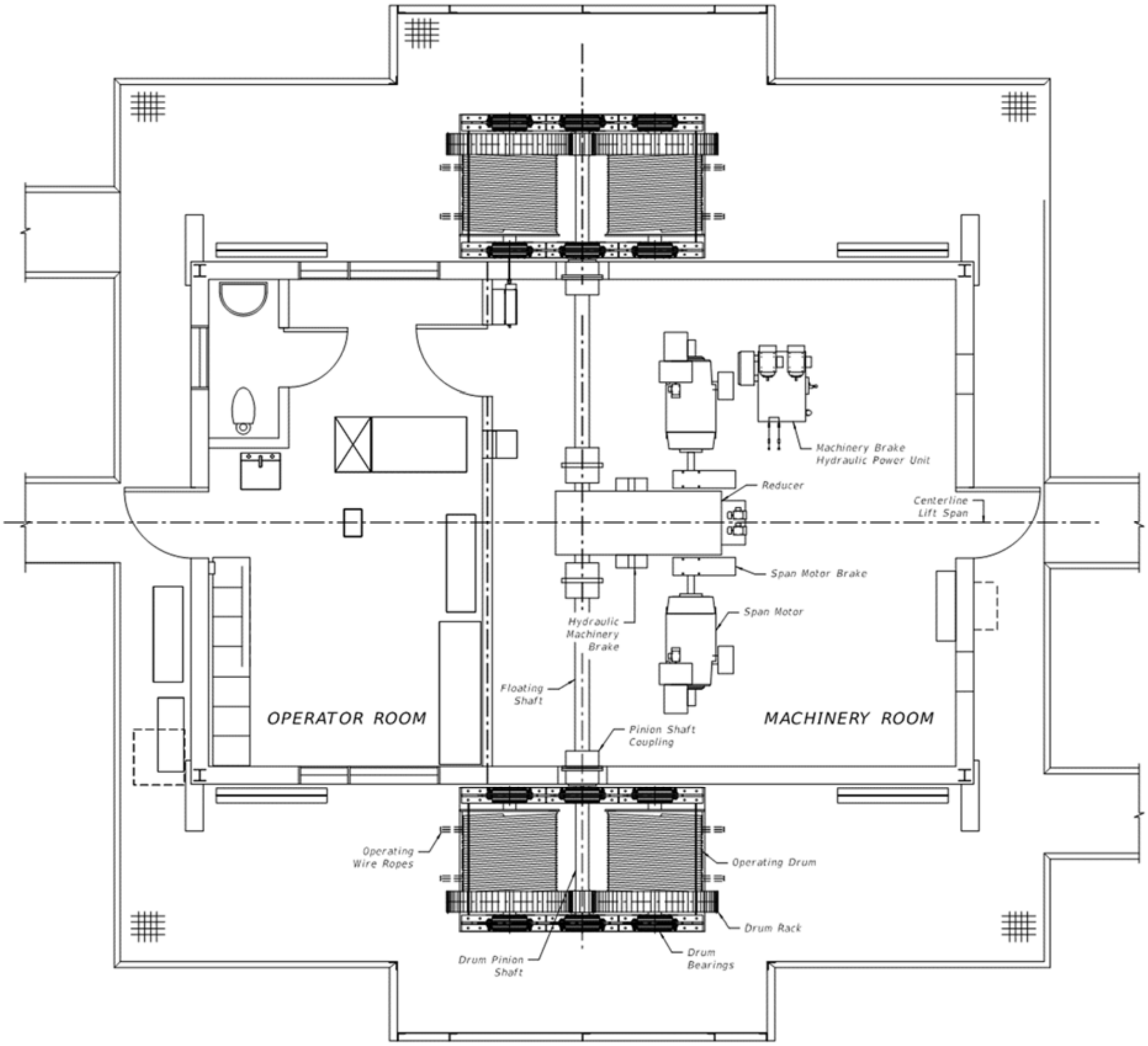

FIGURE 4: Plan View of Operating Machinery Room

Each operating drum assembly consists of two uphaul and two downhaul operating wire ropes attached to opposing ends of the cylindrical drum. The system is arranged so that during operation of the lift span, equal amounts of each wire rope are pulled or played off the drum as the span operates. A double helix rope groove is machined into the circumferential surface of the drum, upon which the operating ropes are wrapped around.

Operating ropes span longitudinally from the operating drum end connections to the end corners of the lift span, which are supported by idler deflector sheaves. Wire ropes then run up (uphaul ropes) or down (downhaul ropes) the towers on the approach at a 90-degree angle against deflector sheaves (the same diameter as the operating drums), connect to rope tension adjusters, and are anchored to the top and base of the tower. The tension adjusters allow for equal tension in the wire ropes to prevent skewing of the span during operation.

FIGURE 5: Operating Drum Assembly

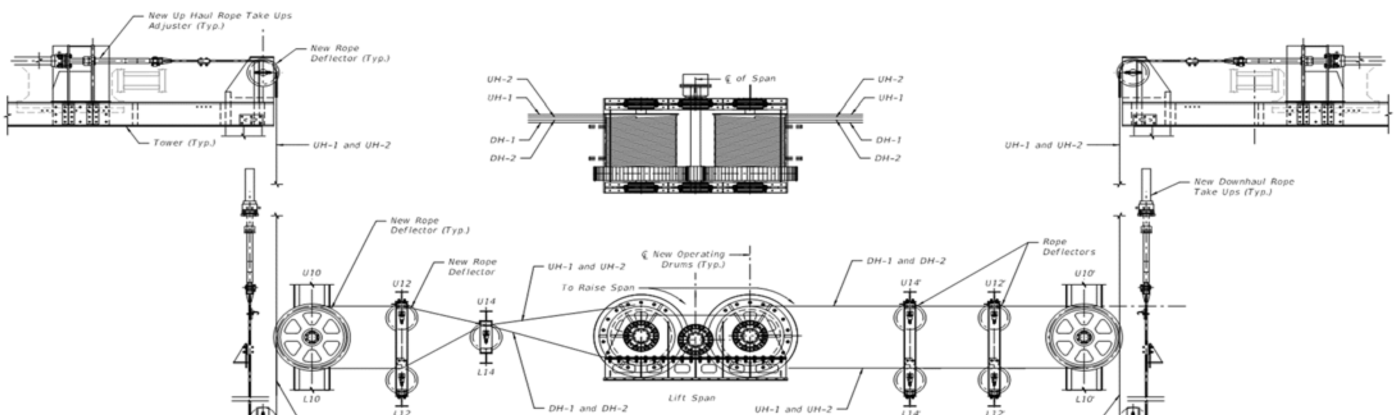

FIGURE 6: Diagram of Operating Ropes

Vertical Lift Bridge Rehabilitation Background and Challenges

The lift span operating machinery was replaced under a $6 million project in 2017. The replaced machinery components included: drive motors, motor drum brakes, hydraulic machinery brakes, pinion coupling, pinion shaft, operating ring gear drum assemblies, operating ropes, operating rope sheaves/deflectors, and operating rope tension adjusters.

The bridge was required to remain operational throughout the duration of construction because of the large amount of navigational and vehicular traffic and proximity to the Jacksonville Jaguars Stadium. The Coast Guard required no disruption to marine traffic but allowed a four-hour window for the Contractor to have the lift span ready to open upon request. Nighttime closures to vehicular traffic were limited to weekdays from 6pm to 6am and selected weekends with detours to the adjacent Acosta Bridge.

FIGURE 7: Operating Ropes Through Deflector Sheave

FIGURE 8: Operating Ropes Through Idler Sheaves

Access to the counterweight and top of the towers is through a platform that connects the span to the counterweight when the two structures are at equal elevations. Personnel cross to the counterweight from the span and ride the counterweight up to the towers as the span is seated. The operation to achieve this elevation is called a high lift and was a requirement during the duration of construction. Additionally, large cruise ships and yachts required high lifts to dock at the popular Jacksonville Riverwalk just past the bridge.

Retaining lift span operation during the replacement of select drive machinery components required operating the span with a single pinion and only one longitudinal pair of operating wire rope assemblies, while the other set was removed and replaced. The same procedure would later be repeated with the other machinery set.

During normal operation, four sets of operating wire rope assemblies support and lift the counterweighted lift span at each corner, allowing for the span to remain level during operation. Removing two sets of operating rope assemblies on one longitudinal side of the span will allow for the span to skew transversely during operation and bind within the supporting towers. The counterweight ropes support the dead load of the lift span, but the operating ropes resist the imbalance, friction, inertia, and wind forces acting on the span. Removal of two sets would cause known and unknown adverse effects. A temporary drive support system was required to assure safe operation of the bridge under single pinion operation.

FIGURE 5: Reducer Output Shaft Coupling Disconnected

Temporary Operating System Design

The temporary operating system design incorporated an arrangement of sheaves and static wire ropes that allowed for single pinion operation, while maintaining the transverse skew of the lift span within the limits of the tower guides. Inspiration for this design was taken from a canal bridge pulley system with drive machinery on one end of the span and static lines at the other longitudinal end of the span to prevent a longitudinal skew during bridge operation.

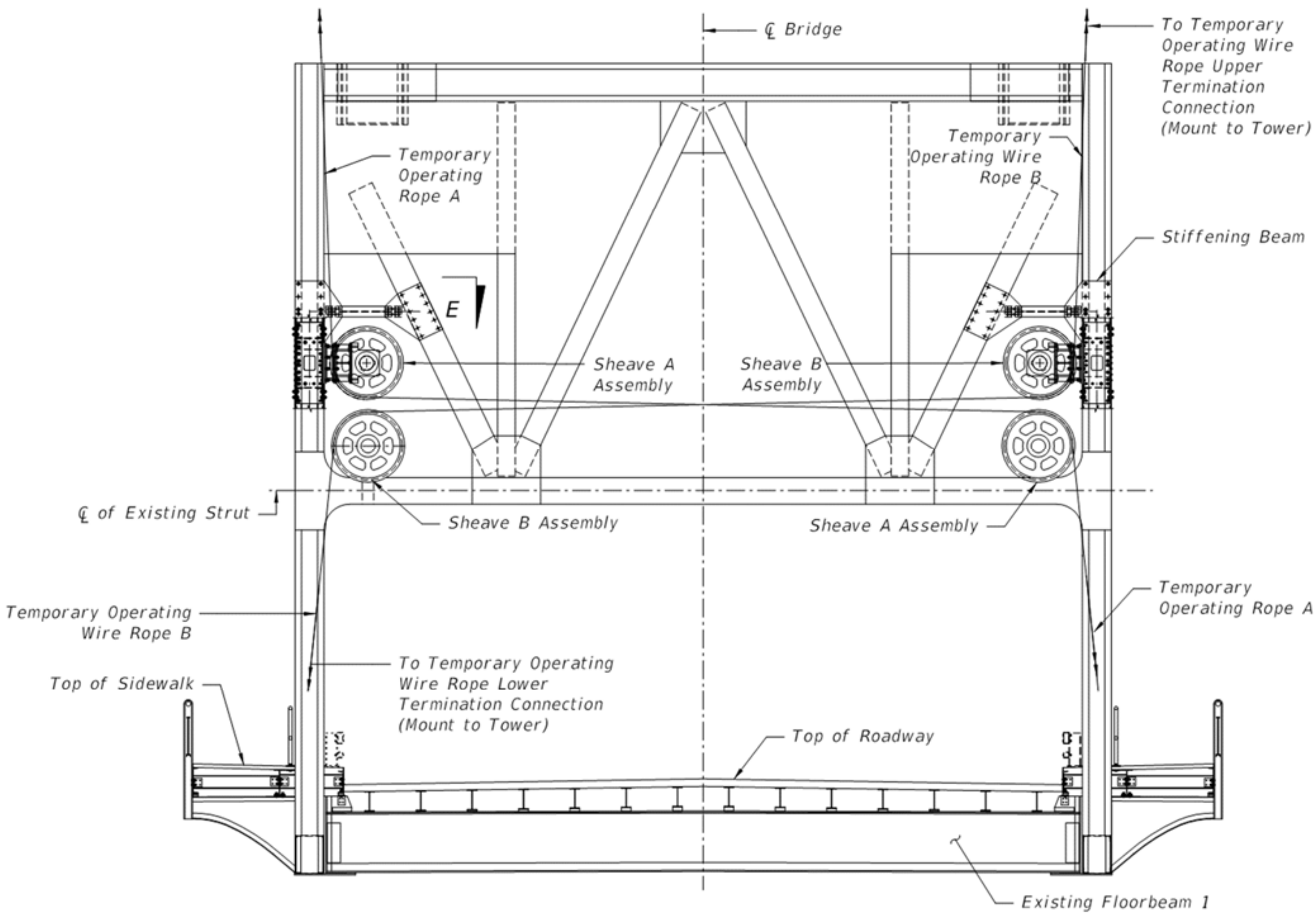

FIGURE 6: Temporary Operating System Layout

The Main Street Bridge would need to correct a transverse skew - not a longitudinal skew. A similar static pulley system would be used to not lift a load, which is what the single pinion gear train would do, but to apply tension to the system. In this case, replacing the missing tension from the eliminated set of longitudinal operating ropes would maintain the lift span level during operation. Each end of the span would contain its own static line pulley system.

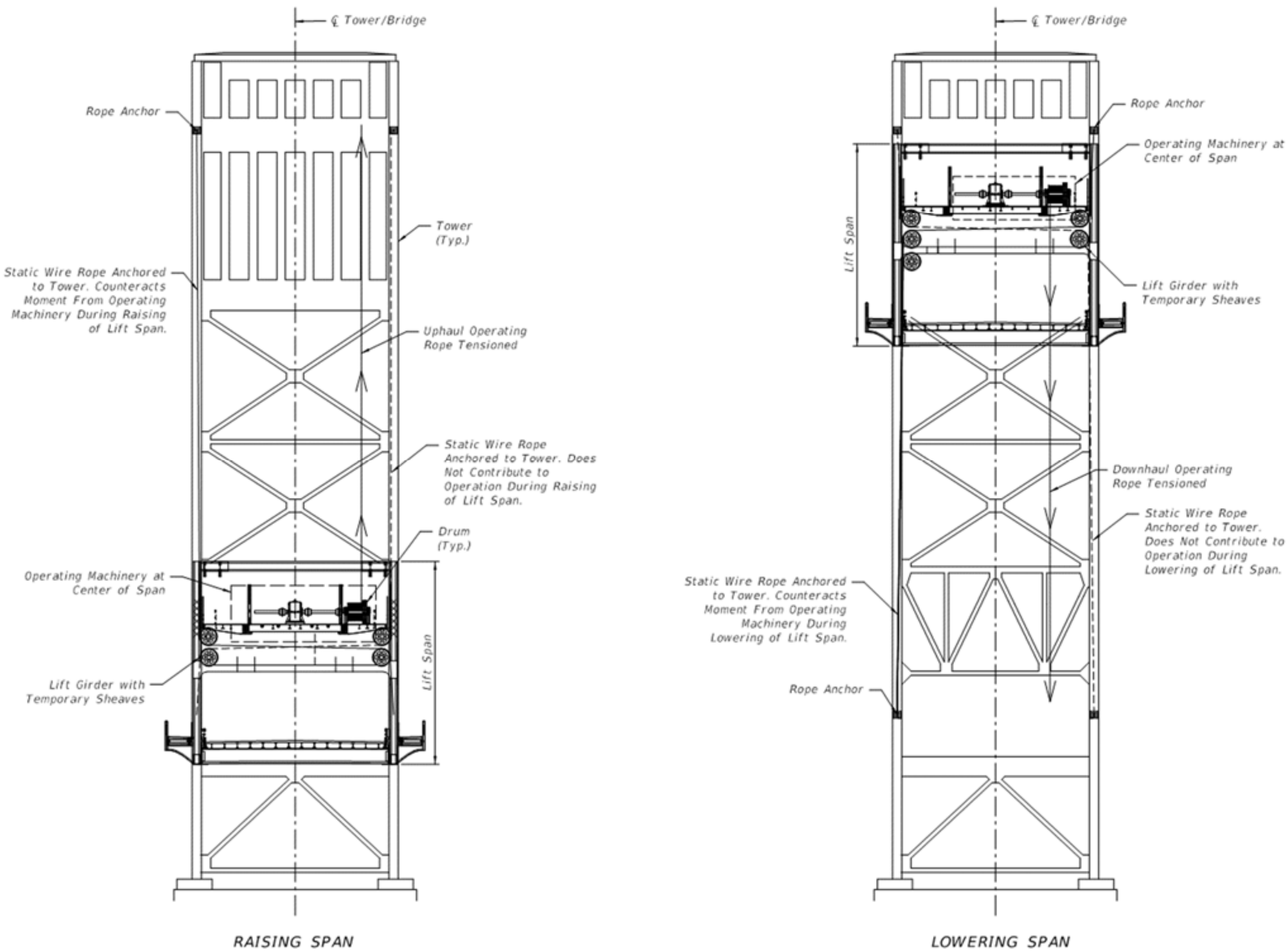

FIGURE 7: Temporary Operating Machinery Raising and Lowering of Span

Each pulley system consisted of four temporary sheaves mounted on the span truss. Each sheave set had one wire rope running along its grooves, with one rope end anchored to upper terminators located at the top of the tower and the other rope end connected to lower terminators anchored at the base of the tower. Each sheave static wire pulley pair served as the tension assembly for the opening and closing operation.

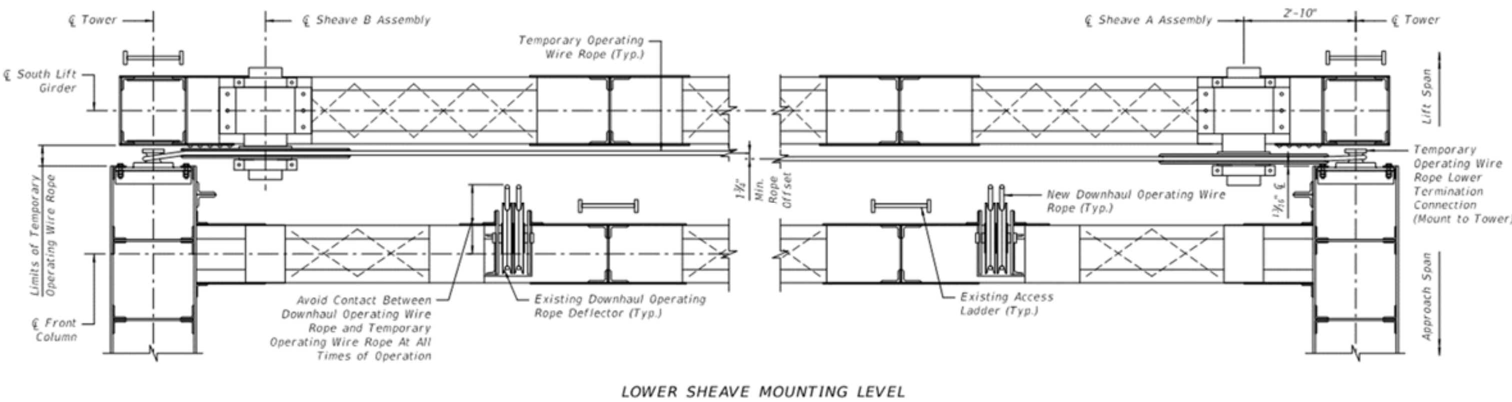

FIGURE 8: Plan View at Open Joint, Lower Temporary Sheave

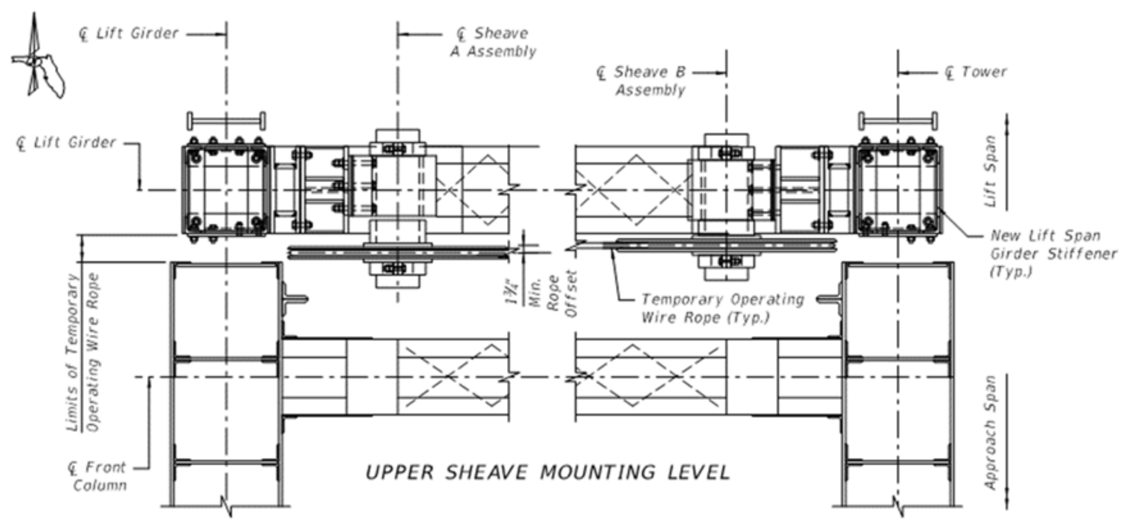

FIGURE 9: Plan View at Open Joint, Upper Temporary Sheave

Each sheave assembly consisted of a wire rope grooved sheave hub mounted on a sheave shaft. The sheave shaft was keyed to the sheave bearing to prevent rotation of the shaft within the bearing. Rotation was achieved at the sheave hub and shaft bushing interface with slotted keeper plates maintaining the locational alignment of the sheave hub.

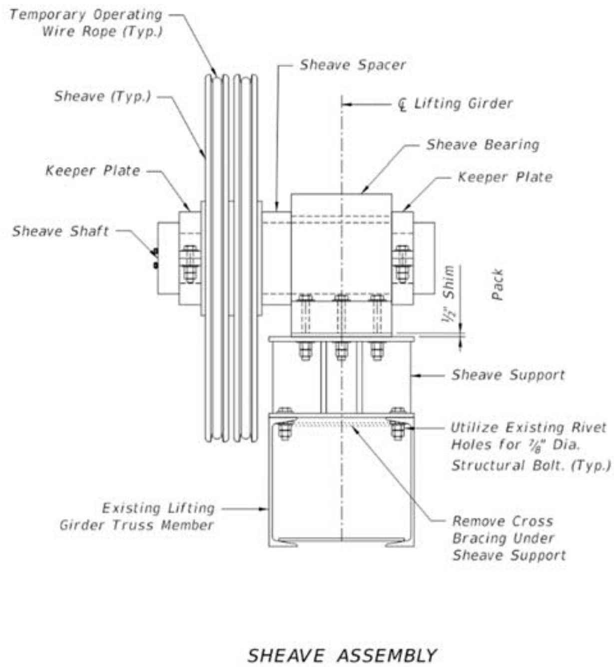

FIGURE 10: Temporary Sheave Assembly Detail

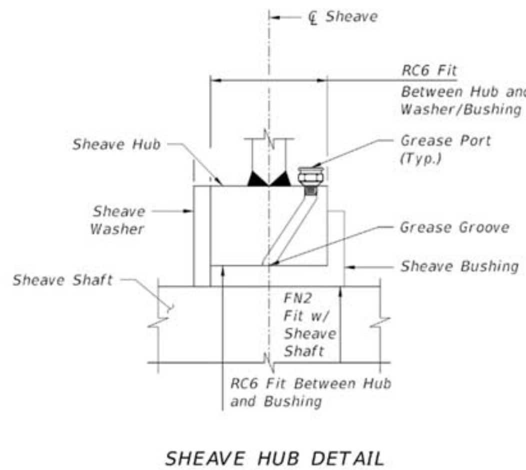

FIGURE 11: Detail of Sheave Bearing

FIGURE 12: Upper and Lower Temporary Sheaves

The upper termination assembly consisted of an open spelter socket wire rope end termination, connected to an adjustable turnbuckle, which was anchored to the top of the tower by connecting pin, support weldments, and turned bolts. The turnbuckle allowed for wire rope tension adjustments to achieve the required tension value for the system. The lower termination assembly consisted of the wire rope end wrapped around an anchored pin, then terminated by wire rope clips.

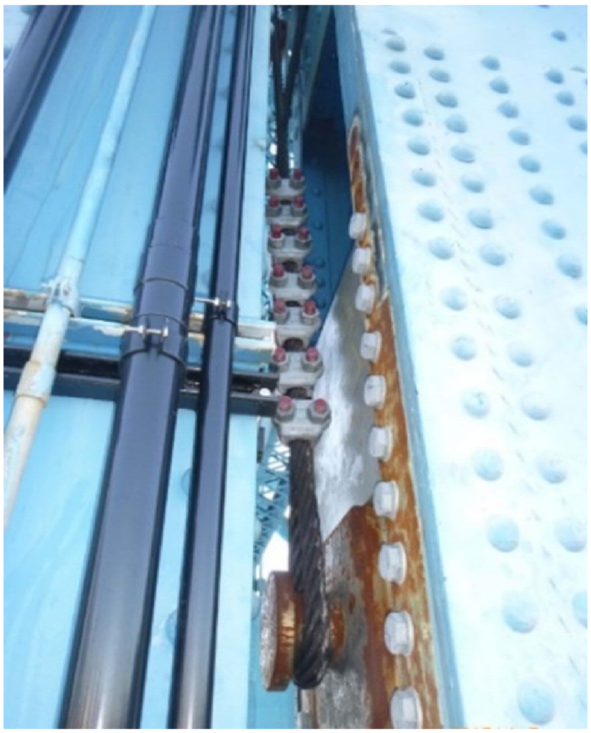

FIGURE 14: Lower Termination Assembly

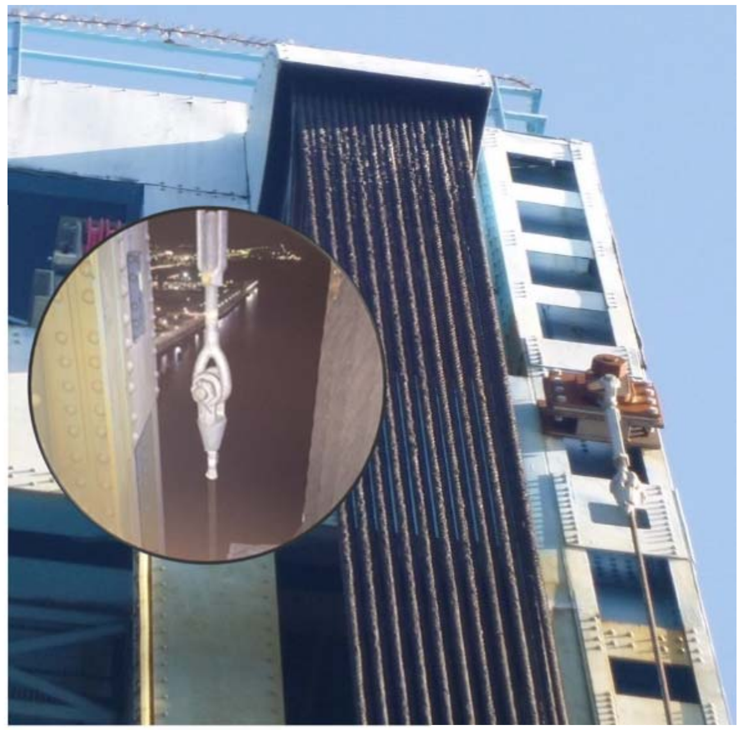

FIGURE 13: Upper Termination Assembly

Main Street Vertical Lift Conclusion

Careful consideration during design and construction of Main Street Bridge's temporary operating machinery was instrumental in the success of the span drive machinery replacement. The innovative design approach utilized in operating a lift span that had one longitudinal pair of machinery out of service reduced the impact not only to project cost and construction time, but also reduced any inconvenience to marine traffic.

Hillsborough Vertical Lift

Hillsborough Boulevard Corridor Introduction

Hillsborough Boulevard (SR 92) is a key east-west arterial connecting I-275 to the Veterans Expressway just north of the Tampa International Airport. Both eastbound and westbound traffic is heavy during peak hours (average daily traffic of 25,500 vehicles) having a mixture of vehicular types servicing Metro-Tampa. The corridor also provides for pedestrian sidewalks and dedicated bicycle lanes.

Hillsborough Boulevard crosses the north-south Hillsborough River with a pair of movable bridges: a double-leaf bascule carries the three lanes of westbound traffic and a vertical lift bridge carries the three lanes of eastbound traffic. The river is mostly used by recreational vessels.

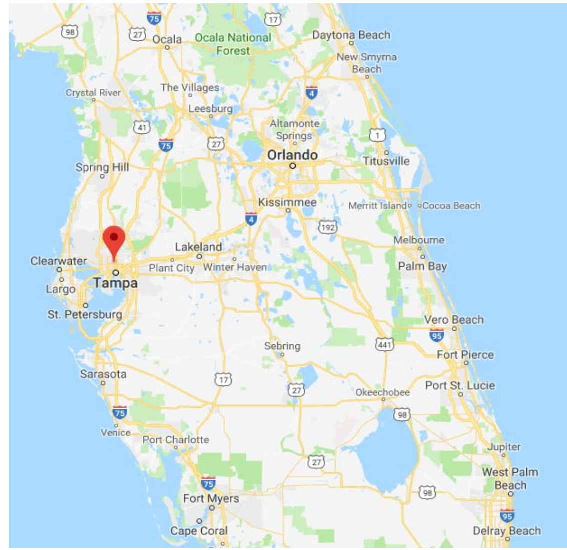

FIGURE 19: Bridge Location


FIGURE 20 - South Elevation

Hillsborough Bridge Introduction

Built in 1939, the historic Hillsborough vertical lift comprises a 93.5 feet Warren steel pony truss lift span at the channel crossing, five 33-foot concrete fixed spans to the west, and three 33-feet flanking to the east. Extending 53.5 feet above the roadway, four steel H-section columns spaced at 43 feet 8 inches transversely, and 7.5 feet longitudinally, carry the tower loads to the foundation. Columns are tied together with portal bracing in each plane to form each lift tower. The lift span roadway is an open grating deck with concrete fill above the machinery room located beneath the deck at midspan.

Steel wire counterweight ropes connect the span to the concrete counterweight that hung from two sheaves between the tower columns. The sheaves are supported by trunnions, which are in turn supported by a pair of sleeve bearings. These bearings are carried by W-shape steel sheave girders which are connected to the tower columns.

Attached to the East Tower on the north side is a vestigial control room that only houses equipment. Both eastbound and westbound movable bridges are controlled from the tower on the newer bascule bridge. Steel wire operating ropes are wound around the drum that drives the lift span up and down. As the bridge moves up, the counterweight ropes rotate the sheaves and allow the counterweight to lower. Lift span guide wheels, housed in the live load bearing assembly, roll along guide rails attached to the tower columns at each quadrant. The guide wheels and rails are intended to provide a low-friction mechanism to limit the transverse and horizontal movement in the lift span during operation. The live load component of the assembly transfers vehicular loads from the lift span to the substructure in the fully closed position. The vertical lift provides for 12 feet of clearance in the closed position and 56 feet in the fully open position.

FIGURE 21 - Original Sheave Assembly

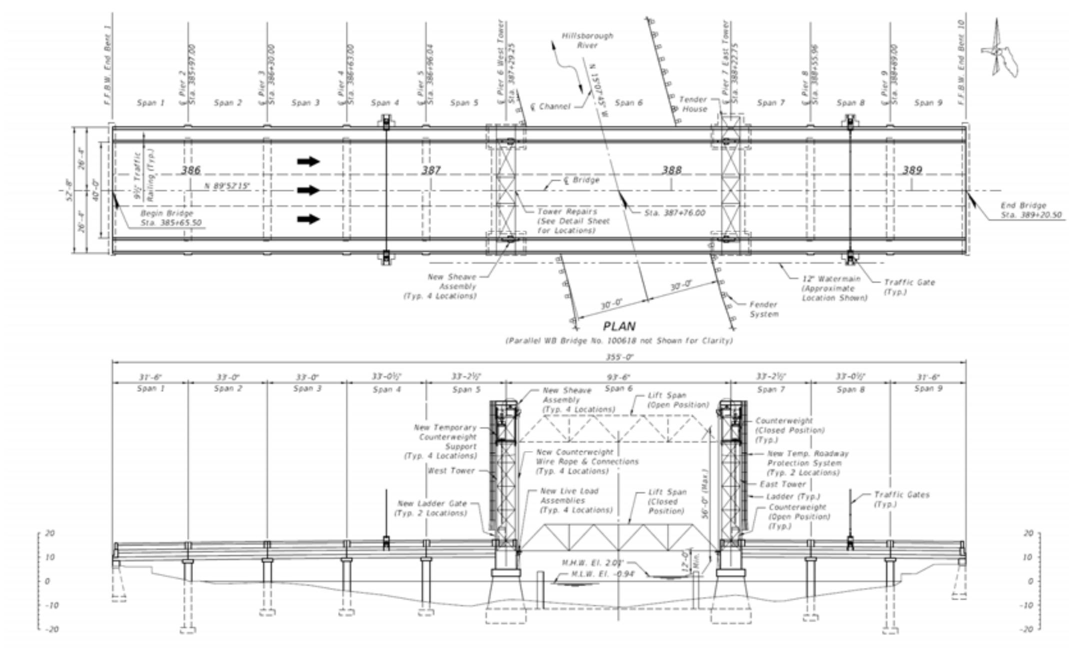

FIGURE 22 - Hillsborough Vertical Lift Plan and Elevation

Hillsborough Vertical Lift Bridge Rehabilitation Background

In December 2013, the bridge experienced an operational failure, which resulted from the lift span being out of horizontal plane and binding against the tower guide rails. Continuous driving in the bound condition snapped an operational cable. For the bridge to be lowered, the remaining operational cables were removed, a large onsite crane lifted the lift span to free it from the bound condition and then lowered it to the fully closed position. Operating ropes replacement activities resulted in one night of bridge closure for the eastbound traffic and four-month closure for navigation traffic.

FIGURE 21 - Span Stuck in Open Position

The rehabilitation scope stemmed from the need to replace the aged counterweight ropes and sheave assemblies, in addition to preventing a recurrence of binding of the lift span and resulting downtime. At the time of the incident, the exact cause was not ascertained which required some additional investigation during the design phase.

Hillsborough Vertical Lift Bridge Rehabilitation Challenges and Solutions

The major goals were established as:

1) Replace counterweight ropes and connections
2) Mitigate possibility of future lift span binding during operation

Achieving these goals were constrained within the following key client criteria:

1) Eight days of vehicular traffic closure for the installation of temporary counterweight supports
2) Outside lane closure of 30 days for the removal and installation of each quadrant of the counterweight ropes, connections, and live load-guidewheel assemblies
3) Navigation traffic closure of three months for those vessels requiring bridge opening

The primary challenge in replacing the counterweight ropes was developing a plan for the temporary support and jacking of the 162,000-pound concrete counterweight. The bridge towers did not have any built-in accommodation for providing temporary support that modern some vertical lift bridges have. The tower pier footing did not offer an area outboard of the bridge to support temporary towers. Any towers outboard would have to have their own subaqueous foundation. Supporting the counterweight inboard of the towers would not allow for vehicular traffic to be maintained.

Our solution to providing temporary counterweight support converged on an innovative system of hanging high-strength rods. A temporary safety platform was installed beneath the counterweight protecting vehicles from any falling objects. The installation of the temporary safety platform and temporary counterweight supports were performed during full vehicular closure.

Temporary Counterweight Support System

Holes were drilled through the top and bottom flanges of each sheave girder to allow for four 1-inch diameter high strength threaded rods. The rods passed through the sheave girder flanges, between the tower top chord channels and outside of the tower column footprint. A pair of steel angle stiffeners were permanently added to the webs at the locations of the rods.

Slotted-tapered bearings at the base of the stiffeners were used to develop a mill-to-bear condition at the interface of the stiffener and top of the sheave girder bottom flange through wedge action. The rods were located near the tower columns as to not significantly change the loads on the sheave girders or the overall tower system.

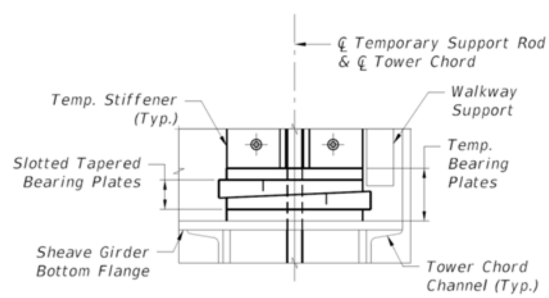

FIGURE 22 - New Stiffener Base

Each pair of rods, located on the same side of the sheave girder, supported a steel tube which spanned beneath the counterweight. The temporary rod beams supported another steel tube that spanned between pairs of rods on the opposite side of the sheave girder. The temporary support beams supported the bearing plates, which in turn carried one side of the counterweight. The tube shapes were chosen for their narrow profile which is beneficial in the tight constraints, flat bearing surfaces, multiple webs for high shear loads, and symmetrical section relative to the rod penetration.

The rods were threaded into high-capacity screw jacks that bore on the top flange of the sheave girders. With the span in the fully closed position, the jacks allowed the counterweight to be raised slightly, relieving any load and elongation in the ropes.

FIGURE 23 - Screw Jack with Tie-Rod and Stiffeners

The operation to install the safety platform, temporary supports, and jack the counterweight were completed during the complete road closure window. With load in the ropes transferred to the temporary support system and outside lane closures, the rope replacement activities could be performed.

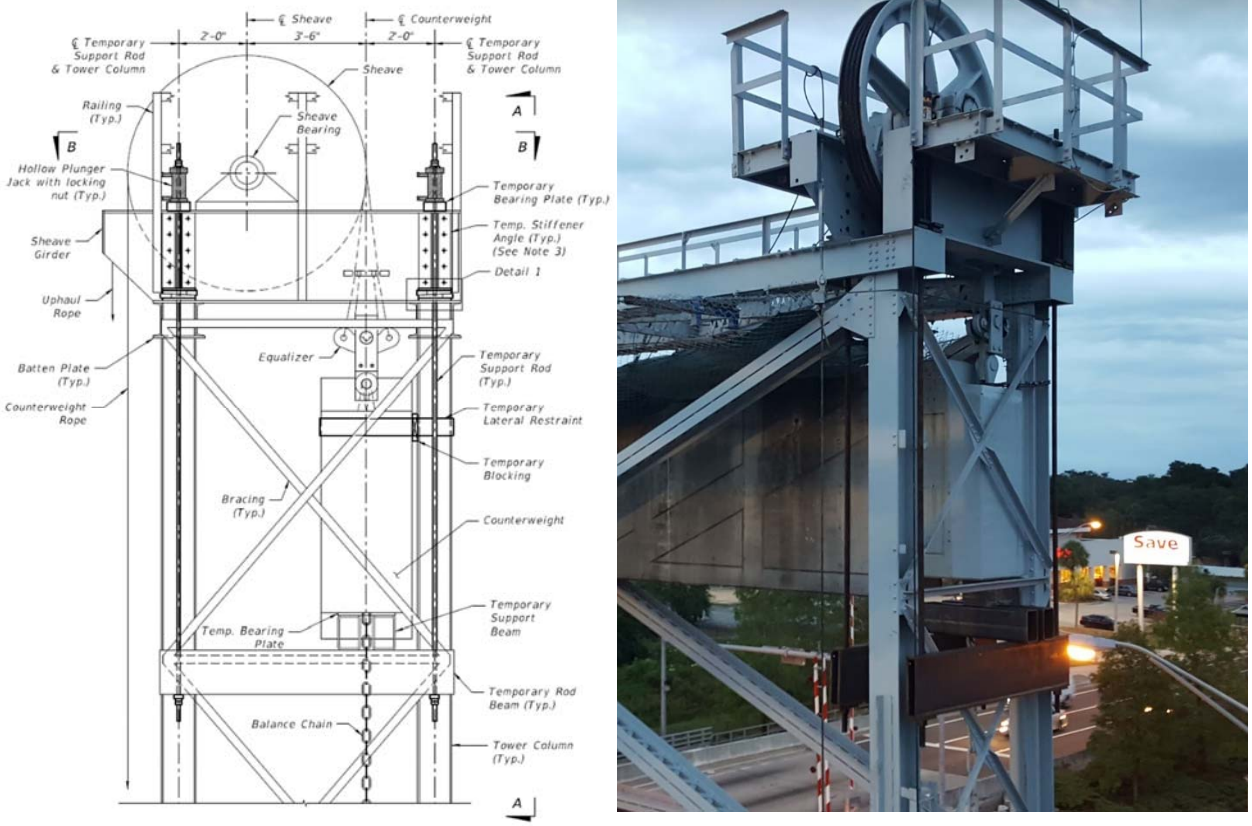

FIGURE 24 - Temporary Counterweight Support System

Counterweight Rope Replacement

The counterweight connection assembly consisted of a new link plate connecting the existing eye bar that was embedded in the counterweight concrete. The link plate connected to two equalizer plates through a hanger pin. The existing arrangement had substandard open spelter socket connection diameters. In addition, the available space for the new equalizer was dictated by the size of the existing system. The new equalizer plates had vertically-offset rope connection pin locations that accommodated the new galvanized forged steel open spelter socket connection diameters to the four ropes.

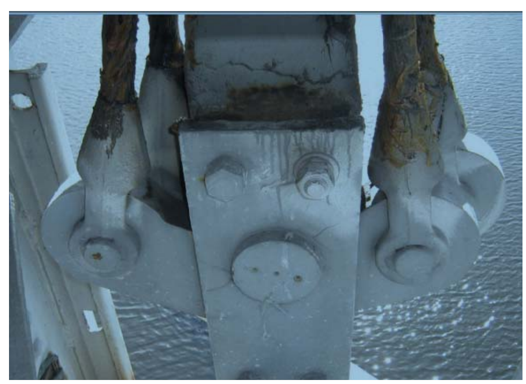

FIGURE 25 - Original Counterweight Connection Assembly

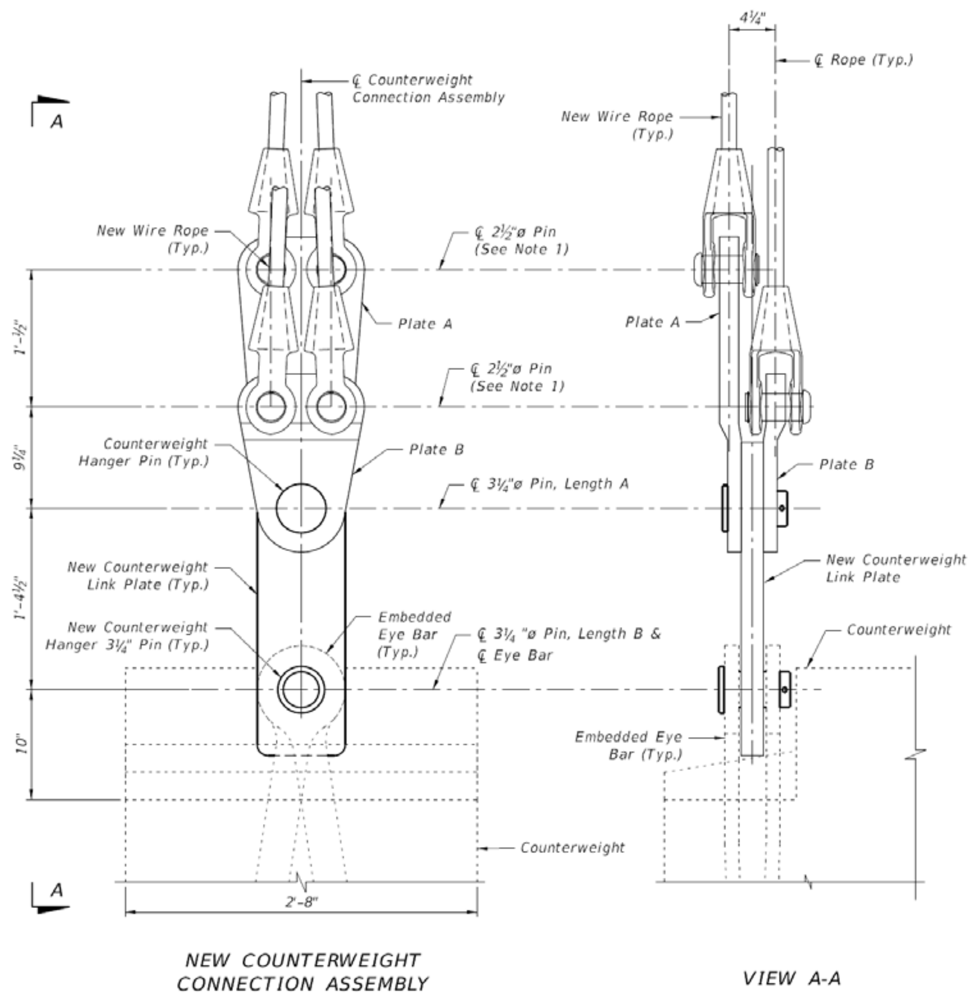

FIGURE 26 - New Counterweight Connection Assembly

Over the first six months of a new counterweight rope installation, it is typical to require an additional counterweight support and jacking operation to remove slack in the ropes that develops due to initial stretching and equalizing of load in the ropes. To avoid disruption to the travelling public, the span connection was configured to allow for the tension in the ropes to be adjusted from the roadway-level using the jacking nuts and shims. The span connection assembly consisted of a new link plate connecting the existing truss to the rope connection forging. The galvanized steel connection forging housed the new block spelter connections to the ropes and the rope pull rod system.

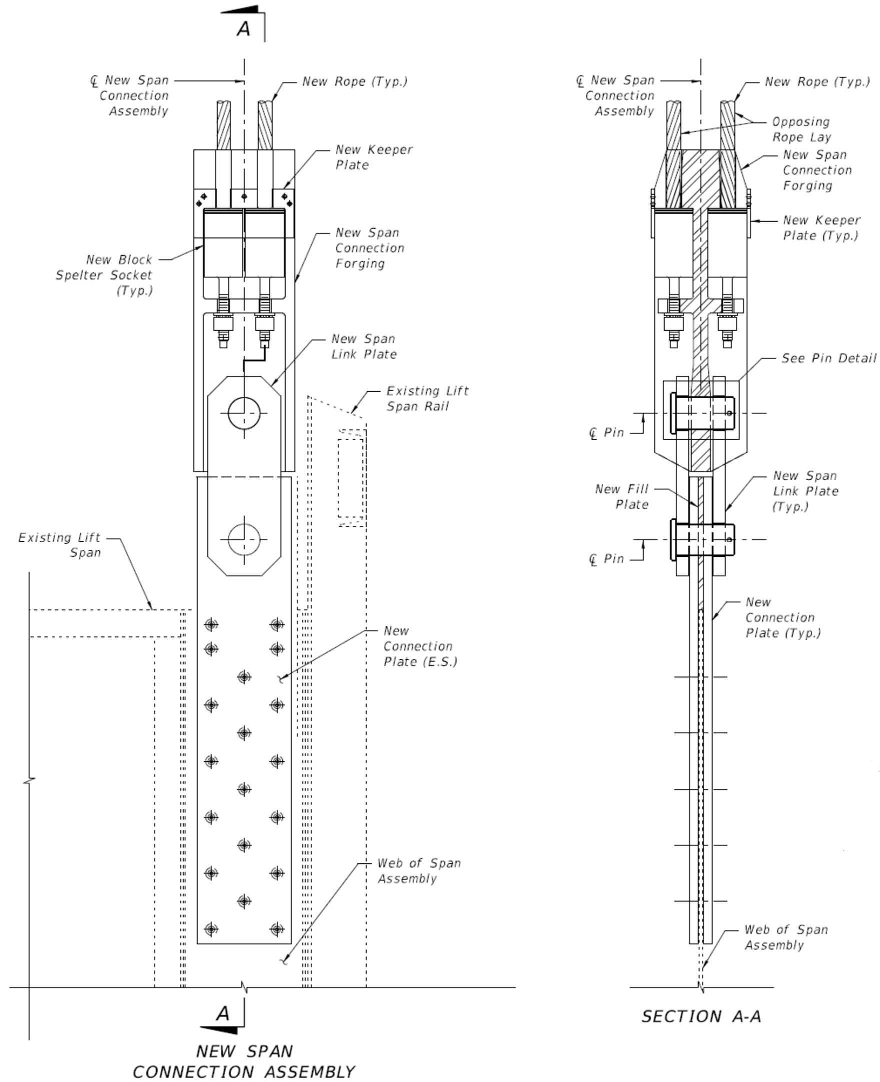

FIGURE 27 - New Span Connection Assembly

Filler Wire (6x25) IWRC (Independent Wire Rope Core) ropes were selected to replace the counterweight ropes. Industry recommendations, that were obtained from discussions with rope manufacturers, indicated that the IWRC high strength was relative to other configurations. Additionally, there was no advantage in providing lubrication that are available in other rope types. Filler Wire has large diameter wires for better corrosion resistance. Although other configuration ropes have superior fatigue resistance than IWRC, the conservative sheave diameter to wire diameter ratio allows for infinite fatigue life.

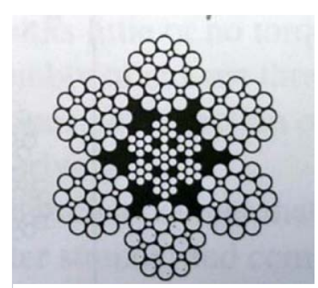

FIGURE 28 - 6x25 Filler Wire Rope (IWRC) Section

Operational Failure Mitigation

Laser survey technology was used to generate a detailed three-dimensional model of the lift bridge and towers. It was discovered that there was a twist in the West Tower top relative to the base, and that the East Tower tops leaned to the west relative to the base. This variation in geometry from the bottom of the tower bases to the top means that the space between the lift span guide wheels and the tower supported rails changes during operation. The maximum change in geometry was measured to be the change in a diagonal line from the southwest tower tip to the northeast tower tip of more than 1¾ inch. These dimensional changes were likely the cause of the December 2013 bridge failure and would need to be remedied.

FIGURE 29 - Original Span Guide System

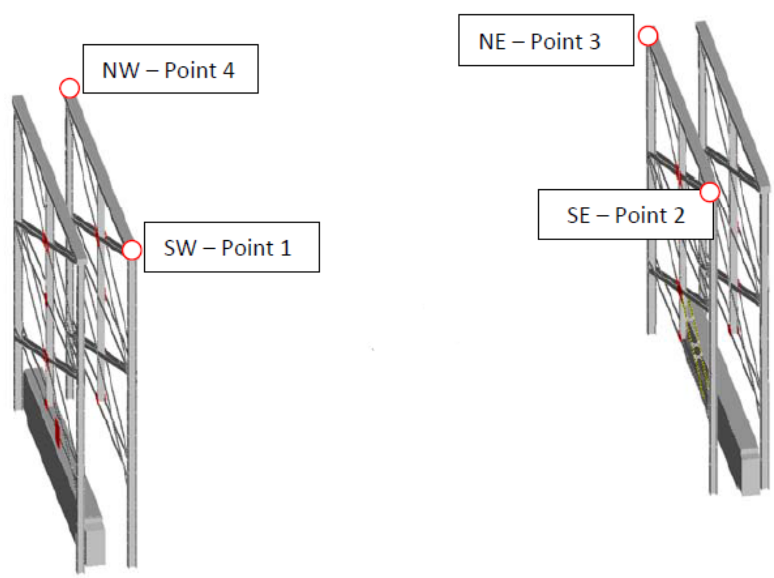

FIGURE 30 - 3D Tower Imaging

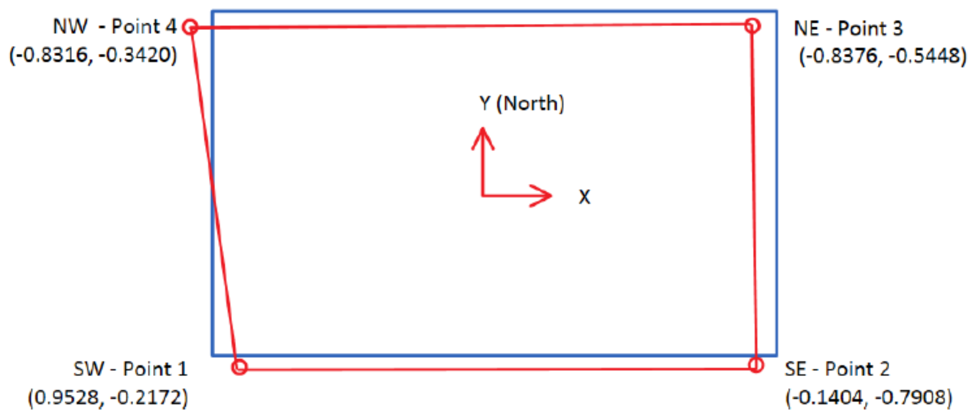

FIGURE 31 - Tower Offset Schematic

A new live load bearing/guide wheel assembly was configured to allow for an adjustable, low-friction guide wheel system. During the single lane closures for the rope replacement, a temporary bearing system was installed to allow for the replacement of the live load shoe guide wheel assemblies. Compact double-tapered roller bearings were used to reduce the friction of both longitudinal and transverse guide wheels. Both wheel shafts are eccentric to the wheel center allowing for adjustment of the wheel location relative to the tower guide rails. Based on the findings in the laser survey, theoretical locations of these wheels were set at the beginning of the operational testing period. The eccentric wheel shafts allow for further adjustment and refinement during testing period to find the optimum positioning for the guide wheels. This positioning and the reduction in wheel friction were provided to mitigate the twisted tower condition and potential for binding.

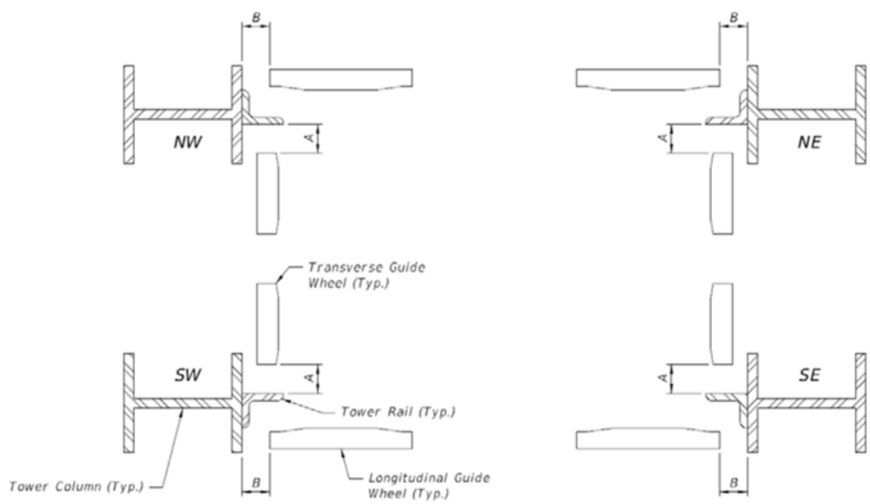

FIGURE 32- Initial Guide Wheel Positioning Schematic

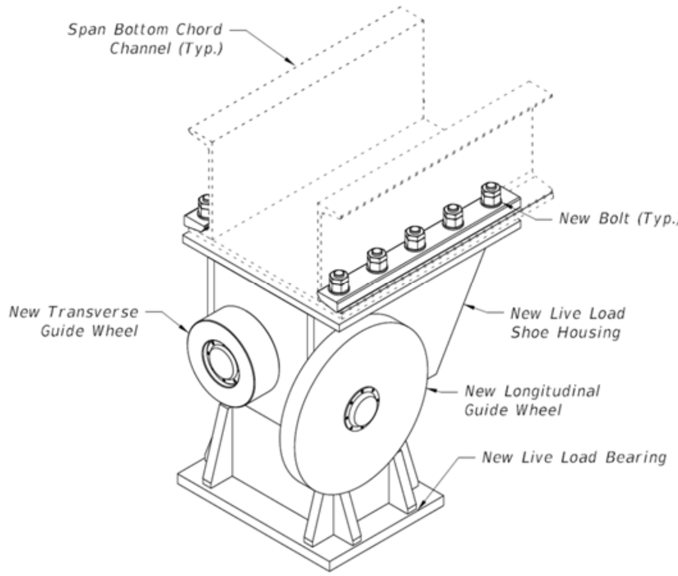

FIGURE 33 - New Span Guide Assembly Isometric

Hillsborough Vertical Lift Bridge Rehabilitation Conclusion

The replacement of the operating ropes of an in-service vertical lift bridge carrying a critical arterial facility requires planning for constructability. The innovative approach to temporarily support Hillsborough Bridge's counterweight accelerated construction and consequently reduced user down time. The minimal material used for the support helped to minimize cost. Diagnosing and solving the bridge operational failure required the use of 3D imagery, innovative details, and provisions for temporary supports in construction. The multi-disciplinary coordination and integrated design and construction approach made this project a success.