Erecting/Moving/Raising/Floating a 1600 Ton Lift-Span Truss

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ABSTRACT: The new Fore River Bridge (a 328-ft, 1600 ton vertical lift span truss) will replace an existing "temporary" ACROW Bridge lift-span. The new truss was constructed on land on 20ft steel towers, rolled onto twin 54ft x 180ft barges on four sets of two (8) axle SPMT units, lifted to a final vertical height of 70ft above the water with self-raising towers and then floated into position with 3" of clearance between the erected towers and each end of the bridge.

INTRODUCTION

The history of the Fore River crossing between Quincy and Weymouth Massachusetts consists of an interesting family tree of four bridge structures (one temporary and three permanent).

The original Fore River Bridge consisted of a swing span truss built in 1902 (see Figure 1). The original swing span was deemed "a hazard to navigation" as it serviced the former Fore River Shipyard (a major source of Navy warships in the early 20th century) and a "bottle neck" to the busy South Shore Route 3A.

Figure 1 - Original 1902 Swing Span

In 1936 the original swing span was replaced with a 175-ft double-leaf bascule span (see Figure 2). Due to a severely deteriorated steel superstructure, the bascule spans were deemed structurally deficient by the U.S Coast Guard in the late 1990's and were ordered to be replaced.

Figure 2 - 1936 Replacement Bascule Span

In 2002 a 210-ft "temporary" ACROW type vertical lift-bridge was constructed a few hundred feet south of the existing bascule span alignment and opened with the full intent of only being an "emergency fix" (see Figure 3). Although well maintained, after 15 years of service, the ACROW structure was rapidly reaching the end of its effective design life and is currently being replaced with a new vertical lift-bridge.

Figure 3 - Current ACROW Lift-Bridge

The new Fore River Bridge (see Figure 4) is being constructed on the original alignment of the old swing span and bascule span bridges. The new lift-span structure consists of two 250-ft tall four-legged towers, the main 324-ft lift-span, a 523-ft steel girder approach structure in Quincy and a 468-ft steel girder approach structure in Weymouth. The new vertical clearance envelope will range from 67 feet when the span is in the seated position to 175 feet when the span is raised.

The new bridge was constructed as part of a very challenging design-build process at an approximate cost of $251 million.

Figure 4 - Rendering of New Fore River Lift-Bridge

ERECTING THE TRUSS

Prior to selecting a float-in date, the contractor had to complete the truss erection and therefore the schedule for the truss erection was set to occur concurrently with the steel erection of the new towers.

This early steel truss erection requirement essentially eliminated the possibility of erecting the truss on the barges due to cost (barge rental for very long periods) and risk (exposure to major storms while floating on the barge). Therefore it was decided to erect the truss on land and eventually move the fully erected truss onto a barge.

The selection of the erection yard then became a critical path item as the site would need sufficient room for lay-down, sufficient room for cranes and access to water. In addition the preferred site location would minimize the travel distance on water.

Fortunately a site less than a mile from the project became available (see Figure 5). The challenge now became the site conditions:

1) The site was a former dry-dock area that had been filled in with material of varying unknown sorts (soil, rock, asphalt, concrete etc/etc) compacted to an unknown densities.

2) The site was densely packed with underground utilities (water, gas, electric and sewer) at varying depths.

3) Although relatively flat, the site required significant grading to accommodate a truly level working surface under the 324-ft truss and to accommodate the slope limits required by the SMPT's that would be used to move the truss onto the barge

4) The barge loading location (ramp landing zone) consisted of an existing concrete wall of unknown construction as all original engineering drawings and calculations had been lost through the many ownership transfers of the property.

Pile foundations were not an option for the temporary falsework foundations therefore spread footings were selected as the best option. Geotechnical studies indicated that the soils could support a net Dead load bearing pressure of 4000 psf and a short-duration dead load plus wind toe pressure of 8000 psf. The studies however noted that the spread footings would experience significant immediate (elastic) settlements of +/-1″ to 2″ with the potential of an additional 1″ of consolidation settlements.

Figure 5 - Truss Erection Site

Because of the settlement concerns, the falsework towers were designed with tower heads that included hydraulic jacks that could adjust the truss support elevation based on settlements that were measured during a monitoring process that was performed twice a week. The worst footing settled over 2.5".

There were two type of falsework towers (lite-duty and heavy-duty). The six lite-duty towers (see Figure 6) were used only as temporary staging to help erect the chords while the eight heavy-duty towers (See Figure 7) were design to carry the truss in groups of four (either four at the L0 panel points or four at the L4 panel points). The purpose for two independent sets of heavy-duty towers was two-fold:

1) The truss was erected with the L0 gussets providing direct support. However, because the specifications required the pins for the bearings to be field bored, at some point the load would need to be transferred four corner supports at L0 to support points at L4 while the bearings were installed.

2) The anticipated footing settlement was significant enough that adjustments to shims in the tower heads would require transfer between the towers.

Due to the eventual long weather exposure duration of the truss on towers a bonus third benefit of having towers at L0 and L4 came when heavy winds were predicted. During those periods of time, load was transferred to all eight towers to distribute the effective wind forces to all eight braced towers.

The maximum dead load plus wind load combination resulted in a vertical design load of 915 kips and a horizontal design load of 65 kips for the heavy-duty towers.

Ironically, the falsework towers were designed as a "temporary" support system with an anticipated maximum duration of 6 months. In the end, with delays due to delivery of the mechanical system, the truss was actually supported on the falsework towers for 25 months and during that time period survived two significant storms with hurricane type winds and survived one winter with significant snowfall. Total snowfall for one month during the 2015 winter exceeded 94-inches (01/24 to 02/22/15).

Figure 6 - Temporary Lite-Duty Erection Tower

Figure 7 - Temporary Heavy-Duty Erection Tower (shown at L0)

The tower heads were designed to support the truss along the bottom chord. The truss was globally designed for support at the L4 panel points during the design process however the local transfer of loads was not considered primarily due to the fact that the temporary support system was an unknown at the time of the truss design. Therefore a unique transfer of load was developed using the bottom flange plate of the bottom chord box section and the corner weld between web and flange plates (see Figure 8).

Figure 8 - 5/8" Fillet Weld at Load Transfer @ L4

Bearing bars were provided under the bottom flange plate (see Figure 9) however the bearing bar plate thickness was insufficient to deliver the load to the corner welds if the center of the 2" bar strayed more than 1.5" from the edge of the bottom flange plate. This created a unique concern during erection to ensure the bearing bars were not only positioned correctly but were also "locked" into the tower head assembly above the Heavy-Duty Erection Towers.

Figure 9 - Bearing Bar Location had Tight Tolerances

Furthermore, there was concern that when the load would be transferred from the erection towers to the SPMT's, the tight tolerances for the bearing bar positions could not be achieved. The decision was made to design the top portion of the tower head above the SPMT's as a bearing block to effectively be secured to the bottom chord and stay with the truss from the start of erection through the final delivery at the project site. This was achieved by post-tensioning the tower head to the bottom chord.

Figure 10 - Erected Truss on Falsework Towers

MOVING THE TRUSS

Once the towers and mechanical systems were erected and functional, the truss was ready to be floated into position.

Step One was to move the truss from the temporary towers to the water's edge. This was accomplished using four sets of two (8) axle SPMT units furnished with self-lifting towers. The truss loads were first transferred to the towers at the L0 panel points to allow the L4 towers to be removed. The SPMT's were then centered under the L4 panel points.

Using the self-lifting towers, the loads were transferred to the SPMT's and the top of the towers were secured to the bearing blocks post-tensioned to the bottom chord. When the SPMT's registered 50% of the total load, longitudinal and transverse bracing was added between the bases of the SPMT units to panel points L3 and L5 of the truss above to stabilize the system during the transport movements (see Figure 11).

Figure 11 - SPMT & Lifting Towers @ L4

The swerving "S" shaped transport path was meticulously planned to miss as many underground utilities as possible however where conflicts existed, steel wide flange ramps were buried flush with the ground surface and effectively were long enough to span over the utility of concern (See Figure 12).

Maintaining a fairly level "table-top" surface between the four corner sets of transports was critical. Each SPMT axle has +12" to -12" of vertical adjustment however due to the length of the diagonal from the left most lead axle to the right most rear axle (See Figure 12), the maximum grade was restricted to 1% forcing the contractor to perform extensive regrading.

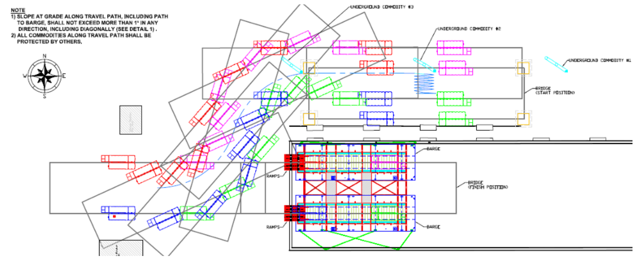

Figure 12 - "S"-Shaped SPMT Travel Path

Step Two was to move the truss from land onto the barge. The first hurdle was to determine where the ramp landing point would occur. The original plan was to land the ramps on top of the wet basin wall however no engineering plans or calculations were available for the existing wall structure (see Figure 13). Without knowing how the wall structure was reinforced or how the wall was founded on the supposed rock stratum, it was decided to move the 1,500,000 lb ramp reactions behind the wall.

Figure 13 - Wet Basin Wall (Ramp landing Area)

A site investigation was performed to verify general wall geometry and water table levels. Information from the site investigation was used to check wall stability for the surcharge loading from the SPMTs.

Moving the ramp landing behind the wall came with its own set of challenges. Three of the more critical challenges included: the changing 9 foot daily tide cycle; the changing barge freeboard due to changes in barge trim as load was added and the requirement of the SPMTs to maintain a maximum +/-1:30 slope on the ramp (see Figure 14 & Figure 15).

Figure 14 - SPMT’s traveling over Ramps onto Barge

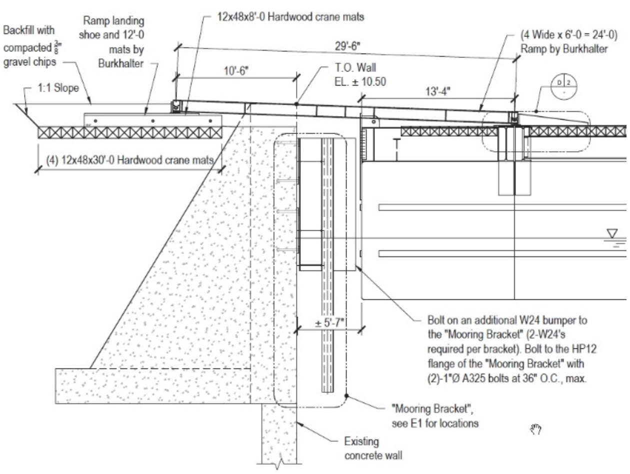

Figure 15 - Ramp Designed for Max. Slope 1:30

The solution required the contractor to remove a 3 foot portion of the existing wall top and required a rigorous engineered ballast plan that moved and/or dumped water stored on the barge to accommodate the additional weight of the truss and SPMT’s as they walked onto the barge (see Figure 16).

Figure 16 - 6” Ballast Pumps (16 used)

The barges consisted of twin 54x180x12 ABS deck barges structured with spine beams which created a catamaran type floatation system providing the necessary stability required when the truss span would be lifted 70 feet above the water. In addition to the spine beams, wide flange “X”-bracing was added between the barges to ensure their alignment was preserved in the case of an incidental impact at any corner location.

Due to the large moving transport loads, a sandbox and mat system was added to the barge deck to help distribute the 1,200,000 lbs per transport group (see Figure 17). The ramp landing location on the barge was centered on a rear internal water-tight bulkhead however the linear ramp reaction exceeded the capacity of the bulkhead wall therefore an additional spine beam was added to receive the ramp reactions.

Figure 17 - Sandbox & Mats Distribute Transport Loads

RAISING THE TRUSS

Once the transports were aligned correctly on the barge and the SPMT's were lashed to the spine beams, the truss could be raised to the height required for installation on the tower foundations at the bridge site.

Step One was removal of the transport pipe bracing and set up of the self-lifting tower conveyor system used to feed "barrels" into the hydraulic jacks as the tower lifts the bridge (see Figure 18). The maximum horizontal force that could be resisted by the self-lifting towers was equal to 2.5% of the vertical force. For this reason, additional studies were performed to determine maximum wind conditions while the truss was raised to ensure stability throughout the lift. The winds generated a direct horizontal shear but also listed (i.e. rotated) the barge which effectively developed a secondary lateral load. The combination of these two effects resulted in a maximum design wind speed of 15 mph while lifting the truss.

Figure 18 - Conveyors "feed" barrels into the towers

Step 2 was to prepare the truss and tower system for transport from the wet basin to the project site. The lateral resistance of the self-lifting towers was insufficient for the 15% impact loads required (combination of wind and barge motion forces during transport). Therefore a secondary wire-rope lashing system was designed specifically for the transport load combinations of wind, list and impact (see Figure 19).

Figure 19 - Truss lashed to truss after lifting

The main challenge was the practicality of installing and tensioning the lashing with the bridge 65 feet above the barge deck (70-ft above the water). The solution was to install the lashing prior to lifting the truss to prescribed lengths and let the lifting process effectively tension the cables. Extensive 3D studies were performed to verify the lashing did not conflict with the numerous pieces of equipment on the barge (ballast pumps, structural framing, towers, SPMT's, SPMT bracing to truss and other cable lashings).

The studies showed that not only did the cable require to be set to a certain length, but they needed to be installed and stacked over each other in a specific order as to minimize the potential for the lashing to "knot up" as the towers lifted the truss (see Figure 20). In addition to the 3D computer studies, a 3D working model was built to confirm the theory behind the cable lengths and cable stacking on the barge deck (see Figure 21).

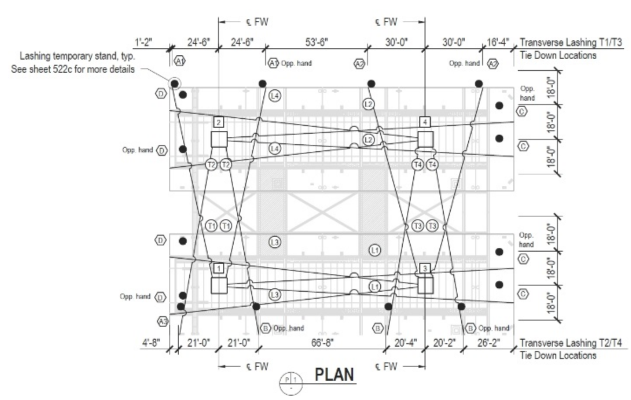

Figure 20 - Stacking plan (order of installation

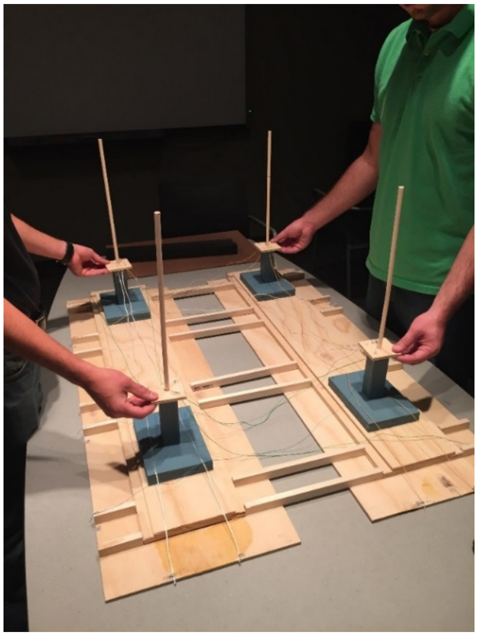

Figure 21 - Lifting Tower & Lashing Working Model

FLOATING THE TRUSS

Once the truss was lifted to the planned elevation and was lashed to the barge, the truss could be floated in between the tower foundations.

Step One of truss float-in was to verify geometry. The first critical measurement was the actual position of the truss on the barge. The alignment and position of the truss relative to the stern of the barge was checked using self-leveling lasers and old-fashion survey instrumentation. These dimensions were critical as there was only 3" of horizontal clearance between the two towers and the ends of the truss (see Figure 22Figure 23 and Figure 23).

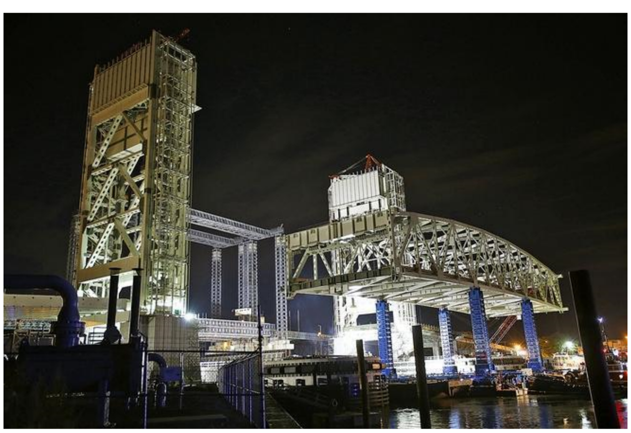

Figure 22 - Truss at Project Site Waiting on Tide

Figure 23 - 3" Working clearance each end of truss

The second critical measurement was positioning of the spacer barges at the project site. The spacer barges were used as a landing place and guide for positioning the main barge carrying the truss. In addition, the spacer barges were used to support the winching systems used to move the barge laterally. The winches provided the necessary "fine-tuned" control of position that the tugs could not. In addition, the winches secured the final position of the barge while waiting for the tide to fall and subsequently transfer the truss load from the barge to the tower foundations (see Figure 24)

Figure 24 - Truss in Final Position waiting on tide

Step Two of truss float-in was to successfully dock, winch and position the barge to align the truss on the required centerlines (both longitudinally and transversely). This was achieved using temporary steel guides bolted to the truss and tower. The guides were used to center the truss longitudinally once the south edge of the truss starting entering the gap between the inside corners of the north legs of the towers. In addition the guides were fabricated with "bumpers" that were used to stop the truss when exact transverse position was achieved (see Figure 25).

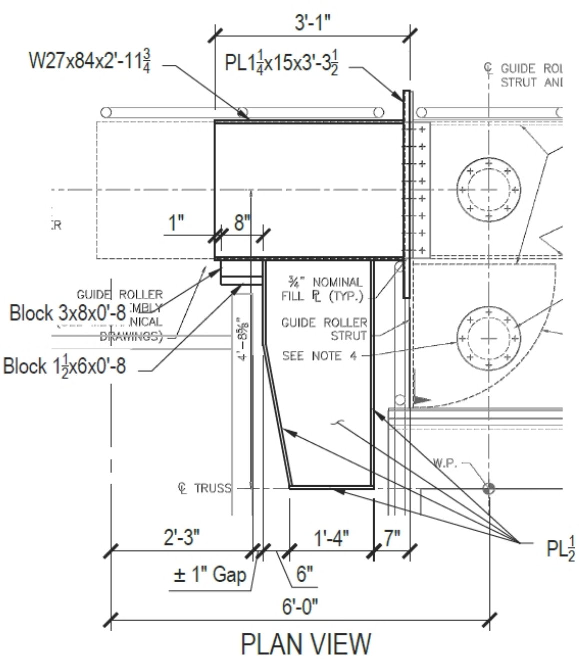

Figure 25 - Float-In Guide and Bumper

Once the towers were free from the truss load, an interesting stability issue had to be resolved. While carrying the truss, the self-lifting towers were locked into the truss bottom chord making the truss a longitudinal and transverse strut between the tops of the towers. By being locked, the towers, the truss and the lashing worked together as a "braced frame". Once the truss load was released from the towers, the remaining tension in the lashing was significant enough to pull a self-lifting tower over at the initial float-in tower height. Therefore two steps were added to the float-in procedure to ensure tower stability after the truss load was removed from the towers. Step 1 was the truss was first floated in high, such that an intermediate lowering of the towers could be performed once the bridge was in its final position. Lowering the towers reduced the tension in the lashing, however this still left enough unbalanced self-weight "sag" tension in the lashing to pull the towers over. Step 2 was the installation of independent tower lashing using small diameter wire rope. The sole purpose of the independent lashing was to ensure the stability of the unloaded towers (see Figure 26).

Figure 26 - Sagging Main & Tower Stability Lashing

After the load was transferred and the truss was free from the barge, survey for the day noted that the truss landed 3/8" off the theoretical trasnverse position and landed right on the theoretical longitudinal position (with a little help from the self-centering fixed bearings).

SUMMARY

The new Fore River Replacement Bridge required intense planning and engineering preparation that lasted over a 3-year period.

The 1600 ton truss was successfully erected on land, transported to and loaded onto a barge and then floated into position. Three years of planning resulted in a total move time of 21 hours:

1) The move from the erection site to the edge of the wet basin took approximately 6 hours.

2) The move from land onto the barge took just under 3 hours.

3) The float-in starting with the fully loaded barge leaving the wet basin and finishing with the empty barge returning to the wet basin was completed in approximately 12 hours and half of that time period was waiting on the tide to fall and unload the towers on the barge (see Figure 27).

The new bridge will be open in September of 2017 with all traffic moved over by the end October 2017 after the demolition of the ACROW is complete. The demolition of the ACROW will take place after traffic is transferred on the new bridge between September to December 2017.

Figure 27 - Barge ready to be pulled from channel

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