Replacing the Memorial Bridge

DAVID ROGOWSKI, P.E. AND JOSH CRAIN, Genesis Structures Inc., Kansas City, Missouri and STEPHEN DELGROSSO, Walsh Construction Company, Canton, Massachusetts

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ABSTRACT: The 90-year old Memorial Bridge served Portsmouth, New Hampshire as a major link to nearby Kittery, Maine. The vertical lift bridge performed daily lifts flawlessly; however, the bridge required replacement due to deterioration of the steel framing. This paper highlights the advantages of the new "gusset-free" truss concept selected for the project and demonstrates the procedures developed to meet the 18-month replacement including the float-out removal of existing spans and float-in installation of new spans.

PROJECT DESCRIPTION

The original Memorial Bridge was erected in 1923 and served the City of Portsmouth, New Hampshire well as a major vehicular and pedestrian link to nearby Kittery, Maine. The innovative original three-span structure (See Figure 1) was designed by the patent holder for the first modern vertical lift bridge, J.A.L. Waddell.

Figure 1 – Original Bridge taken out of service to vehicular traffic in 2011

The deficiencies of the original bridge were of no fault to the movable bridge design aspects of the original structure. The 300-ft vertical lift bridge was able to perform daily lift activities flawlessly from a mechanical perspective; however, neglect of the floor framing and lower truss chords had allowed deterioration beyond repair (See Figure 2). Similar deterioration (See Figure 3) was seen on the two adjacent 300-ft fixed spans, and eventually the bridge was taken out of service to vehicular traffic in July of 2011.

Figure 2 – Bridge still able to perform daily lift activities

Figure 3 – Deterioration of lower chord and floor system

After extensive research and community outreach, the States of New Hampshire and Maine decided that a bridge in this location remained necessary for the transportation needs of the region and that a completely new bridge was required. However, due to the importance of the bridge for the local economy and circulation of local pedestrian traffic, the DOT mandated that the existing bridge be removed and replaced in less than 18-months.

The Walsh Group[1] Design Build Team won the honor to build the new bridge as part of a creative design build selection process. The Walsh team included HNTB as their designers and Genesis Structures as their erection engineer. All three worked to develop a structure type and erection method that would not only satisfy the design requirements, but also the limited construction time-line. The final replacement bridge structure selected was a cold-formed steel "gusset-free" truss (See Figure 4 and Figure 5). Advantages to this "gusset-free" design over the conventional truss were both to avoid potential costly future gusset retrofits due to corrosion and to minimize the quantity of bolts used per connection, making it faster to erect and easier future maintenance.

Figure 4 – Cold-formed steel Gusset-free truss reduced quantity of bolts per connection

1. Archer Western Contractors was the General Contractor for this Project. Archer Western Contractors is a member of The Walsh Group

Figure 5 - New "Gusset-free" truss upper chord and diagonal connection

The final demolition and erection method would be a float-out of the existing spans and a float-in of the new spans with all truss erection and demolition being performed on the deck of the barges.

The main focus of this paper will be on the following construction activities:

- Procedures developed for the float-out removal of the existing spans
- New truss fabrication and erection, including machine room erection under the deck of the lift span
- Installation methods of the new spans

In addition, this paper will highlight the advantages the new "gusset-free" truss concept brought to the project.

EXISTING BRIDGE REMOVAL

EXISITNG SPAN FLOAT-OUTS - The total bridge demolition, which included the removal of the three 300-ft truss spans, the existing concrete counterweights (CTWTs), the 200-ft vertical lifting towers, and approach span structures, was accomplished in 5 months, from January 2012 to May 2012. In that time, the existing 300-ft truss lift span was floated out in a 36-hr channel closure.

Figure 6 – Original Bridge just prior to demolition

The first and most critical truss span removed was the 1,800 kip, 300-ft vertical lift span (See Figure 7 and Figure 8). The importance of the lift span removal was due to the complexity associated with simultaneously supporting (or having control of) both the lift span and the two 900 kip concrete CTWTs (See Figure 10). Due to the high risk and critical nature of the lift span removal, a falsework tower system, capable of +/-20ft of vertical stroke was utilized to move the lift span. The falsework tower system was supported by a single 250-ft x 72-ft ocean going barge (the sea vessel lovingly named the "Cape Cod").

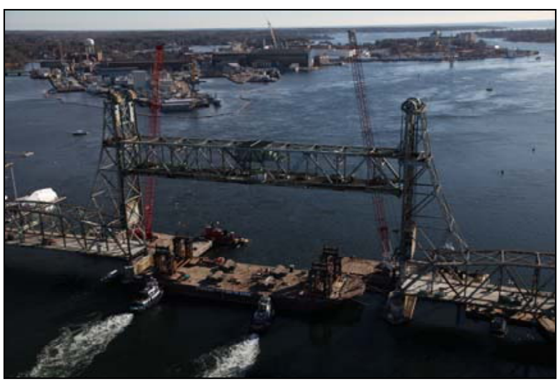

Figure 7 – Float-Out Falsework configuration in place for Lift Span removal.

Figure 8 – Lift Span removed and supported on barge

Figure 9 – 900 kip Concrete CTWT prior to demolition

The complexity of floating out the lift span (and each subsequent span) was fueled also by the extreme and unforgiving nature of the Piscataqua River. The river's daily 8-ft changes in tidal elevation along with roaring stream flows made predictions of tidal elevations during anticipated times of removal critical. For the lift span removal, it was determined that the risk of complication during float out was too great and the falsework tower system had to be able to vertically self adjust under any potential tide elevation.

The existing lift span truss was picked up by the float out falsework at thoroughly inspected interior panel points which were determined to require no additional local strengthening. The falsework tower system, used at each pick point of the existing truss, was comprised of (4) Tower "Jacking Corners" (See Figure 10). Each Tower "Jacking Corner" was comprised of a multi-level "jacking beam" system power by (2) 400-T hydraulic jacks. The elevation of the "jacking beam" system was adjusted with the use of (4) 2-1/2" 150 ksi Williams All-Thread Rods.

The "jacking beam" systems were supported on each end by a (4) 24" diameter pile tower groups. The 24" diameter tower piles rested directly on HP cribbing, this steel cribbing transferred the load to the barge deck through crane mats resting on a confined 12" "sandbox" poured directly on the barge deck.

The stability of the (4) 24" diameter pile tower groups were provide by an additional 24" diameter pipe "strut" located at the bottom of the tower piles just above the HP cribbing (See Figure 10).

Figure 10 – Falsework Tower System for float-out of Existing Lift Span Truss

One unique aspect of the falsework tower system, used to remove the existing lift span truss, is that the majority of the falsework tower system components were to be designed for reuse for the new truss span installations. Because of the heavier anticipated new truss weights, the design loading of falsework tower system was controlled by an assumed "truss self weight" for the new trusses to be installed a year later.

The following (2) 300-ft fixed spans were float-out with a much less intricate falsework tower system (See Figure 11). The towers used to float out the existing lift span, capable of +/-20ft of vertical self adjustment, were replaced with stacks of hardwood mats resting directly on the barge deck. The power of the river's tide was relied upon to take the load and lift the existing fixed trusses off their bearings. Relying on the power of nature is always the preferred method; however, risk and potential consequences due to complication during removal must always be considered.

Figure 11 – Fixed Span removed and supported on barge

TOWER AND CTWT REMOVAL – The 200-ft vertical lift towers and (2) 900 kip CTWTs were removed outside of channel closures. The CTWTs were supported on newly installed cribbing beams spanning the existing tower's CTWT support girders. The CTWTs rested on these newly installed grillage beams during the lift span removal and until the CTWT was surgically removed. Genesis Structures performed a finite element stress analysis (FEA) (See Figure 12) to determine temporary stress in the CTWTs during the lifting removal operations (See Figure 13). The lift tower was also removed surgically with the use of cranes on barges.

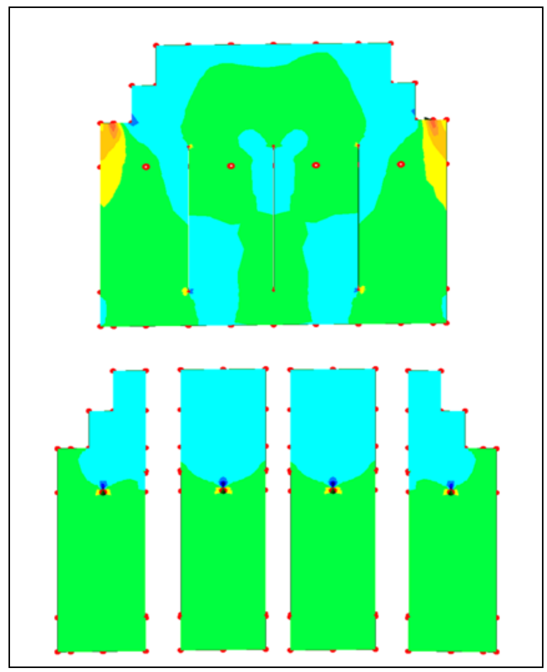

Figure 12 - FEA Model of 900 kip Concrete CTWT, analyzed for temporary stresses during removal

Figure 13 – Existing CTWT removal

NEW PIER CONSTRUCTION OVER EXISTING – The piers used for the new bridge were constructed over the top of the existing and reused the 1922 granite faced concrete piers. The purpose was to avoid disturbance of the river bed and to ensure the protection of the water quality in the Piscataqua River.

The existing pier foundations were reinforced with micropiles (See Figure 14 and Figure 15) and new Pier Caps were cast over the top of the reinforced existing foundations. This "reinforcing" process of the existing substructure was completed in a 7-month period from May 2012 to January 2013.

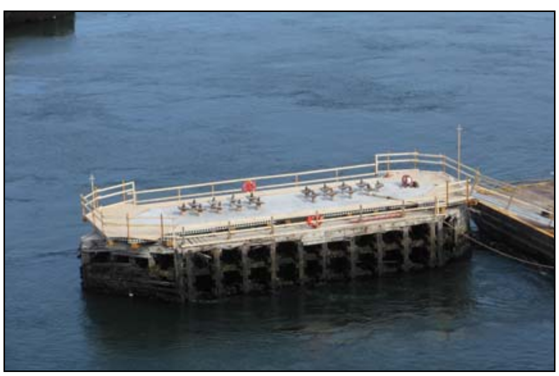

Figure 14 – Existing Pier after span float-outs, strengthened for reuse with new bridge

Figure 15 – Micropiles installed in existing foundations

NEW TRUSS ERECTION

NEW TRUSS FABRICATION – The new truss' "gusset-free" design got its first opportunity to prove its merit in the fabrication phase. With the truss' gusset plates removed, the diagonals connected to the top and bottom chords with a more conventional splice connection. The splices were located up in the diagonal; the chords therefore had to be designed to accommodate these splices. In order to accommodate this complex geometry, the truss was fabricated entirely from 50 ksi or 70 ksi cold-formed steel (See Figure 16).

Figure 16 – Cold-formed steel truss chords shown during fabrication

Both the chords and diagonal were comprised solely of I-shaped sections. The chords were connected (similar to the chord to diagonal connection) with a more conventional splice, which again was used for the purpose of expediting fabrication and assembly (less bolting that typical gusset connection).

The two fixed span trusses were designed and constructed identical in both overall geometry and member size. The vertical lift span maintained a similar geometry to the fixed spans, but varied the plate thicknesses of the chords and diagonals. The chord depths remained constant between both the fixed and lift span.

The entire fabrication process, which included two fixed spans, one vertical lift span and the vertical lift towers was completed in an 8-month time period, between September 2012 and April 2013. The fabrication process also included the application of a "grey colored" molten zinc metalized coating (referred to the locals as *Piscataqua Mist*). This coating was used with the purpose of minimizing corrosion and future deterioration to not repeat the mistakes made in the past.

TRUSS ERECTION ON BARGE – As soon as a new truss was fabricated, the truss components were immediately moved to the job site staging area and erection of the new trusses on the same barge used for the existing truss float-outs, the Cape Cod, was set in motion (See Figure 17)

Figure 17 – New Fixed Span Truss partially erected on Cape Cod Barge

The new trusses were built one-at-a-time on the Cape Cod, starting with the New South Fixed Span. Genesis Structures performed all of the barge stability analysis, falsework design and rigging analysis required during the truss erection operations. The center of gravity calculations proved complicated at times due to the unique nature of the truss chord geometry (See Figure 18).

Figure 18 – Top chord segment installation

One of the goals of the new fixed span truss erection plan was to provide a falsework system that could accommodate self weights of the trusses in various stages of completion. This was done in order to account for the uncertainty of the where the trusses would be in the fabrication process when float-in dates arrived. The main objective was to maximize output, better to be prepared for additional weight if fabrication was running ahead of anticipated float-in closure windows. The additional anticipated weight included partial vertical lift tower erection, new CTWT box assembled on float-in trusses and formwork and rebar for the deck pours.

The lift span was erected with the deck fully poured and ready for installation. Another key difference between the fixed span erection and lift span erection was that the lift span had to be erected with the two Machine Rooms located underneath the deck level prior to float-in.

MACHINE ROOM ERECTION UNDER LIFT SPAN DECK – Another first of its kind, the mechanical system was installed entirely below the deck level. The purpose was both for a clean aesthetic look and to allow for easy access for future inspections without interruption of traffic.

The (2) machine rooms were located at the (2) end floor beams at each end of the 300-ft vertical lift span. The machine room framing was comprised of two outer trusses which utilized the (2) end floor beams on both sides of the truss as their top chords. The inherent challenge of this design configuration is the main lift span truss was erected in its entirety (include end floor beams) prior to the machine room installation. What was left was a machine room truss that had to be lifted (with all of the mechanical equipment) into its final position without a top chord.

Genesis Structures and Archer Western Contractors went through several iterations to determine the appropriate machine room lifting plan. The final method utilized a jacking grillage system supported directly on the bottom chords of the previously erected lift span (See Figure 19 and Figure 20)

Figure 19 – Machine Room prior to installation, Jacking Grillage installed on Lift Span

Figure 20 – Jacking Grillage for machine room lift, grillage supported by bottom chord of New Lift Span Truss

During lifting operations, because the machine room truss was supporting the full weight of the mechanical systems and was without a top chord, a "temporary" erection top chord had to be installed on the machine room truss. The "temporary" top chord had to be stiff enough to maintain the machine room truss' geometry, allow for in-the-field adjustments to geometry, as well as not interfere with the permanent machine room top chord (the end floor beams). A "temporary" top chord consisting of bar plate and two end 2.5" diameter turn buckles was used.

Figure 21 – Machine Room Truss "Temporary" Top Chord utilized during machine room lift

Figure 22 – Machine Room fully installed

NEW TRUSS INSTALLATION AND CONSTRUCTION

NEW FIXED SPAN FLOAT-IN PROCEDURES – The first new truss spans installed were the South and North 300-ft fixed spans (installed in January and March of 2013 respectively). The float-ins took places during slack tide when the current on the river was changing direction. These short durations in the tide cycles allowed the barge to be transported and positioned with slower currents. The trusses were installed during varying stages of erection. The first span installed, the South Fixed, was floated in with only a small portion of the vertical lift tower components erected (See Figure 23).

Figure 23- New South Fixed Span en route to bridge site

Much of the falsework tower system used for the new span float-ins was reused from the existing lift span float-out. As mentioned in the Existing Bridge Removal section of this paper, falsework tower system, capable of +/-20-ft of self adjustment, had already been designed for the approximate 2,300-2,700 kip float-in weight of the new truss spans. Several minor adjustments had to be made to the falsework tower system, including increasing the size of the underslung beams (those in direct support of the truss, spanning the falsework lift towers) and increasing the area and thickness of the timber crane mat "sandbox" system used to support the falsework towers system.

The major adjustment made to the falsework tower system was a result of the increased width of the new bridge trusses (49'-6" chord-to-chord) versus the existing trusses (31'-8" chord-to-chord). With only a single 72-ft wide barge for support, it became readily apparent that because of the clearance issues of the "sandbox" support system, the falsework towers were going to need to cantilever off the end of the sandbox supports (See Figure 24). The (4) 24" Pile "Jacking Corners" were now supported directly by heavy W36 grillage beams oriented perpendicular to the length of the truss. The W36 grillage beams were directly supported by the timber crane mats resting on the "sand" box supports.

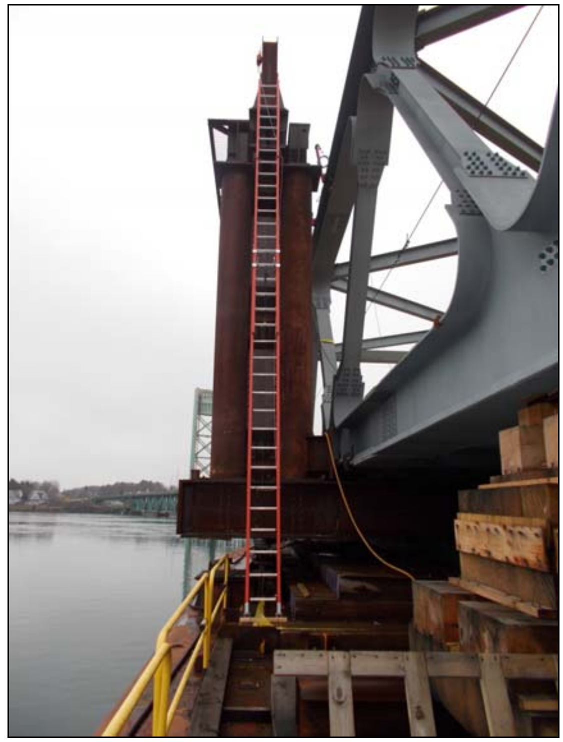

Figure 24 – New Truss installation grillage, jacking corner cantilevered off "sandbox" supports

Figure 25 – South Fixed Span Truss rotated into position to set down on permanent bearings

LIFT TOWER CONSTRUCTION – The completed Lift Towers would provide 150-ft of clearance above high tide while the lift span was raised. The construction of these towers began immediately after the fixed span trusses were installed. The towers were stick built using cranes to move the tower segments into position (See Figure 26). The vast majority of the splices were field bolted by hand. The iron workers, performing the splice connections, utilized "tower-float" access platforms that were connected directly to the falsework tower member being spliced (See Figure 27).

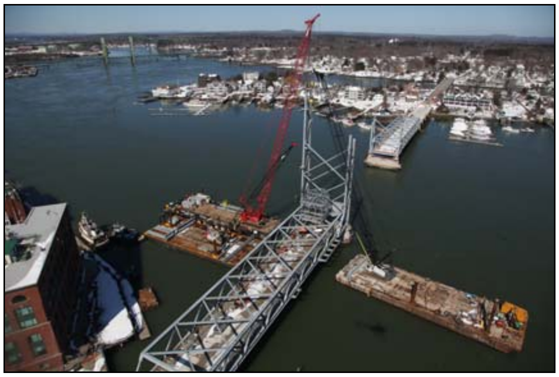

Figure 26 – Lift tower construction of South Fixed Span

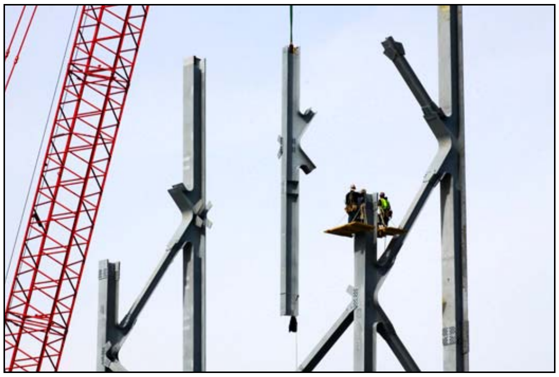

Figure 27 – Iron Workers on "Tower-Float" access structures connected to lift tower

The lift towers were outfitted with a "Push-pull Jacking" system installed at a lower splice of both tower back legs. The "Push-pull Jacking" system was bolted to the tower legs and would accommodate up to +/-¾" of adjustment as required to plumb the lift towers once the 11'-2" diameter sheaves (see Figure 28) and 1,250 kip CTWTs were installed. The bolt holes for the final splices (at the "Push-Pull Jacking" locations) were field drilled once tower alignment was satisfied and the "Push-Pull Jacking" system was removed.

Figure 28 – Installation of 11'-2" Diameter Lift Tower Sheave

CTWT CONSTRUCTION – The concrete CTWTs were constructed on falsework towers located directly below the permanent CTWT alignment and supported by the installed fixed spans. Construction of the 1,250 kip CTWT began immediately following the spans installation and even before the bridge deck had been poured (See Figure 29).

Figure 29 – New CTWT constructed on installed fixed span

The CTWTs were built directly below their final position. They were hung in place with (4) 180-Tonne strand jacks supported directly by the upper lift tower framing (See Figure 30 and Figure 31) and filled with concrete and steel before they were hoisted to the top of the towers. Once the CTWTs were supported by the lift towers, Genesis Structures and Archer Western worked closely to compare tower alignment survey data with anticipated design models. All required final tower adjustments was a coordinated effort between Genesis Structures, HNTB and Archer Western.

Figure 30 – Strand Jacks Supported by upper lift tower framing

Figure 31 – CTWT in final lifted position, supported by strand jacks

LIFT SPAN FLOAT-IN – The 300-ft Lift Span was floated in June of 2013. The lift span installation occurred once the lift towers had been fully erected and the CTWTs were lifted into position and supported by the strand jacks. With the machine rooms installed and the lightweight concrete deck poured, the lift span weighed a total of 2,500 kips during float-in.

Figure 32 – New Lift Span installed prior to being released by float-in barges

Once floated in, the new lift span truss was placed on load cells to measure the final truss weight to confirm balance with the CTWTs. All final balance and tower alignment adjustments were again a collaborative effort between Genesis Structures, HNTB and Archer Western.

Figure 33 – Adjustments to lift tower continued after lift span balanced and installed

CONCLUSIONS

The $90 million dollar Memorial Bridge replacement was successfully accomplished in the projects initial 18-month schedule and opened in August 8th of 2013. The Archer Western crews had to work at times 20-hrs a week 7-days a week to ensure this aggressive schedule was met. The schedule was able to be met due to several integral components of the both the bridge's design and methods of construction and erection, which included:

- Minimized bolting required with "Gusset-Free" truss allowed for shorter time of erection
- Reuse of Existing Piers saved time required for complete demolition and eliminated the need for costly cofferdams.
- Truss erection on barges allowed for float-in installation of new trusses, erection of vertical lift towers and erection of subsequent trusses span to occur both rapidly and efficiently

The existing 1923, Memorial Bridge was an innovative feat in its day. With the exception of the deterioration due to salt water expose, the lift span could still be in use today. The new bridge structure aimed to continue this trend of innovation while maintaining the look and feel of the original structure. The "Gusset-Free" truss design proved its merit in both the design build and ABC fields. The "Gusset-Free" concept is one that is anticipated to be utilized again for its advantages both in fabrication and for its anticipated advantages in ease of maintenance.

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Memorial Bridge Project Website