HEAVY MOVABLE STRUCTURES, INC.
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THE SARAH MILDRED LONG BRIDGE REPLACEMENT PROJECT

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MARRIOTT'S RENAISSANCE HOTEL AT SEAWORLD
ORLANDO, FLORIDA

Introduction

The Sarah Mildred Long (SML) Bridge Replacement Project is a joint venture between the Maine and New Hampshire Departments of Transportation, with Maine DOT serving as the lead.

The original SML Bridge, built in 1940, provides a regional road and single-track freight rail link between Maine and New Hampshire and is the critical backup route in case of disruption on the Interstate 95 Bridge. SML carries crucial commercial traffic along the US Route 1 Bypass including movement of people and goods to the Navy Shipyard in Kittery.

The design of the new bridge was performed by the Joint Venture Team of Figg (Approach Spans) and Hardesty & Hanover (Lift Bridge). A unique aspect of this project is the design phase utilized the CM/GC (Construction Manager/General Contractor) process during the design phase. Cianbro was the selected contractor for the CM/GC and construction phases. The CM/GC design process began in late 2012 and was completed September 2014. Construction started in the winter of 2014/2015 and was completed in early 2018.

Figure 1 – Original 1940 Dual Level Bridge: Upper Level Roadway, Lower Level Rail

The SML Bridge carries vehicular, pedestrian and freight rail. The design of the lift bridge incorporates many innovations in lift bridge technology.

Lift Bridge Concept Development

Development of the concept for the new vertical lift bridge crossing involved interaction between the local communities and the CM/GC team; through a series of Public Design Workshops. These workshops identified community preferences for bridge aesthetics. the workshops also helped galvanize the community’s acceptance of the design.

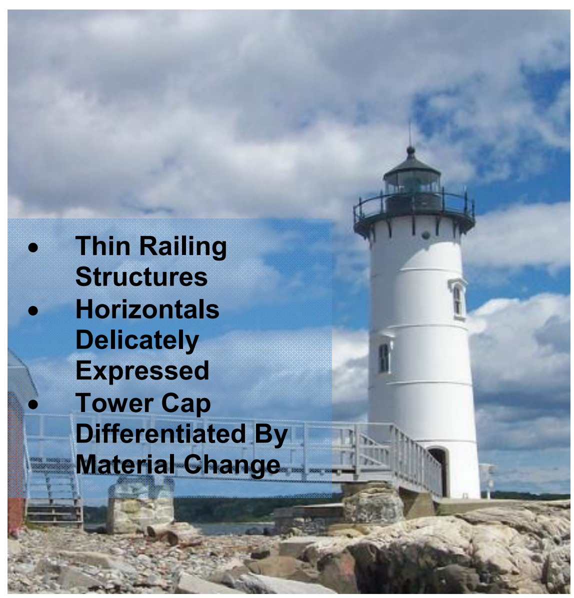


Figure 2 – Traditional Maine Lighthouse Features Used For Tower Architecture

Several popular themes established during the workshops for the new bridge included:

- Simplicity
- Working Waterway
- Modern Maritime
- Piscataqua

The lift span structure type designed for this site has a sleek structural steel box girder superstructure supported by four attractive context sensitive towers that meet desired project themes for simplicity and modern maritime. Lighthouses are a historic tie to working waterways in New England. We used features of Maine Lighthouses in the new bridges towers (Figure 2).

Local relevance to modern maritime- and Piscataqua-region themes was drawn on to style the towers that are the most prominent feature of a lift bridge. The decision to expose the main counterweight sheave at the top of each tower was based on the sailing aesthetic of a Halyard Lock for atop sailboat masts. Local architectural elements drawn from lighthouses and textures and proportions drawn from local structures were utilized to articulate the scale of the towers. Figure 3 shows an early tower concept and Figure 4 a revised tower cross-section with an internal stairwell that improved the structural rigidity and overall scale of the towers.

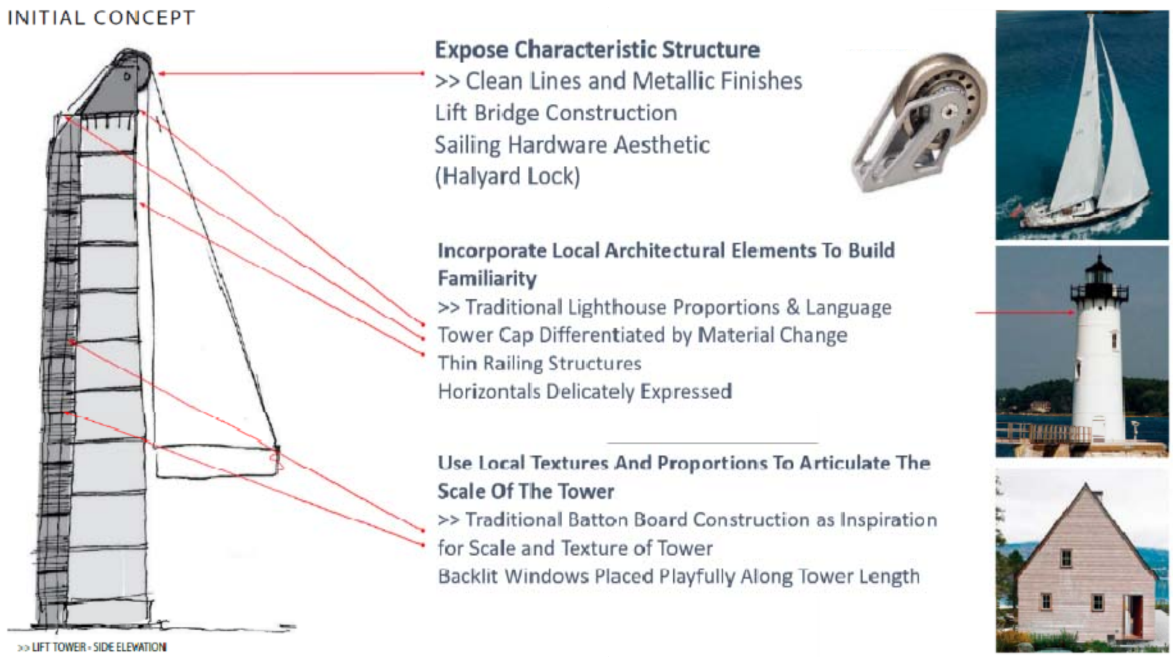


Figure 3 – Early Tower Concept

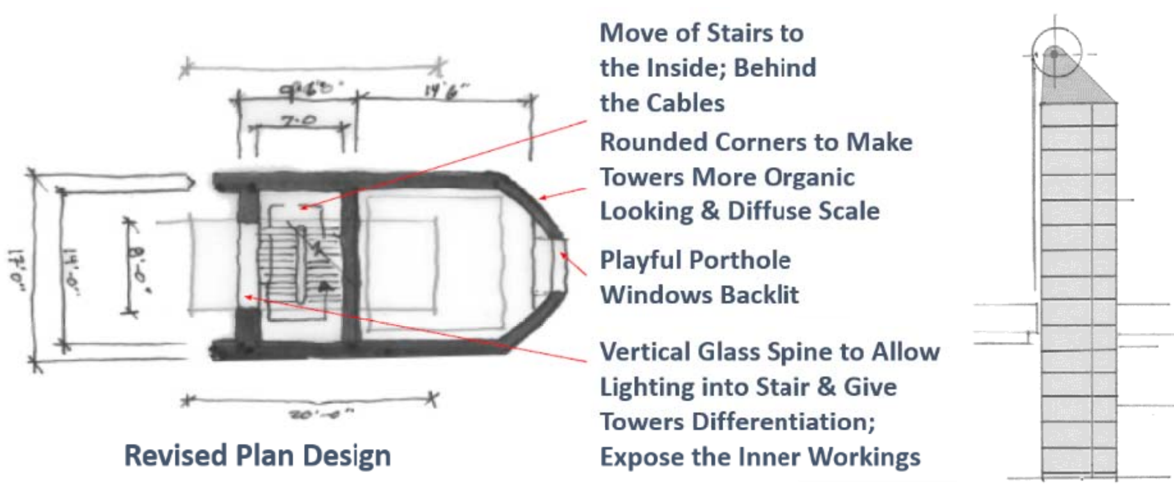


Figure 4 – Revised Tower Cross Section And Elevation

The four supporting towers incorporate many innovative and attractive features. A tower is positioned at each of the four corners to the lift span, without any cross members. This provides an open and slender view of the structure (Figure 5).

Exposing the counterweight and operating sheaves at the tower tops became an important architectural theme for a lift bridge in New England (Figure 6).

Figure 5 – Photo of Completed Bridge

Figure 6 – Open Tower Top

Overview Of Key Features

The original Sarah Long Bridge was a bi-level bridge with a two-lane roadway on the upper level and a single-track freight rail line on the lower level. Stacking the vehicular bridge over the railroad bridge was found to be the most economical solution, it was used for the approach spans to the vertical lift (Figure 7).

Figure 7 – Dual Level Approach Spans

An innovative concept of incorporating both the road and rail on the same level was used for the lift span to mate with the dual level approach spans (Figure 8). The rail track is embedded in the median to minimize the width of the bridge.

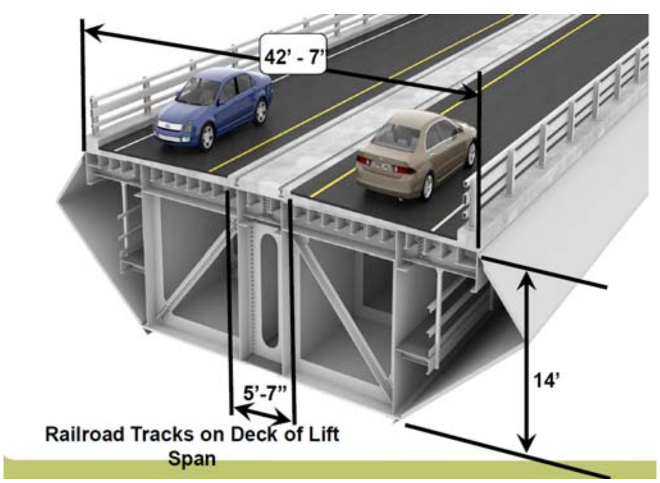


Figure 8 – Lift Span Cross Section

The result is additional clearance under the lift span while in the normal vehicular operations position (Figure 9). This eliminates extra structure below the vehicular lift span and supports a separate rail line and therefore provides increased navigational clearance during normal operations. As such, the new lift span has fewer lift span operational bridge closures. In the fully raised position, the bridge provides 135-ft vertical clearance (Figure 10). The lift span is simply lowered down to match up with the railroad bridge approach when the trains are traveling across the river (Figure 11).

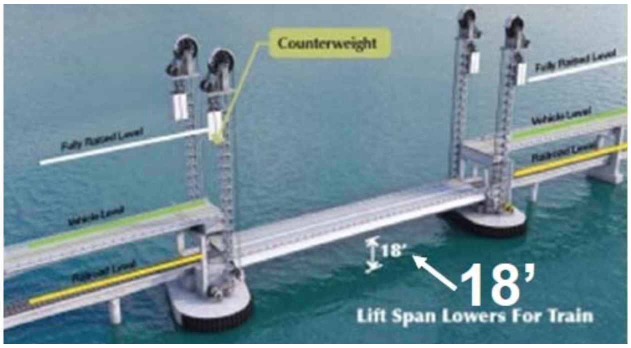


Figure 9 – Lift Span In Roadway Position

Figure 10 – Lift Span In Raised Position

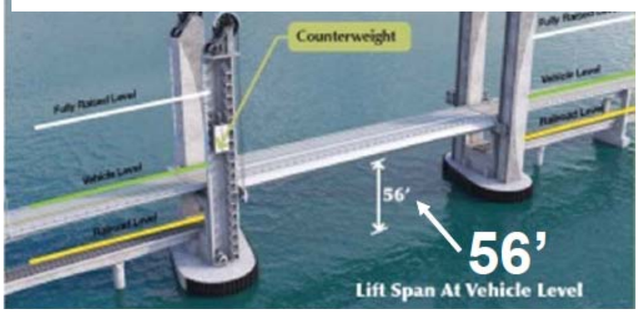
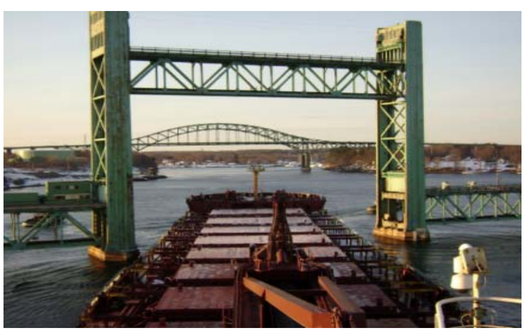


Figure 11 – Lift Span In Rail Position

To improve navigational safety through the bridge, a span length of 300-ft was chosen (Figure 13) which provides a 250-ft channel compared to the original 175-ft channel (Figure 12). It allows the largest vessel clearance when vessels are guided by tugboats (Figure 14).



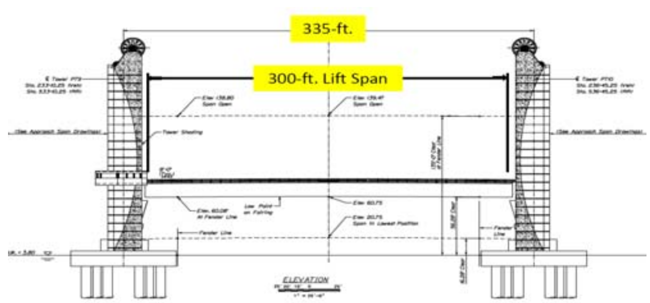


Figure 12 – Existing Lift Span 175-Ft Channel

Figure 13 – New Lift Span Elevation

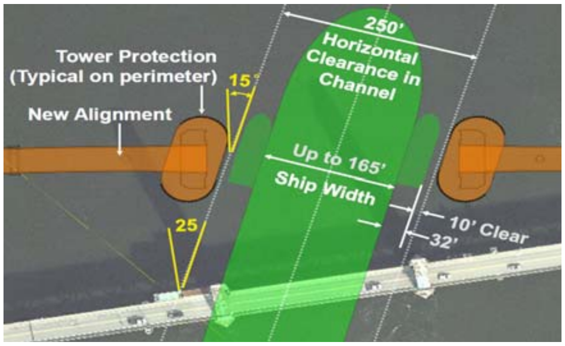


Figure 14 – Increased Channel Width For Largest Vessels

The lift bridge quality is enhanced by predominately fabricating the lift span steel box girders in a controlled off-site plant and by utilizing precast concrete tower segments.

A twin box girder design with a continuous top plate was employed for the lift span superstructure to facilitate shipping to the site by truck from inland fabricators (Figure 15). This allowed the final configuration of the lift span to be assembled on site (Figure 16), with low-cost local labor, reducing the construction schedule and planned existing bridge closure; therefore, adding economy to the project.

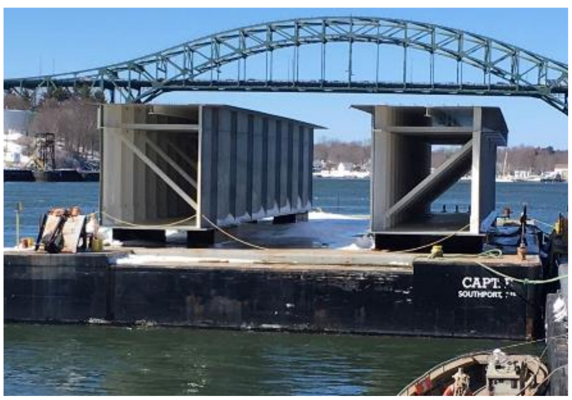


Figure 15 – Steel Tub Girders Trucked/ Barged To Site

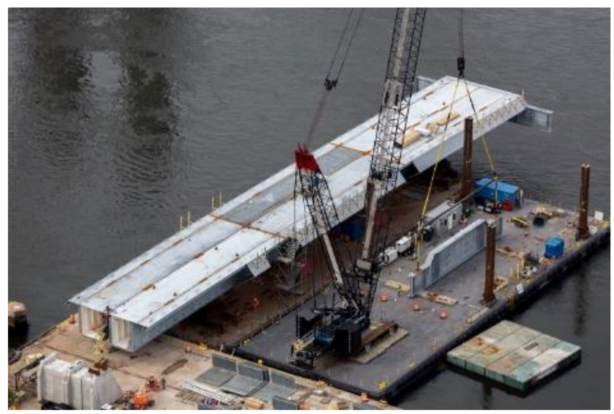


Figure 16 – Final Lift Span Assembly At Site

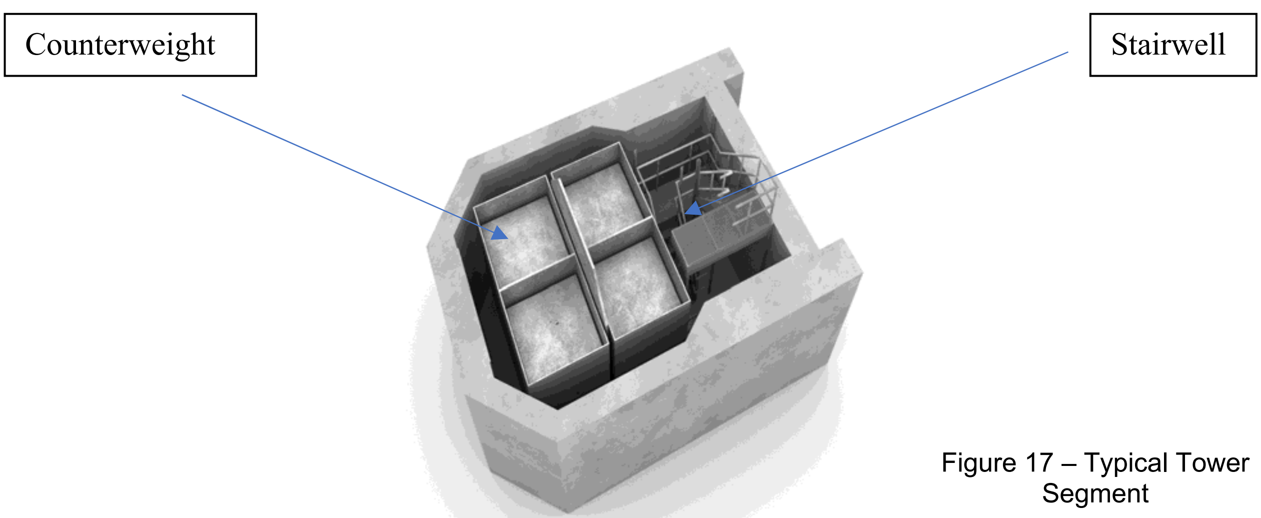


Figure 17 – Typical Tower Segment

The lift span superstructure was topped with a concrete deck and wearing surface. A metalizing finish was installed on the structural steel which represents the most durable protection for structural steel bridge members in the industry. The four towers are closed concrete structures that are constructed with precast concrete segments, post-tensioned together. To our knowledge, this is the first utilization of segmental concrete construction for lift span towers. The tower section is a closed box that is structurally rigid, requiring no external bracing (Figure 17).

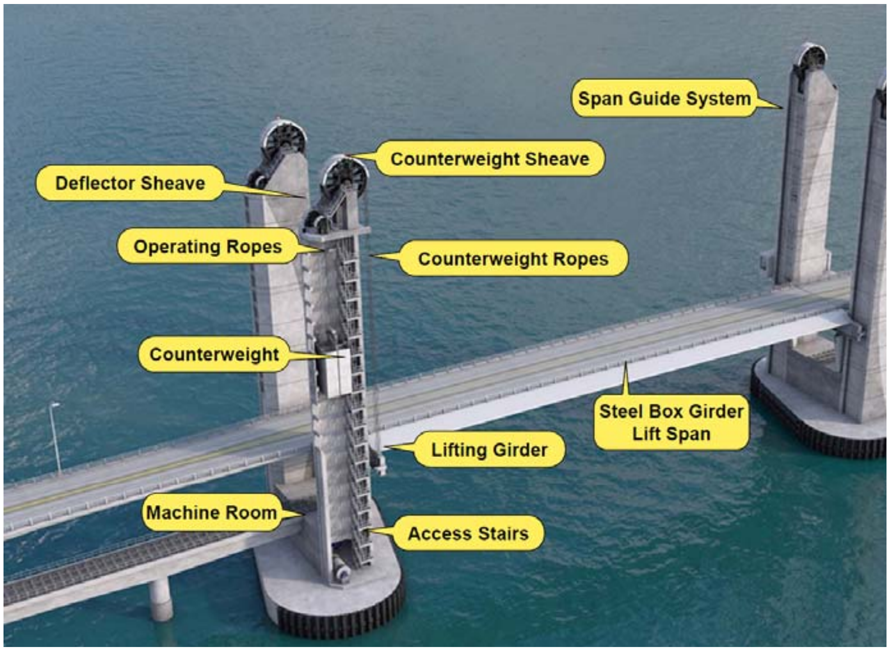


Figure 18 – Exploded View Of Tower

Often lift towers are comprised of an open framework that is exposed internally to the weather conditions. The closed towers offer the advantage of protecting the counterweight and ropes. Stairs used for access are also inside the towers to provide a controlled condition for access by operators between the control, mechanical and electrical rooms (Figure 18).

The mechanism for lifting and lowering the span is generally comprised of two parts. First, the lift span is balanced by a counterweight. The counterweight and lift span are connected with steel counterweight ropes that travel over a rotating sheave at the top of the tower. A second system of ropes is used for span lifts. These ropes are connected between the operating machinery (rotating drums) and counterweights. One pair of ropes travels from the drum up over a secondary sheave at the top of the tower and back down to the top of counterweight. A second set of ropes are connected between the drum and bottom of the counterweights (Figure 19). The ropes are reeved on the drum so as one set pays out, and the other set is wound on the drum. The span is raised or lowered by pulling on the bottom or top of the counterweights.

Placing the operating machinery at the base of the tower is an innovation that is recent to the movable bridge industry. By locating the lifting machinery, mechanical systems and electrical systems lower in the tower, all this equipment was installed before completing tower erection and lift span float-in. This provides for quicker construction, reducing initial costs and providing easier access for future maintenance.

The electrical systems employed for the span drives incorporate state-of-the-art flux vector drives with AC variable frequency motors.

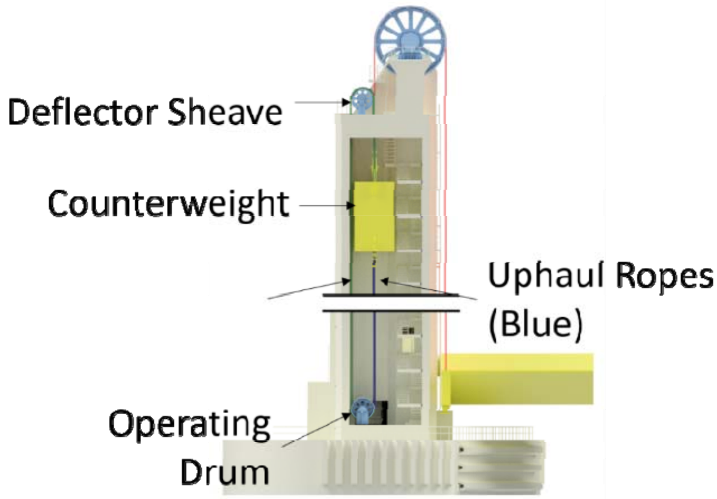


Figure 19 – Modified Tower Drive

Two 125-hp motors power the bridge during lifts. The drives provide precise control of span movements with proven reliability. Full redundancy was employed in the electrical systems. A separate system is used to measure span movements to ensure the span does not skew during operation.

Control of the bridge is performed in a control room that is placed to provide maximum visibility to the navigable channel and roadway (Figure 20). To facilitate construction, the control room was fabricated from precast concrete and cantilevered off the tower segments using post-tensioned connections.

Figure 20 – Cantilevered Control Room

To further improve safety, a complete CCTV system was employed to provide the operator with complete visual site lines and eliminate any blind spots.

CM/GC Leads To Innovations/Cost Savings

The CM/CG (Construction Manager/General Contractor) process was employed for delivery of contract design documents. In addition to the consultant design team, an experienced contractor and an independent cost estimator were chosen to work with the owner and design consultants during the design phase. The following process was followed:

- Designer is selected by traditional process (FIGG/H&H JV Selected September 2012)
- CM/GC Contractor is selected by RFP process, scored on qualifications and price component (Cianbro Corp. Selected January 2013)
- Owner also issues RFP for Independent Cost Estimator (ICE) (HDR Engineering Selected February 2013)
- Cianbro selected as General Contractor December 2014

The CM/GC process varies from standard design-bid-build delivery as follows:

- CM provides Constructability Reviews
- CM Provides Construction Schedules
- CM & ICE Provide Cost Estimates at Incremental Design Completion Phases
- Owner and CM work on negotiating a Construction Contract
    - Agree on price – CM becomes GC
    - Cannot agree – Owner advertises for competitive bid

Following selections, the CM/GC team met for week long workshops each month during the design phase.

With CM/GC, the design team got immediate feedback related to cost and constructability for design concepts and details throughout the design phase. This led to design refinements that reduced construction costs and improved the schedule.

One example where the CM/GC process had an impact was the design of the towers. Initial discussions with the team pushed the design of the towers toward cast-in-place construction using self-climbing formwork.
As design approached the 60% level, an excellent site for casting segments adjacent to the bridge became available. This made precast construction a viable option. We immediately developed a precast segmental tower alternative that was included in our 60% submission. Both options were priced by the CM and ICE, and the precast option was selected as the preferred alternative.

Advantages using precast segmental concrete construction include:

- Better Quality Control
- Speeds Construction
- Lowers Cost

Steel forms were utilized for the tower segments. The walls of the forms were spread using hydraulic cylinders. This allowed for a quick turnaround. The steel forms ensured dimensional stability. Tower segments were match cast (Figures 21).

Figure 21 – Tower Segment Form

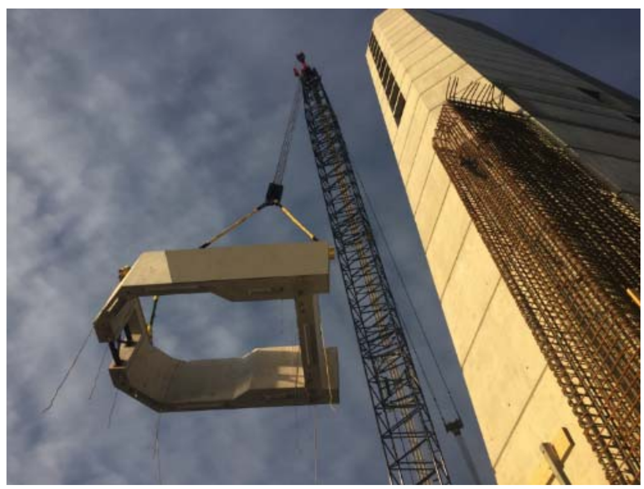


Figure 22 – Placement Of Tower Segment

The tower segment depth of 8-feet was established to keep segments under a 100-ton crane pick limit (Figure 22). Individual units were tied together with PT bars for construction. The contractor's erection procedure called for continuous adjustments between segments with shims to achieve required verticality. Tolerances were set based on permissible adjustments in the span and counterweight guide systems. After all segments were placed, the towers were post-tensioned together with tendons that run continuously from the tower top down into the pile cap and back up to the tower top. Jacking of tendons was done at the tower tops (Figure 23).

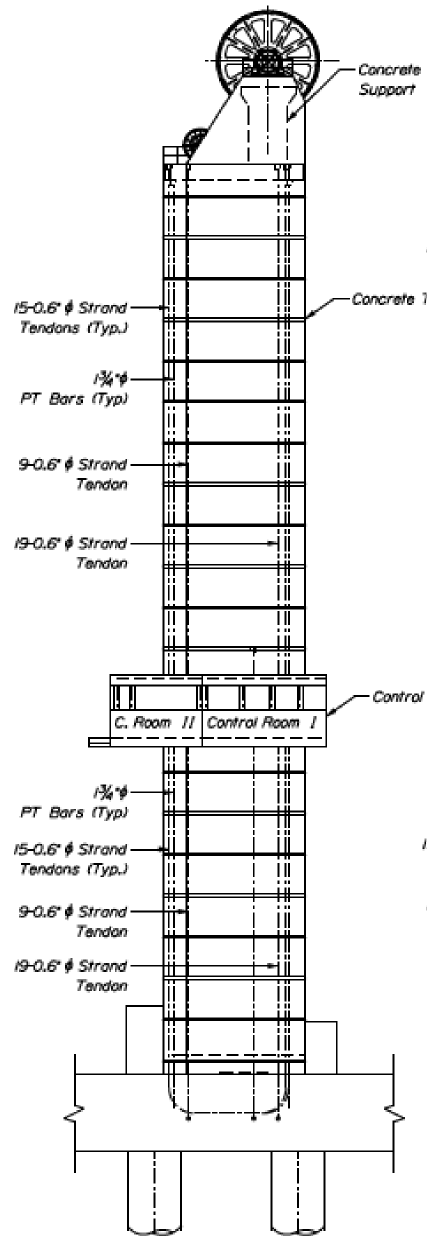


Figure 23 – Lift Span Tower Constructed Using Post Tensioned Precast Segmental Concrete

Another example where the CM/GC process had an impact was the design of the lift span.

Feedback from inland fabricators led us to come up with a design that would allow fabrication of the boxes at inland facilities. The individual boxes could then be trucked to a barge near the site for final fabrication (Figure 15). When fabrication costs were compared between the two alternatives, the multi-box girder design reduced fabrication costs significantly.

The lift span girder is a multi-box steel structure with a composite concrete deck. The primary longitudinal load-carrying members include two main boxes with separate bottom flanges, two fascia box beams, and a composite concrete deck (Figure 24). The use of a composite deck eliminated fatigue-prone orthotropic details. Deck plate details in the longitudinal direction were not a fatigue concern as the flange always remains in compression.

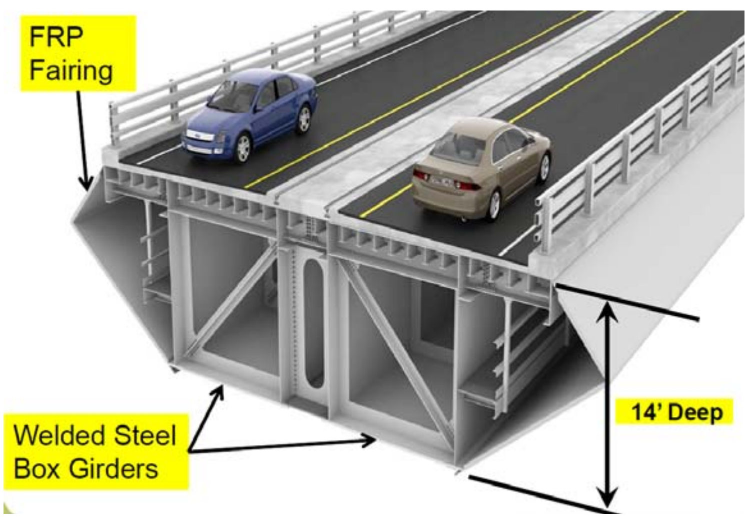


Figure 24 – Revised Lift Span Superstructure With Multi Steel Box Girders And FRP Fairing

The aero shape of the orthotropic box was maintained by use of FRP fairings. Besides reducing wind forces on the span during lifts, the FRP fairings protect the steel fascia from salt-laden runoff.
The main boxes were aligned such that the interior webs are located directly below each rail track. The track was embedded within the concrete deck, with minimal cover to the top of steel, and a direct load path into the box section webs. In addition to providing a predictable load path, this alignment eliminated the need for supplemental track support structures and ultimately reduced the span weight.

The lift span superstructure was designed to support both vehicular and rail live loads. The structure was designed according to the requirements of the AASHTO LRFD Bridge Design Specifications, AASHTO LRFD Movable Highway Bridge Design Guidelines, AREMA Manual for Railway Engineering (ASD) Specifications, and the Maine Department of Transportation Bridge Design Guide. The design highway liveload is HL-93 with 25% increase in Truck Axle Weight per the Maine Department of Transportation Bridge Design Manual, Section 3.2. The design railway liveload is a specific U.S. Navy train configuration, including a 12-axle special hauling car, KRL 370350, with a maximum axle force of 72 kips (Figure 25). The span was also evaluated for the Cooper E-80 loads identified in the AREMA Manual for Railway Engineering.

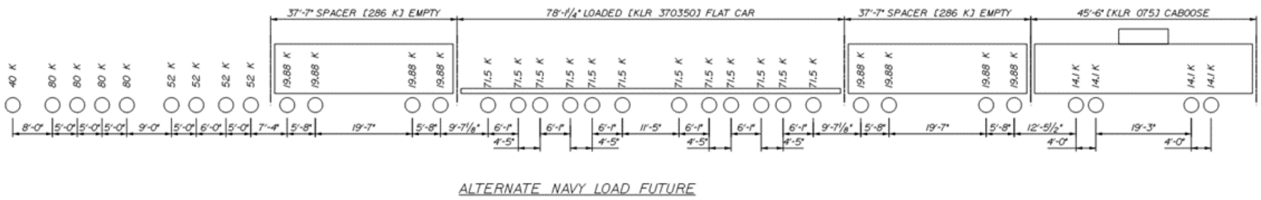


Figure 25 - Specified Rail Load

Design For Vessel Collision

Design for vessel collision was complicated by the size of the vessels that use the channel and the lack of suitable overburden over bedrock at the river bed.

The design vessel (Figure 26) gross tonnage is 40,000 tonnes. For a design vessel speed of four knots, the vessel impact force is 12,000 kips.

Figure 26 - Design Vessel Harmon Oldendorf

Protecting a vertical lift bridge from substantial vessel impacts is usually accomplished with large fender systems employing cellular cofferdams at the noses of the lift piers along with a pile bent along the face of the pier. However, due to the lack of overburden, cellular cofferdams and bents required drilled shafts to tie them to bedrock. This was the main reason drilled shafts were utilized for the piers themselves.
The use of drilled shafts for a separate fender system drove the entire project over budget. As an alternative to a separate fender system, the pier was designed to resist the vessel impact.
Two load cases were established for an extreme event and one for an operating event.

As per AASHTO specifications, the extreme event was designed for survivability. For this case, AASHTO specifies that substructure elements must not be damaged (linear behavior) and limits of damage to superstructure elements must be established by the owner. For superstructure and machinery elements it was decided that some damage would be acceptable (bearings, guides, etc.). Since the towers themselves could not be easily repaired, they were designed for linear behavior. The design for the lift span piers is a conventional drilled shaft foundation (socketed to rock) with a tidal zone concrete cap. Since the pier (drilled shafts and pile cap) and towers are essentially one structure, they were analyzed in one complete model. A non-linear time-history methodology was employed. Various time histories were developed for the 12,000-kip design force (Figure 27). This approach was adopted because we saw the similarity of the vessel impact scenario to a large scale seismic event. Exhibits varied large lateral forces over time.

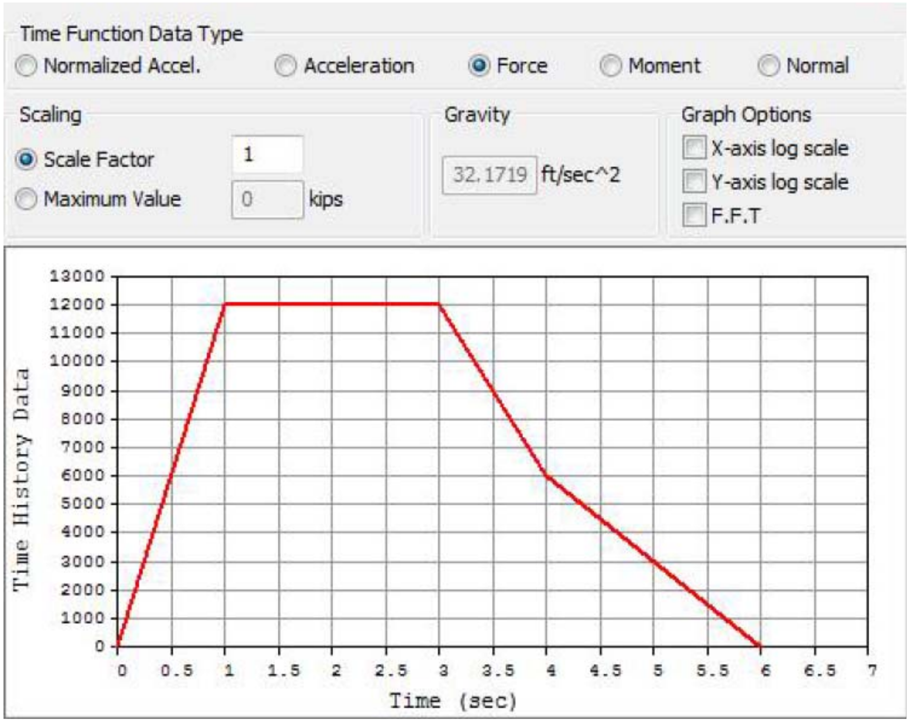


Figure 27 – Time History For Vessel Impact

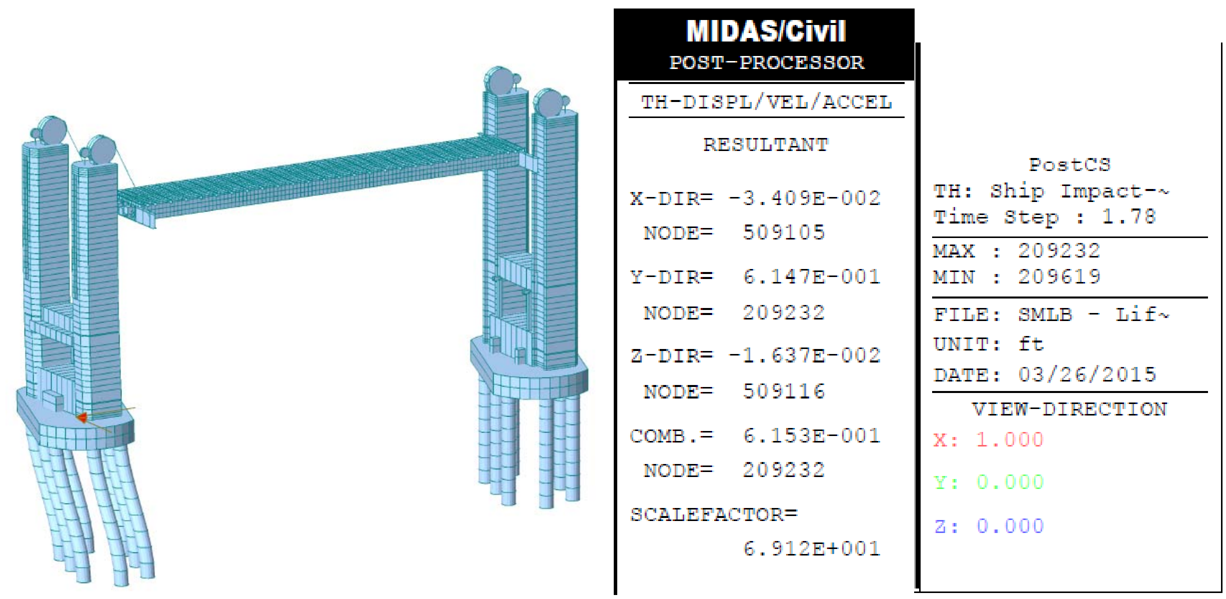


Figure 28 – Midas Model For Vessel Impact

The final pier configuration (Figure 29) shows that six 10-foot drilled shafts were required to resist the vessel impact.

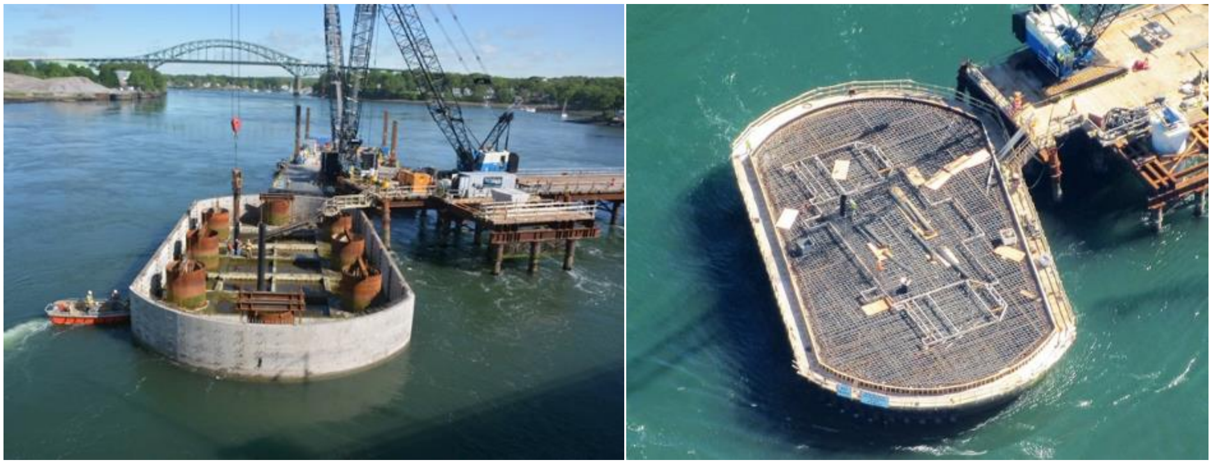


Figure 29 – Lift Span Pier

The model also led to changes in tower reinforcement and connections. Most notable change included the addition of ties typically employed in high seismicity regions.

Summary

In all, this project is an example of how cooperation between owners, designers, a contractor and stakeholders leads to innovation and cost savings in bridge design. We set out to design a bridge that would:

- Unite local communities of Maine & New Hampshire
- Develop signature bridge architecture
- Improve navigation through bridge
- Improve traffic flow (reduce bridge openings)
- Provide a vital rail link to the Naval Facility in Kittery
- Address vessel collision
- Provide a reliable and low maintenance structure
- Minimize Impacts
    - Historic Resources
    - Essential Fish Habitat & Endangered Species
    - Local Business & Traveling Public
- Manage Project Risk
    - River Currents & Foundation Obstructions
- Meet Budget Goal

These project goals were met with a bridge that will serve the region for the next century.