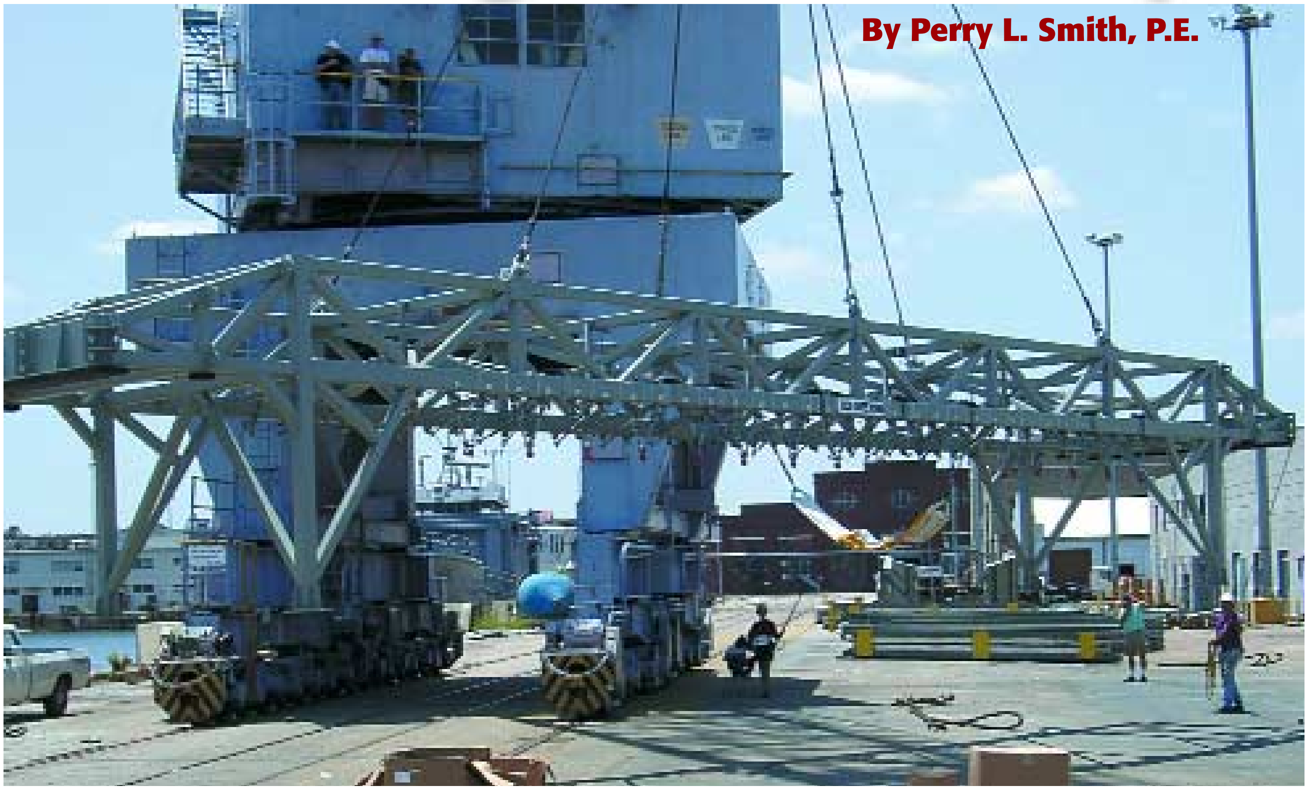
Raising the Hunley

By Perry L. Smith, P.E.



On August 8, 2000, Oceaneering International, Inc., a marine operations company, successfully recovered the H.L. Hunley, a Confederate States submarine used during the Civil War. Hunley and her crew of nine mysteriously disappeared during the night of February 17, 1864, after it delivered an explosive charge to the union ship Housatonic, a blockade-runner with a crew of 150. The Housatonic sank within five minutes of being hit and took the lives of five crewmen with it. The South used the Hunley as an attempt to end the union ship blockade of Charleston Harbor in Charleston, SC. Hunley became the first ever submarine to sink an enemy ship during warfare.

Friends of the Hunley (a non-profit organization responsible for the recovery and preservation of the Hunley) contracted Oceaneering to recover the approximately 40′ long and four ft., three in. diameter wrought iron submarine from its resting place in 35′ of water in the Atlantic Ocean five miles off the coast of Sullivans Island near Charleston, SC. Project Manager for the recovery project was Steve Wright from Oceaneering's Maryland Division. Ken Edwards from Oceaneering's Americas region in Louisiana was responsible for all diving operations.

Oceaneering's recovery method consisted of two 18′ diameter foundation suction piles and a 63′ span steel truss. Nylon slings, suspended from the truss, acted as a cradle to provide continuous support for the Hunley during recovery and transport. A jack-up rig, positioned alongside the Hunley, set the piles and truss and made the lift to recover the sub. Oceaneering transported the sub in the truss to the former Charleston Naval Base at the Lasch Conservation Center, where it is to be conserved in a 75,000-gallon, steel chiller tank designed by Oceaneering. The sub will remain in the tank for up to a year while the bodies of the nine crewmen inside are recovered.

Recovery Operations Plan

The general arrangement plan to recover the Hunley consisted of a 63′ long span steel truss supported by two 18′ diameter steel suction piles located fore and aft of the submarine. The truss utilized 32-12″ wide nylon slings attached to the bottom chords on the port and starboard sides. The slings were attached to the port side of the truss, slipped under the sub and terminated on the starboard side.

Since the Hunley was buried three feet beneath the ocean floor, 25,000 cubic ft. or 1,200 tons of sand and clay had to be removed by Oceaneering divers using dredges and high pressure jetting nozzles before the suction piles and truss could be placed. Existing sediment was left undisturbed around the haunches of the Hunley to provide continuous support until the suction piles and truss were placed. The diving operations that removed the sediment took less than four weeks working typical offshore 12 hour shifts seven days a week.

The suction piles designed by Delmar, Inc., weighed 85,000 lbs. each. The jack-up rig's 330-ton pedestal crane placed the piles. A submersible pump placed on top of the piles with 6x4-jet pumps topside suctioned the piles down to the required elevation. Divers on the bottom guided the piles into the desired location as flooding valves left open on top of the piles allowed air to vent. Suction operations began after both piles were placed at the required position. The piles own weight created a seal in the mud around the 12′ long pile skirt. The water was evacuated from inside the pile using the jet pump tied into to the submersible pump on the pile.

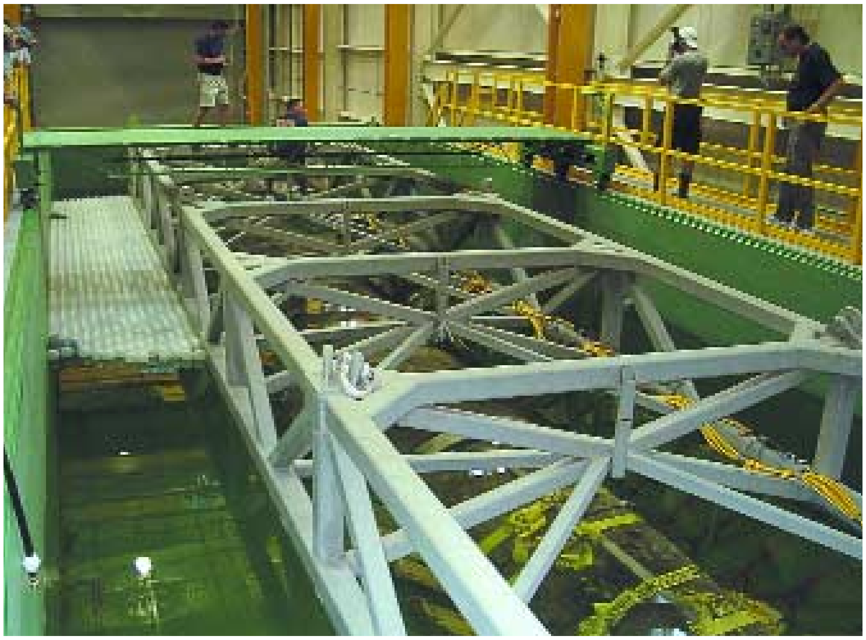
Due to the relatively shallow depth of 35 fsw, a large pile cap area was required to provide enough force to penetrate the pile 12′ into the ocean floor. The pile began penetrating as water was being evacuated from inside the pile. Topside personnel operating the pumps as divers directed operations on the bottom controlled penetration of the piles. The tops of the piles were suctioned down at the same elevation as the bottom of the submarine. The same procedure was reversed when removing the piles after the truss and Hunley were recovered.

After the piles were placed, the truss was lowered to bear on top of the 4′-6″ tall adjustable caisson tower tables bolted to the top of the piles. The caisson tower tables, designed by Oceaneering, enabled divers to adjust the horizontal and vertical position of the truss in the event pile placement was off. The truss was then positioned parallel and above the Hunley. The final removal of sediment around the Hunley's haunches and the installation of the slings under the sub took 11 days.

To effectively monitor the load transfer of the sub from the soil to the slings, load cells were installed on each sling on the starboard side of the truss. It was necessary to calculate the load for each sling due to the non-prismatic shape of the sub. Personnel monitored a computer topside as the divers adjusted the tension in each sling ensuring a smooth load transition from the soil to the slings and that each sling

Hunley sub being lifted out of the ocean.

Hunley sub on dry land, cradled in by support slings.



The Hunley sub submerged in a tank of chilled water for preservation.

carried the proper load. Only enough sediment was removed around the sub to install three slings at a time.

The truss supporting the Hunley was recovered using the jack-up rig's 330-ton crane. The truss and sub were placed on a materials barge, secured to the deck and towed by two tugs into Pier Juliet at the former Charleston Naval Base. From the pier, a 200-ton rail gantry crane transported the sub approximately 200 yards to the conservation lab.

Truss Design

Several factors influenced the design of the truss. The truss had to be accessible enough for divers to work efficiently and continuously for the jetting and sling operations. It had to be light enough for the two 20 ton bridge cranes already purchased and in place in the new conservation lab. In addition, the structure had to perform dual roles as a long span truss in the water and as a braced frame when supporting the Hunley topside.

Due to the corrosive environments of seawater and the chiller tank, an all welded structure was required. For ease in fabrication, welding and rigging points for the divers, hollow structural sections were chosen using ASTM A500 Grade B steel.

The top chord plan of the truss would have vierendeel panel openings making it easier for diver access during recovery operations. The bottom chord plan utilized HSS 3x3x$\frac{1}{4}$ chevron braces tied into the lateral HSS 4x4x$\frac{1}{4}$ X-braces and the HSS 8x6x$\frac{1}{2}$ bottom chords. The HSS 3x3 braces served two purposes: to take lateral forces (due to current, wind and vessel motion) and react against the slings horizontal force component due to the gravity load of the Hunley. The HSS 3x3 members were in compression at all times. In addition to axial load, the bottom chord members were also in bending and torsion due to sling placement between truss panel points and eccentricity of the padeyes located on the inside face of the bottom chords.

The truss, modeled as a pinned/roller structure when supported by the piles in the water, transformed into a braced frame after the sub and truss were recovered and sitting on the deck of the barge. Chain and ratchet chain binders secured both ends of the truss to the caisson tower tables during underwater operations. Since it was possible for differential settlement of the piles to occur because of eccentric loads from the truss, it was important that at least one end of the truss behaved as a roller to prevent high bottom chord forces and unnecessary lateral thrust. This made it easier and safer for the divers when releasing the truss from the caisson tower tables.

The truss required removable end bearing seats due to length restrictions for the chiller tank in the lab. The 6′-6″ bearing seats would be burned off topside during transit to the pier. Sacrificial weld plates installed in the shop were added so that the braced frame's legs were protected during burning operations. The legs of the frame were braced with K-braces in the lateral direction. K-braces were also added in the longitudinal direction to eliminate any column shear or bending. This also protected the legs from buckling if all four of the legs did not land simultaneously on the deck of the barge due to vessel motion. Total weight of the frame without bearing seats was 17,400 lbs.

Over 20 load combinations were checked which included two knot currents, basic wind speed of 100 mph, vessel movements and dynamic loads from the crane. The truss can withstand 2 g vertically, 0.2 g longitudinally and 0.4 g laterally. Using historical documentation and drawings, the sub was calculated to weigh 58,500 lbs., which included being filled with sediment. The dead load of the sub was approximately 22,500 lbs. Actual weighed of the sub (filled with sediment) upon recovery was 47,700 lbs. The Hunley tapered more than historical documents depicted which resulted in less interior volume fore and aft of the conning towers.

Due to the instability of the sub's structure because of potential rivet loss, the deflection of the truss should be L/500 or less. This requirement would be difficult to meet without adding more weight to the truss. Since the lift through the interface was the most critical load combination, six slings would be used. The center slings would be designed with turnbuckles installed to eliminate the possibility of slack in other slings and reduce the deflection of the truss substantially. The center slings were preset during dry land exercises to ensure that each one would take their calculated share of the load

The truss and chiller tank was designed using LRFD 2nd Edition. In addition, the truss was quickly checked using ASD 9th Edition as a design comparison since the live loads were particularly high and deflection requirements were a significant factor. Deflection of the truss was checked using service loads. The actual maximum deflection of the truss at midspan was approximately 5/8″. Due to the controlling deflection criteria, a small amount of savings was realized using LRFD (approximately 1-1.5%).

Fabrication/Inspection

Oceaneering provided periodic inspection during fabrication. The fabricator, Able Iron Works, Inc. of Charleston, SC, an AISC certified shop and member, worked closely with Oceaneering by providing a fabrication schedule to coordinate inspections. The fabricator was required to have a certified weld inspector on site to sign off on all weld procedures. The contract specifications required all complete penetration weld splices at the top and bottom chords of the truss to be dye penetrant tested per ASTM E165 in compliance with the AWS code.

The truss was coated with Sherwin-Williams Dura Plate 235 epoxy. The specification required an SSPC-10 surface preparation and two coats of the epoxy. The coating needed to be compatible with the electrolyte solution that would be used in the chiller tank during conservation and the salt-water exposure.

The Hunley appears to be in excellent condition despite being submerged in salt water for over 135 years. Although the rivets appear to have corroded substantially, the plates (fabricated from wrought iron) used for the hull of the Hunley are in remarkable condition. For now, the Hunley sits in its new home waiting for archaeologists to unlock further mysteries as to why she sank.

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