ATTACHMENT (2)

H.L. Hunley General Recovery Procedures

Submitted by:
Oceaneering International, Inc.

February 10, 2000

00-106

H.L. Hunley
General Recovery Procedures

Submitted to:

The Hunley Commission

Submitted by:

Oceaneering International, Inc.
501 Prince George's Boulevard
Upper Marlboro, MD 20774

February 10, 2000

Executive Summary

Oceaneering International, Inc. (Oceaneering) developed this recovery procedure for the H.L. Hunley at the request of the Friends of the Hunley, Inc. and he Hunley Commission.

The primary objective of this effort was to develop a detailed plan for the recovery of the Hunley. This plan is based on the Preliminary Study for the Recovery of the Hunley and input from numerous other experts in marine archaeology and engineering. Oceaneering performed a Finite Element Analysis of the hull of the Hunley based on historical information regarding the construction of the hull. Data regarding hull thickness, rivet placement and condition gathered in October was also used in the analysis. This finite element analysis was used to evaluate the proposed recovery method and is provided in Appendix B of this report.

Oceaneering is proposing to recover the Hunley utilizing an all welded steel tube box truss with bolt on bearing seats and a removable sling support system incorporated with load cells for data acquisition. When deployed for recovery, the truss will bear on two rigid cylindrical caissons installed by suction methods. Divers will work to recover the Hunley by excavating 1'-2' at a time and installing the slings to provide for continual support of the vessel. A diving platform utilizing a permanent 4 point mooring system will support the diving operations and may or may not be configured to provide for the lifting requirements of the Hunley, in which case a separate crane barge will be utilized when required. After recovery, the Hunley will be transported to the conservation site at the Naval Shipyard in Building 255 in Charleston Harbor.

The recovery is tentatively scheduled for the May, June, July timeframe. This was based on historical weather data for the area and provides the best tradeoff of calm seas vs. the chance of severe storms.

Table of Contents

List of Figures

List of Tables

H.L. Hunley General Recovery Procedures

1.0 Introduction

The following document describes the recovery operation for the H.L.Hunley. It will detail personnel and equipment mobilization, diving operations, site excavation, recovery truss foundation, recovery truss (frame) placement and rigging details.

2.0 Personnel & Equipment Mobilization

Oceaneering (OII) will mobilize a 21-man dive crew and commercial diving equipment from their Gulf Coast Division located in Morgan City, Louisiana. The dive crew will consist of 10 divers, 8 tenders, 2 supervisors and 1 superintendent for 24-hour operations. Two dive crews will be formed, each working 12-hour shifts (see Table 2-1).

Table 2-1 Dive Personnel – 24 Hr. Ops.

Title	Job Description	No. Personnel
Superintendent	Project Manager	1
Supervisors	Shift Supervisor	2
Divers	Construction Divers	10
Diver-Tenders	Dive & Assist	2
Tenders	Assist Divers	6

A diving platform will be mobilized to the Port of Charleston where operations personnel will load diving equipment, excavation equipment, recovery structures, and recovery materials summarized in Table 2-2 and Table 2-3. The diving platform will transit to the site and utilize a permanent 4 point mooring system for diving operations. The 4-point moor will remain deployed for the duration of the recovery. Should the diving platform need to pull off of the site for weather or other considerations the permanent moor will remain in place, minimizing return time and anchor handling near the site.

Heavy lifting equipment may be located on the diving platform or transited to the site on as needed basis. The major lifting operations will be setting the recovery frame foundation, setting the recovery frame, and recovering the Hunley. The final determination of diving platform and lifting configurations can only be determined at time of reserving these assets, depending on availability.

Table 2-2 Equipment Deck Space

EQUIPMENT	ESTIMATED DECK AREA (Sq. Ft.)	ESTIMATED WEIGHT (Kips)
Diving	1100	25.0
Suction Pile	6000	30.0
Excavation	400	12.0
Recovery	1000	30.0
Hunley	N.A.	≈ 35.0

Table 2-3 Dive Related Equipment

Item	Quantity
* Shallow Air Package	2
Barge Support Package	1
Dive Control Van	1
Deck Decompression Chamber-Double Lock	1
Jetting/Excavation Package	3
Air Tuggers-10 k	3
Pneumatic Tool Package	1
Underwater Burning Package	2
Wet Welding Package-300'	1
Topside Welding/Burning Package	1
Standard Tool Box Package	2
Sluice Box Package	1
Standard Diving Consumable Package	6
Rigging Boxes	4

* Note: Equipment packages include all required supporting gear and related items.

3.0 Diving Operations

A team of archaeologists will be on site fulltime to lend recovery support and consultation to the diving operations. The archaeologists, using their own diving equipment, will team with OII divers during excavation and assist in the rigging of the Hunley to the recovery frame. A team of archaeologists will begin work at the stern, where recovery of the possibly disarticulated stern parts and other artifacts may be necessary. OII divers and archaeologists will start excavation and rigging operations from the bow and work aft.

The recovery effort will be based on a 24-hour operation. Dive operations will normally be 2 OII diver/archaeologist teams in the water simultaneously during excavation and rigging operations. Additional archaeologists may be needed to monitor the orientation of the Hunley in the recovery frame during rigging operations, to determine if any adjustment in the support rigging is required.

4.0 Survey and Site Marking

Prior to the arrival of the diving platform, archaeologists will have completed their pre-recovery site work, and will have marked the bow and stern of the Hunley with survey buoys. These buoys will enable proper positioning of the platform for diving operations. Once moored, dive teams will perform initial inspection dives to verify the position of the Hunley and observe any unusual circumstances prior to recovery. Site conditions will be assessed and discussed with on site archaeologists to determine special requirements during recovery operation.

5.0 Site Preparation

5.1 Excavation Equipment

The excavation system will consist of a large pump to supply pressurized seawater, two sluice boxes to filter the excavated effluence for artifacts, two suction hoses to transport the excavated material to the sluice boxes and two excavation hoses to assist in loosening the seabed matrix. Each dive team will operate a suction hose and excavation hose to excavate the bottom matrix surrounding the Hunley.

The excavation system will be powered by a single 6" x 6" jet pump, which produces up to 1,500 gallons per minute (GPM) of seawater at 300 psig. The jet pump output will be connected to a manifold, which will supply the 1 ½" hoses for the inductor of both sluice boxes and excavation hoses. Additionally, the manifold will supply hoses for deck wash-down of artifacts.

The sluice box inductors inject a stream of water into the upper portion of the suction hose, just below the water line. This venturi creates a suction that will draw the loosened seabed material up the suction hose and deposit it into the sluice box, where artifacts can be recovered from the effluence. The sluice boxes have 3 sieve plates, of decreasing mesh size, to maximize effluent flow rate and artifact recovery (see Figure 1). The 4" ID suction hoses will extend from the inductors down to the divers, terminating in swivel suction heads. The suction heads will have handles for ease of use and rubber covered nozzles to minimize damage to the Hunley. (see Figure 2)

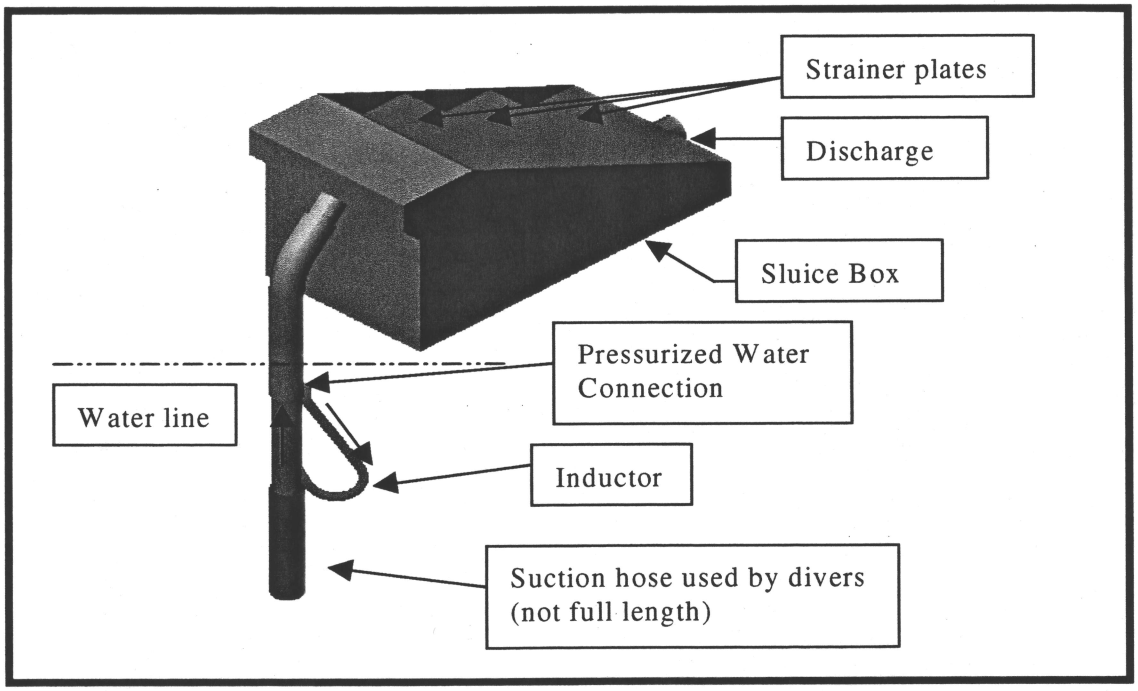


Figure 1: Sluice Box

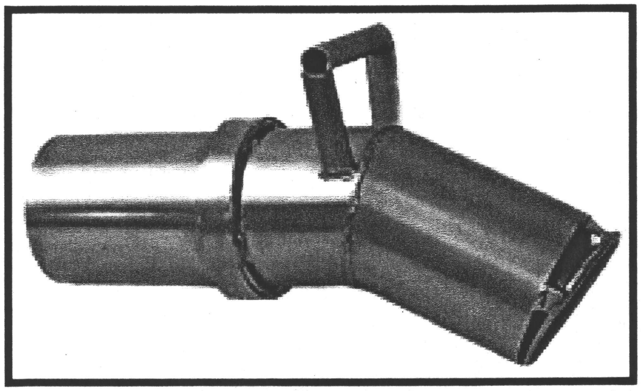


Figure 2: Swivel Suction Hose Head (rubber tip not shown)

The excavation hoses will be used by the dive teams to aid in seabed excavation. The 1½" ID hoses terminate with T-shaped nozzle heads, which allow the divers to loosen the bottom matrix in a controlled manner, with a balanced water stream. As the matrix is excavated, the divers will be looking for imbedded artifacts for documentation and recovery. The loosened material is suctioned to the surface for further examination.

5.2 First Stage Excavation

The first stage excavation operation will excavate an area approximately 40 feet wide by 130 feet long by 4 feet deep. Excavating this size of an area will be necessary for slope stabilization for diver safety as excavation depth increases, and to excavate the areas to be occupied by the suction piles.

After first stage excavation has progressed to expose the top of the Hunley, divers will set buoys at extreme points of the vessel. One buoy at the bow and stern and one buoy at the center of the Hunley will be set approximately 2-3 feet above the vessel for the alignment of the truss during deployment.

Divers will continue to excavate around the Hunley until 1/3 of the vessel is exposed, leaving the majority of the matrix around the Hunley undisturbed for structural support (see Fig. 3).

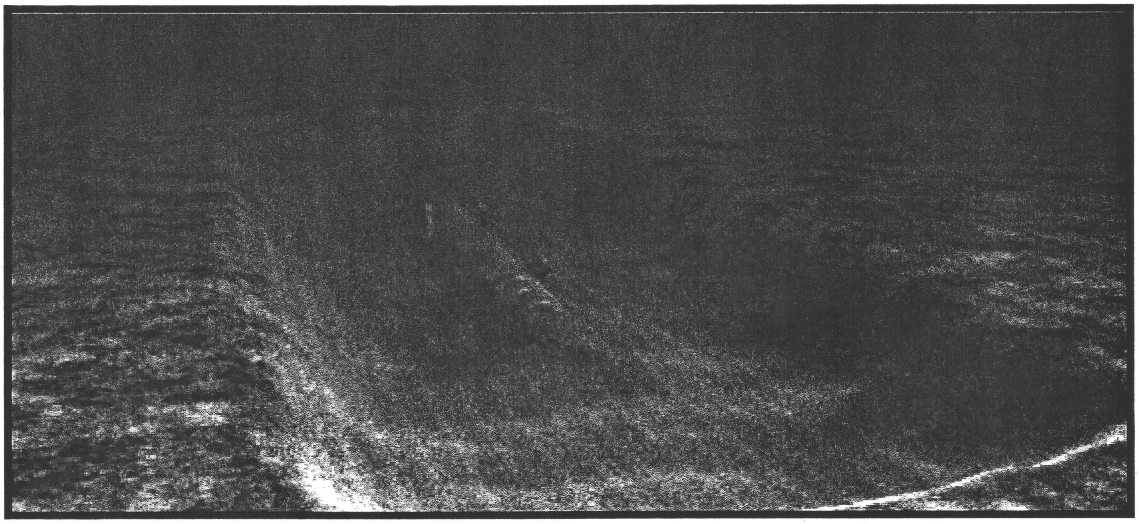


Figure 3: Initial Excavation

6.0 Recovery Frame Foundation

Eighteen-foot diameter suction piles will be used for the structural support of the truss and Hunley during recovery operations. Each pile will have an articulating bearing pad, installed on the pile cap, to ensure the truss is set level for final positioning relative to the Hunley (see Figure 4). Dive support personnel will set up for suction pile installation topside. After first stage excavation is complete, each pile will be lowered into position. OII Divers will guide piles into place. The topside crew will begin suction operation to set piles at required depth to carry the recovery frame/Hunley load. Divers will monitor levelness of pile caps during installation. Any adjustments to maintain a level foundation will be made by rigging the pile to the crane, and applying tension to one point while the pile continues to penetrate. This will ensure a level foundation for recovery frame stability. The following is a summary of how suction piles work.

Suction Pile Description (From Delmar Systems, Inc.)

Suction piles were originally developed by Delmar Systems, Inc. Suction piles are typically used in the Gulf of Mexico for oil rig mooring systems in deep water.

The system works on the principle of differential pressures between the surface and the water depth of the pile.

The support system uses a steel suction caisson as the pile. The caisson is cylindrical in shape with the bottom end open. The top of the pile is capped with a steel structure to support the truss while the recovery of the vessel proceeds. Installation and embedment of the caisson is accomplished by evacuating water out of the top of the pile (creating a pressure differential pushing the pile into the sediment) until the required penetration is reached. The process is reversed to recover the caisson after the truss and the Hunley has been lifted.

The advantage of the suction piles is less penetration required than conventional driven piles, ease of recovery, location accuracy and minimal disruption to the site (see Table 6-1 for Suction Pile Equipment).

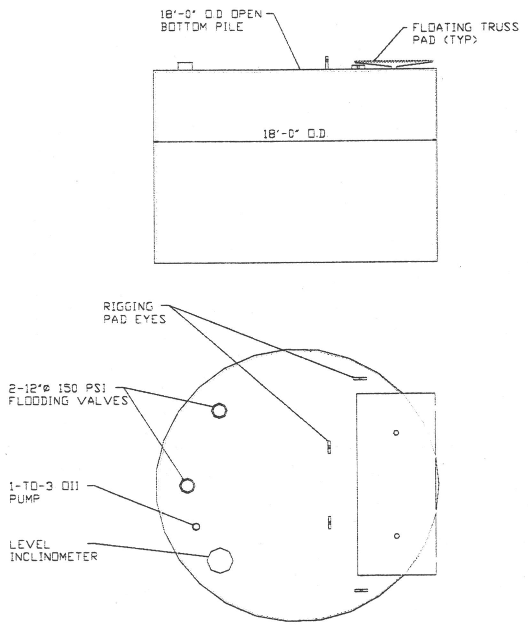


Figure 4: Suction Pile

Table 6-1 Suction Pile Equipment & Personnel

Item	Quantity
Steel Suction Caissons – 18' Diameter	2
Crane Barge Rigging Package	2
Pumping Unit Packages	2
TO-3 Fibroc Evacuation Pumps	4
Norwegian Buoy Assembly – 18" Dia. (300 lb)	30
Delmar Project Coordinator	1

6.1 Pile Installation Preparation

To prepare for suction pile installation, dive teams will excavate an area 25 feet out from each end of the Hunley. The depth of excavation will be determined in the field for pile top elevation. Divers will maintain slope repose of 45 degrees or less.

6.1.1 Vessel Requirements

The vessel used to for the suction pile installation will also be used for the recovery lift of the Hunley. To maintain station positioning, a four point mooring system will be utilized (see Figure 19). A 150-ton crane aboard the main vessel will be in service for the installation of the piles. Additional deck space is required for suction piles and the pumping unit.

An assist vessel, if required, could be utilized for suction pile alignment, safety support, and shuttle duties for equipment.

6.2 Pile Installation Procedures

6.2.1 Initial Sediment Removal

Pile sites will require 4' to 6' of detrimental soil, clay, and sediment removal below original mudline (see Figure 3). The removal of this soil will ensure proper pile embedment and stability.

6.2.2 Buoy Installation

Divers will be employed to set buoys marking precise caisson location relative to the Hunley. 18" diameter Norwegian buoys utilizing 300 lb. clump weights and taut lines will be set in a circular array fore and aft of the Hunley. The buoys will be offset 1'-0" out from the outside diameter of the pile location. The centerline distance between the piles has been preliminarily set at 72'-0".

6.2.3 Vessel Stationing

The main vessel will be set in position for caisson installation # 1. The vessel will utilize the four point mooring system to maintain position during installation. Positioning will be accomplished through the use of four air tugger winches.

6.2.4 Safety

Safety during the pile installation operation will be maintained through proper communication, adherence to pile installation procedures and verification that all performance requirements have been met. In addition, an equipment inspection and function test for all gear and deck equipment will be carried out prior to caisson installation.

6.2.5 Pile Installation

With divers on deck, the crane on the main vessel will lift the first pile into position over the buoy array. Deck air tuggers will control vessel positioning to maintain accurate placement of the pile. Divers will re-enter the water once the pile is fully submerged.

The pile will be lowered within 3 feet of the excavated seabed. Divers will confirm position of pile in buoy array by referencing clump weights and taut lines. After position is verified, the pile is lowered to mudline and self-penetration begins.

The rate of penetration, amount of embedment, and vertical orientation will be continually monitored until pile is lowered to refusal by its own weight. After leveling and correct attitude is confirmed, the lift rigging is released and brought to the surface.

6.2.6 Pile Suction Operations

After the pile has penetrated to refusal under its own weight, suction operations will begin to set pile to required depth. The soils engineer will determine required embedment depth. Allowable skin friction values will dictate depth of embedment into the existing mudline. An embedment depth of 12-20 feet has been set preliminarily.

Divers will close the flooding valves and prepare to receive the pump umbilical from topside. The diver will mate the male umbilical stabbing guide to the suction pile female pump orifice and actuate the quick connect fitting. Diver 1 will then communicate topside to begin pumping operations to evacuate the pile.

Diver 2 will observe pile depth indicators, pre-marked on the side of the pile, as pumping operation and penetration proceeds. During pumping operations, pump pressure, gauge pressure, pile level, and penetration is continually monitored.

The pile is pumped down until pile top end cap structure has made contact with bottom sediment. Pumping operations are then terminated and the quick disconnect for the umbilical male stabbing guide and the safety line is de-mated. A continuous suction source or valve is not required to maintain embedment of the pile.

Installation preparation, pile installation and suction pile operations are repeated for suction pile No. 2. See Figure 5 for an illustration of pile installation.

6.3 Suction Pile Recovery Procedures

After the recovery truss has been deployed and the Hunley has been successfully recovered, the main vessel will be positioned to begin pile recovery operations.

6.3.1 Flooding Pile

Divers will be employed to inspect the piles, stab into pile flood orifice, actuate quick connect/disconnect and attach safety lines to pump hoses.

Pumping operations begin after all necessary umbilical and stabbing guides are attached. The pile is then flooded during pumping operations to release its hold on the soil. Data documentation concerning pump pressure and pile uplift are continually monitored as pumping operations (flooding) continues.

6.3.2 Extracting Pile

Once skin friction has been broken and the pile begins to lift, pumping is terminated. Lift rigging is attached to the crane block and pumping is reestablished. Coordination is required between crane uplift and pumping to extract pile successfully. Pumping is continued until pressure is equalized inside the pile. Once free and the lower perimeter seal has been broken, the pile is recovered to the main vessels deck.

This procedure is repeated to recover the second pile.

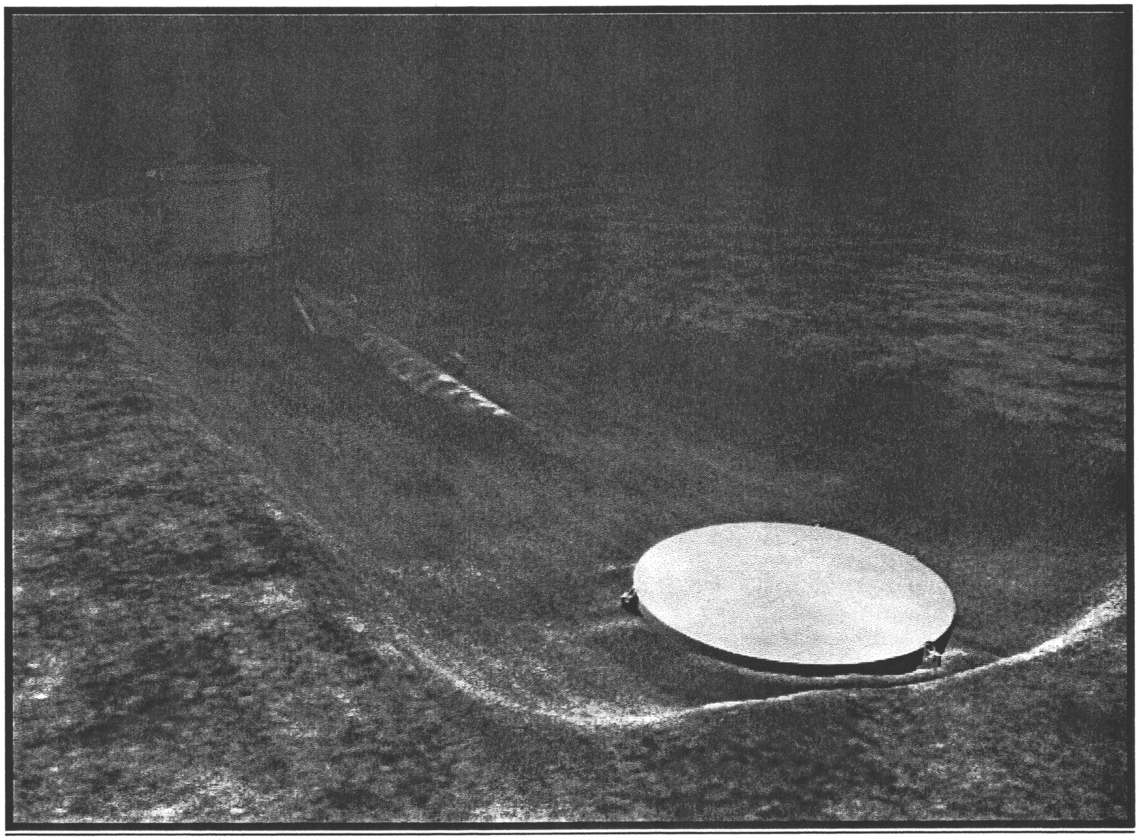


Figure 5: Pile Installation

7.0 Recovery Frame (Truss) Mobilization

7.1 Mobilize Truss

The truss will be prepared for deployment topside by dive support personnel. Necessary rigging for the lift is prepared and installed on the main truss and coordinated with crane operator for proper lifting procedures. Bearing seats will be shop welded to each end of the truss for landing on the suction piles (see Fig. 6).

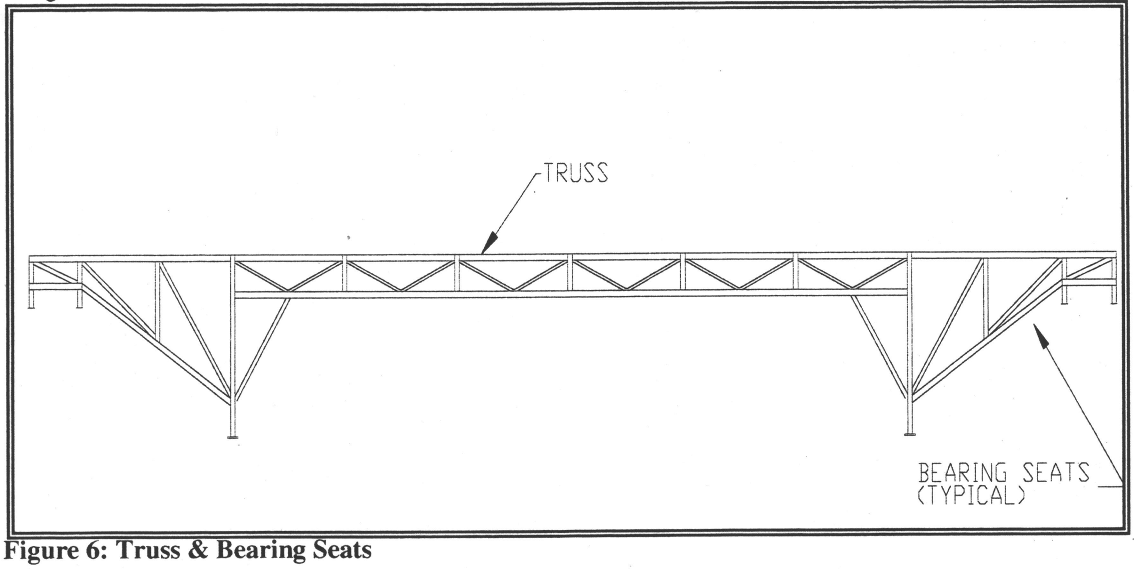


Figure 6: Truss & Bearing Seats

7.2 Truss Placement

The truss is positioned over the site by heavy lifting equipment, and guided into a position by OII divers to straddle the Hunley (see Fig. 7). The truss is slowly lowered, ensuring the Hunley remains centered in the truss space, to make contact with the floor of the excavation. Buoys, previously set on the centerline of Hunley, will be utilized to guide the truss into alignment with the Hunley.

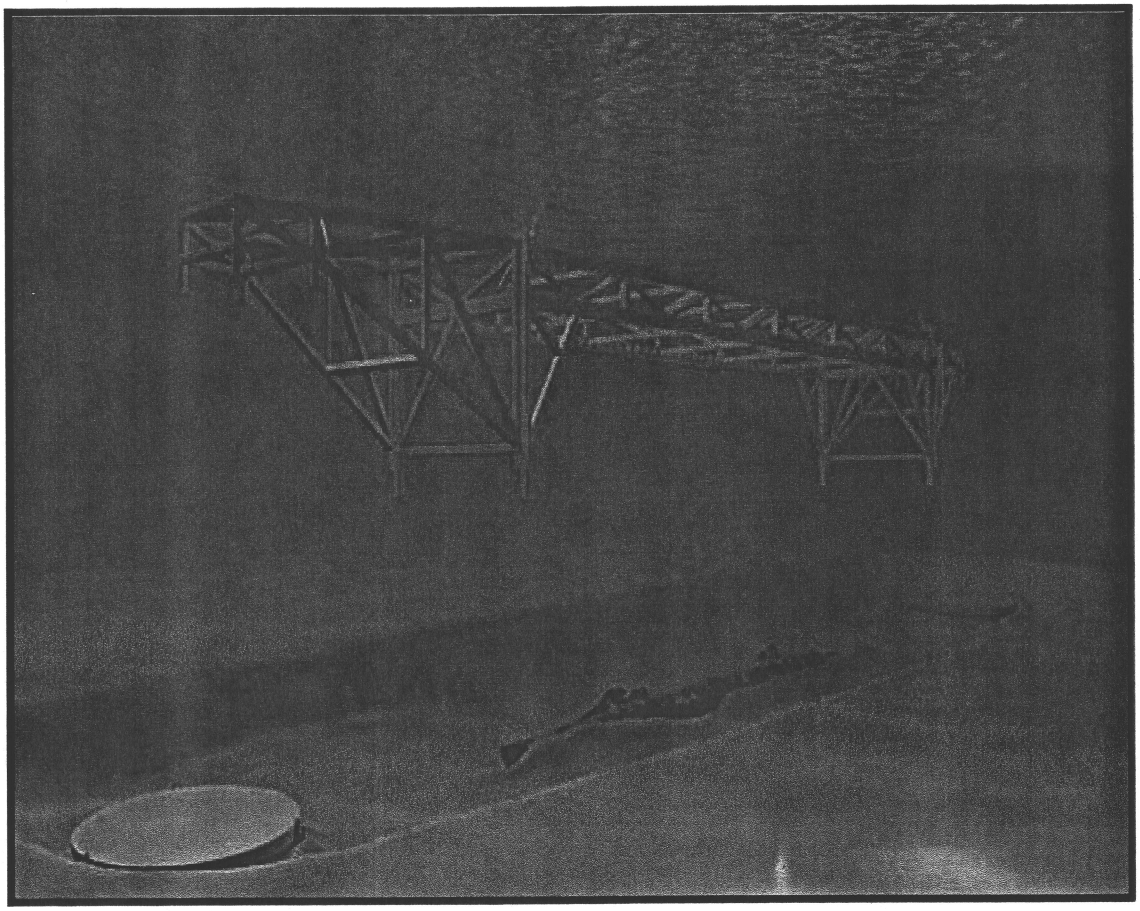


Figure 7: Truss Placement

Jetting nozzles, installed on each of the four truss legs, will allow the truss legs to penetrate the seabed with minimal disruption to the supporting matrix under the Hunley (see Fig. 8). Divers will have to perform some hand excavation at the truss knee braces, to lower the truss into the final recovery position. The truss will be in final recovery position when the bearing seats land firmly on the suction pile. After the truss is excavated to the required depth, divers will begin to rig the truss to shop installed padeyes on the pile cap to secure the truss for stability.

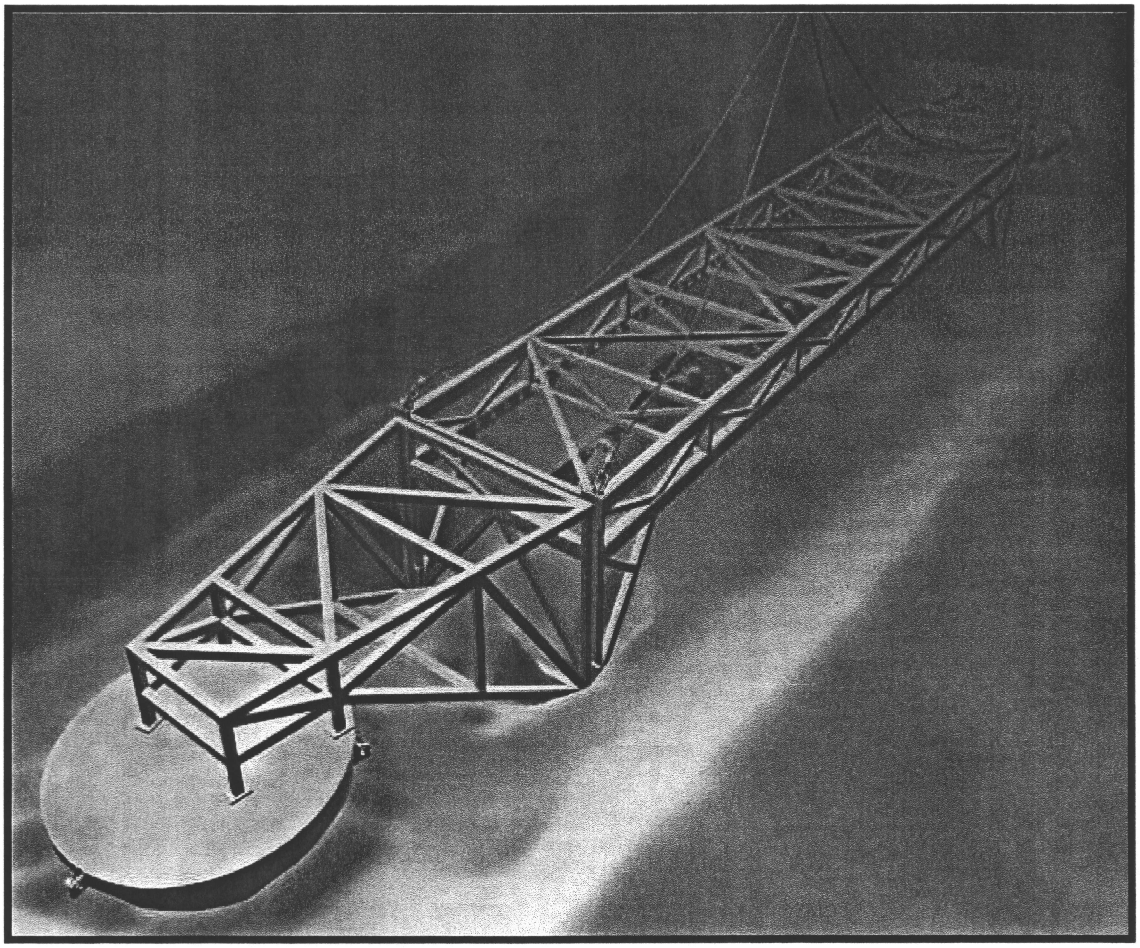


Figure 8: Final Recovery Position of Truss

8.0 Final Excavation and Rigging

8.0 Final Excavation

Once the recovery frame is secured to the piles, OII divers and archaeologists will begin final excavation of the Hunley. OII divers and archaeologists will begin excavation from the bow of the vessel, while archaeologists alone will start work at the stern. The archaeologist's methodology for stern excavation is not detailed here, however, the rigging details will be the same as described below. As for the bow, the hull will only be excavated enough to rig and tension a single sling at a time before excavation and rigging continues towards the stern. This will ensure that the Hunley is continuously supported by either the surrounding matrix or the truss, as the weight of the Hunley is transferred to the truss.

8.1 Rigging Methodology

As each section of the hull is exposed, the condition of the hull will be documented before positioning the rigging. Measurements will be made to determine the configuration of compliant support materials to conform to hull features, such as keel weights and dive planes. These support materials and padded blocks will distribute the weight of the Hunley to the rigging, and prevent the rigging from making contact with hull features, such as the dive planes. The Hunley will be supported by 12" wide nylon slings, which will be draped under the exposed section of the hull and connected to the recovery truss (see Figure 9). The custom padding and blocking will be positioned against the hull, and the sling will be snugged up to hold the padding and blocking in position. The padding and blocking will then be secured to the sling with ties or fasteners. Turnbuckles, which connect each end of the sling to the truss, will be used to tension the sling to support the weight of each portion of the hull. Load cells, which form part of the sling rigging, will monitor the tension of the slings. When the required load in each sling has been reached, the divers will stop tensioning the sling.

There is evidence that the port side of the hull may distort when the surrounding matrix is removed. This distortion is based on the FEA model of the Hunley for worst case conditions of a weak hull filled with sand, which could exert an outward force. To resist this outward distortion, 8" slings will be rigged over the port side and attached to the truss on the starboard side. The 8" slings will be tensioned to remove slack, but will not apply an inward force to the hull. The sole purpose of these slings is to keep the port side from distorting outward.

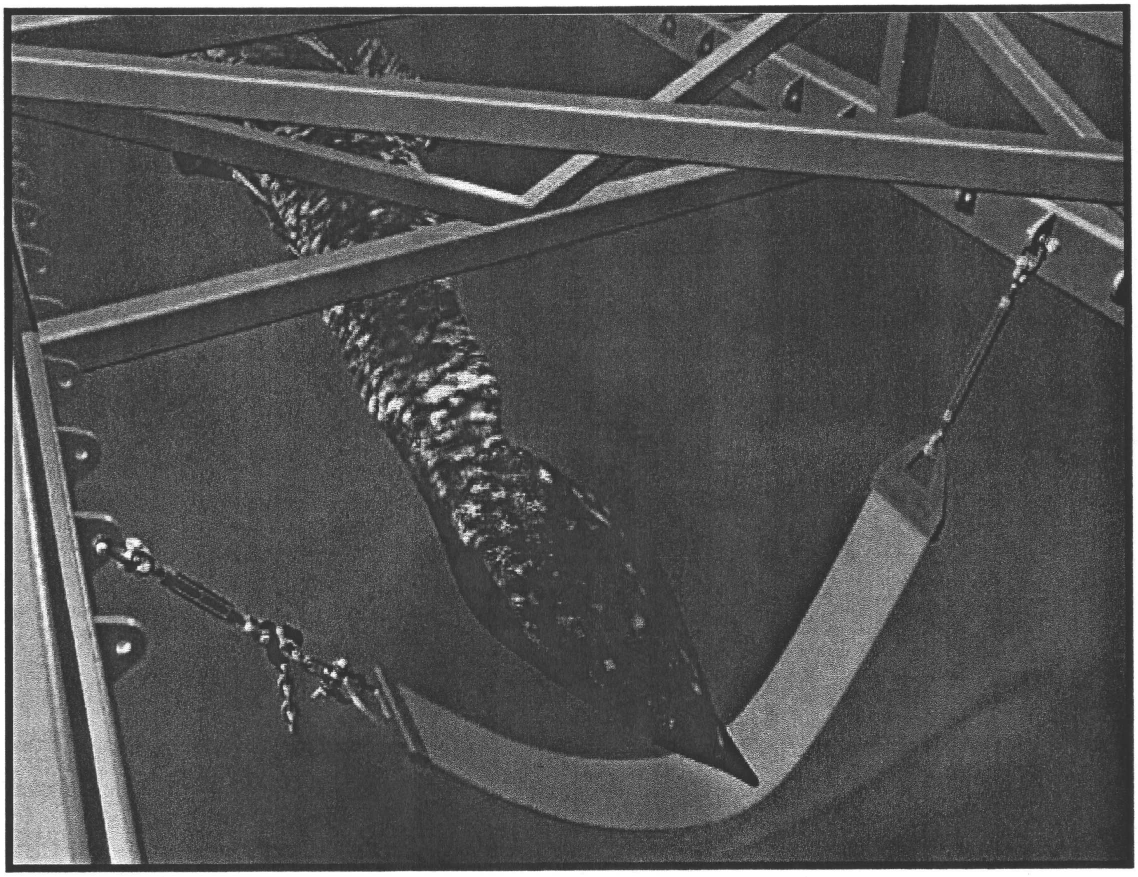


Figure 10: Sling Installation

8.3 Rigging Hardware Details

The Hunley will be supported by 12" wide nylon slings, nominally spaced on 14.5" centers. Each end of the slings will be attached to the recovery frame with turnbuckles, which provide the mechanisms for tensioning the slings. The starboard side turnbuckles are attached directly to the recovery frame padeyes. The port side turnbuckles use a chain and hook arrangement to accommodate various rigging lengths, allowing the sling to be snugged up to the hull without wasting valuable turnbuckle travel. The starboard side turnbuckle assemblies also include load cells, which determine sling tension. Figure 10 illustrates the starboard sling end rigging hardware and Figure 11 illustrates the port sling end rigging hardware.

All slings will be constructed of nylon, which is unaffected by sodium hydroxide used in the conservation phase. However, due to possible long term exposure to the sodium hydroxide, the sling manufacturer recommends periodic strength testing of the slings during the conservation phase. The 12" slings have a working capacity of 16,600 pounds and 6% stretch at full load, resulting in a maximum elongation of 1". The 12" slings will be fabricated in a woven fashion to provide a matrix of 1" square holes, used to secure padding, blocking, and the 8" slings to the 12" slings (see Figure 12).

The port side turnbuckles, which have 12 inches of travel, will be used to pre-tension the slings and compress compliant support materials. Once pre-tensioned, the turnbuckles at both ends will be shortened simultaneously, minimizing the torsional loads induced by sling tensioning.

The turnbuckles on the starboard side have only 6" of travel, due to rigging length restrictions. The 12" turnbuckles must be used for pre-tensioning, or else the 6" turnbuckles may bottom out before the load of the Hunley is fully supported. All hardware has a minimum working load of 5,200 pounds.

The 8" slings will be fastened to the 12" slings as low on the port side a possible. These slings can be used on every 12" sling, or applied where deemed necessary as the rigging progresses. The slings will cross over the port side, and be fastened to the starboard side of the truss with turnbuckles. Neoprene pads will be inserted between the slings and the hull to distribute the load and protect the Hunley. The slings will be tensioned only enough to compress the neoprene pads, applying no appreciable force on the Hunley. Figure 15 details these secondary support slings.

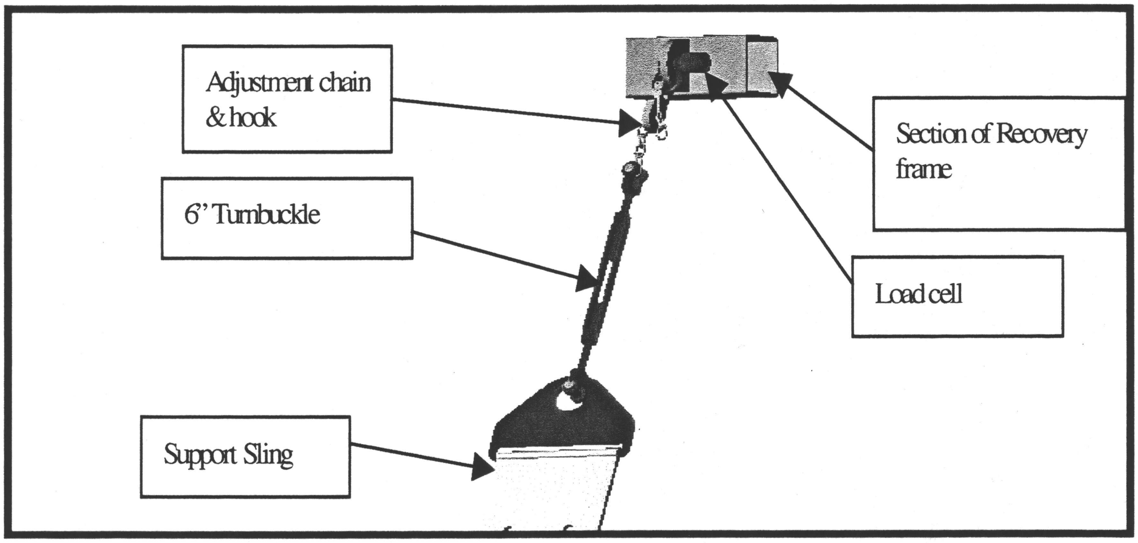


Figure 10: Sling Detail - Starboard Side

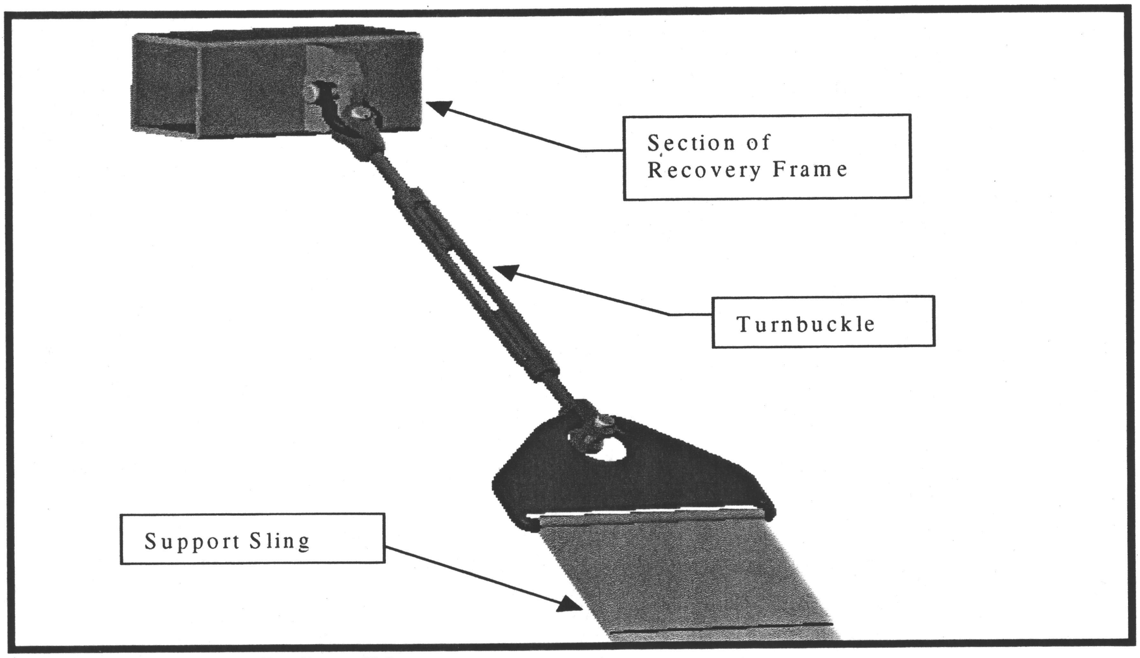


Figure 11: Sling Detail – Port Side

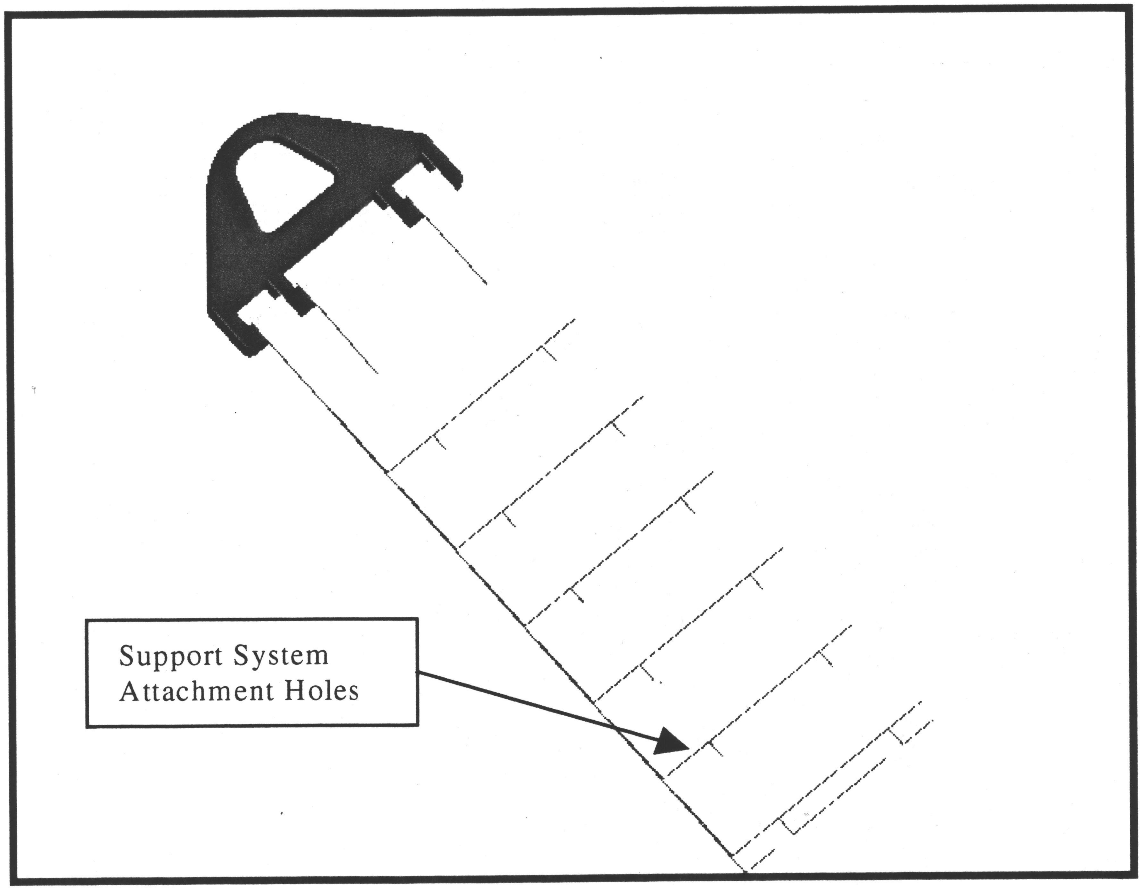


Figure12: 12" Sling (Partial Length)

8.4 Load Cell Details

Load cells will be integral to the rigging system to monitor the tension in each sling during the recovery operation, see Figure 11 for load cell location. Each load cell will be monitored topside by support personnel. The load cell data acquisition system, illustrated in Figure 13, will provide individual sling tension, total weight of the truss load and alarm signaling (if required) during recovery of the Hunley.

The weight of each portion of the hull being supported by each sling will be calculated, resulting in a tension value for each sling. During initial rigging of the slings, top side personnel will direct the divers in the tensioning procedure until the proper tension has been achieved. During the entire recovery procedure, the loads in all slings will be monitored and adjusted if required. Sling tension will be critical to ensure the load of the Hunley is distributed properly, to minimize hull distortion and induced stresses.

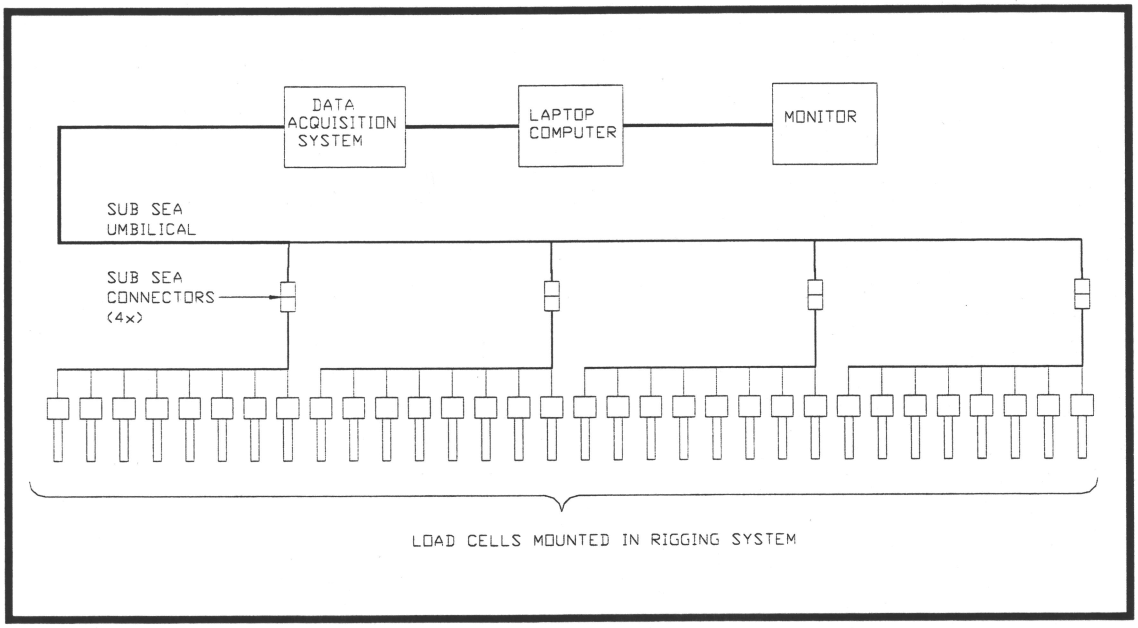


Figure 13: Load Cell System

The load cell system could also be utilized during the conservation phases of the project. Individual slings could be loosened for conservation considerations, then re-tensioned to the original value.

8.5 Compliant Support System

A compliant support system will be utilized to distribute rigging loads, and protect the hull and hull features. Two materials are currently being proposed. A urethane based foam injection system may be utilized for compliant support of the vessel and protection of hull features. Alternatively, or in conjunction, neoprene pads of various durometers (softness) may be fabricated and inserted between the slings and the hull for compliant support of the vessel and protection of hull features.

The foam injection system can be installed and can conform to irregularities in the hull with little fabrication. A vinyl bag can be secured to the sling (see Figure 14) before the sling has been snugged to the hull. Foam would then be injected into the bag through a surface supplied hose assembly, where the material would expand in the bag to conform to the hull. Foam bags can be placed along the dive planes, stern, and keel to minimize damage, see Figures 15 and 16 for foam bag installation.

However, a vendor search for an injection foam material that meets the strength, installation, and chemical compatibility requirements yielded no perfect candidates. Several vendors do have foam systems that can be injected, but lack physical data that would predict how the foam would perform in this sub-sea installation and conservation application. These materials are typically used in the building insulation industry, and the electronics equipment packaging industry, not used as a submerged structural component. This foam injection concept has many attractive feature, making it worth pursuing. In order to determine it's worth, all candidates will have to be tested in sub-sea conditions similar to what will be encountered. It is the intention, as part of the final engineering effort, to conduct such testing.

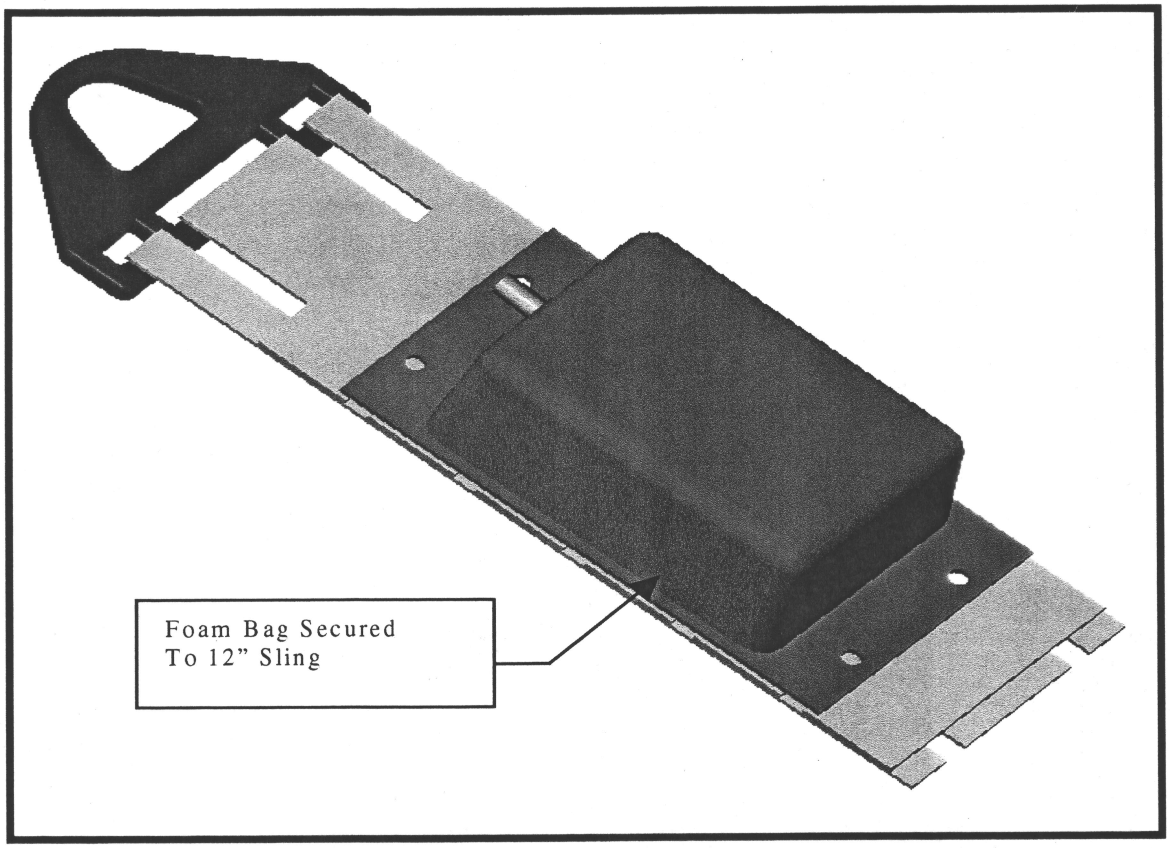


Figure 14: Foam Bags

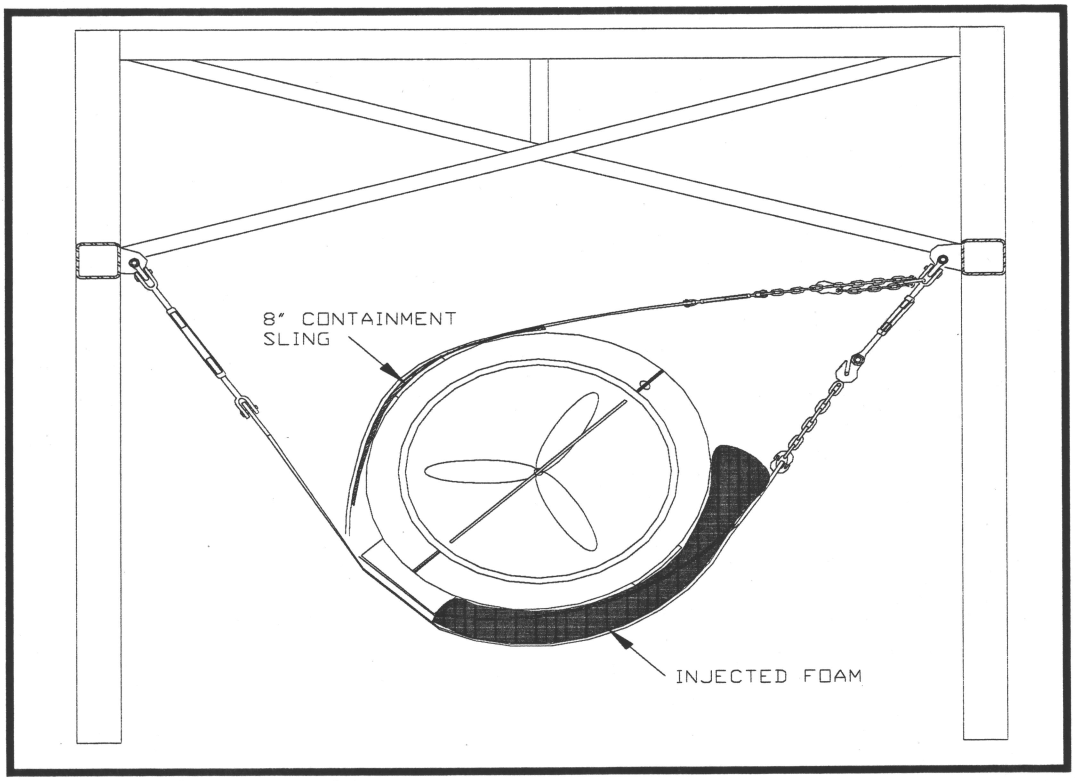


Figure 15: 8" Containment Slings

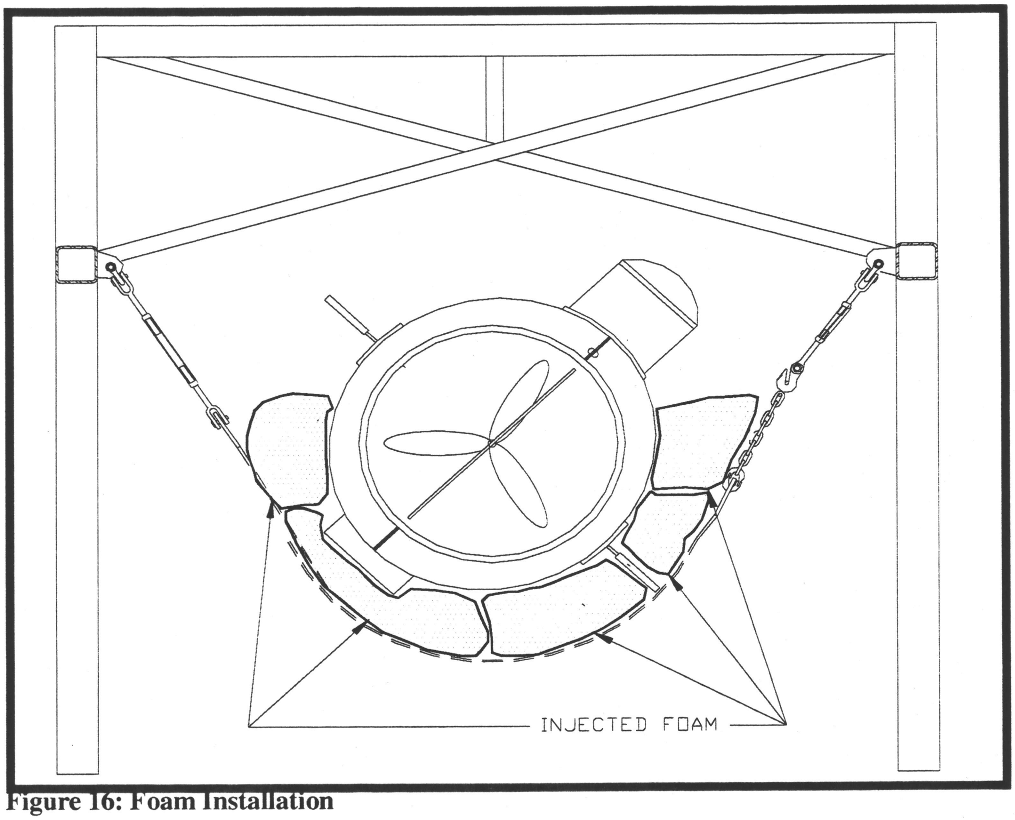


Figure 16: Foam Installation

As an alternative, or in conjunction with the injection system, a compliant support system can be fabricated from sheets of neoprene. Neoprene has chemical compatibility with 10% sodium hydroxide, and comes in various densities. The physical properties, compressive strength and amount of deformation under loads, are known. Neoprene is relatively inexpensive, readily available, and easily fabricated on site.

Prior to setting a support sling in position, the total pad thickness and length can be measured. Top-side personnel can fabricate a pad out of 1" thick by 12" wide strips of neoprene, which can be fabricated over a form that replicated the curvature of the hull. Successive layers can be glued together, starting with a very soft durometer (30-50 Shore 00) close to the hull, and end with a firm durometer (75+) to make contact with the sling, until the desired thickness is achieved. To rig around the dive planes, thicker neoprene pads would support the keel, and padded wood blocking would prevent the slings from contacting the planes. The blocks are easily fabricated and would have to be counterweighted to assist the divers in fastening them to the 12" slings. Lay-up time for a nominal pad is estimated at several hours, however, the majority of the hull has a uniform cross section that may except a standard fabricated pad that can be made from the initial measurements. See Figure 17 for neoprene pad installation under keel, and Figure 18 for neoprene pad and blocking installation around dive planes.

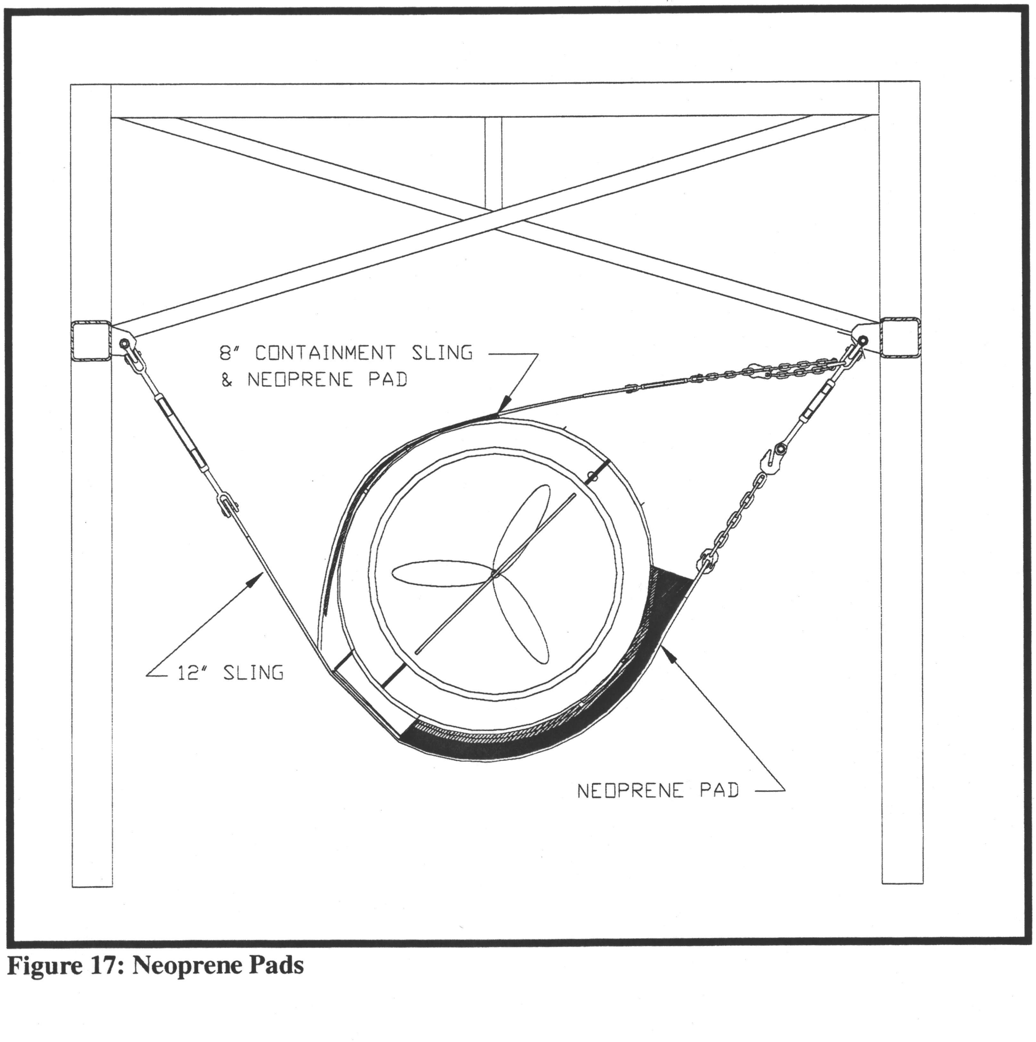


Figure 17: Neoprene Pads

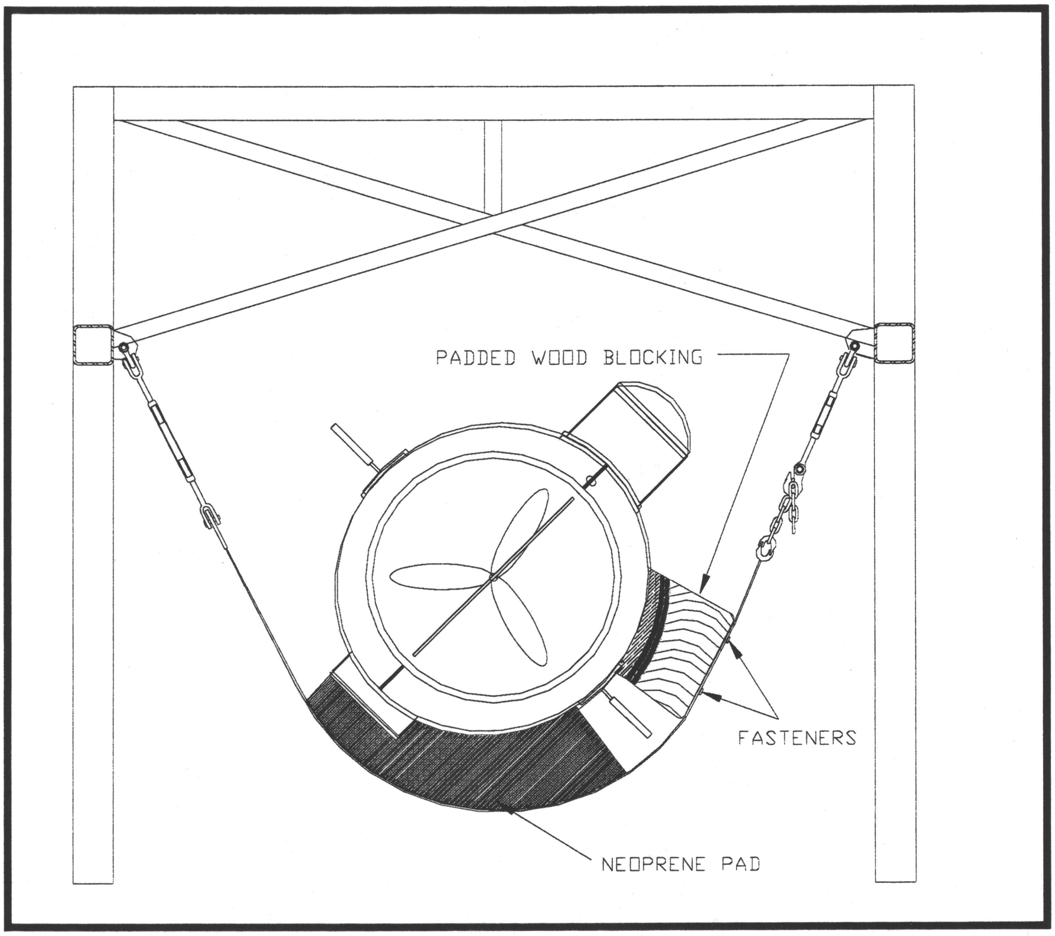


Figure 18: Neoprene at Dive Planes

The final design of the rigging configuration and support material choice(s) will result in a support system that maximizes hull compliance, load distribution, and hull protection.

8.6 Deflection Monitoring

Vertical deflection of the Hunley will be monitored closely during excavation and sling installation operations. A datum will be established prior to excavation and sling installation. After the truss has been lowered into position, vertical measurements taken at each truss panel point will be recorded and act as the datum for vertical deflection monitoring as each sling is installed.

A cylindrical sleeve will be installed at each panel point on the centerline of the truss. Divers will be able to obtain vertical measurements at the centerline of the Hunley to accurately record differential deflections from its original resting position to its suspended position. Any discernable deflections can be corrected by tensioning or de-tensioning the slings.

9.0 Recovery of the Hunley

Preparation for lifting the Hunley will begin after all slings and required supports are installed. To dampen longitudinal movement of the Hunley during the lift, a number of 12" slings on each end of the Hunley will be rigged to the truss legs. Load cell data will be analyzed prior to raising the vessel to make certain slings are carrying distributed load and the vessel is stabilized. If deemed necessary, a semi-permeable membrane can be slung under the Hunley to capture any small artifacts that may fall from the hull during the lift. The semi-permeable membrane will allow water to drain through, so as not to unnecessarily load the truss and crane.

Weather and sea conditions are major consideration when attempting a critical heavy lift. Once authorization has been given to proceed, divers will rig a 6-sling bridle to the truss. OII divers will monitor the tensioning of the bridle to ensure the slings are evenly loaded, and rigged correctly. Once the recovery frame is being supported by the crane, the divers will be removed to a safe area, and the lift will be completed (see Fig. 20).

Once the Hunley has been set on a transport barge, support personnel will secure the truss to the deck and remove (by burning) the bearing seats from each end of the truss. The Hunley will be stabilized in the truss using tension straps placed at critical locations inside the truss to prevent movement during transit and install the bolted bottom struts. A soaker system will be in place to continually wet the Hunley with seawater to minimize oxidation during transit to the Port of Charleston.

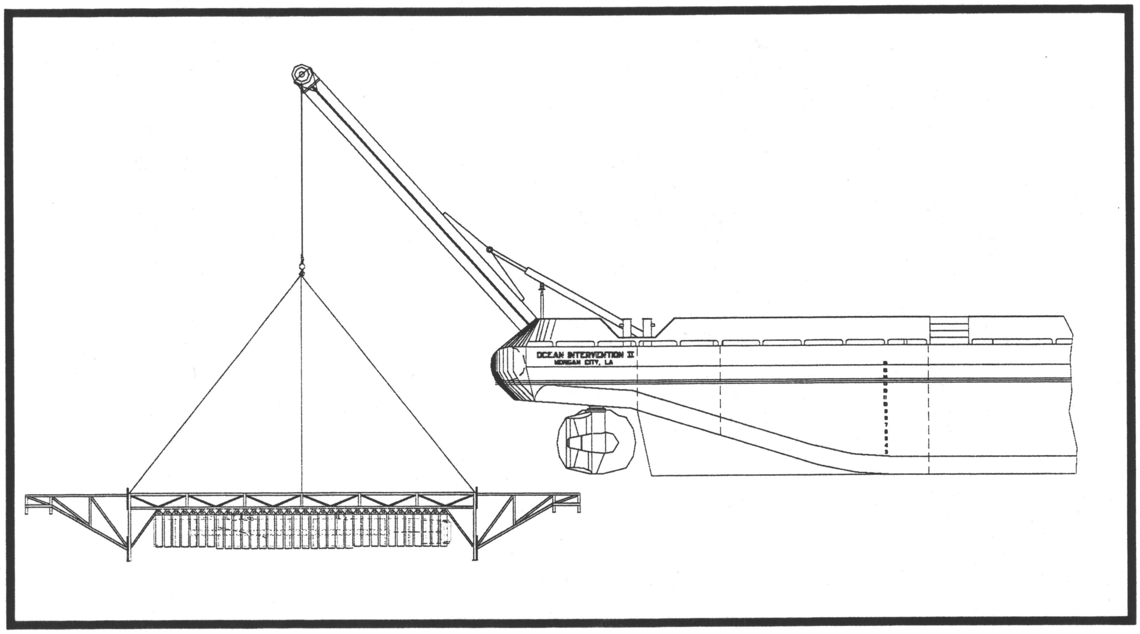


Figure 20: Diving Platform

10.0 Weather Contingency

During the operation to recover the Hunley it will be necessary to closely monitor the weather in the South Atlantic and Carribean. In the event of a hurricane or severe tropical storm it will be necessary to evaluate the recovery operation and take appropriate action to protect the Hunley from the effects of any storm surge. The recovery truss and pile system are capable of withstanding any potential impacts of a storm. To protect the Hunley and stablize it in the truss assembly sandbags will be stacked around and beneath the hull to replace any soil that has been removed during the recovery operation. It is only necessary to install sandbags within the envelope of the truss. The truss itself will help to protect the Hunley and to stabilze the sandbags. A sufficient number of sandbags to handle any portion of the recovery operation will be staged on pallets ready for shipment offshore on short notice. Sandbags will be lowered to the bottom using the onboard crane and a cargo net. This method allows the divers to guide the sandbags into position and a minimum amount of time will be necessary to place them in their final configuration. The installation of the sandbags and the protection of the Hunley should be accomplished in 12 hours from the time the sandbags arrive on site. This is based on actual experience installing sanbags on offshore oil platforms and pipelines. The sandbagging of pipelines and other subsea structures is the standard method used in the shallow waters of the gulf of mexico to protect them from hurricanes.

The decision to abandon the work site and seek cover from any potential weather event is one that needs to be made in a timely fashion. The time to transport the sandbags to the work site, install them on the Hunley and then transit the work platform to a safe hurricane mooring will all need to be considered.

Appendix A
Schedule

Schedule

Appendix B
Hunley Structural Investigation

The HUNLEY Recovery Structural Investigation

The successful and uneventful recovery of the HUNLEY depends upon a realistic evaluation of the residual strength of the submarine's hull. The hull consists of a collection of disparate parts of unknown origin and properties. The parts, which were riveted together, may no longer be structurally connected. The purpose of the structural investigation is to establish the possible failure modes of the hull and to direct the recovery plan to address them.

To adequately investigate the structural integrity of the HUNLEY the following data is required:

- Dimensions including shape and hull thickness
- Material properties including modulus of elasticity, yield and ultimate strength of all parts
- Rivet details including size and pitch
- Contained material density and amount

A. Description of HUNLEY Hull from the Record

The HUNLEY cross section is obround[1]. The dimensions of the hull are not accurately known. The measurements made by divers do not agree with the record and the record is inconsistent (reference 1). Accounts in the record place the hull thickness at 5/8" but speculation is that the hull may be as thin as 1/4".

It is known from the record that the hull was constructed from a riveted boiler that was split longitudinally. A plate, called a strake, was inserted between the cut edges and the assembly was riveted. The bow and stern ends were reported to be castings but the transition pieces between the hull and the ends are not described. None of the material properties are known.

The rivet pattern was not clearly established in the record. Artist drawings show longitudinal and circumferential seams. It is not evident if the rivet patterns are accurate or representative. An attempt was made to infer a rivet pattern by review of contemporary literature or artifacts. The earliest reference to riveted boilers was written much later in 1917, and represents the distillation of many lessons learned from boiler failures (reference 2). No artifacts of riveted construction could be located.

The hull is ballasted with cast iron. The cross sectional dimensions of the casting are known approximately, however the length and number of the castings is problematical. It is assumed that the castings are attached to the hull near their ends so they could be released in an emergency. No details of the connecting member such as size, strength or material composition is known.

B. Findings from Site Investigations

The record data that is relevant to the structural analysis includes the hull inclination of about 45 degrees, that the hull probably contains sand and the hull is covered with an accretion layer. Speculation is that the hull may be nearly full of sand.

The most recent dive was motivated by the need for data on the hull. Specifically hull thickness and rivet characteristics were needed for the structural analysis. The dive established the rivet size and pitch and that the rivets may have corroded, perhaps to nonexistence. The hull material was reported to slough off when an attempt was made to remove the accretion layer by grinding.

---

[1] Obround. "An obround opening is one which is formed by two parallel sides and semicircular ends." ASME Boiler & Pressure Vessel Code, Section VIII, Division 1, paragraph UG-36.

The softness of the hull material is characteristic of a wrought iron. The rivet pitch and size are introduced into the structural models as is a variation representing a material more flexible than steel and thinner than the hull.

The rivet pattern was measured at 2" between adjacent rivets located in the same plate and about 2" across the butt interface of adjacent plates. The rivets are countersunk with a nominal maximum diameter of 1" and a rivet shaft of 5/8". One rivet was examined in detail by a diver and was found to have corroded to nonexistence. The hull region that was cleaned was relatively small and may or may not represent all riveted joints. Also there is no reported indication of more than one circumferential riveted joint.

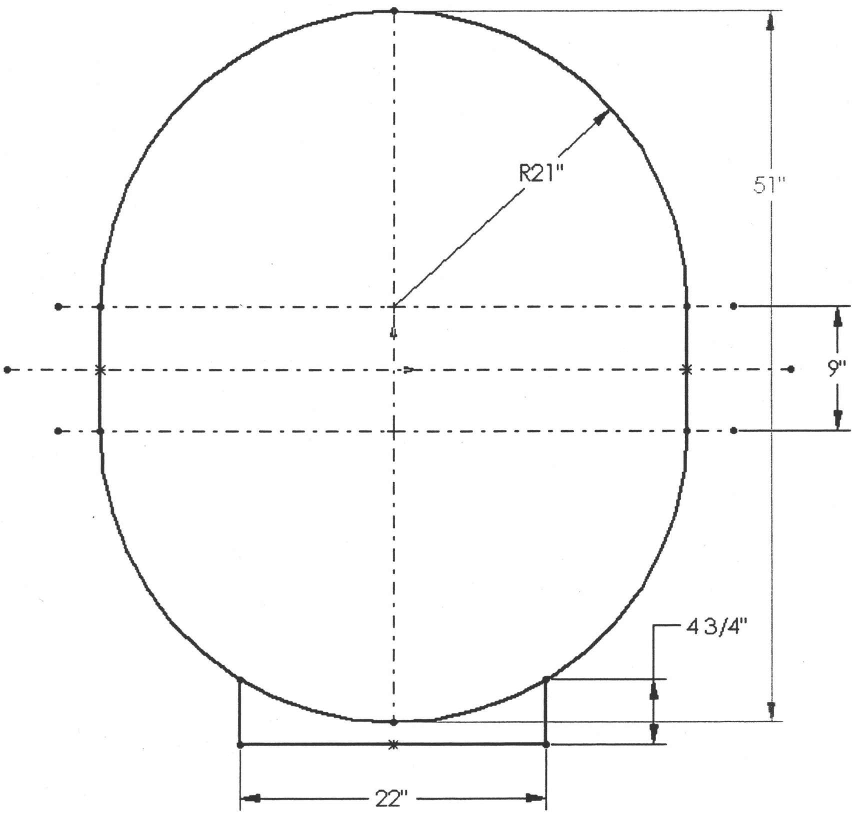
The dive also successfully collected UT hull thickness measurements. While there was some variation in hull thickness the nominal thickness was found to be somewhat less than 3/8". See Appendix A for the hull thickness measurement data. The minimum average hull thickness of 0.340" was used in the structural analysis.

A sample of the accretion layer was obtained and will be tested to establish if the accretion has inherent strength. If the accretion layer is reasonably strong it may reinforce the hull connections where rivets have corroded.

C. Mathematical Model of the HUNLEY

There is very little factual data available for development of a structural analysis. Of the four items listed in the opening section above, only the rivet pitch and size is known.

The structural analysis findings are strongly dependent upon the geometry assumed. To clarify the contrasting dimensional data, see Table 4.1 of reference 1, cross sections of the dimensional data attributed to McClintock and that reported by site divers are generated. Figure 1 shows the cross section per McClintock's account and Figure 2 from the divers measurements. In both the strake is set at the 9" measured by the divers. The "beam" data is used to develop the obround shape. Also noted is the resultant "depth" dimension. The difference between the "depth" dimensions in the record is 3" ("4 feet" versus 51" shown) for the McClintock data and 4" for the diver's measurements. Since the larger beam will generate higher stress, and conservatism is warranted, the diver data is used in the structural investigation.



II. Figure 1 Cross Section Based on McClintock's Notes

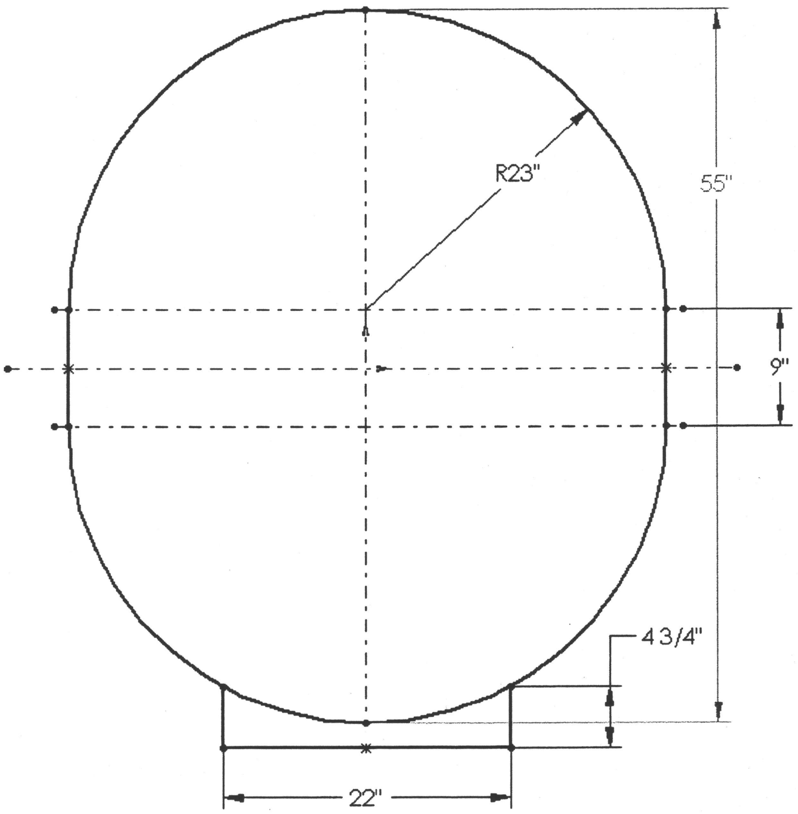


Figure 2 Cross Section based Upon Site Measurements

In an attempt to establish overall geometry, a three dimensional CAD model of the hull was created from data in the record. The three dimensional model is shown in Figure 3. A segment from this model is used to investigate rivet strength.

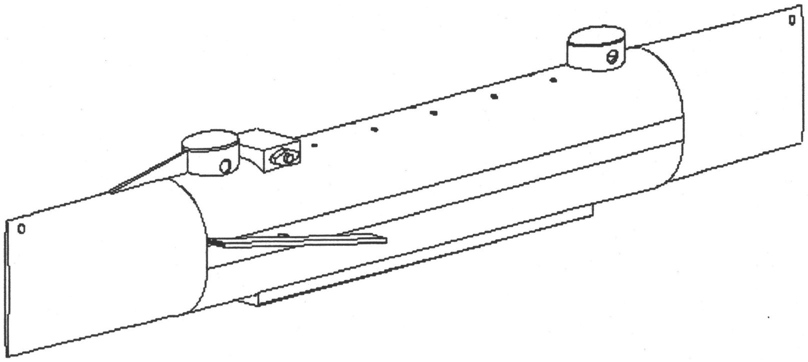


Figure 3 3D CAD Model of HUNLEY

Objectives of the Structural Investigation

Many risks exist in the Hunley recovery. Two concerns that can be investigated using finite element techniques are an assessment of the inherent strength of the hull and movement of the hull in the slings. While it is difficult to arrive at absolute assurance that the hull will be recovered intact since so little is known of the hull condition, the structural investigation was directed at quantifying the likelihood of hull collapse and uncontrolled hull movement.

The assessment of structural integrity of the hull is overshadowed by the moderate to high probability that the rivets have corroded. The absence of rivets reduces hull strength to the strength of the accretion buildup. It is reasonable to surmise that if this situation exists, then the recovery operation must ensure that the hull is supported during recovery much as it is supported at the site.

Therefore, uncontrolled hull movement is to be avoided. In an attempt to assess the potential for uncontrolled movement a series of 2 dimensional finite element models were generated. The models represent a slice of the hull and are used to investigate the stability of the hull in the flexible strap. Of particular interest is any circumstance of contained sand and hull inclination that could develop an unstable condition causing the hull to "topple".

In an attempt to understand the effect of loss of rivet integrity, a 3D plate model of the hull was created. The model simplifies the rivet to a series of low modulus, thin strips. The strips of rivets run along and around the hull. These models are useful to assess the effect of rivet integrity along the length of the hull.

The investigation of the rivet integrity is refined further with a solid model segment of the hull. The region where the divers took hull thickness measurements is recreated. The hull parts are represented as accurately as known. Rivets are included.

The ANSYS finite element program, version 5.6, was used for finite element studies. The Solid Works 99 CAD program was used to generate geometry.

A. Two Dimensional Finite Element Models

The two-dimensional models represent a 1" longitudinal slice of the hull. Plane strain elements are used which imply that there is no strain perpendicular to the elements. This is a reasonable assumption. The strap is assumed to be 1/4" thick with material properties derived from test data. The elastic modulus used for the strap is 10,000 psi. The hull is assumed to have a modulus of 30,000,000 psi., a value typical for ferrous metals. The hull and strap are separated by a series of springs. The spring constant, 10 psi, is representative of the foam padding that will be used in the recovery. The springs accept both compression and tension. The extent of the effective spring interaction is adjusted to minimize any tensile action. Two mass elements are included. The ballast is attached at the bottom of the hull and the contained sand is located at its probable center of gravity. The sand is attached to the hull with springs. The problem is highly nonlinear due to the thin and very flexible strap and the flexible foam springs.

Three cases are investigated. A base case assumes the hull rotated 45 degrees from the vertical and 80% full of sand. A second case assumes a 45 degree inclination and no sand and the third a 30 degree inclination and 80% full of sand. The strap is fixed at the upper ends. This represents connection to the lifting frame. The model is released from its initial position under the force of gravity. The hull and straps move to a location that is statically stable. Stability requires movement of the hull and straps, compression of the foam and stretch of the strap.

Deflections are shown in Figures 4, 5 and 6 below. The maximum deflection is listed in the right column as "DMX". Note that in all cases the hull shifts to the left. This consistency of motion suggests that the hull is in a stable condition. Sudden movement is considered unlikely.

However, the large displacements predicted are cause for concern. As the support of the hull is transferred to the slings, the hull has a definite tendency to move sidewise. This action if permitted would apply a moment to the hull, an undesirable condition. To control the side sway additional straps extending across the top of the hull are specified. These additional straps arrest the side sway. Figure 7 shows the predicted displacement.

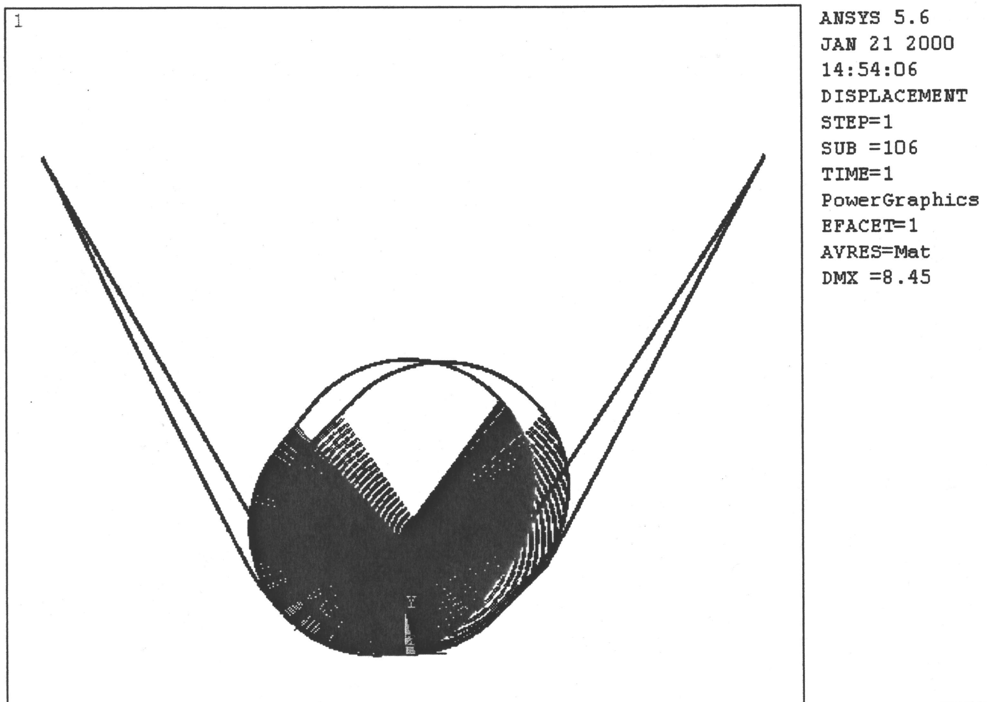
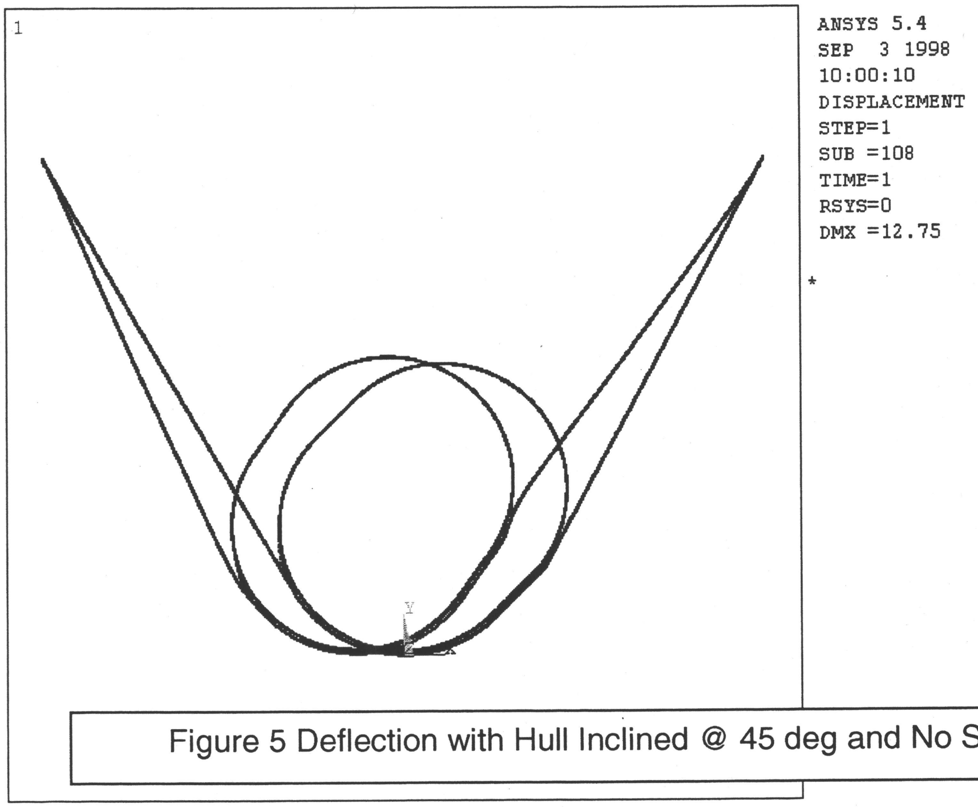
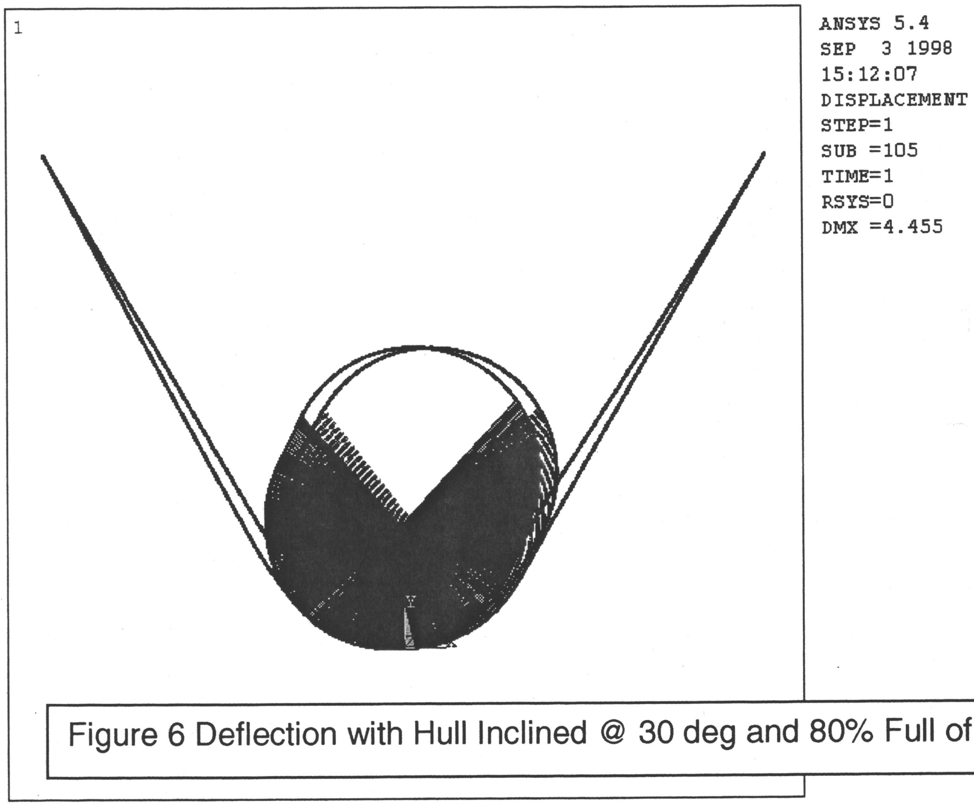


Figure 4 Deflection with Hull Inclined @ 45 deg and 80% Full of Sand



```
ANSYS 5.4
SEP  3 1998
10:00:10
DISPLACEMENT
STEP=1
SUB =108
TIME=1
RSYS=0
DMX =12.75
```

Figure 5 Deflection with Hull Inclined @ 45 deg and No Sand



```
ANSYS 5.4
SEP  3 1998
15:12:07
DISPLACEMENT
STEP=1
SUB =105
TIME=1
RSYS=0
DMX =4.455
```

Figure 6 Deflection with Hull Inclined @ 30 deg and 80% Full of Sand

B. Three Dimensional Plate Finite Element Models

The 3D plate model is useful for evaluating the gross stiffness effects of compromised rivets. This model is a linear extension of the 2D plane strain geometry. The longitudinal extension allows inclusion of circumferential rivets and the local effect of a single point ballast connection. Uniform hull thickness is assumed. The rivet backing strips, that are assumed to exist, are ignored. The rivets are modeled as 5/8-inch wide strips of reduced properties that extend longitudinally and circumferentially at 24" increments along the hull. Three hull sections are modeled. The center section includes two mass elements, a mass representing the ballast weight and another the conning tower. Both mass elements are attached to the hull. The ballast weight is calculated for the length of the model and is about 2100 lbs. The estimated weight of the conning tower is 100 lbs.

The model is constrained with symmetry conditions at either end. Restraints are applied where the straps contact the hull. A side motion restraint is applied along the bottom of the hull. This latter restraint represents the interaction of the ballast and strap. The ballast is permitted to move vertically and thereby induce a moment on the hull.

An applied pressure of ½ psi is used to represent the contained sand. The ½ psi is derived for wet sand submerged.

The pressure and displacement boundary conditions are illustrated on Figure 8. Note that the pressure is not applied to the strake on the left. It is assumed that the sand pressure could offset the effect of the conning tower mass in a non-conservative manner and is therefore not applied.

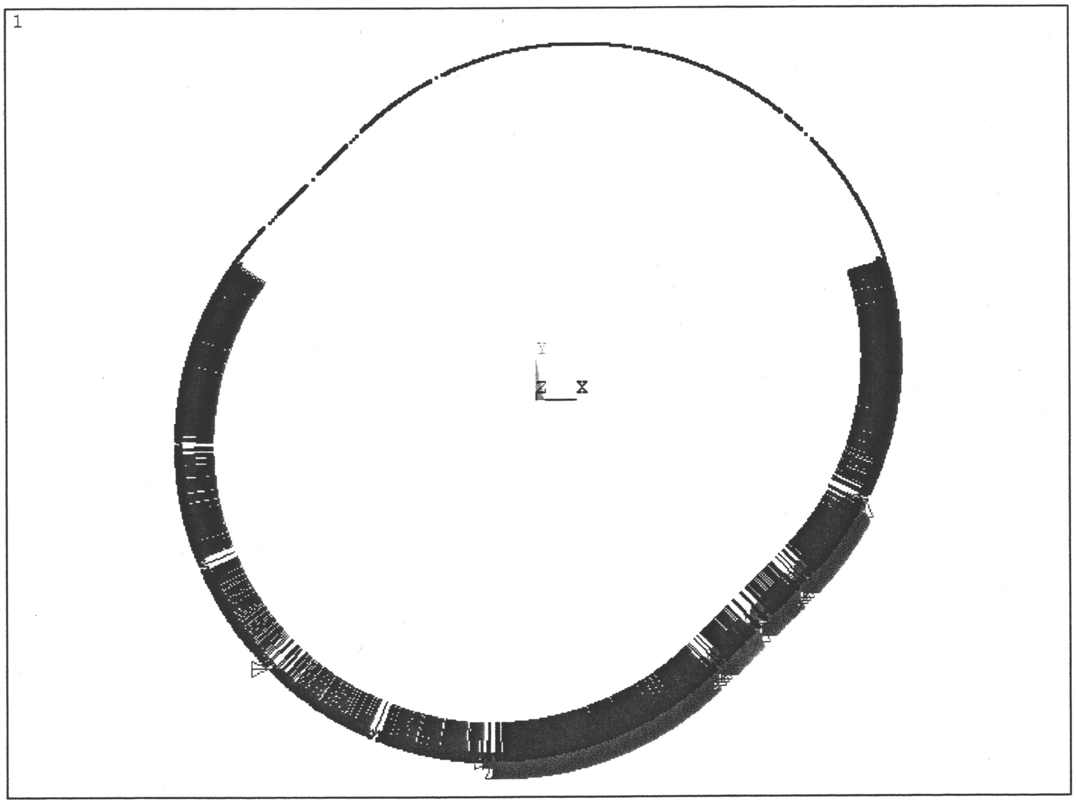


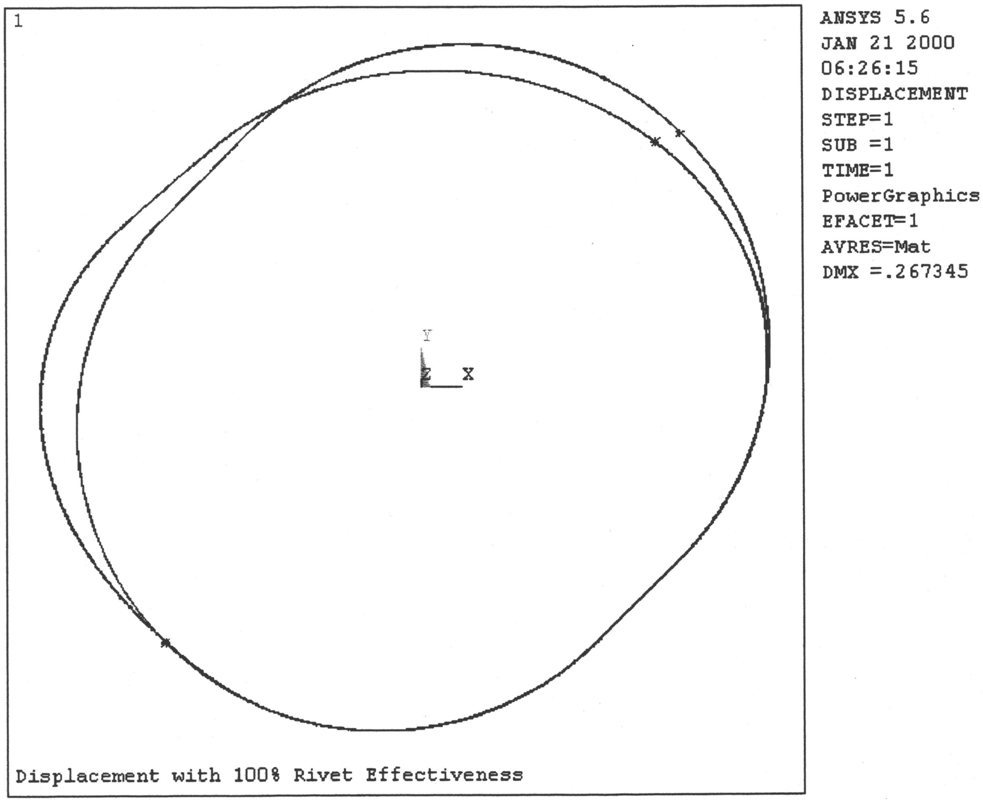
Figure 8 Plate Model Showing Restraints (blue) and Internal Pressure (red)

The model is generated with a nominal element size of 5/16" in the rivet strip and 1" elsewhere. The material in the rivet region is assumed to have 100%, 50%, 20%, 10%, 5% and 2% of the stiffness and thickness of the hull. For example, in the 2% rivet strength case both the elastic modulus and the element thickness is reduced to 2% of the hull properties.

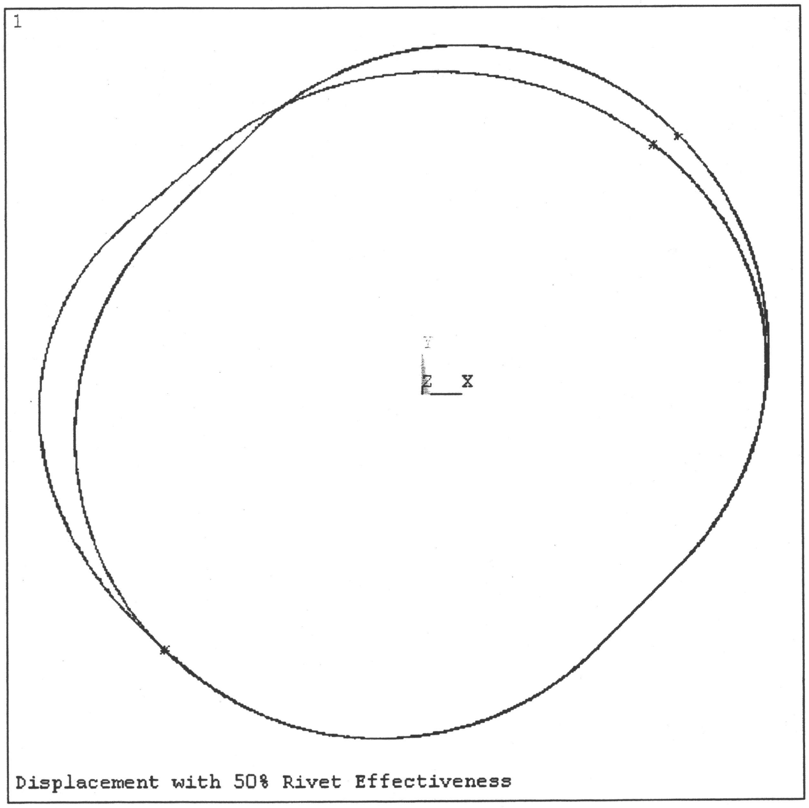
The assumption that the loss of rivet capacity can be modeled by a reduction in both thickness and elastic modulus is problematical. It can be argued that a reduction is thickness alone is sufficient to allow for rivet loss. The corroded condition of the rivet however suggests a significant change in elastic modulus. Lacking any data, the combined reduction in thickness and modulus is thought to be conservative and not unrealistic.

The following plots show the effect of rivet strength on hull displacement. The displaced shape of the hull is superimposed on the original unloaded shape.
The displacement for the 100% and 50% cases are essentially the same. The 20% case shows that the reduced rivet stiffness allows a "kink" to develop and the displacement more than doubles the 50% case. Hull displacement doubles again from the 20% to 10% case and then levels off at 5% and 2%. Note that the right hand side of the model is assumed to be adequately supported by the support strap.

Following the displacement plots, stresses are shown. The hull stress and rivet region stresses are displayed.

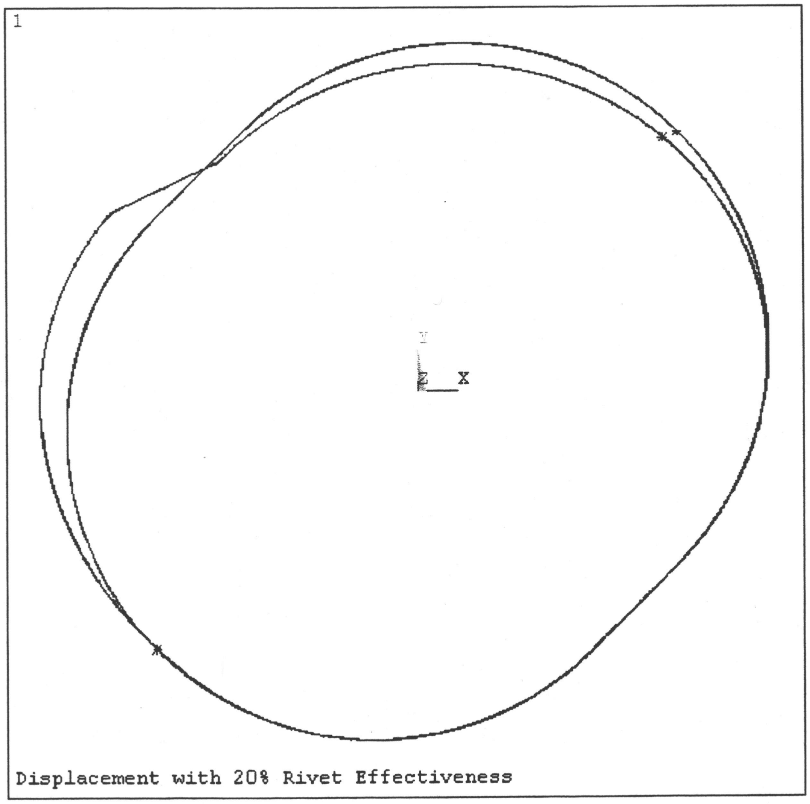


Displacement with 100% Rivet Effectiveness



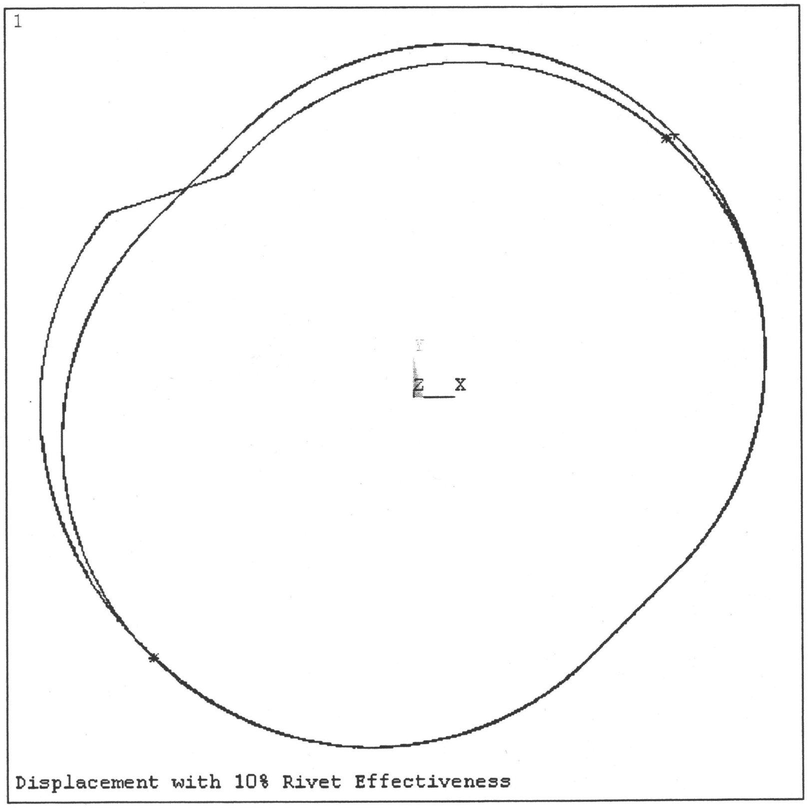
Displacement with 50% Rivet Effectiveness

ANSYS 5.6
JAN 21 2000
06:27:24
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.292103



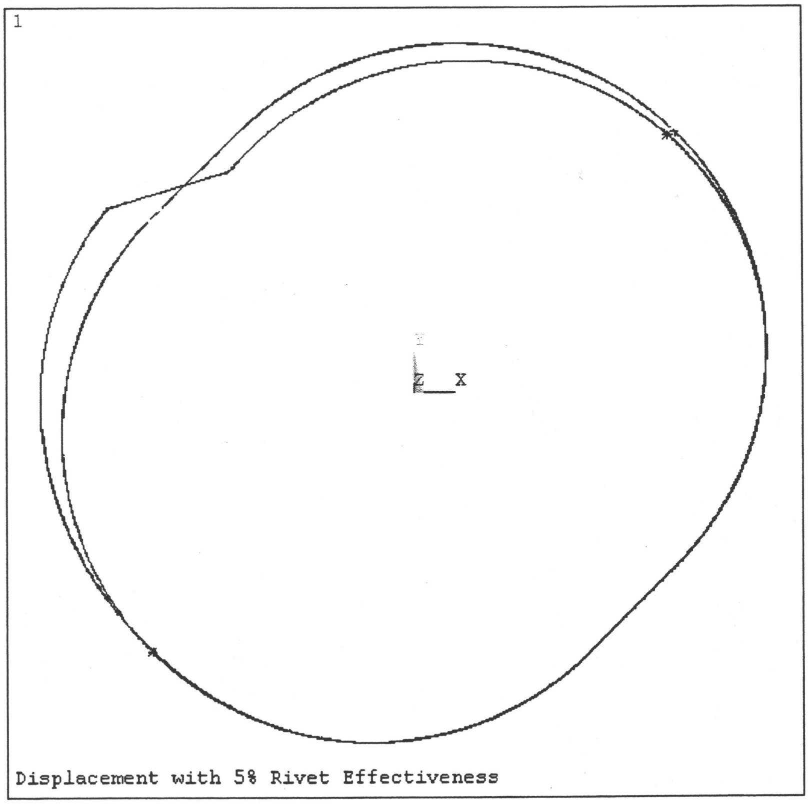
Displacement with 20% Rivet Effectiveness

ANSYS 5.6
JAN 21 2000
06:28:41
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.625032



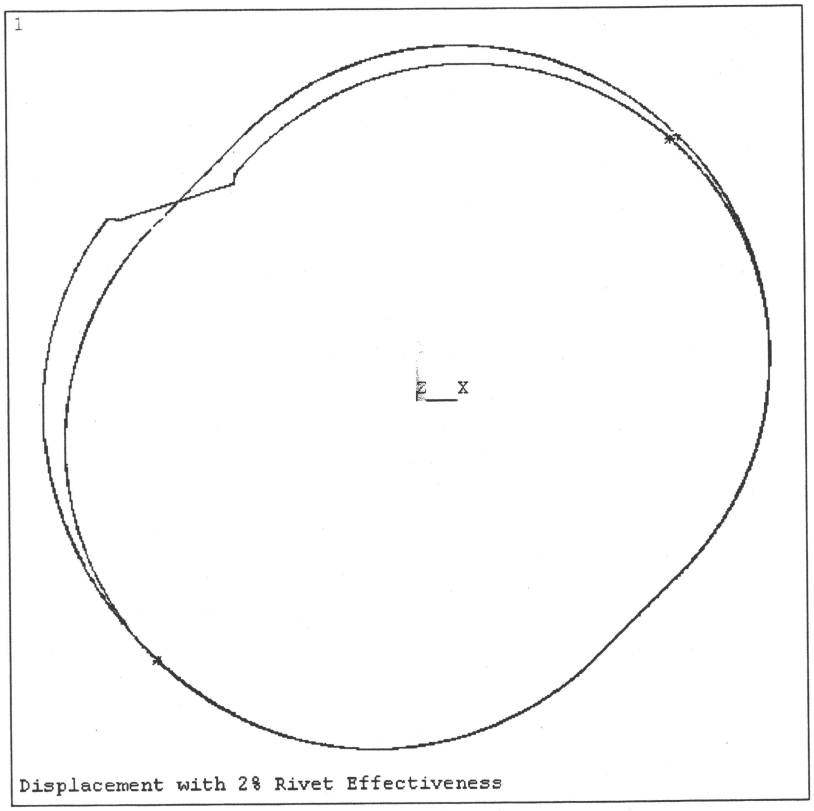
Displacement with 10% Rivet Effectiveness

```
ANSYS 5.6
JAN 21 2000
06:29:54
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =1.352
```



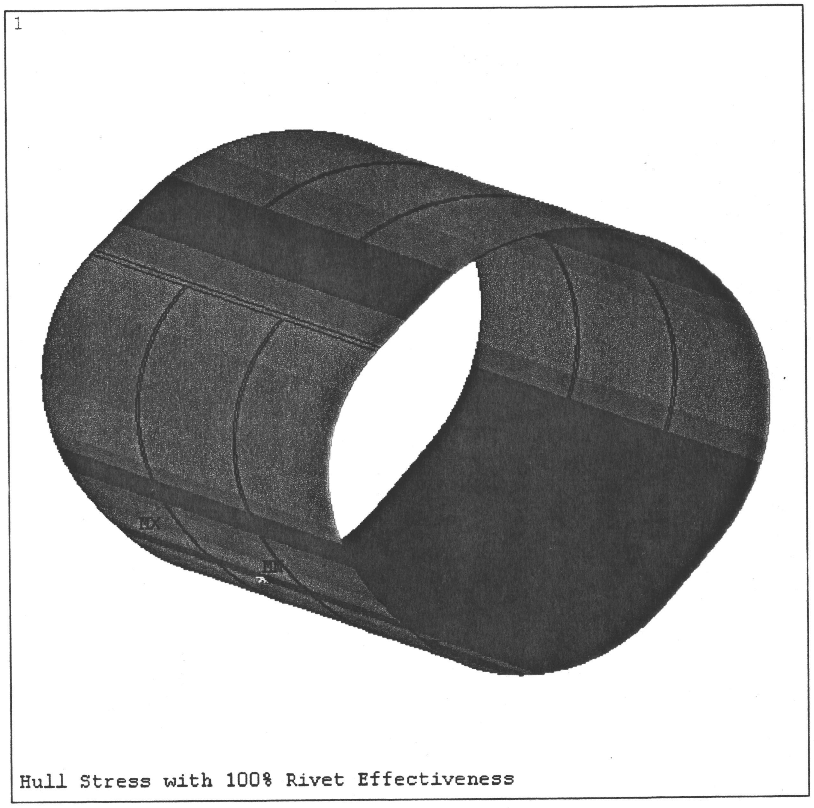
Displacement with 5% Rivet Effectiveness

```
ANSYS 5.6
JAN 21 2000
06:31:07
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =1.529
```



```
ANSYS 5.6
JAN 21 2000
06:31:47
DISPLACEMENT
STEP=1
SUB =1
TIME=1
PowerGraphics
EFACET=1
AVRES=Mat
DMX =1.542
```

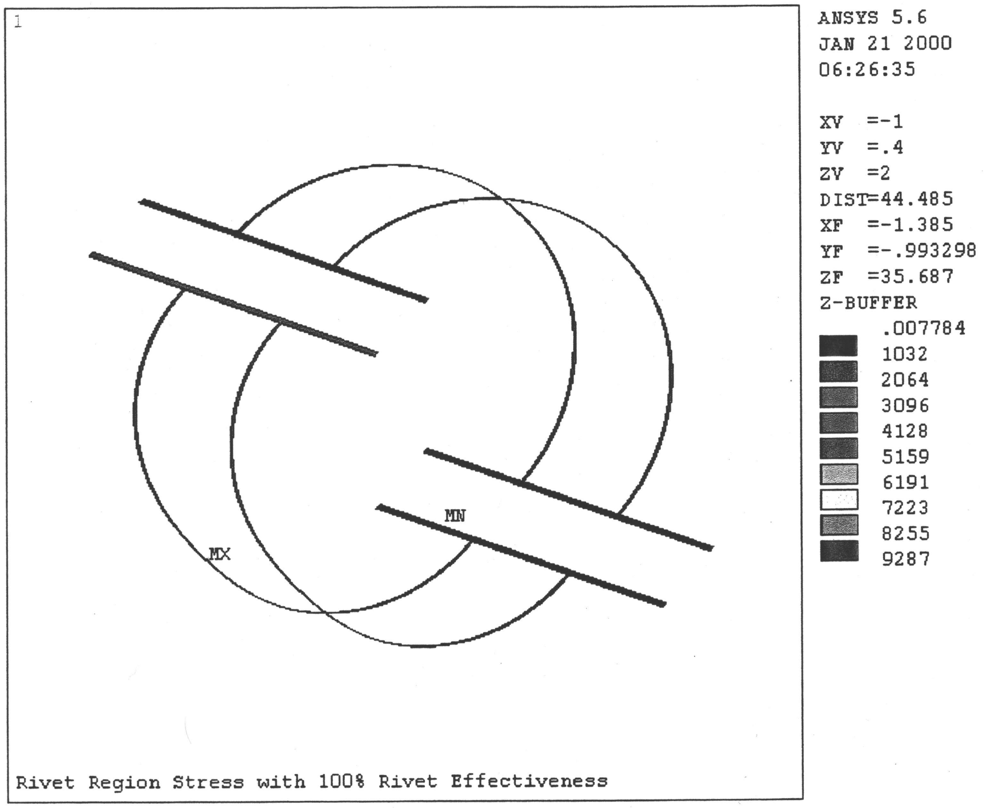
Displacement with 2% Rivet Effectiveness



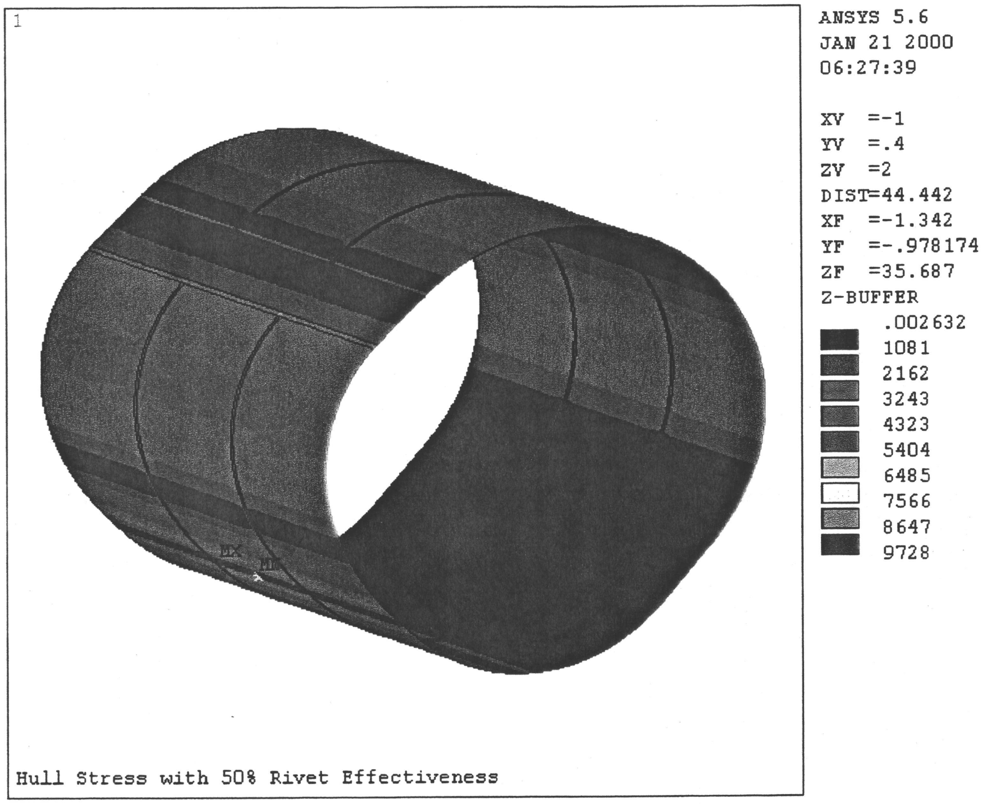
```
ANSYS 5.6
JAN 21 2000
06:26:30

XV  =-1
YV  =.4
ZV  =2
DIST=44.489
XF  =-1.379
YF  =-.993932
ZF  =35.687
Z-BUFFER
     .001971
▨    1037
▨    2074
▨    3111
▨    4148
▨    5185
▨    6221
☐    7258
▨    8295
▨    9332
```

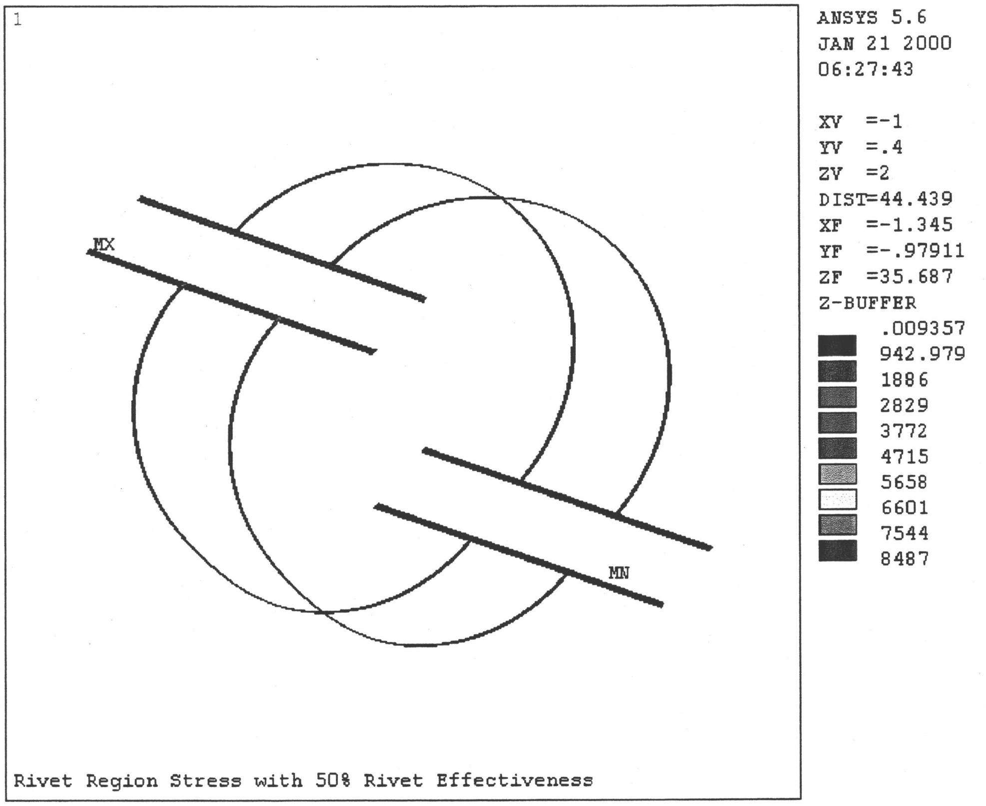
Hull Stress with 100% Rivet Effectiveness



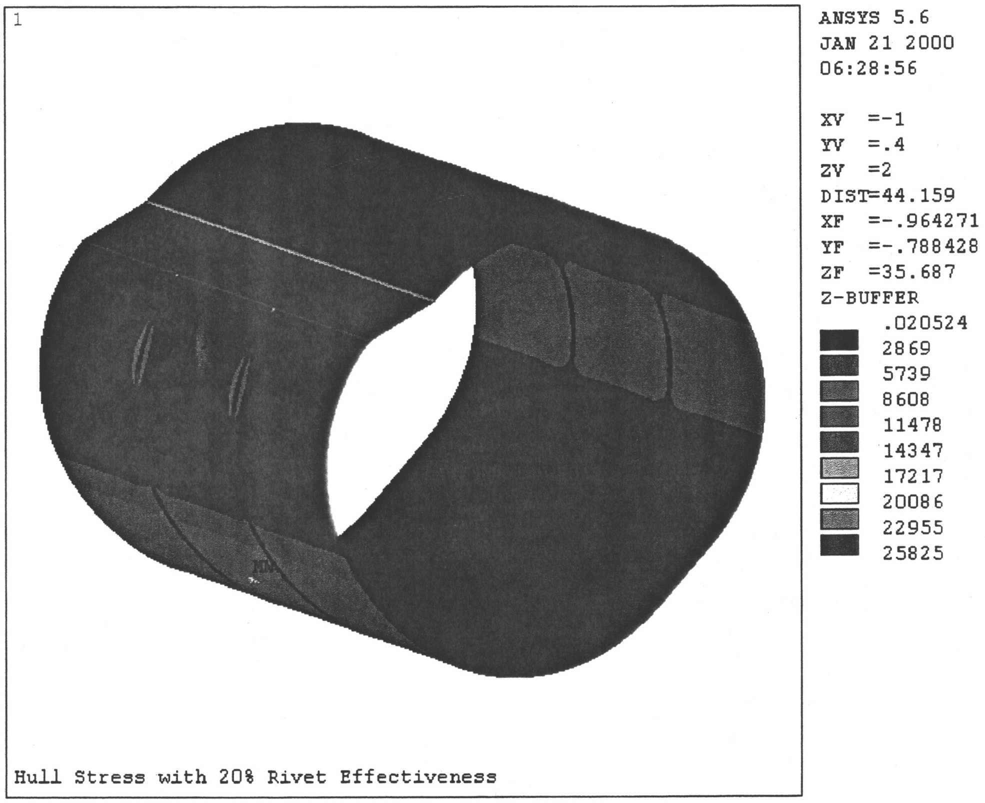
Rivet Region Stress with 100% Rivet Effectiveness



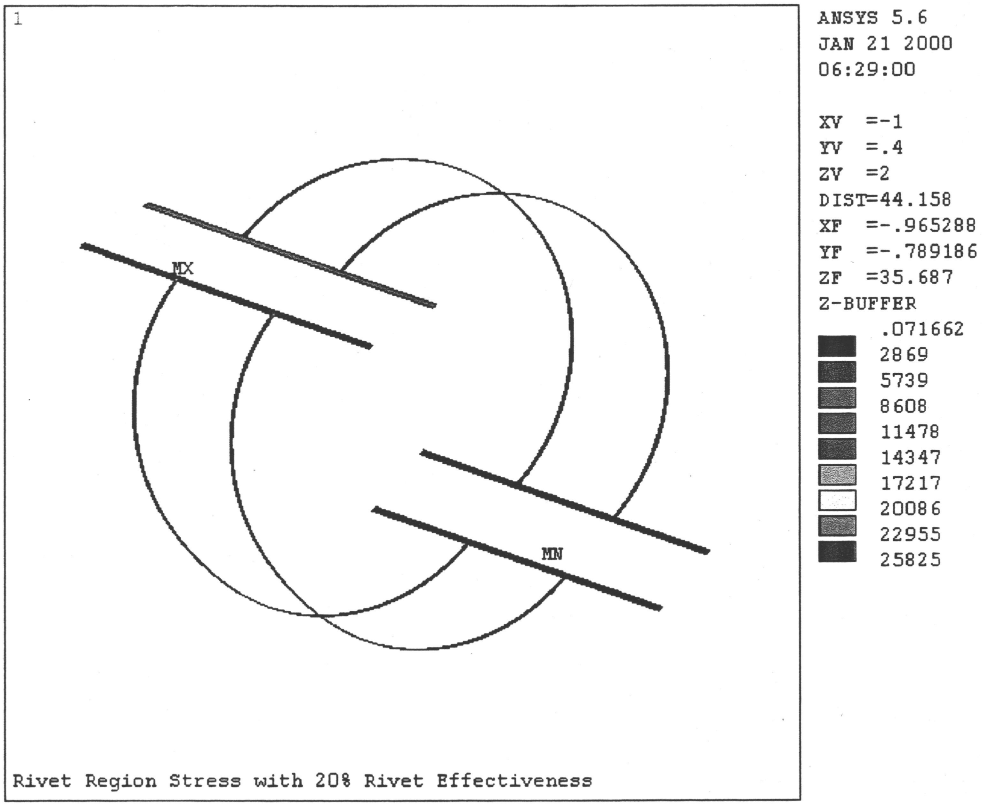
Hull Stress with 50% Rivet Effectiveness



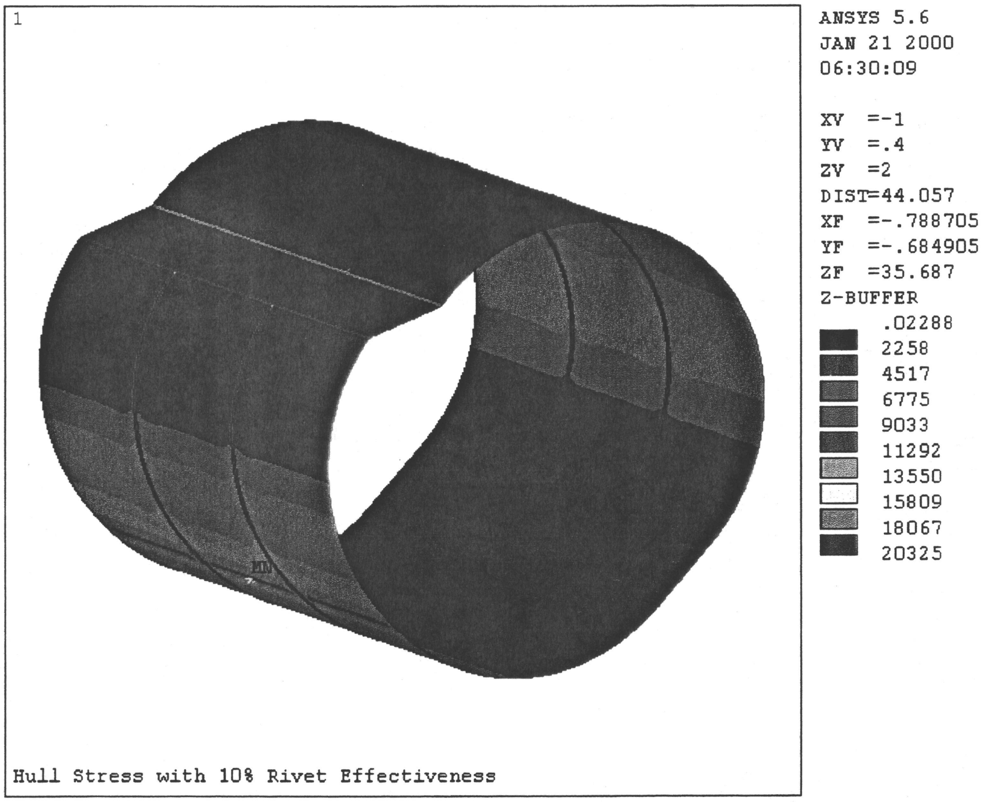
Rivet Region Stress with 50% Rivet Effectiveness



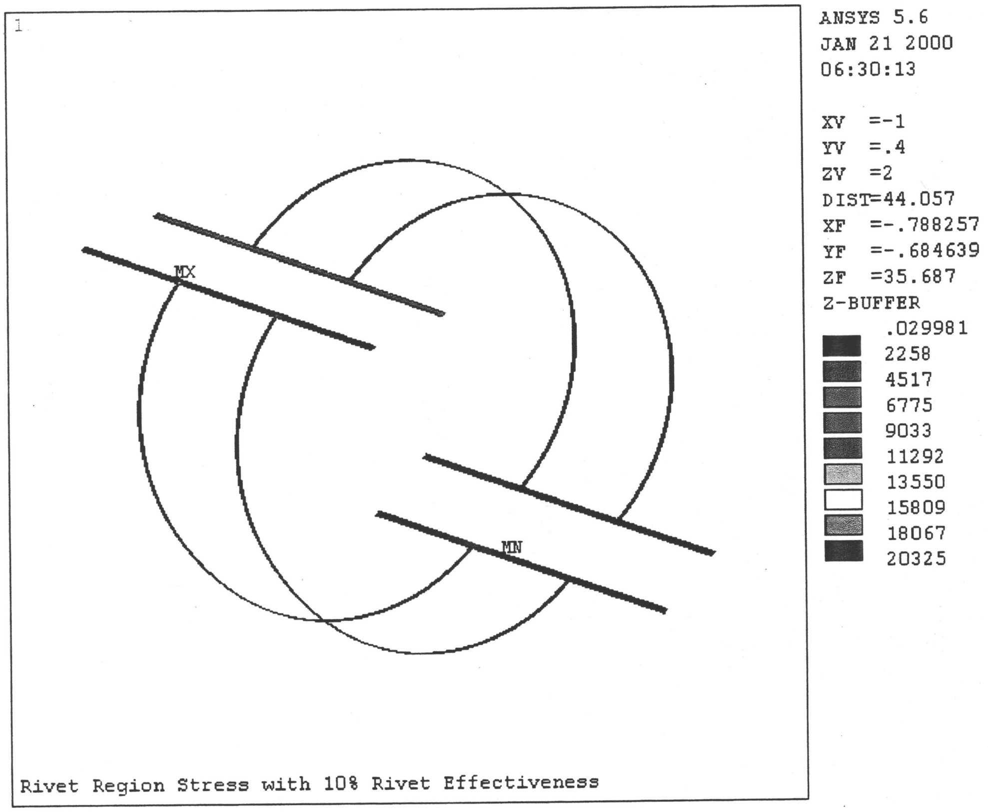
Hull Stress with 20% Rivet Effectiveness



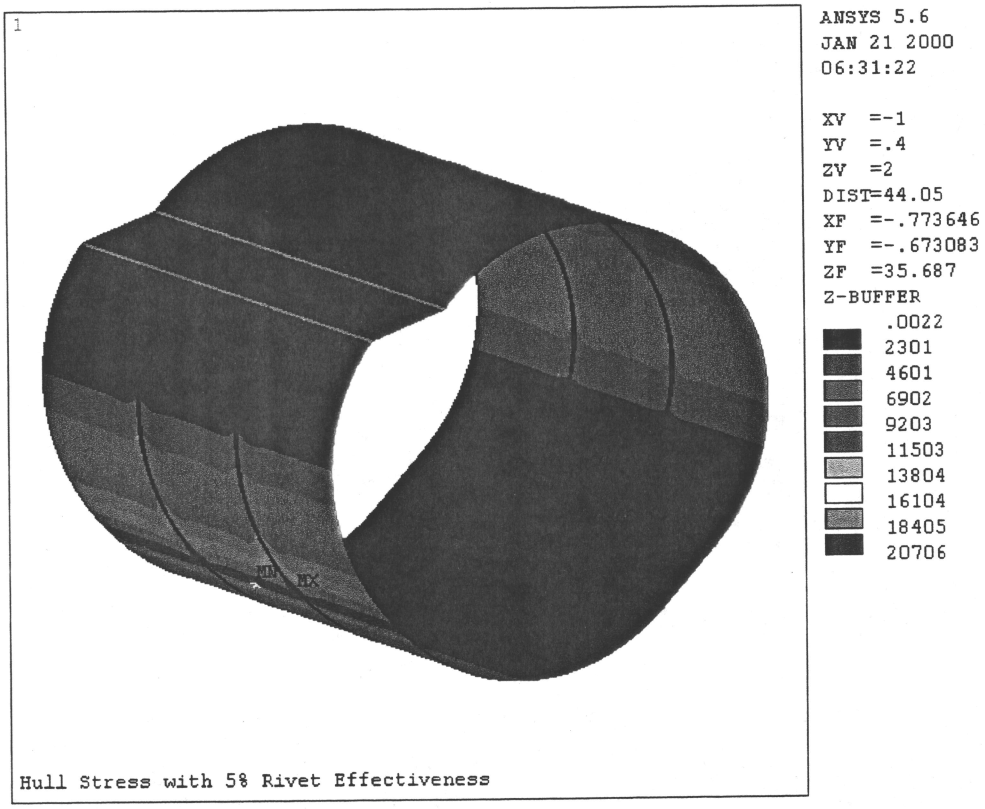
Rivet Region Stress with 20% Rivet Effectiveness



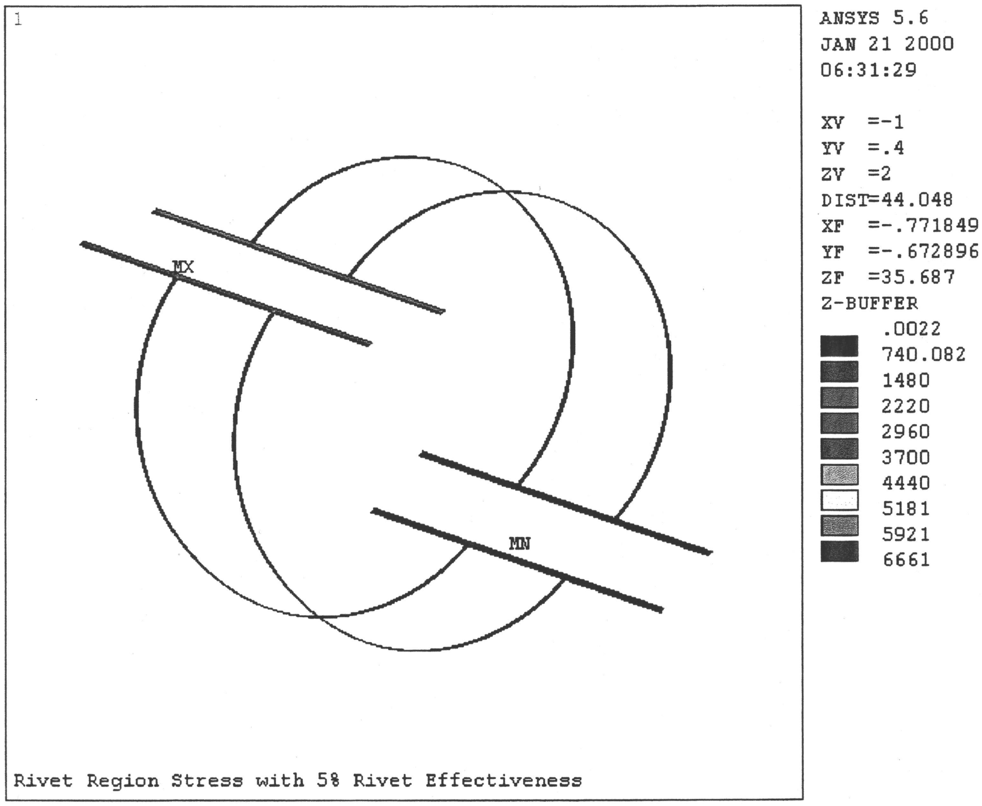
Hull Stress with 10% Rivet Effectiveness



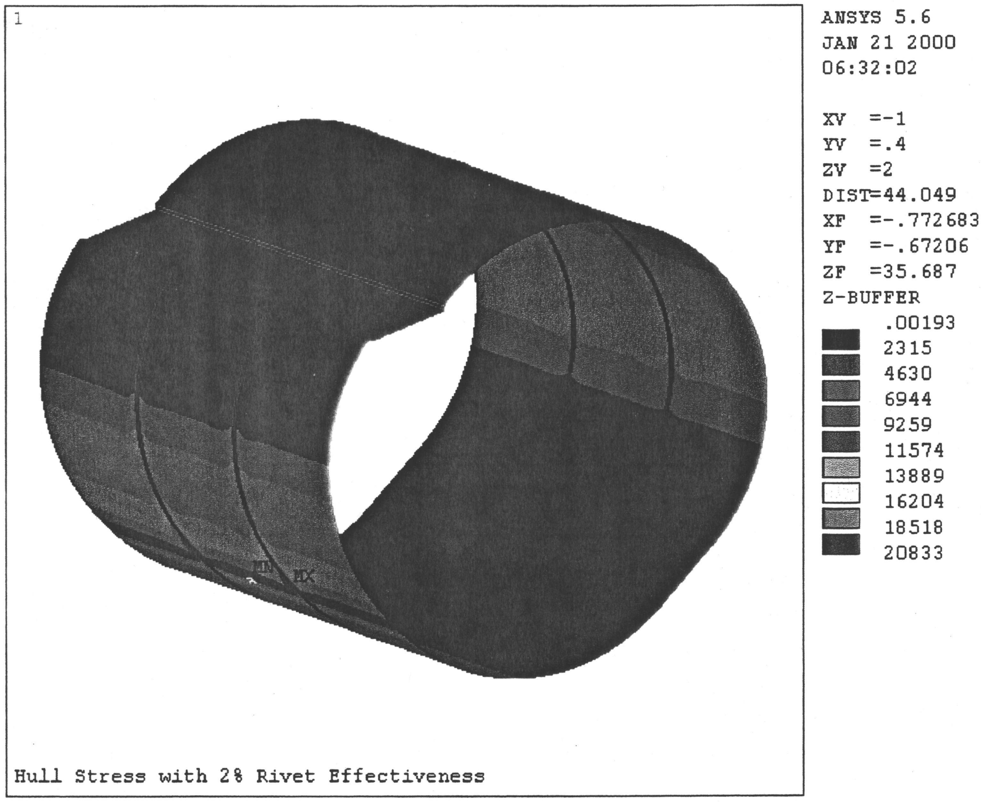
Rivet Region Stress with 10% Rivet Effectiveness



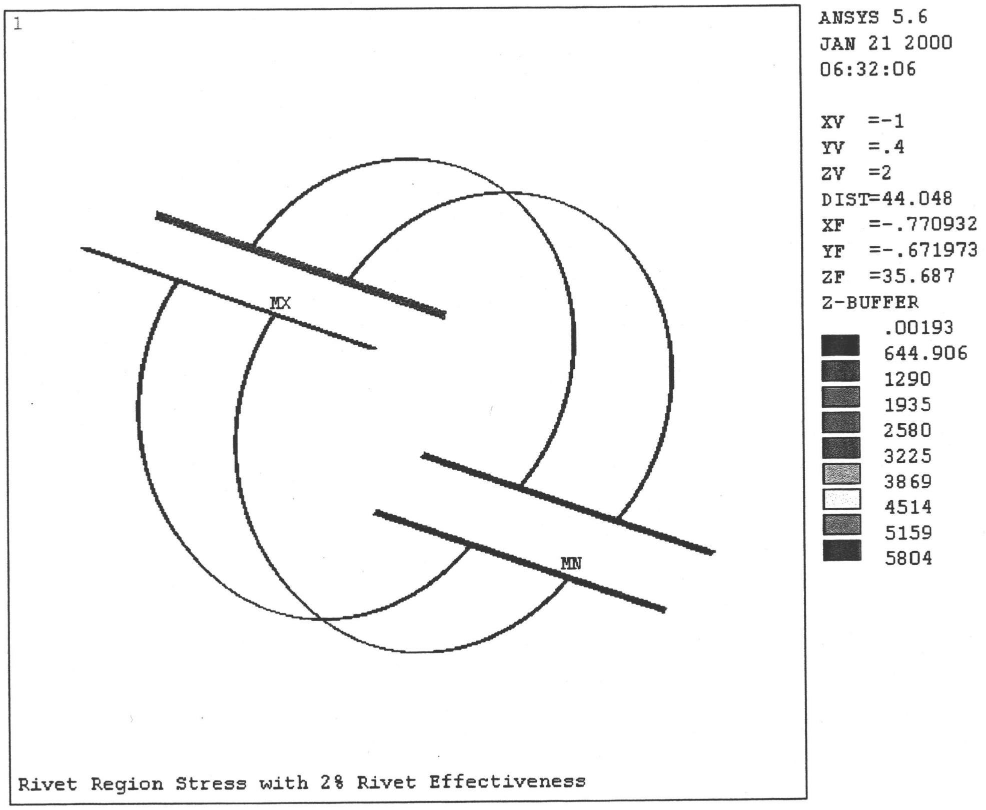
Hull Stress with 5% Rivet Effectiveness



Rivet Region Stress with 5% Rivet Effectiveness



Hull Stress with 2% Rivet Effectiveness



Rivet Region Stress with 2% Rivet Effectiveness

“MX” and “MN” denote the maximum and minimum stresses on the plots. The highest stresses develop in the 100% and 50% cases along the bottom of the hull. This is caused by the restraint at the ballast. As the “kink” develops in the 20% case, maximum stress shifts to the rivet region. Finally as the rivet region becomes very flexible, in the 5% and 2% cases, the maximum stress reverts back to the ballast area. While the stress results may appear counter intuitive, the combined reduction in thickness and elastic modulus account for the effect noted. In the 100% and 50% cases, the pressure load from the contained sand is resisted by membrane action of the hull. At 20% the “kink” develops and bending in the rivet region occurs resulting in high stress. As the stiffness is further reduced, the 5% case, the strake effectively separates from the lower hull and the hull sees bending.

The above suggests that the loss of 50% of the rivet stiffness and thickness is inconsequential. At a greater reduction in rivet capacity, to 20% of the hull, stresses in the rivet region exceed that of the hull. Any further reduction in rivet capacity does not lead to a stress increase in the rivet region. Accordingly, rivet strength 20% of the hull strength appears to be a “worst case”. Considerations of rivet capacity less than 20% does not seem to be warranted.

C. Three Dimensional Solid Finite Element Models

The rivet region is studied further with a three dimensional solid model. A slice of the hull, including backing strips, was generated, see Figure 9. No details of the manner of rivet connection are known. The scheme shown is fairly simple. Many rivet schemes are documented, reference 2, but for the low-pressure application of the Hunley anything more complicated seems unlikely. After a successful recovery, this speculation will be resolved.

Close up view of the rivet region is shown in Figures 10 and 11. The rivet length is 20% of the thickness of the hull and backing strip. The backing strip is assumed to be the same thickness as the hull. All plates are assumed to be separated by 1/16" gap. The rivet spans the gap and extends 1/16" into each adjoining member.

A section of the hull where the circumferential seams abut the strake is isolated for further study. This represents the region where UT measurements were made and is the only region where rivet dimensions are known, see Appendix A. A solid finite element model was generated; see Figures 12 and 13, from the CAD geometry. The edges of the model are restrained with symmetry conditions. The lower edge of the strake is fixed and a 1.35 psig external pressure is applied. The external pressure is derived by dividing the weight of the 2D plane strain model which includes ballast and sand by the linear length of strap to hull contact. The resulting stresses are shown below.

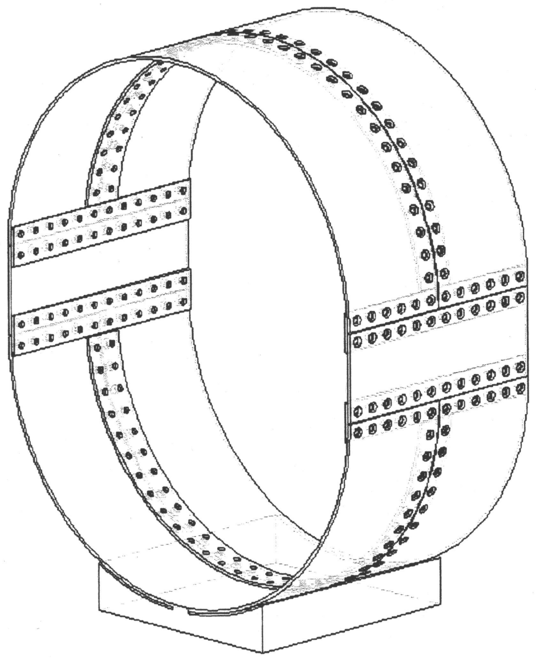


Figure 9 Three Dimensional Solid Slice of Hull

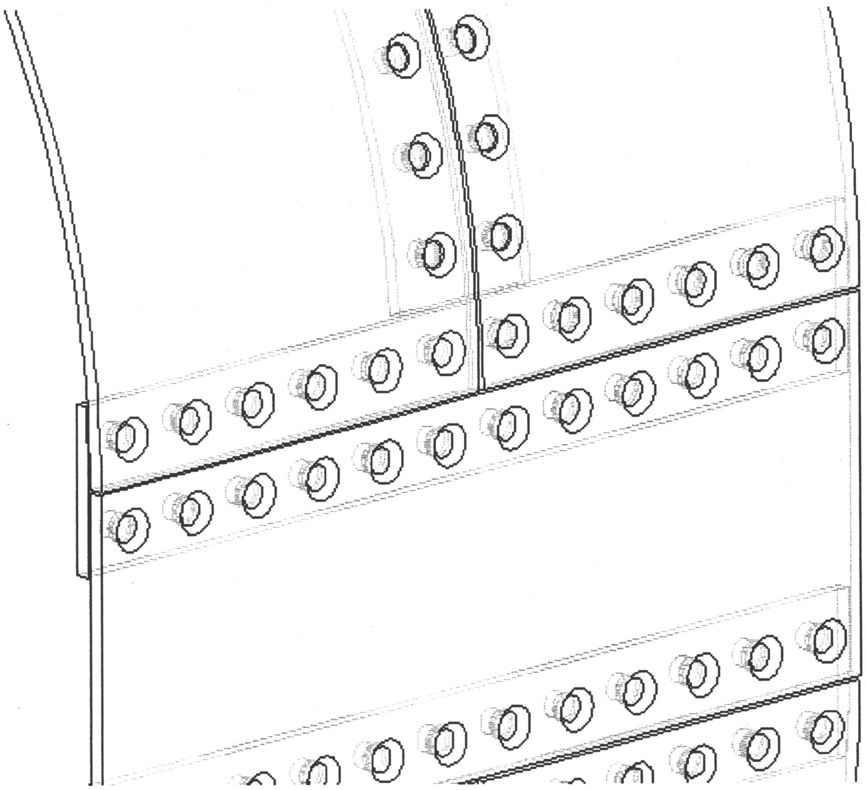


Figure 10 Close Up View of Rivet Region

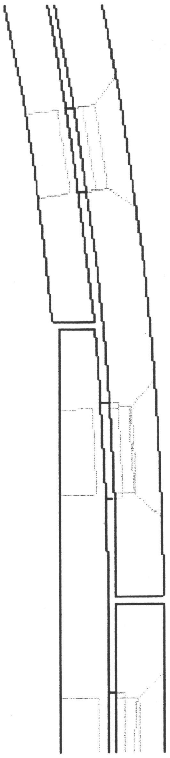


Figure 11 End View Showing Gaps

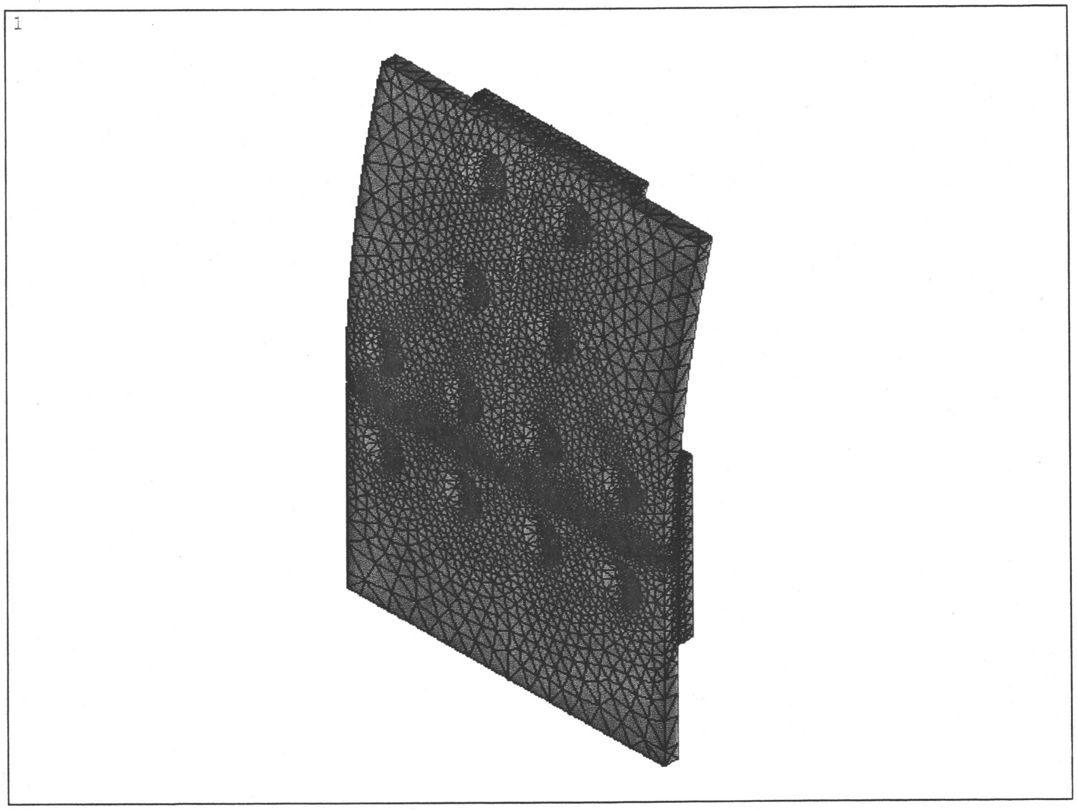


Figure 12 Finite Element Solid Model

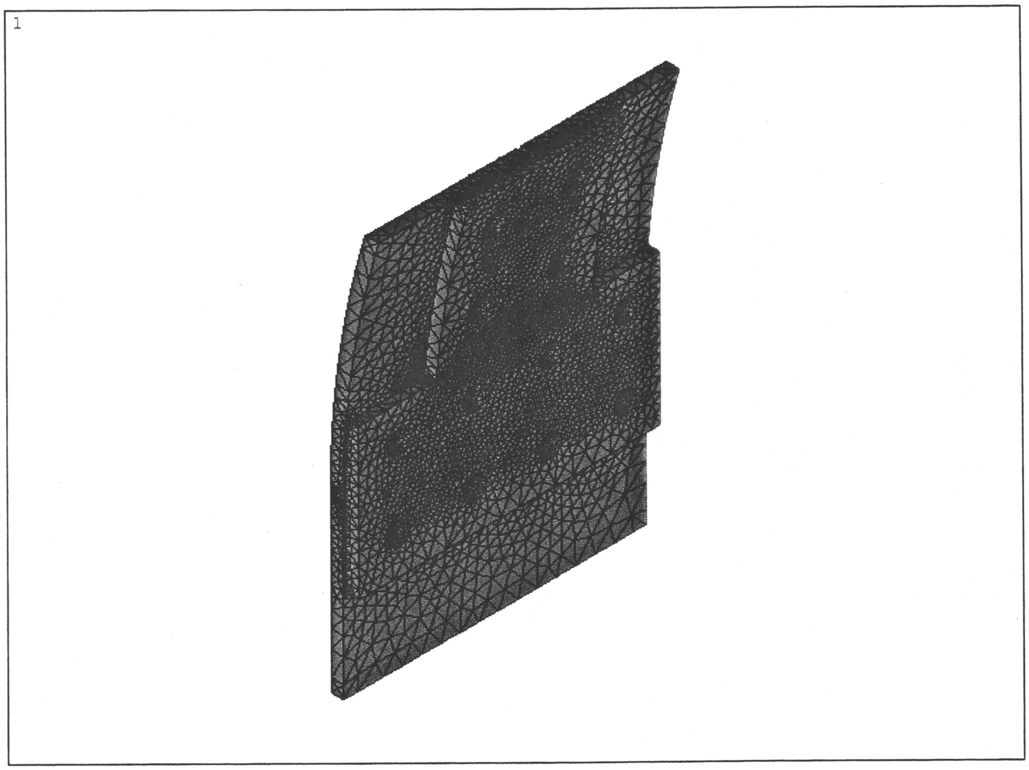


Figure 13 Inside View

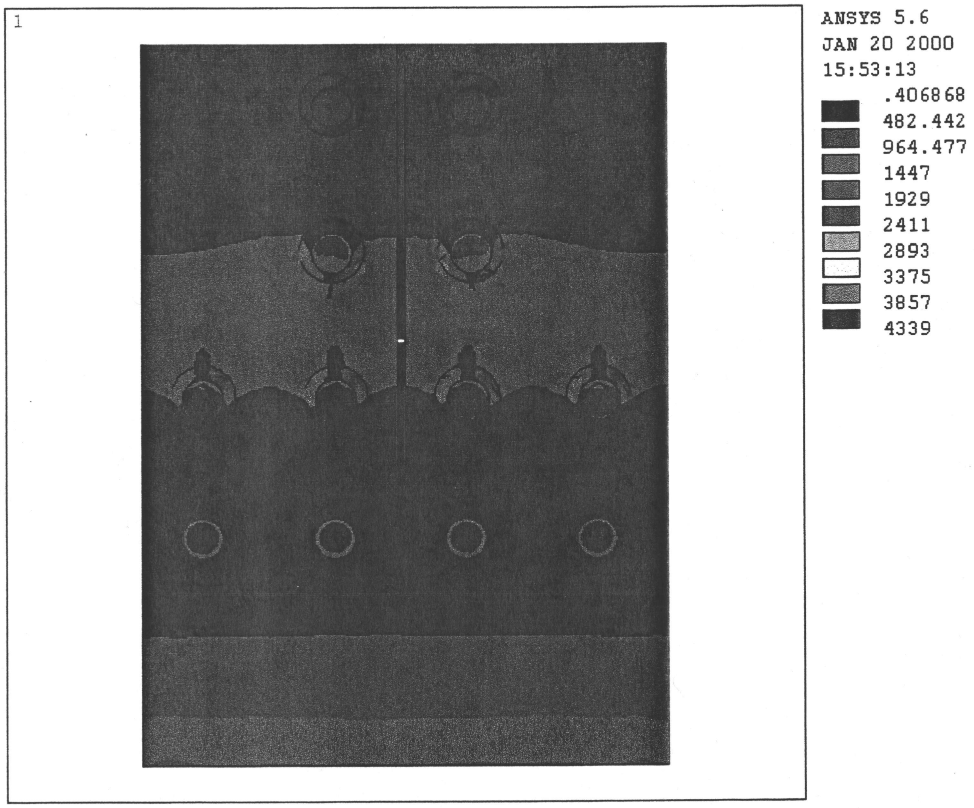


Figure 14 Strake and Hull Stress

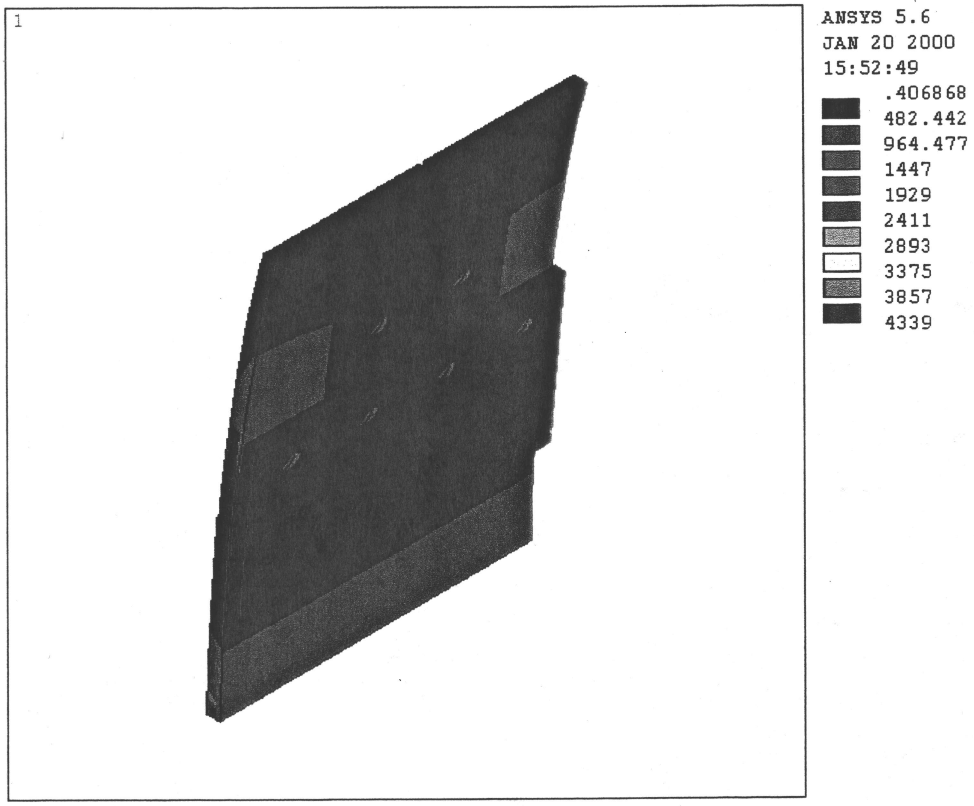


Figure 15 Stress on Inside of Hull

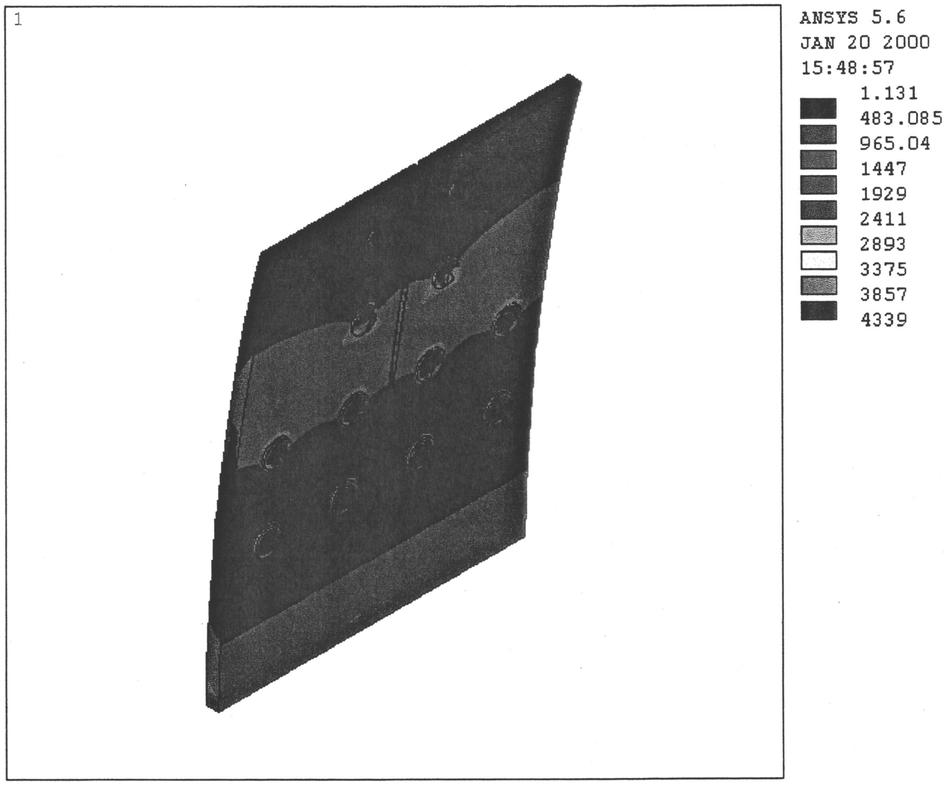


Figure 16 Stress in Rivets

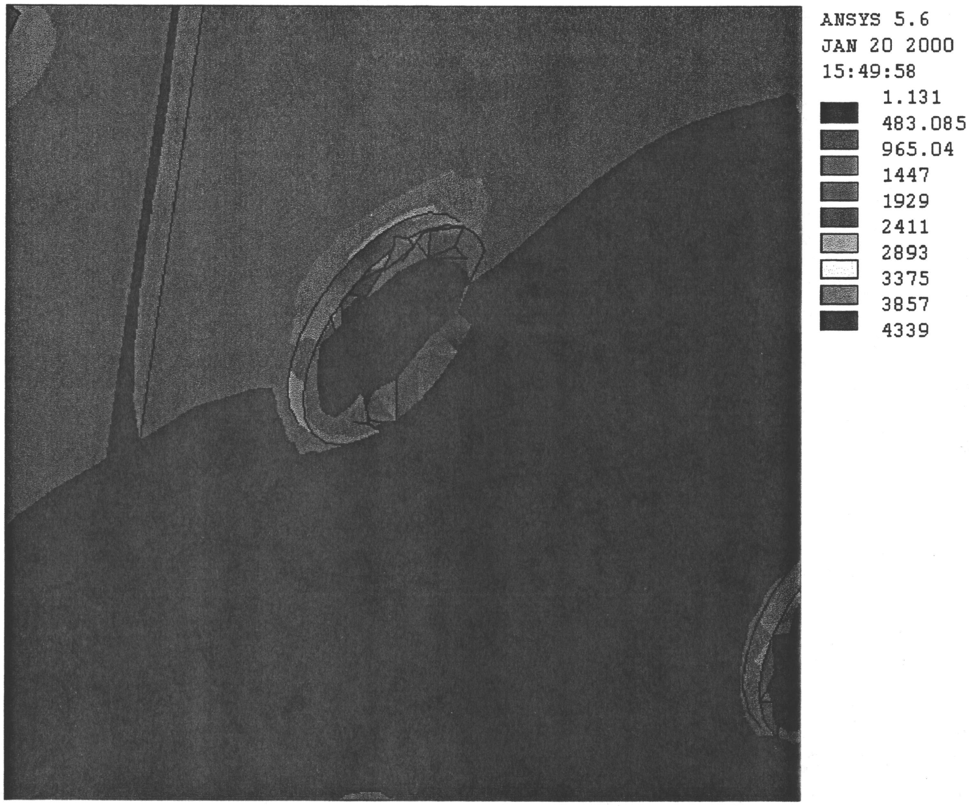


Figure 17 Close Up View of Rivet Stress

The stresses in the riveted hull assembly are shown in Figures 14 from the outside and Figure 15 from the inside. The inner backing strips are removed to reveal stress in the rivets, as shown in Figures 16 and 17.

The stress level in the rivet under the assumed pressure of handling is low relative to the nominal strength of wrought iron. Wrought iron exhibits ultimate compressive strength that varies from 30,000 to 40,000 psi. (reference 3). The stress analysis indicates the rivet stress is less than 20% of the minimum strength and therefore it seems prudent to observe that even for significantly reduced rivet length and engagement, a uniformly loaded hull does not overload rivets.

D. Findings

The objectives of the study were to develop a reasonable level of assurance that the recovery of the Hunley was feasible. This investigation showed that the likelihood that the Hunley would right itself in a sudden manner is remote. The study also showed that the loss of rivet strength greater than 80% will likely produce similar behavior at the riveted connections. The most significant finding however is the need to enclose the hull with straps to contain movement and to apply a uniform pressure to the hull.

E. References

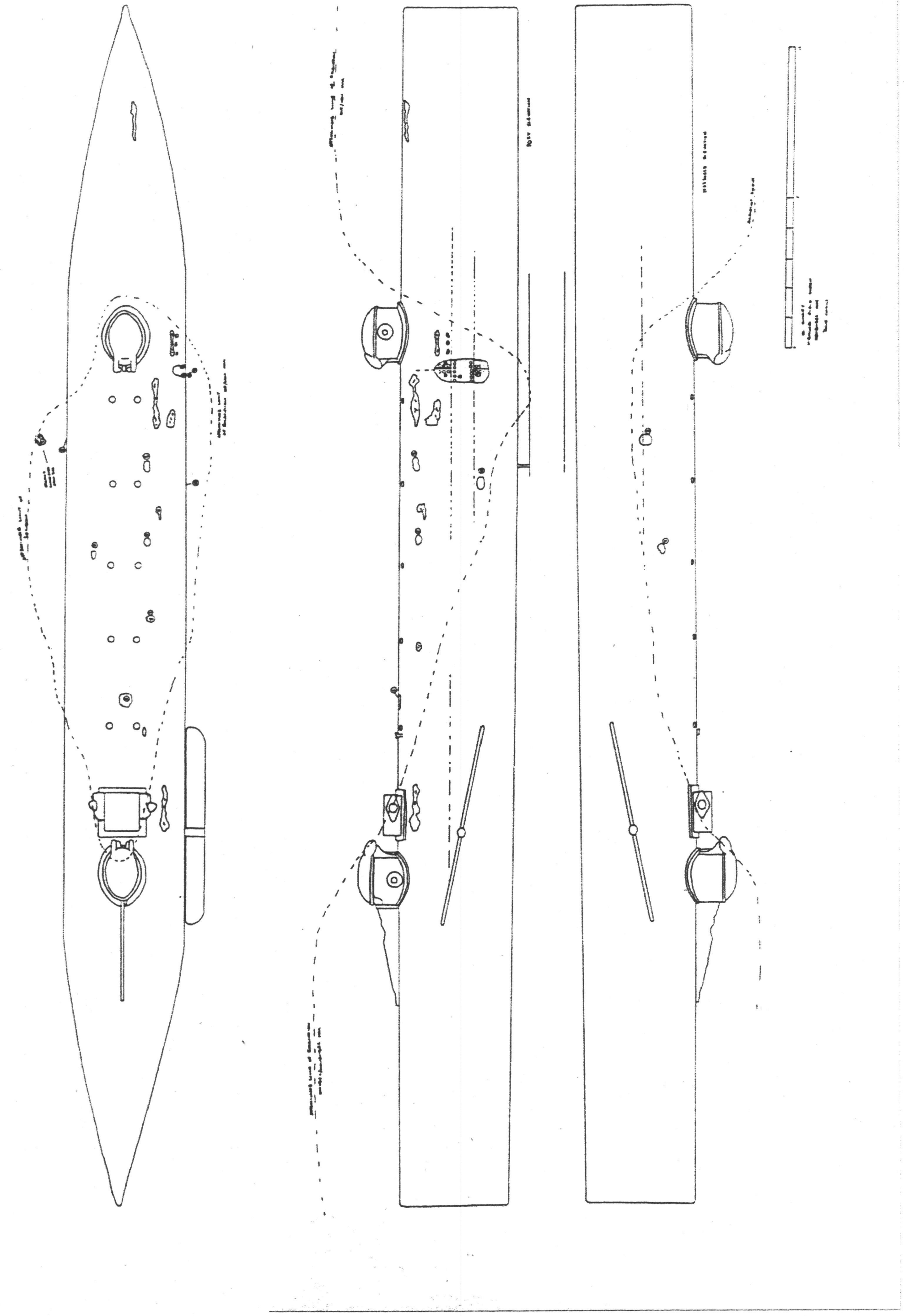
1. H.L. Hunley Site Assessment, National Park Service, Submerged Cultural Resources Unit, 1998, 198 pgs.

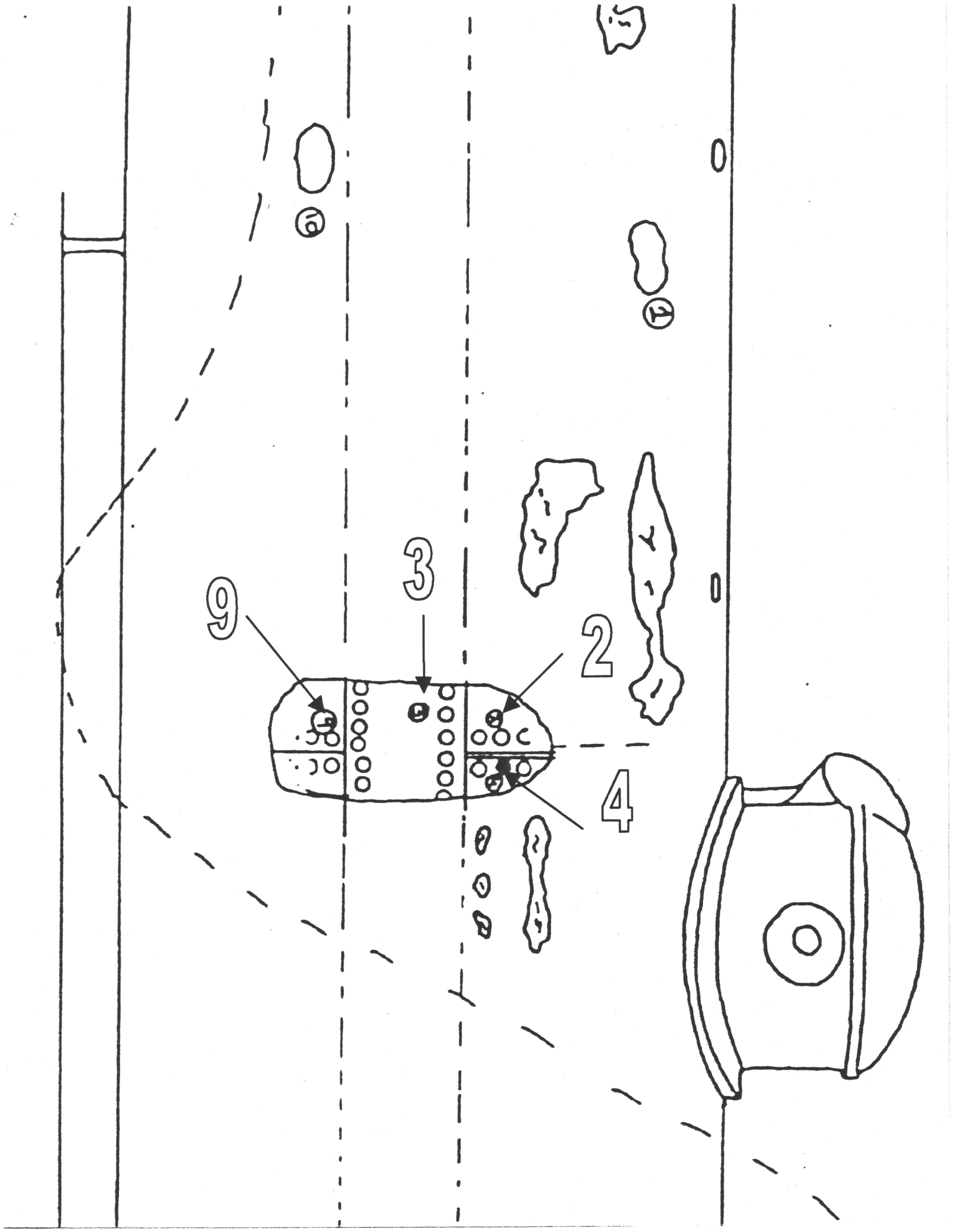
2. S.F. Jester, “Riveted Boiler Joints, A Treatise on the Design and Failure of Riveted Boiler Joints with Numerous Original Diagrams Enabling the Designer to Design any Desired Joint without Calculations”, McGraw Hill, NY, 1917, 155 pgs.
3. Murphy, G., Properties of Engineering Materials”, International Book Co, 1947, pg 198.

APPENDIX C

Hunley Ultrasonic Thickness Data

A diver on the Hunley to illustrate the locations where ultrasonic measurements were made created the figure below.





III. Close-Up of Regions Measured by Divers and Analyzed for Stress

Hunley Ultrasonic Thickness data

Area #1	
1	0.394
2	0.394
3	0.407
4	0.408
5	0.407
6	0.396
7	0.398
8	0.398
9	0.398
10	0.398
11	0.398
12	0.398
13	0.397
14	0.398
15	0.399
16	0.398
17	0.398
18	0.398
19	0.398
20	0.397
21	0.396
22	0.399
23	0.398
24	0.396
25	0.397
26	0.396
27	0.399
28	0.406
29	0.406
30	0.404
31	0.406
32	0.406
33	0.411
34	0.404
35	0.406
36	0.416
37	0.414
38	0.414
39	0.415
40	0.412
41	0.423
42	0.422
43	0.415
44	0.398
Mean	0.403
Range	0.029
Std.Dev.	0.008

Area #2	
1	0.338
2	0.334
3	0.333
4	0.333
5	0.338
6	0.336
7	0.339
8	0.317
9	0.370
10	0.315
11	0.350
12	0.320
13	0.321
14	0.317
15	0.333
16	0.315
17	0.319
18	0.344
19	0.356
20	0.356
21	0.381
22	0.343
23	0.343
24	0.343
25	0.339
26	0.338
27	0.341
28	0.338
29	0.340
30	0.334
31	0.348
32	0.347
33	0.348
34	0.351
35	0.348
36	0.373
37	0.340
38	0.339
Mean	0.340
Range	0.066
Std.Dev.	0.015

Area #3	
1	0.380
2	0.380
3	0.373
4	0.406
5	0.406
6	0.407
7	0.406
8	0.404
9	0.404
10	0.404
11	0.404
12	0.404
13	0.404
14	0.404
15	0.404
16	0.404
17	0.404
18	0.329
19	0.391
20	0.293
21	0.294
22	0.291
23	0.294
24	0.288
25	0.289
26	0.288
27	0.287
28	0.299
29	0.290
30	0.294
31	0.288
32	0.288
33	0.366
34	0.366
35	0.366
36	0.366
37	0.366
38	0.366
39	0.366
40	0.366
41	0.366
42	0.366
43	0.366
44	0.366
45	0.366
46	0.363
47	0.367
48	0.367
49	0.393
50	0.298
51	0.295
52	0.283
53	0.369
54	0.371
55	0.373
56	0.383
57	0.389
58	0.391
59	0.391
60	0.391
61	0.390

Area #5	
1	0.417
2	0.416
3	0.416
4	0.416
5	0.416
6	0.417
7	0.417
8	0.417
9	0.416
10	0.417
Mean	0.417
Range	0.001
Std.Dev	0.001

Area #6	
1	0.326
2	0.351
3	0.349
4	0.348
5	0.348
6	0.349
7	0.348
8	0.348
9	0.348
10	0.348
11	0.347
12	0.348
13	0.348
14	0.348
15	0.350
16	0.351
17	0.351
18	0.350
19	0.348
20	0.351
21	0.351
22	0.350
23	0.350
24	0.350
25	0.351
26	0.351
27	0.348
28	0.353
29	0.351
30	0.351
31	0.353
32	0.364
33	0.363
34	0.370
35	0.385
36	0.384
37	0.384
38	0.385
39	0.385
40	0.385
41	0.383
42	0.383
43	0.383
44	0.383
45	0.382
46	0.383
47	0.383
48	0.382
Mean	0.360
Range	0.059
Std.Dev.	0.016

Area #7	
1	0.363
2	0.363
3	0.363
4	0.365
5	0.364
6	0.362
7	0.364
8	0.363
9	0.363
10	0.365
11	0.365
12	0.366
13	0.365
14	0.365
15	0.366
16	0.364
17	0.365
18	0.365
19	0.365
20	0.369
21	0.369
22	0.370
23	0.336
24	0.336
25	0.332
26	0.314
27	0.299
28	0.299
29	0.300
30	0.300
31	0.322
32	0.322
33	0.415
34	0.411
35	0.411
36	0.413
37	0.411
38	0.414
39	0.413
40	0.415
41	0.416
42	0.416
43	0.406
44	0.407
45	0.407
46	0.407
47	0.406
Mean	0.369
Range	0.117
Std.Dev.	0.035

Area #8	
1	0.372
2	0.372
3	0.372
4	0.372
5	0.372
6	0.373
7	0.372
8	0.372
9	0.372
10	0.372
11	0.372
12	0.373
13	0.373
14	0.372
15	0.372
16	0.372
17	0.372
18	0.372
19	0.372
20	0.372
21	0.372
22	0.373
23	0.374
24	0.373
25	0.372
26	0.372
27	0.370
28	0.370
29	0.370
30	0.375
31	0.376
32	0.376
33	0.375
34	0.376
35	0.376
36	0.377
37	0.376
38	0.376
39	0.375
40	0.376
41	0.377
42	0.376
43	0.376
44	0.376
45	0.376
46	0.376
47	0.376
Mean	0.374
Range	0.007
Srd.Dev.	0.002

Area #9	
1	0.313
2	0.312
3	0.321
4	0.312
5	0.309
6	0.307
7	0.307
8	0.307
9	0.307
10	0.307
11	0.308
12	0.357
13	0.358
14	0.358
15	0.359
16	0.359
17	0.359
18	0.358
19	0.359
20	0.358
21	0.359
22	0.358
23	0.359
24	0.359
25	0.359
26	0.359
27	0.359
28	0.359
29	0.358
30	0.358
31	0.359
32	0.359
33	0.361
34	0.343
35	0.343
36	0.343
37	0.343
38	0.343
39	0.343
40	0.343
41	0.343
42	0.343
43	0.343
44	0.343
45	0.343
46	0.342
47	0.343
48	0.343
49	0.343
50	0.343
51	0.316
52	0.316
53	0.316
Mean	0.341
Range	0.050
Std.Dev	0.019

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	
39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	
50	
51	
52	
53	
54	
55	
56	
Mean	
Range	
Std.Dev.	

Appendix C
Resumes

LEONARD T. WHITLOCK
1687 Kingsbridge Court
Annapolis, MD 21401

Experience Summary

More than 24 years with specialized experience related to engineering, design, manufacturing and operation of specialized deep ocean ROV, manned submersibles, and diver tools; USN underwater ship repair; supervision of submersible lock-out diving operations; Unmanned Underwater Vehicle (UUV) mine search systems; underwater nondestructive testing (NDT) and inspection of USN facilities; and project management of complex marine operations.

Education

Florida Institute of Technology, 36 credit hours toward major, School of Marine & Environmental Technology, Associate of Science in Oceanographic Technology, 1971.

Florida Institute of Technology, 72 credit hours toward major, School of Marine & Environmental Technology, Bachelor of Science in Oceanography/Ocean Engineering, 1973.

College of Oceaneering, Diploma in Underwater Technology- Saturation and Mixed Gas Diving, Diver Medic & Life Support, 1975.

Johns Hopkins University, Master of Science in Technical Management (in progress, 24 credit hours completed), 1998.

Employment History

Oceaneering International, Inc. Upper Marlboro, MD Program Manager 1993-Present

Program Manager for the Submarine Rescue Diving Recompression System (SRDRS) under contract with NAVSEA to develop the initial conceptual design of the Pressurized Rescue Module (PRM), the preliminary design of the Submarine Decompression System (SDS) and the Concept of Operations for the next generation of US Navy submarine rescue system. He has been responsible for the technical performance, cost control and delivery schedule for SRDRS during the past 18 months. He is also the East Coast point of contact for PMS 395, Deep Submergence Unit Program for the Unmanned Vehicles Planning Yard.

Previously, he has been Program Manager on a classified deep ocean work package system and for the Naval Research Laboratory's feasibility study for the Deep Ocean Relocation of Contaminated Sediments. This research and development program investigated the use of various delivery vehicles down to 15,000 FSW and the use of a resident autonomous underwater vehicle for monitoring the environmental impact.

Lockheed Engineering & Science Corporation, San Diego, CA Test Director 1989-1993

Directly responsible for the development, scheduling, implementation and supervision of prototype testing for the DARPA/Navy Unmanned Underwater Vehicle (UUV) Program. His assignments included: daily planning and scheduling; participating Joint Test Group member; writer & editor of test and evaluation master plan, test implementation documentation and report documentation; design review presentations and interfacing with the DARPA/Navy Program Office; review of software generated test dive profiles and responsibility for overall safety of test operations. Supervised and directed UUV test operations that included subsystem integration, open ocean system testing and final demonstration on a Navy acoustic test range. Security Coordinator for off-site facility security, Automated Information System (AIS) and test documentation classification. He was lead author for the test and evaluation section of the winning proposal for Mine Search System UUV.

American Bureau of Shipping, New York, NY Senior Field Engineer 1984-1989

Reviewed and verified for compliance to industry and regulatory specifications, codes, and standards the fabrication and installation procedures of offshore structures, deepsea moorings and subsea pipelines for domestic and international projects. Directly responsible for on-site verification worldwide of the installation of offshore structures, moorings and subsea pipelines, including heavy lifts, pile driving, positioning, as-laid surveys, subsea trenching, and hydrostatic testing. He reviewed and site-verified for compliance to industry and regulatory specifications, codes and standards the in-service inspections of offshore platforms and subsea pipelines including damage surveys, photogrammetric & stereo photography, underwater nondestructive testing and cathodic potential measurements using undersea vehicles and divers. Developed and maintained databases, spreadsheets and manpower loading for project coordination.

Oceaneering International, Inc., Houston, TX Program Manager 1978-1984

Managed international offshore projects, including bid proposals, contract negotiation, logistical support, manpower loading, and project cost accounting. **January '83 - General Manager - Trinidad, West Indies -** Responsible for the operations and administration of a joint venture offering marine technical services. **May '81 - Program Manager - Los Angeles, CA -** Developed and managed in-house technical training programs in nondestructive testing and underwater inspection. Supervised the program conception, budget planning, production scheduling, editing, and implementation. **February '81 Staff Engineer - Houston, TX -** Assisted in preparing bids, specifications and proposals for marine construction projects in the Caribbean and North America, and provided technical sales support. **January '77 to February '81 - Assistant Supervisor / Senior EMT - Durham, NC -** Participated as a diver medic in a series of experimental research dives at Duke University to monitor cardiopulmonary and neurological responses to mixed gases to a simulated depth of 2250 feet. **Gulf of Mexico -** Participated in the repair of offshore platforms using hyperbaric welding techniques. Supervised qualification of welding procedures and diver/welders. **Brunei, South China Sea -** Assisted in the start-up operations and development of an inspection program for over 200 structures, and marine construction operations. **Brazil -** Assisted in saturation diving operations for exploration drilling support and installation of subsea production modules.

Harbor Branch Foundation, Ft. Pierce, FL Submersible Life Support Specialist 1975-1977

Supervised submersible lock-out diving operations to support of oceanographic research. He assisted in the design certification to ABS Rules and fabrication of a 4-man submersible rated for 2000 feet of sea water.

Florida Institute of Technology, Melbourne, FL Assistant Diving Officer 1973-1975

Responsible for development, production, and implementation of college-level training courses in SCUBA, diving physiology, hyperbaric chamber operations, advanced life support, and underwater photography.

SECURITY CLEARANCE: **SECRET, 27 May 1994, DISCO, Active; SSBI, Inactive**

Steve Wright
2211 Shore Drive
Edgewater, Maryland 21037

Experience Summary

Over 20 years of experience in offshore diving, ROV and underwater industry. I have been involved in the design, fabrication, testing, operation, and repair of manned and unmanned diving, hyperbaric, and deep submergence systems. The last twelve years have been primarily as a project manager on deep ocean search and recovery operations. Background includes contract negotiations, proposal manager and writer on several multi-million dollar proposal efforts.

Experience has also been attained in the Civil Engineering field as a survey crew party chief in Alaska, and as a rigger, welder, crane operator, and heavy equipment operator throughout the U.S and overseas. A licensed pilot for single engine aircraft, and holds a Department of Defense security clearance rated Secret.

Education

BS, Business Administration, Washington State University, 1973
Certificate in Air/Mixed Gas Diving, D-102 College of Oceaneering
Certificate in Magnetic Particle and Ultrasonic Inspection, Lloyds of London
United Kingdom Diver Training Certificate, Part II, No.II/853/82

Employment History

Oceaneering International, Inc. Upper Marlboro, MD Program Manager 1988 to Present

Liberty Bell 7 recovery, Project Manager. Successfully located and recovered Gus Grissom's Mercury Capsule from 16,000 fsw in the Atlantic Ocean near the Bahamas. This operation was performed for the Discovery Channel and was the subject of a 2 hour television documentary broadcast in December 1999.

Swissair Flight 111 recovery, Project Manager. Successfully performed recovery of major items of interest in investigation of Swissair Flight 111 crash, including over 400 hours of bottom time in 20 days of offshore operations using a US Navy owned ROV.

Nitrox Breathing Gas System for Johnson Space Center, Project Manager. Responsible for the design, fabrication, and installation of a Nitrox Breathing Gas system for NASA's Neutral Buoyancy Training Facility. This approximately $3M system was provided on a turnkey fixed price contract and was completed under budget and over 2 months ahead of schedule.

World Record Deepwater Salvage, Project Manager. Performed the deepest successful salvage ever, with the recovery of a CH-46 helicopter from over 17,250 fsw near Wake Island. The helicopter was recovered in two pieces over the course of two months and several new methods of attaching lift lines at extreme depths were perfected.

US Navy Submarine Hull Test Program, Operations Manager. Directed engineers and technicians in the evaluation of US Navy certified and AWS certified welding techniques to be used for the SSN 21 Seawolf Class submarine program.

CH-46 Helicopter Salvage, Project Manager. Directed the mobilization and operation to recover CH-46 helicopters from the waters off Mogadishu Somalia. On two different occasions I directed the mobilization of equipment from the US by sea freight and the charter of a US Air Force CVB Galaxy aircraft, installation of the equipment aboard a US Navy vessel in Mambasa Kenya and the successful recovery of the helicopters.

20,000 foot Heavy Lift System, Project Manager. Supervised the modification of a deep ocean mining system for use as a 20 ton capacity 20,000 fsw capable heavy lift system for ROV salvage. Subsequently employed the heavy lift system on several projects including the salvage of a 747 aircraft in the southern Indian Ocean.

College of Oceaneering, Wilmington, CA Director of Saturation Diving & Rigging 1985-1986

Responsibilities included upgrading the College's curriculum to the latest standards for North Sea Certification. Other duties included design, fabrication, and installation of all equipment used in the saturation diving program, and teaching classes in commercial diving techniques.

Wharton Williams, Bombay, India Off shore Supervisor 1982-1984

Directed saturation and surface diving crews in installation, maintenance, and inspection of offshore loading facilities, pipelines, and oil production platforms.

Global Diving Services, Aberdeen, Scotland Offshore Supervisor 1980-1982

Directed construction and inspection programs involving saturation, surface mixed gas and surface air diving operations primarily in the North Sea, West Africa, and India.

Subsea International. Aberdeen, Scotland Diver 1979-1980

Performed air and mixed gas diving operations in the North Sea.

Universal Services, Inc. Seattle, WA Offshore Supervisor 1975-1978

Directed maintenance and catering crews for large offshore construction projects in the North Sea.

Publications

Commercializing External Works Systems, Wright, S.R. et. Al. NASA, Houston, TX, 1995.

PERRY L. SMITH

STRUCTURAL ENGINEER/COMMERCIAL DIVER

Perry L. Smith has over six years experience as a structural design engineer and project manager involving the design of heavy industrial structures, buildings, and off shore components. In addition, Smith has over 12 years experience in construction involving bridges and buildings. In his career, Smith has served in positions ranging from iron worker, concrete finisher, structural draftsman, structural design engineer, and project manager. Smith's capabilities include major structural design for heavy industrial and project management, written proposals, overall planning, construction cost estimating, construction surveying, and commercial dive tender. Proficient in RISA 3D and AutoCAD 14.

Nevada Department of Transportation Las Vegas, Nevada 1982 - 1989

Project Manager in field for NDOT for bridge construction projects:

- New Las Vegas I-95 Expressway

  -Harmon Structure overpass – post-tensioned cast in place concrete bridge – Las Vegas
  -Mountain Vista Structure viaduct – post-tensioned cast in place concrete bridge – Las Vegas
  -Tropicana Structure Interchange – post-tensioned cast in place concrete bridge – Las Vegas
  -Desert Inn Road overpass – Steel tub girder bridge – Las Vegas
  -Russel Road Interchange – post-tensioned cast in place bridge – Las Vegas

- New Highway & 93 Lane Widening

  -15 Reinforced Concrete Boxes – cast in place concrete bridges – Searchlight, Nevada

- Boulder Highway Roadway widening

  -12 Reinforced Concrete Boxes – cast in place concrete bridges – Boulder City, Nevada

- I-15 Structure Widening

  -Toqoup Canyon Bridge deck and parapet widening N & S bound structures - Mesquite, Nevada

Roberts & Thomas, Inc. Consulting Engineers Lubbock, Texas 1989 - 1993

Structural draftsman part time during college. Residential home structural inspections.

- AutoCad R10, R11.
- Drafting for commercial structures, schools, churches, warehouses, etc.

Lembeck Associates, Inc. Kansas City, Missouri 1993 - June 1998

Representative of projects for which Smith has had principal responsibility and completed structural design are:

- Steel Mill - Rail Building Dust Loadout System - Nebraska
- Flour Mill - Rigid Steel Fame Rail Shed - Minnesota
- River Grain Terminal - Bulk Loadout Structure and Warehouse - Illinois
- Steel Mill - 15,000 cubic feet Steel Dust Bin - Nebraska
- Cement Plant - Steel Hopper Structural Revisions - Kansas

- Cement Plant - Fuel and Sand Tank Foundations and Truck Safety Platforms - Kansas
- Port Grain Terminal - Steel Grain Bins - Ningbo, China
- Port Grain Terminal - Steel Towers and Bridges - Dekhila, Egypt
- Fiberglass Insulation Plant - Washwater Reclaim Tanks and Steel Towers - Kansas
- Concrete Block Manufacturer - Tank foundations - Missouri
- Rice Mill - Steel Equipment Tower and foundations - Arkansas

IV. Oceaneering International, Inc. AWS - Bayou Vista, Louisiana June 1998 – May 1999

<u>Representative of projects for which Smith has had principal responsibility and completed structural design are:</u>

- Ocean Intervention - ROV Cursor
- Ocean Intervention - Fwd & Aft Upper Moonpool Door Redesign
- Ocean Intervention - Fwd Lower Moonpool Door Redesign
- Ocean Intervention - 02 Deck Assist Winch Support Structure
- Magnum 30 C. Kirk Rhein - Cursor Umbilical Guide

V. Oceaneering International, Inc. Diving - Morgan City, Louisiana May 1999 – Sept 1999

- Oilfield Construction Diver (Tender) Jetting, pad eye cleaning, jacket leg cleaning, bolt torquing– Gulf of Mexico

VI. Oceaneering International, Inc. Advanced Technologies - Upper Marlboro, Maryland Sept 1999 – Present

<u>Representative of projects for which Smith has completed structural design are:</u>

- H.L. Hunley Recovery Project – Steel Recovery Truss, 80,000 Gallon Steel Conservation Tank

Education:

- Texas Tech University, B.Sc, Civil Engineering - Structural Option 1993.
- Oceaneering Hydraulic and Mechanical Maintenance Course 1998.
- Louisiana Technical College - Commercial Dive Program 1999
- Chi Epsilon National Civil Engineering Honor Society
- E.I.T Registered Kansas

Publications:

"Professionalism: Cornerstone of Engineering", ASCE Journal of Engineering and Education. June 1992.

RESUME' of Jack R. Maison, Ph.D. P.E.

SPECIALIZATION: Mechanical Engineering & Finite Element Analysis

WORK EXPERIENCE:

1982-Present, Engineering Cybernetics, Inc. President.
Provide technical support to users of engineering software finite element programs. Commercial software programs include mechanical CAD, structural, fluids, thermal, electrical, multibody dynamics and plastic flow capabilities. Software used in consultation studies for government and industrial clients. Studies included structural design and analysis of the USNavy Seawolf 1/3 scale model, mechanical and thermal analysis of pressure vessels and piping systems; dynamic and fatigue analysis of commercial washing machinery and structural analysis of a jet aircraft. Recent studies were thermal mechanical analysis of aircraft piston, analysis of all composite commercial truck trailer, buckling design and analysis of 2000 FSW submarine rescue chamber, failure analysis of downhole tools and plastic capacity determination of jackup chord. Currently involved with effort to integrate WAMIT wave loader and AISC/API Code checks into the ANSYS finite element program.

1995-Present, Engineered Medical Systems, Inc., President
Created company to apply software tools to medical equipment. Designed, buil;t and tested innovative medical treatment chambers for exposing patients to 100% oxygen under pressure (hyperbaric oxygen therapy). Developed rectangular post-tensioned concrete pressurized room under SBIR contract from US Air Force. Built and tested full scale prototype that received world wide acclaim. Developed single person monoplace chamber that is in final stages of FDA approval. Prototype built and tested. Developed modular concept for in hospital construction of multi patient chambers. First installation scheduled for 2000 at the renowned Brook Army Medical Center for burn treatment. Performing test programs on collapsible and acrylic plastic chambers.

1973-1982, Southwest Research Institute, Manager, Assistant Director, Director Structural Research Dept. Performed analytical and experimental studies of ocean structures including jackups, semis and fixed platforms, risers, underwater pipelines, and pipeline repair equipment; space hardware and conventional equipment ranging from buildings to overhead transmission structures. Utilized many finite element programs for linear and nonlinear static, dynamic and thermal analysis of structures. Conducted failure analyses on offshore and underwater equipment. Served 10 years on the ASME Boiler and Pressure Vessel Committee and on numerous code-writing and research committees. Created a welding fabrication shop that built high performance underwater hardware. Built numerous diving systems to both Division 1 and 2 of ASME Boiler & Pressure Vessel Code. Conducted experiments using SWRI test tanks and high capacity test fixtures. Conducted tests of fixed platform grouted leg models for Cognac. Reduced strain data and compared to finite element predictions.

1970-1973, NCELaboratory, Sr. Research Structural Engineer. Analytical and experimental research on deep ocean structures. Used finite element methods to design submersibles and other pressure resistant structures.

1968-1970, Univ. of Delaware, Research Assistant. Conducted research and taught. Research done on shell structures for deep ocean applications. Sponsored by AISI fellowship won in national competition.

1964-1968, DuPont Co, Process Mechanical Engineer. Performed hydraulic system design, material handling equipment design and pressure vessel and piping design.

PROFESSIONAL AFFILIATIONS:

ASME, Member: Boiler and Pressure Vessel Code, 1972-1982.
Pressure Vessel Research Committee, 1971-1982.
Board on Pressure Technology, Codes & Standards, 1994-1999.
PVHO, Chairman 1994-1999.
Design Chairman, 1981-1994.
ASCE, Member: Tubular Offshore Structures, 1979-1982.
Overhead Transmission Structures, 1981-1984.
ACI, Member: Composite Concrete & Steel Pressure Vessels, 1988-1993.
UHMS Full Member

PROFESSIONAL CERTIFICATIONS:

Registered Professional Engineer, Texas. #40257

EDUCATION: BSME, 1964, University of Kansas
MSMAE, 1968, University of Delaware
Ph.D., 1970, University of Delaware

Mark van Emmerik
30W Jones Station Road
Severna Park, Maryland 21146

Professional Objective

To design, construct, and/or implement robotic and automation applications. Of particular interest are remotely operated vehicles and manufacturing.

Experience Summary

Engineering:
Designing hyperbaric life support and gas storage systems for the Submarine Rescue System.
Designed and fabricated a transceiver mounting system for an underwater acoustic navigation system.
Designed a cofferdam for the US Navy 688 class submarine.
Proposal team member for the Recovery plan of the USS MONITOR, for which Oceaneering International received an Al Gore Environmental Award, 1998.
Designed robotic silicon wafer handler for Strasbaugh Inc., San Luis Obispo, California.
Integrated the automation of an IBM 7565 assembly robot with a specrtaLIGHT machining center.
Analyzed gas distribution networks for a local utility on a Stoner Workstation to ensure sufficient gas supply during peak periods or network expansion. Wrote documentation of the analysis methods.

Technical:
Published a paper on the conceptual design of a hyperbaric oxygen rebreather.
Commercial diver, job supervisor, job planner in offshore petroleum industry. Skills included wet welding, inspection, rigging, explosives, search & recovery, and report writing.
Complete rebuild of a 750cc motorcycle engine and two VW engines.

Sales:
Lumber sales, ordering from vendors, customer service, and problem solver.

Education

BS, Mechanical Engineering, California Polytechnic University, San Luis Obispo June, 1996
Air and mixed gas diving training, Commercial Diving Center, Long Beach, CA May, 1979

Employment History

Oceaneering International, Inc., Upper Marlboro MD	Mechanical Engineer	1996-Current
Hayward Lumber Company, Morro Bay, CA	Lumber Sales	1993-1996
Pacific Gas & Electric, Concord, CA	Gas Flow Studies	1990, 1991
California Wood Stoves, Benicia, CA	Spa Technician	1987-1990
Sonar Subsea Services, Morgan City, LA	Diver/Supervisor	1985-1987
Continental Diving Services, Morgan City, LA	Diver	1979-1985