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Unusual Hull Design Requirements, Construction and Operating Experience of the SEABEE Barge Carriers

Stuart W. Thayer, Member, Lykes Bros. Steamship Co., Inc., New Orleans, La.
Alfred H. Schwendtner, Associate Member, J. J. Henry Co., Inc., New York, N.Y.

ABSTRACT

The SEABEE barge carrier, because of it's unique configuration and versatility as a cargo liner, presented a challenge for it's designers in the area of structural arrangement. Where the decks, reserved for barge traffic and stowage, did not permit full transverse bulkheads for the provision of shear panels against racking, finite element stress analyses provided today's tools for the structural design necessary to obtain adequate strength without undue weight. Cantilevers aft, providing support for a submersible elevator, capable of lifting two fully loaded barges on and off the vessel, also were subject to detailed structural analysis as a result of potential vibration and transverse strength problems. Experience during operation has proven the vessel to be structurally sound to perform its unusual requirements.

INTRODUCTION

In the continual search for methods to increase the speed of loading and discharging shipborne cargoes, the most recently developed SEABEE concept accomplishes this task by loading and discharging fully loaded barges from the water, through the use of an elevator at the stern of the vessel. Cargo handling rates of up to 3500 tons per hour drastically reduce the time the vessel must spend in port.

The SEABEE concept, while progressing through a number of conceptual design changes, always retained the barge module size at half the length and the same beam as the standard Mississippi barge, permitting it to be integrated into regular tows. The initial design phase of the SEABEE concept carried the barges on two levels, using a float-on/float-off principle. Unfortunately, some of the ports where the ship intended to trade, had insufficient water depths to permit the vessel to sink deep enough to use the float-on/float-off technique, and the use of stern elevator, supported by two cantilevers, was introduced.

The cantilevers, elevator and barge stowage arrangements required unique structural solutions. The satisfactory resolution of these design requirements, the subsequent construction and operation of the SEABEE vessels, are discussed in this paper.

SEABEE VESSEL DESCRIPTION

The SEABEE vessels have the following principal characteristics:
L.O.A. = 875 feet, L.B.P. = 720 feet, Beam = 106 feet and depth = 74 feet - 9 inches, with a 36,000 shaft horsepower single screw steam turbine power plant. The vessels are designed to carry 38 barges, each having a maximum displacement of 1,000 long tons and a length of 97' - 6", a beam of 35' and a depth of 15' - 10" to the top of the coaming. The barges are stowed on two lower decks each 600 feet long and on the open upper deck. The barges are lifted from the water by a 2,000 long ton capacity submersible elevator, capable of handling two fully loaded barges. The elevator lifts the barges to one of the three cargo decks, where a low profile self powered electric-motor driven transporter moves onto the elevator and under each barge. A series of jacks mounted on the transporter lifts the barge clear of the elevator by 3 inches and the loaded transporter then moves forward to the first empty position, where the barge is lowered onto a series of pedestals. The profile and midship section are shown in figures 1 and 2 respectively.

The SEABEE vessels have a number of unique structural design problems as a result of their special cargo handling system, some of which will be discussed in further detail. Figure 3 gives a partial view of the lower barge deck port side showing a stowed barge in the #2 position and a transporter aft of the barge. Transporter rails and barge support pedestals can be seen in the foreground.

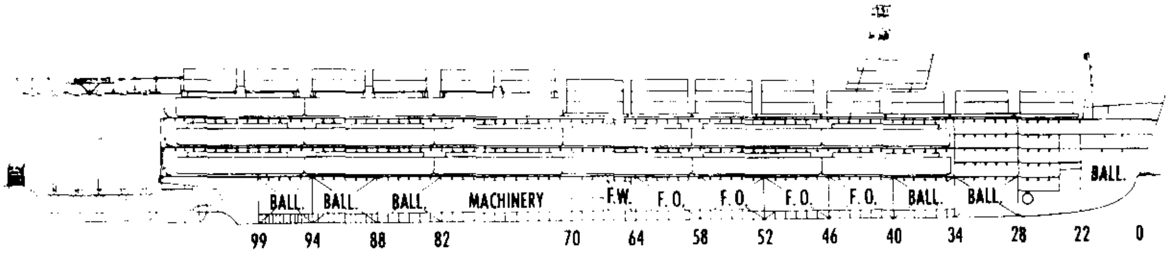

Fig. 1 Profile 7' off centerline

CANTILEVERS

The two cantilevers supporting the elevator are each 114 feet long, 70 feet high and 12 feet wide. The cantilever depth permits the elevator to be guided in both the fore and aft and transverse directions even when the elevator is at the bottom of its travel. Alternative cantilever shapes, including those which cleared the water in the fully loaded condition and which could not provide full guidance to the elevator, were resistance model tested. Surprisingly, the best of these alternative shapes offered only marginal savings in resistance and therefore the deep cantilever, with its superior barge fendering and simpler elevator guidance, was adopted. The partially completed cantilevers, with the elevator under construction, are shown in figure 4.

The at-sea loads on the cantilever were determined by model tests in which the model (fig. 5) was run in irregular waves at various headings. Due to the lower section-modulus in the transverse direction, the loadings in this direction were of most interest and had a peak value of 720,000 inch kips in waves of 35 feet significant height. The other primary cantilever design condition occurs when the elevator is handling barges. Good structural continuity was possible between the cantilevers and the vessel proper. Classic beam calculations without supporting computer analyses were sufficient for this design problem.

RACKING STRENGTH

Since the barges are moved horizontally along the decks from the aft to the forward most cargo location, it is impossible to provide fixed transverse bulkheads in the 600 feet long cargo area. Above the lower cargo deck all transverse racking strength must be provided in the 15 feet wide wing spaces outboard of the cargo area. Since over 40 percent of the available cargo cubic is above the upper deck, significant racking loads are applied at the upper deck as well as at each of the main and lower cargo decks. Between the main and upper deck the space outboard of the cargo area is used for crew quarters, thereby severely limiting the possible structural arrangements in this area. Openings for passageways and the various hotel services were required in the narrow bulkheads in the wing spaces, and web-frame depths were minimized to reduce interference with the quarters arrangement. A frame

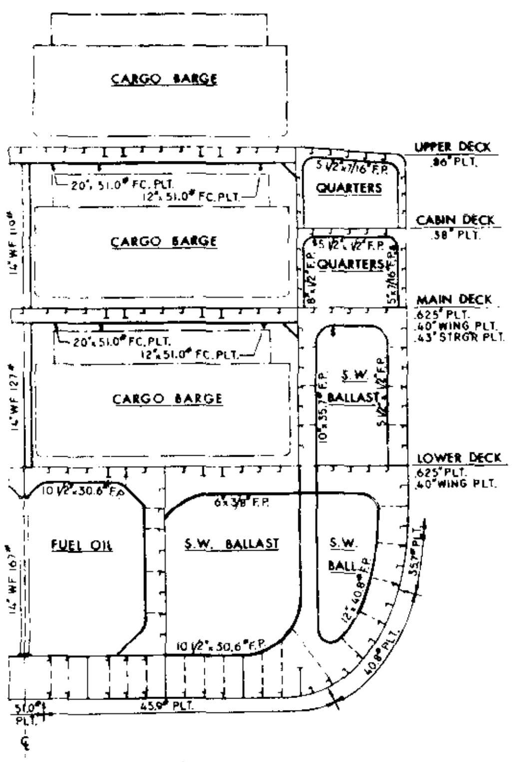

Fig. 2 Midship section

Fig. 3 Lower barge deck

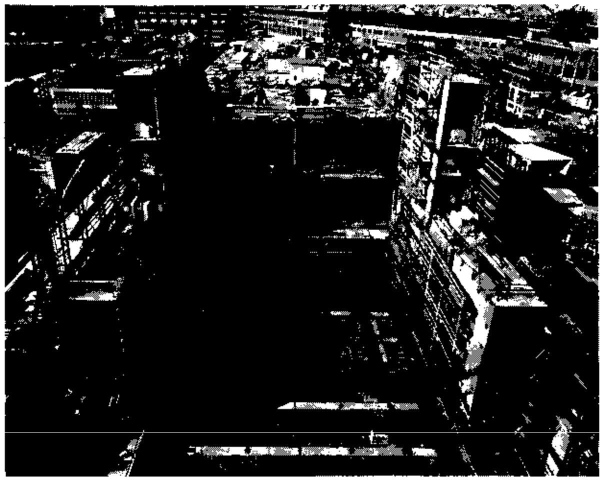

Fig. 4 Stern under construction

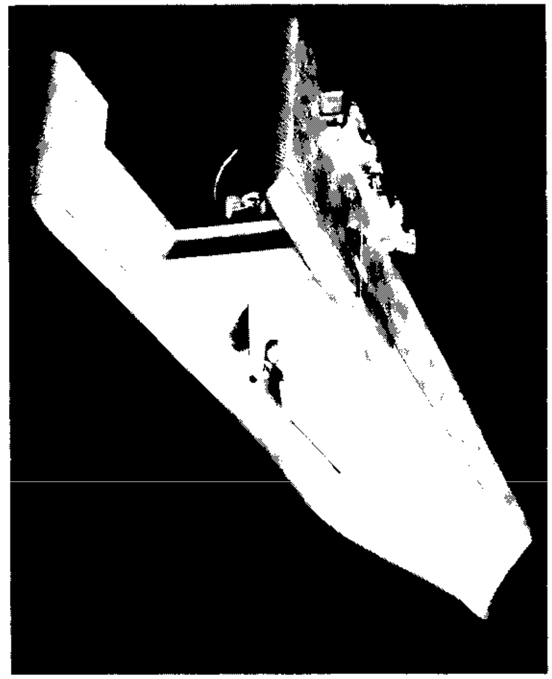

Fig. 5 Dynamometer installed on top of cantilever

analysis of the structure indicated structural problems, and it was decided to carry out a three dimensional finite element analysis of the vessel structure in three representative areas where barge cargo loadings would predominate, as follows:

1 Barge decks forward, where adjacent wing space areas are devoted to quarters.
2 Barge decks in way of machinery spaces.
3 Aft portion of vessel.

LOADING ASSUMPTIONS

With a smaller cargo container, particularly if it is adapted for stacking, it is possible to have 4 known support points. However, in the case of the 97.5 feet long SEABEE barges, this is relatively impractical and a line support was decided upon. Load transfer then became a function of the relative flexibility of ship and barge structures and the initial curvatures of the vessel deck and the barge bottom. Over the life of the vessel and barges it can be expected that some barges will suffer permanent deformation. Extreme deformations will be rejected by the loading system but lesser deformations can lead to significant load concentrations.

A number of cases with different loading distributions from the barges were investigated in order to determine the worst situation for each structural member. In one case, loads from the barges were peaked at the bulkheads; and in another case, loads were concentrated on the web-frames farthest from the bulkheads.

Accelerations used were based on a $\pm$ 30° roll in 12 seconds simultaneously with a $\pm$ 5° pitch in 7 seconds. The sea load tends to reduce the racking movements introduced by the barges. However, when a wave trough passes the area under examination the restoring moment is small, particularly above the main deck, where the arrangements made the structural problems most severe. Accordingly, a conservative approach was adopted, namely, neglecting the counteracting forces due to the sea. Loads due to the weight of the ship structure were included.

FINITE ELEMENT ANALYSIS

In each case the structure was modelled as a series of beam elements and shear panels. In order to minimize the number of members under consideration, a number of bending members were lumped together into convenient equivalent members. It is believed that bending about an axis parallel to the plane of the plating was reasonably represented.

ANALYSIS OF BARGE DECKS FORWARD

The area modelled, including one partial bulkhead in the wing spaces and 6 web-frames, is 48'-9" long and represents one tank length or one half a barge length. The structure below the lower deck consists of deep-tank structure and is relatively stiff. The structural model, shown in figure 6, was assumed fixed at the lower deck level.

The results of the finite element analysis indicated the importance of even the partial bulkheads in the wing space to absorb the racking forces and the need for an increase in strength in the web-frames (but considerably less than indicated by a frame analysis).

ANALYSIS OF MACHINERY SPACE

Barge loadings exist over the machinery space the same as in other parts of the vessel. However, machinery arrangement considerations required the interruption of the longitudinal bulkhead under the lower deck located 19'-4" off centerline. The transverse bulkhead spacing under the lower deck which elsewhere is 48'-9" was increased to 97'-6" in way of the machinery space. Loads from the barge decks are transmitted to the double bottom by pillars.

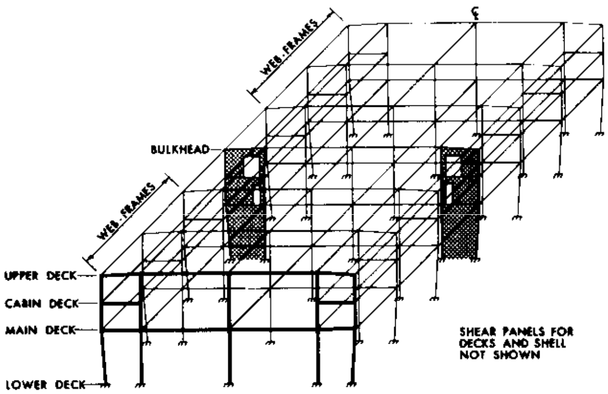

Fig. 6 Finite element model of ship substructure

The structural model used was similar to that described previously, except that it is 97'-6" long and extends from the upper deck to the intermediate flat in the engine room. In addition, a separate study was made of the machinery space double bottom and the connecting pillars. This study confirmed the adequacy of the double bottom and pillars which were designed to "rule" requirements.

ANALYSIS OF AFT CARGO AREA

The cargo decks and their barge loadings continue aft to the elevator. The necessity for maintaining full cargo area width aft, and the criteria for the cantilever elevator support, required that the full beam of the vessel be maintained aft in way of the cargo decks. Transom immersion was minimized to reduce hull resistance, and the lower cargo deck was located as low as possible to minimize cubic loss and to keep the center of gravity of the cargo as low as possible. As a result, the supporting structure under the lower deck is tapered to a depth of about 2 feet at the aft end, and the depth in way of the rudder stock is only 6 feet. The use of roller bearings for the top and bottom support of the rudder stock saved considerable space compared to conventional phenolic and white metal bearings. In addition, a full size mock-up of the steering gear and bearings was constructed, to determine construction and maintenance accessibility. While this represented considerable extra effort, the alternative of raising the lower deck 2 feet, for example, would have resulted in the loss of cargo space of 600 feet x 70 feet x 2 feet or 84,000 cubic feet.

The hull form increases rapidly in section under the lower deck moving forward from the transom. At frame 99 (74 feet forward of the transom), the structure under the lower deck is very substantial and for the purpose of our structural model we considered the structure fixed at this location. The loadings applied to the model were the barge loadings, cantilever forces and deadload of the structure.

SUPERSTRUCTURE AND PILOT HOUSE ANALYSIS

The forwardmost barges on the upper deck are located within 45 feet of the forward perpendicular, leaving inadequate room for a wheelhouse forward of the barges. The wheelhouse and the deck officers quarters were therefore located further aft over the second pair of barges, necessitating support by two relatively narrow structures outboard of the barges. The entire superstructure was modelled as a series of beams and shear panels. The loads applied to the model were from accelerations from ship motions on outfit weights, weight of the structure, and wind loads.

The result of a three dimensional analysis indicated only minor modifications were needed, primarily in way of openings. The structure required was considerably less heavy than that predicted from a frame analysis.

BARGES

Transporting cargo in stowed barges aboard the SEABEE clipper not only presented novel structural design problems for the ship, but also resulted in stringent requirements for the barges. The barges experience their most severe loadings when stowed on the barge support rails and subjected to dynamic loads at sea. A three dimensional finite element model of a typical barge was developed (fig. 7) to examine the implications of the possible modes of loading on the barges. Making use of symmetry and antisymmetry, conditions permitted a reduced model, one half of the barge length, to be representative of the complete structure. This finite element model was comprised of 129 node points, 238 beam elements, and 109 shear panels. Reduction of the structural components of the barge to such a limited number of idealized members required the grouping of adjacent bending members into equivalent substitute members.

A variety of cargo loading cases were studied with the barge stowed on the support rails on the vessel. The individual loading conditions, with each barge containing 850 tons of cargo, included distributed loads, concentrated loads and container loadings. The barges were also analyzed with loading conditions in still water and waves. When the classification of the barges was changed to "Ocean Service", the regulatory bodies were concerned with the torsional response of the fully loaded

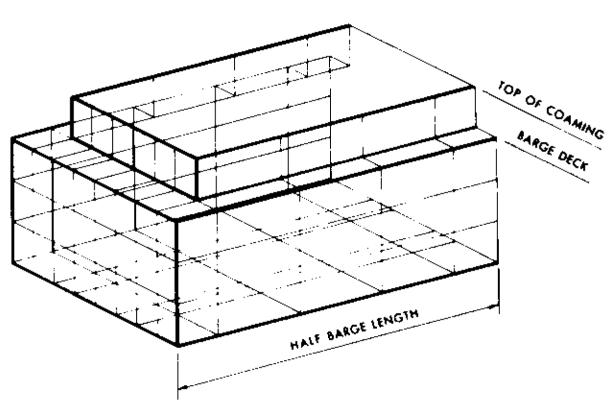

Fig. 7 Finite element model of barge

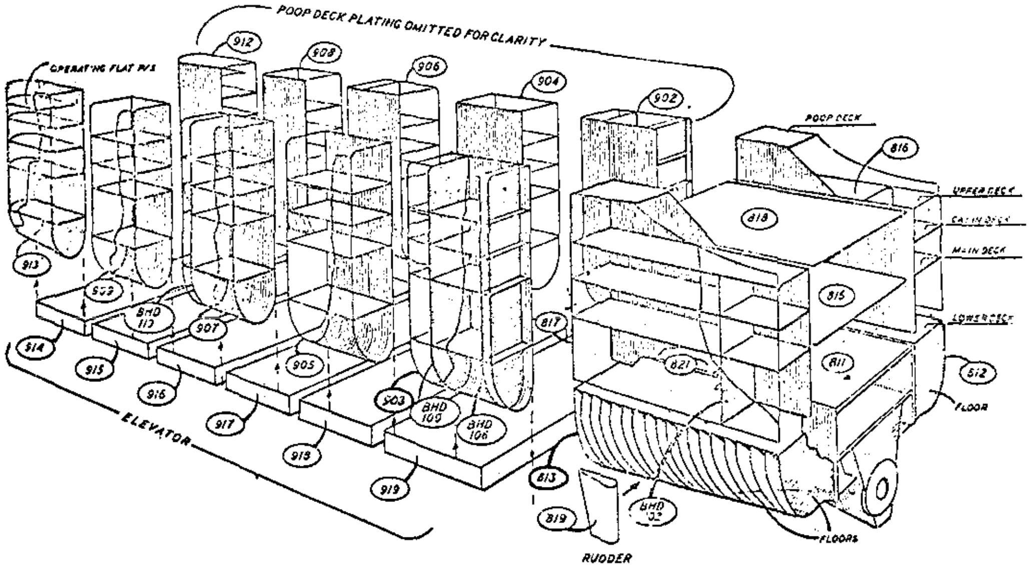

Fig. 8 Module locations aft

barge. Past experience has indicated that the most severe condition for torsional loadings is a 60° wave heading with either the wave crest at bow and stern or wave trough at bow and stern. At the 60° heading this corresponds to a wave length equal to one half the vessel's length or 48'-9" for the SEABEE barge. Both cases were investigated with a wave height of 9 feet, which exceeds the theoretical maximum for a breaking wave having a length of 48'-9". The model in figure 7 was again used and the resulting stresses were found to be satisfactory, indicating that the structure of the barge is suitable for ocean service.

CONSTRUCTION

The design concept for the barge carrying SEABEES, which started in 1964, passed through a number of design and development stages which ultimately resulted in final contract plans and specifications in 1968. In October of the same year a contract was signed between Lykes Bros. Steamship Co. and General Dynamics Corp., Quincy Shipbuilding Division for the construction of 3 SEABEE vessels with delivery of the first ship in June of 1972.

The shipyard elected to construct the vessel using the modular principle. This involved the assembly of 149 packages of ship structure each as complete as possible. By fabricating the modules away from the building basin they could be positioned and turned to utilize down hand welding and automatic welding equipment to the maximum possible extent. Items which are normally fastened to the overhead such as piping and lighting could be installed with relative ease when the module was placed upside down. The modules varied in weight averaging about 100 tons with some as high as 200 tons. Each module had its own package of working plans which included the structural assembly, electrical wiring and piping. Certain items, such as painting schedules, welding details, etc., were not contained on all the modular drawings, however, they were cross-referenced and identified by module number.

Figure 8 shows those modules in the stern of the vessel. Unit numbers 914 - 919 constitute the barge elevator platform and were assembled by welding 6 modules together on the building basin floor. It was then lifted to the stowage position between the cantilever wing walls utilizing the barge elevator winches installed on top of the poop deck.

In order to describe the complexity of some of the structure, the steps used in the fabrication and erection of Modules 812 and 902 (Figure 9) will be described. Most of the modules were built away from the building basin and in the inverted position. The first step in the construction of Module 812 was to lay out the lower deck plating since the unit was built in the inverted position (Figure 10A). In actual fabrication, the deck plating was divided into two sections with the cut fore and aft through the rectangular access opening which appears at about

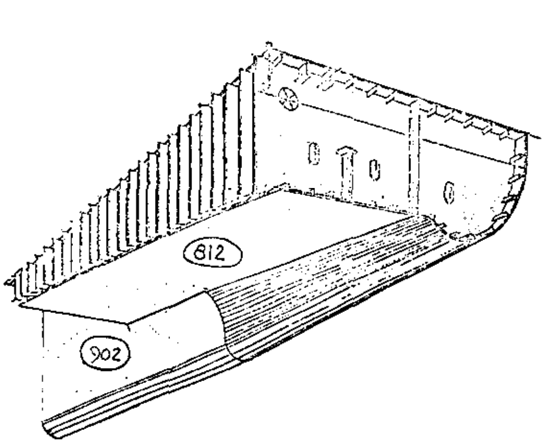

Fig. 9 Modules 812 to 902 assembly

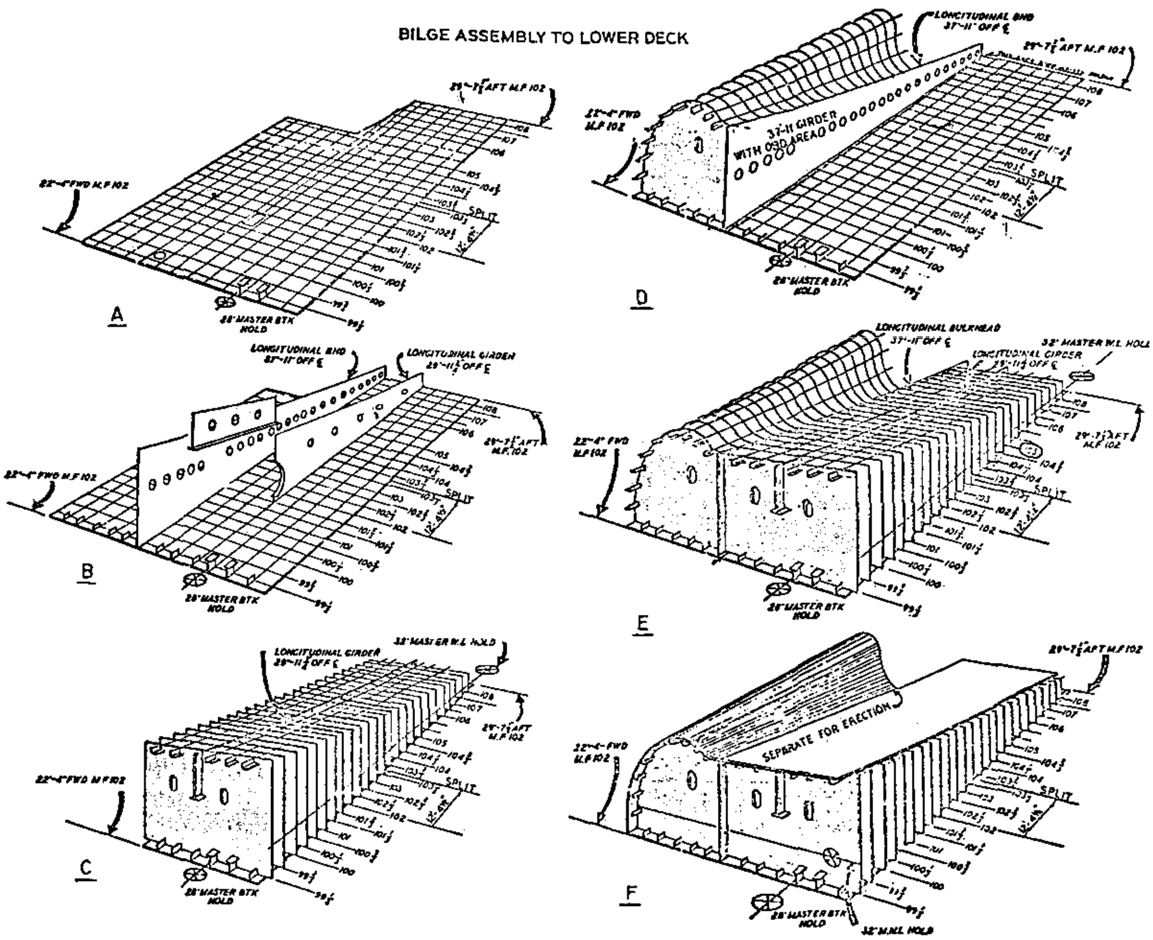

Fig. 10 Sequence of erection - Modules 812/813

Fr. 101-1/3. The location of the main longitudinal girders which are part of the assembly are shown in Figure 10B. The right hand portion of the assembly after the floors, longitudinal girder and various stiffening members had been installed on top of the lower deck plating, is shown in Figure 10C. After this portion of the unit had been completed, it was sent to a facility where it was blasted and painted. Figure 10D shows the left hand side of the unit after the various shaped floors had been erected. The transition from the bilge shaped portion of the vessel to the lower narrow portion of the cantilever can clearly be seen. It should be noted that the lower deck plating which appears on the right hand side of Figure 10D is for illustrative purposes only as this portion of the deck is actually attached to the right hand side of the assembly as previously discussed. When the left hand side of the assembly was completed as shown in Figure 10D, it was also sent to the blasting and painting facility. Figure 10E shows the right and left hand portions of the assembly placed together, lacking only the shell and bottom plating to make then complete. Figure 10F shows Units 812 completed and ready for erection and attachment to the ship in the building basin. When completed, Module 812 weighed about 153 tons and was 71 feet long; 33 feet wide, 14 feet deep and had 25 transverse floors of 9/16 inch plate. An example of a typical floor is shown on Figure 11.

Unit 902 was assembled upside down in a similar manner to 812 as shown in Figure 12, however, this particular unit was split in two vertical pieces rather than two horizontal pieces during its sub-assembly erection. The description of the fabrication of Units 902 and 812 was selected as those two units form the major transition from the stern of the vessel into the cantilever area and were subject to considerable study during the design period of

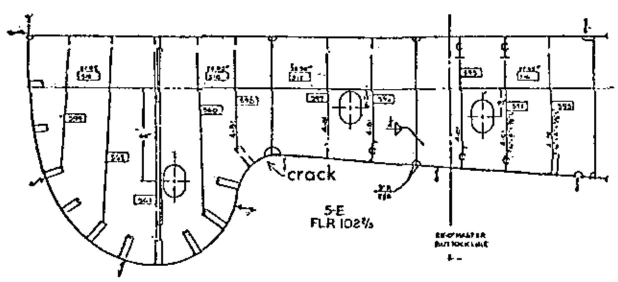

Fig. 11 Typical floor in Module 812

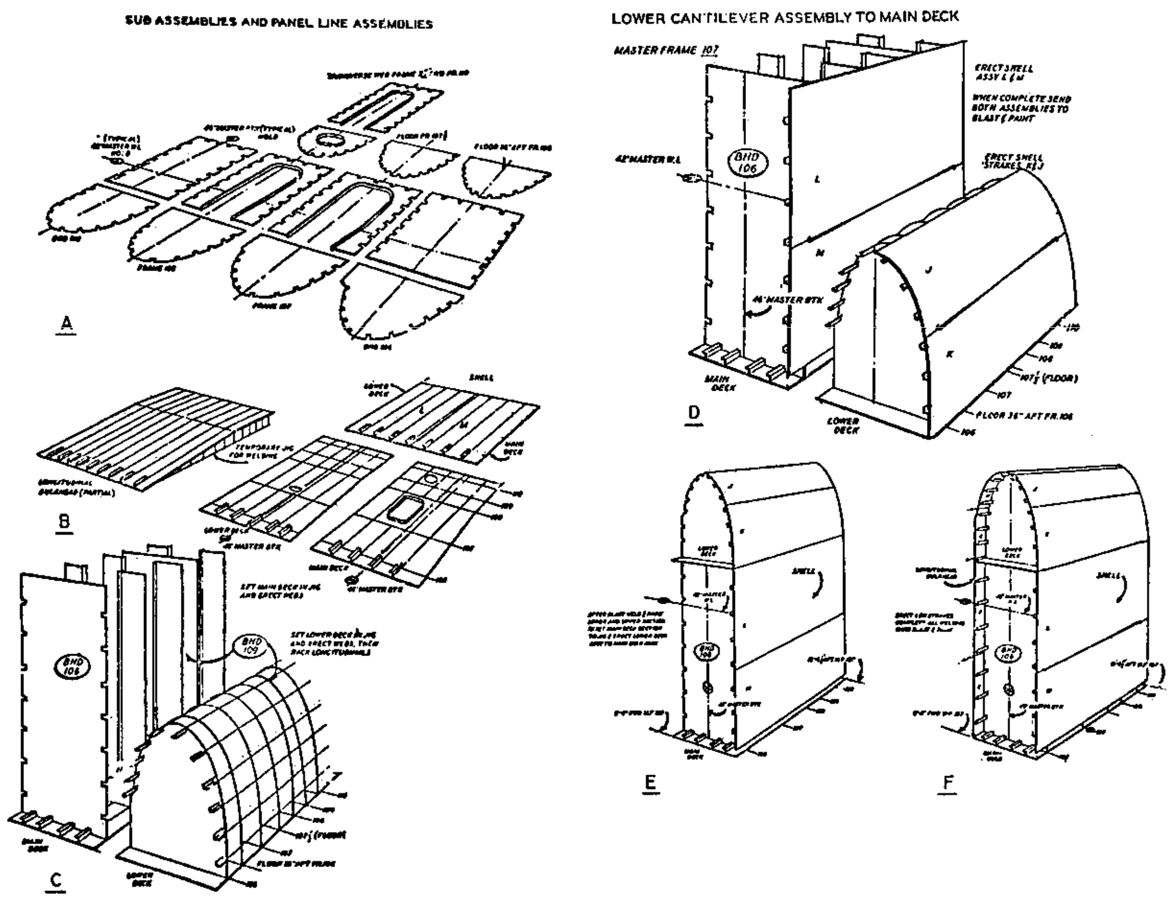

Fig. 12 Sequence of erection - Modules 902/903

the SEABEE.

Figures 13 and 14 illustrate the actual installation of Modules 812 and 902 at the lower outboard corners of the vessel. The completed cantilevers are shown in figure 15 with the elevator platform between them on the drydock floor. The port stern door is clearly visible and the after end of the rudder can be seen just forward of the elevator platform.

While many of the shapes involved in the modules which went into the stern of the SEABEE were very unique as compared with normal ships, General Dynamics did not experience any unusual difficulties in the assembly of the modules. Automatic welding equipment was used to the maximum extent possible, even on vertical butts; rewelding and repairs were negligible.

Another unusual feature of the construction of the SEABEES was the sequence of events in which the modules were assembled in the building basin. Under normal circumstances a vessel with machinery slightly aft of amidships, similar to the SEABEE, would have the keel laid within the machinery space and the structure worked forward and aft at the same time with some slight emphasis on the after structure. This assures that stern tube boring, fitting of shafting and propeller can be accomplished prior to launching. The SEABEE, however, presented a completely different situation since the elevator had to be raised from the basin floor to its stowed position on the vessel prior to launching. The only means available to raise this platform were the ships barge elevator winches. The scheduling therefore dictated that stern of the vessel had to be completed at a very early stage to allow installation and testing of the barge elevator winches. Since the winches are hydraulically operated and electronically controlled, all piping and wiring associated with them also had to be complete. The shipyard thus proceeded after keel laying to work very rapidly towards the after end of the vessel. While the time from keel laying to launch was estimated at about 47 weeks, the last cantilever sections were scheduled to be installed at week 23, less than half way through the assembly process.

ELEVATOR TESTING

Some very high loads were placed on the barge elevator during the testing period and shock loads were introduced. Prior to the construction of the elevator platform its weight was estimated to be about 450 tons. As construction progressed, the weight estimates went up to 540 tons and finally reached 615 tons. Including an allowance for the weight of the transporters and a margin, the final gross load on the winches was about 2900 tons. One further aspect introduced into the testing, which proved that the design and construction were more than satisfactory, was the so called "emergency stop" test. The barge winches which raise and lower the elevator platform are powered by hydraulic

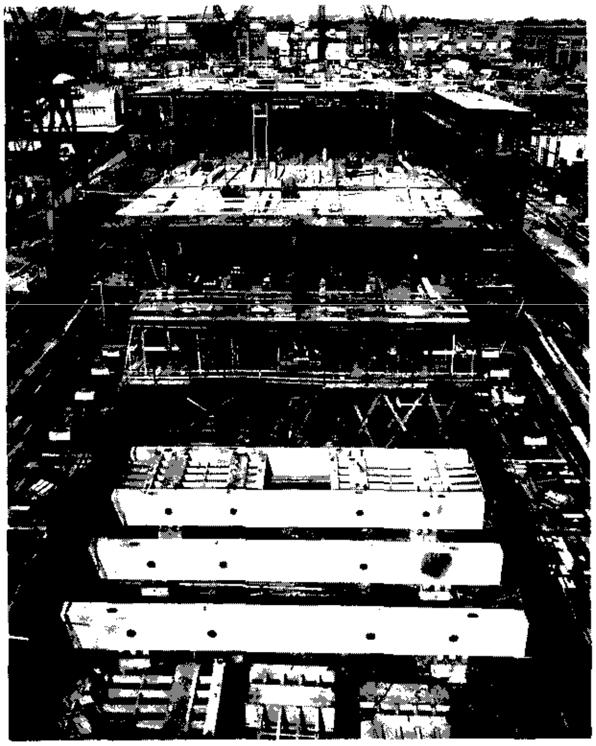

Fig. 13 Stern with Module 812 in place

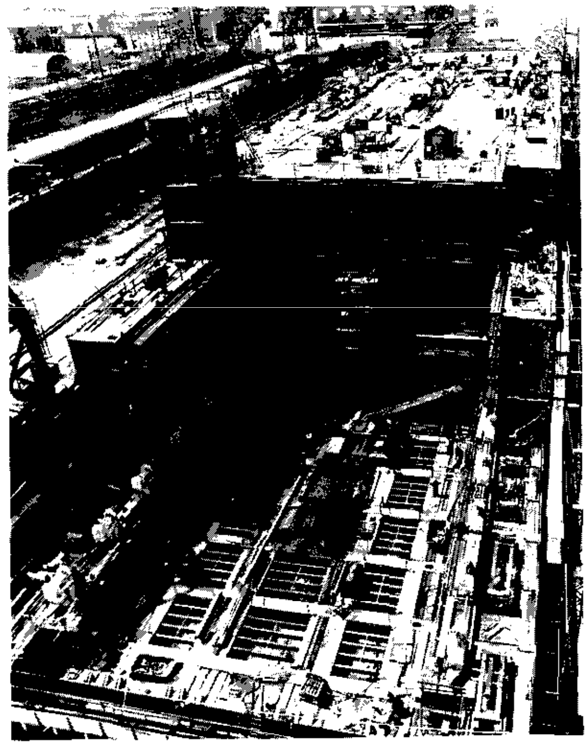

Fig. 14 Stern with Module 902 in place

motors that are driven by variable stroke pumps. In the case of the "emergency stops" all electric power was shut of instantaneously. This slammed on the elevator winch brakes and stopped the hydraulic pumps on full stroke, all with the elevator going in the down direction at maximum speed (4 feet per minute) with a gross load of 2900 tons. While this exercise shook the stern and the cantilevers considerably, no structural defects or cracking occurred.

OPERATION

The three SEABEE vessels have now been in service for a total of about 100 ship months and have handled well over 6,500,000 tons with their elevator system. Only one class type structural defect has developed. Interestingly, this problem was submitted as a guarantee item on the first vessel stating that the crew was unable to pump all of the salt water ballast out of No. 11 ballast tank. It later turned out that there was no problem with the pumping system but that there was a split in the shell plating which allowed water to flow in as fast as it was being pumped out and maintained the level of the sea water in the ballast tank at the draft of the ship. Figure 11 shows the location of this crack, which was caused by a hard spot as a result of a radius cut-out in the floor which provided clearance for the shell to longitudinal bulkhead weld. It is identified by the word "crack" where the bottom plating joins the reverse curve of the underside of the cantilever. On one vessel this same hard spot resulted in a failure in the fillet weld between floor and shell plating without any through crack in the shell. The problem was corrected by placing a liner between the floor and shell plating. Some other minor cracking has occurred in some of the welded joints; however, most of them appear to be due to faulty welding and have been very minor in nature.

The two cantilevers not only provide the support for lifting cargo to be carried on the vessel but also provide a means for supporting the elevator platform while the vessel is at sea. During its sea passages the elevator sits on hinged brackets which are swung out from the inboard wall of the cantilever. A locking device holds the platform down on these brackets and provides a connection between the two cantilevers. No problems have yet been encountered with regards to the elevator or cantilevers while the vessel is at sea, even in the North Atlantic.

CONCLUSION

The design of the SEABEES, while using "Yesterday's Technology applied to Today's Designs," did benefit from advanced techniques because of their unique requirements. These included the frame analysis used by the shipyard that uncovered the racking problem. The subsequent work with the finite element studies described herein was used for the final scantling determination. Without the finite element program it is probable that we would have overestimated the steel and arrangement changes required to obtain a satisfactory design.

The vibration analysis done by Littleton Research and Engineering Corp. represented the state of the art. Vibration studies included the propeller excited vibration due to the lateral motion of the cantilevers, the vertical motion of the stowed barges, the lateral vibration of the unusual superstructure and the effect of alternate skeg designs. Vibration

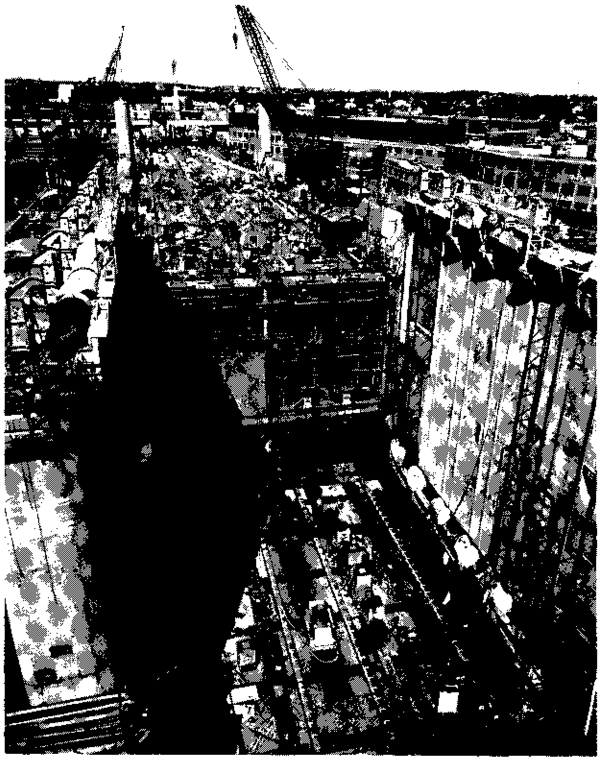

Fig. 15 Completed cantilever

tests, run by the Maritime Administration during sea trials, showed that the SEABEES had significantly less vibration than recent vessels of comparable size with lower installed horsepower.

The design techniques used have proved their value both during construction and in service, where the SEABEES have been totally free of hull structural problems except for the one minor defect noted.

In the seven years, since the main structural analysis was completed, there have been significant advances in the tools available to the vessel designer. The definition of ship accelerations, motions and hydrostatic wave forces is now available as a working tool to the naval architect as a result of the Ship Structures Committee sponsored effort resulting in the SCORES program [1]. The SCORES program and the resulting loads would replace the traditional but somewhat arbitrary loads used for the SEABEE design.

The size of structural problems that can be solved on the computer has gone up several orders of magnitudes in the same seven year period. The increased "computer capacity" is not attributable to computer hardware but is directly related to the significant research effort devoted to the development of improved solution methods and internal data management. These developments have had a pronounced effect in the application of finite element computer programs to the solution of very large structures. For example, at the time this work was undertaken, the size of each finite element model considered was limited by the capacity to carry out the computations in core. Making use of the algorithms then available, restricted a typical problem to 300 node points, having an average of 5 degrees of freedom and a semi-band width of less than 53 in the stiffness matrix. Within one year of the time that SEABEE was analyzed, the restriction that the stiffness matrix had to reside in the core of the computer had been removed and was replaced by the less demanding restriction that the semi-band width must be less than 350. This permitted significantly larger problems to be undertaken. Since that time, greater strides have been taken and at present, the structural analysis of large segments of ships is more commonplace and routine.

Were we to undertake the SEABEE design today, our initial models for design purposes would be rather similar to those described herein. However, as a result of the increasec computer capacity available today, we would perform a final analysis of the major areas of the ship, which would be comprised of the component models or substructures used in the initial design phase. Such an analysis could permit further insight into the interaction between the barge hull and the ship hull. The modelling of the barge and ship simultaneously is also more practicable today since we can measure barge contours on a number of in-service barges. Hopefully, the use of the SCORES program for loads and the increased finite element capability will reduce the weight of future vessels.

REFERENCES

1 Program SCORES - Ship Structural Response in Waves - Final Report on Project SR-174, "Ship Computer Response" to the Ship Structure Committee - SSC 230.