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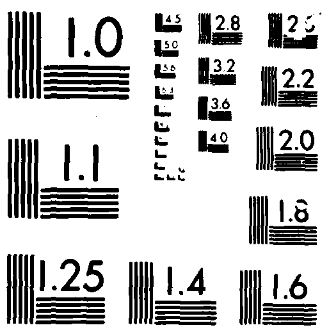

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ENGINEERING INVESTIGATION REPORT

ON

LOSS OF THE SEACON'S CENTER WELL DOORS

BY

C.E. BODEY DIRECTOR, ENGINEERING AND DESIGN DIVISION FPO-1

DR. C. CHERN STRUCTURAL MECHANICS SPECIALIST

FPO-1-80(2)
DECEMBER 1979

OCEAN ENGINEERING
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report and U/W TV tapes made by the divers 3. Study of the ship-drawings and discussion of design deficiencies and proposed corrections with a representative of the design agent (J.J. Henry) 4. Conducting a failure-mode analysis of the design and the operating procedures 5. Developing engineering design recommendations for correcting design and/or operational procedures.

ENGINEERING INVESTIGATION REPORT
ON
LOSS OF THE SEACON'S CENTERWELL DOORS

1.0 SCOPE

This is an engineering investigation report on the loss of the center well doors of the NAVFAC Ocean Construction Platform SEACON while under tow the night of 12 November 1979. The investigation included:

- inquiry into events leading to the loss,
- review of the underwater inspection report and U/W TV tapes made by the divers,
- study of the ship-drawings and discussion of design, deficiencies and proposed corrections with a representative of the design agent, (J. J. Henry)
- conducting a failure-mode analysis of the design and the operating procedures, and
- developing engineering design recommendations for correcting design and/or operational procedures.

2.0 OBJECTIVES AND GROUNDRULES

The prime objective of the investigation was to arrive at a sound engineering recommendation for restoration of the vessel to service in January 1980. Priority was placed on meeting the NAVFAC commitments to the Linear Chair Project and the St. Croix Underwater Range-Expansion Project on schedule. Either temporary or permanent fixes were acceptable, providing that the towability of the vessel and the utilization of the center-well feature were assured. It had already been determined that there was no drydock facility in the Norfolk area that would be available in time to do the job; consequently, practical solutions were limited to those which could be accomplished by use of a cofferdam, or those that could be installed through the center well of the vessel. The investigation was conducted by Mr. C. Bodey (FPO-1 Engineering Division Director) and Dr. C. Chern (FPO-1 Structural Mechanics Specialist) under tasking from the FPO-1 Construction Division Director, Mr. Edmund Spencer. The broad aspects of a Board of Inquiry were not involved.

3.0 CHRONOLOGY OF EVENTS

This is a chronological summary of the pertinent events which culminated in the loss of the center well doors and the aft hatch cover.

3.1 Initial Service (1976 to May 1979): The SEACON was converted from a NASA YFNB to an ocean engineering and construction work platform by NAVFAC in 1976. Figure 1 shows the general arrangements of the vessel, the center well, the underwater doors and the hatch covers. Since its' launching, the SEACON has been utilized on a variety of Navy ocean engineering and construction projects. Many of these missions have used the launch and recovery capability of the center well feature; and no difficulties were experienced with it either self-powered, or under tow prior to this.

3.2 Shipyard Maintenance and Outfitting (7 May to 6 August 1979): The Bellinger Shipyard, Jacksonville, Florida performed maintenance and outfitting on SEACON during this period. While drydocked, the center well doors were removed and reinstalled. No damage to the doors hinges or hinge-pins was reported. However, after the accident, it was discovered that the shipyard had omitted one of the spacer washers from each of the four hinge assemblies. Also the washer that was put in the assembly was 1/8" thick (vs. 3/16" on the drawing). This permits 1/4" more side motion freeplay than was designed for.

3.3 Resupply and Ballasting (6 August to 19 August 1979): SEACON was resupplied and ballasted at the Mayport Naval Station, Jacksonville, in preparation for an U/W TV sled test off of the Bahamas -- and for the subsequent run to Fort Lauderdale. No pertinent event respective to center well equipment was reported.

3.4 Jacksonville to Fort Lauderdale (15 August to 19 August 1979): SEACON proceeded from Jacksonville to Fort Lauderdale under her own power. However, a lube oil leak in a propulsion unit led to a change of plans. The SEACON went first to Fort Lauderdale for reserve lube oil, then to the Bahamas for the TV sled test. It returned to Fort Lauderdale on 19 August with no trouble reported with the door equipment. The U/W doors were closed during the test and transiting.

3.5 Fort Lauderdale Operations (19 August to 5 November 1979): Sea Trials were run and the Linear Chair underwater surveys and installation work was accomplished. The center well was utilized and no difficulties were reported. The doors were closed and dogged down; and the hatch covers for the well were set in place for the tow to Norfolk.

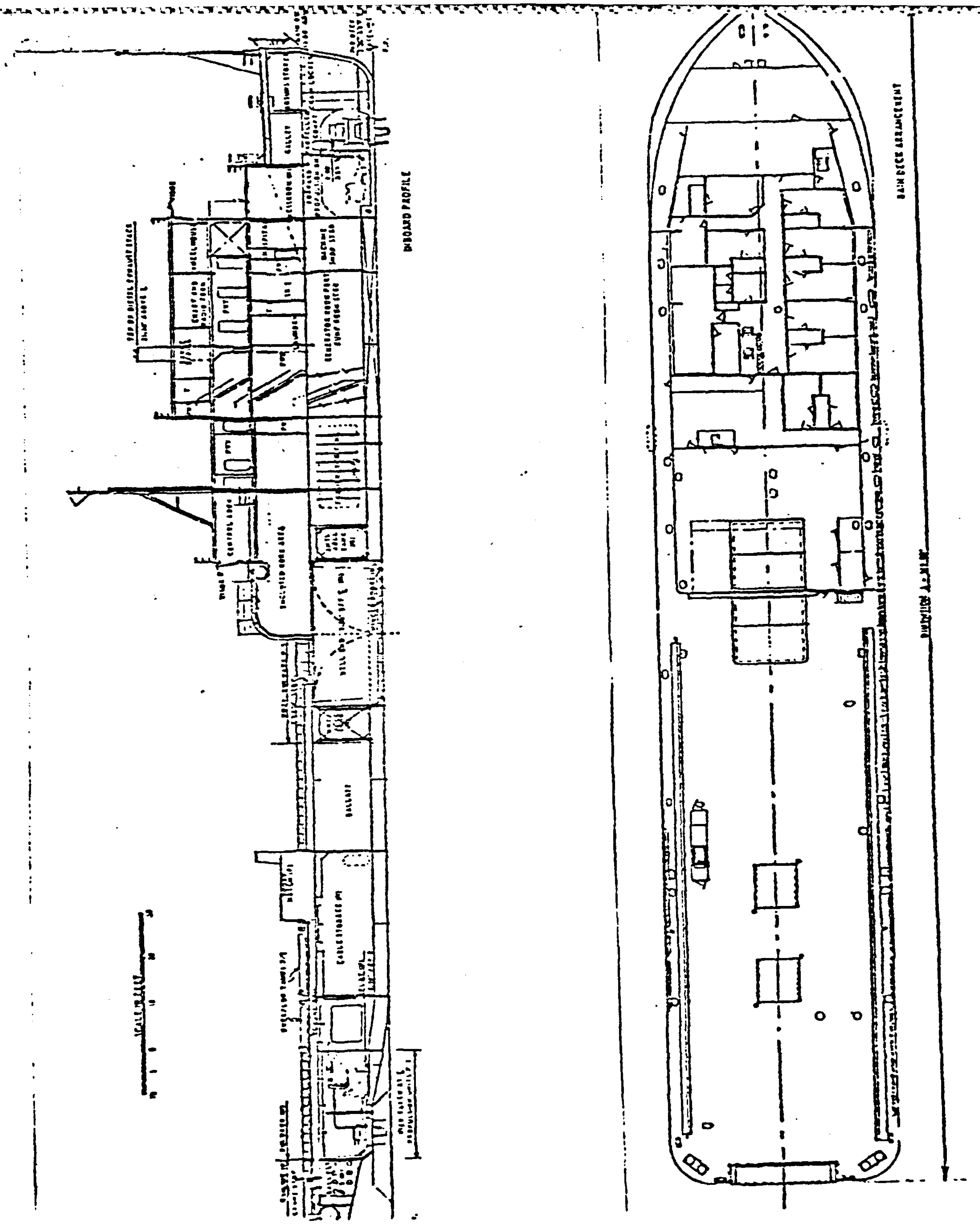


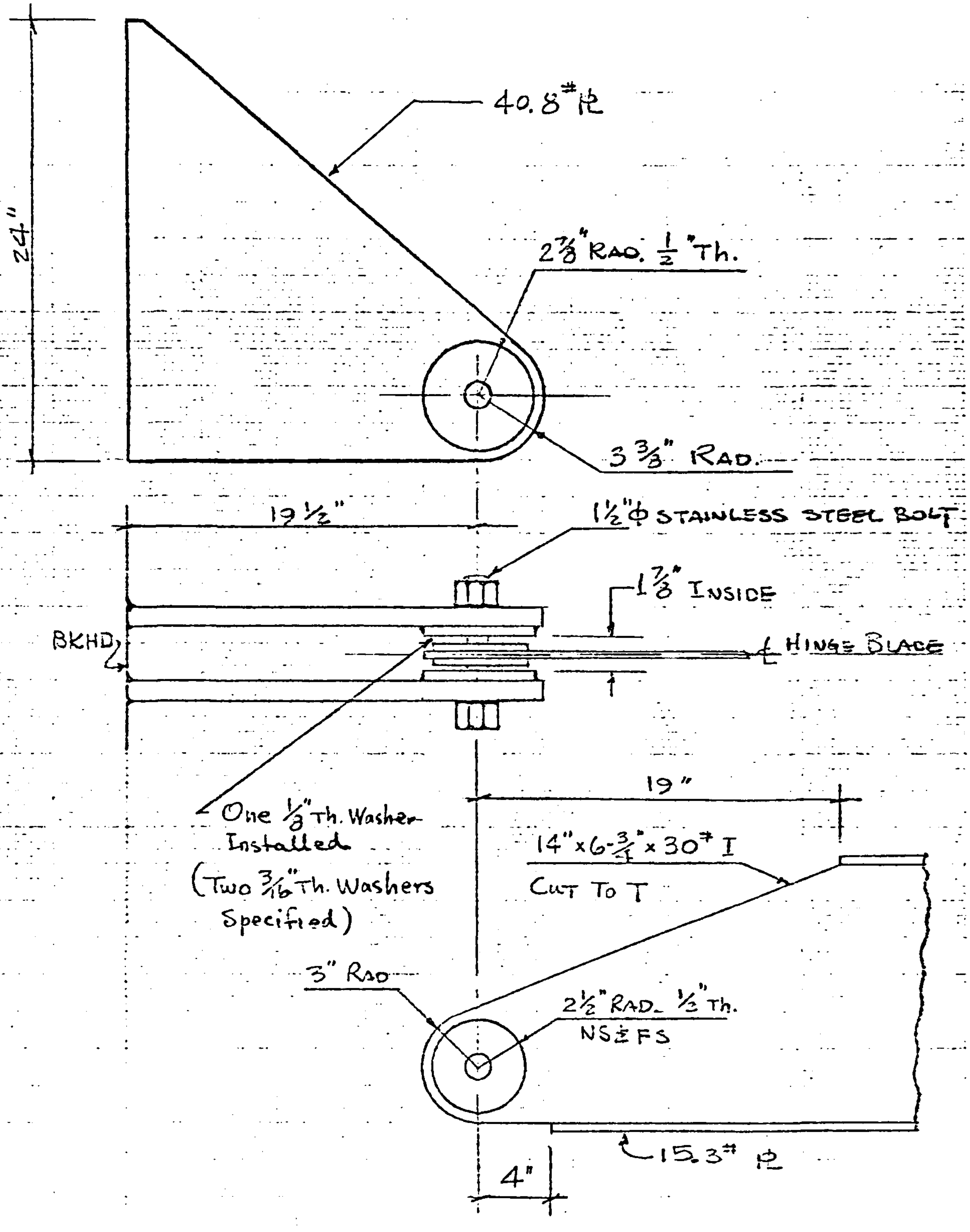
Figure 1. SEACON, GENERAL ARRANGEMENTS

3.6 Fort Lauderdale to St. Juliens Creek (6 November to 14 November 1979): SEACON was towed to Little Creek and reached St. Juliens Creek with tug assist. During the afternoon of 12 November, the second engineer heard unidentified noises in the center well compartment. The Captain described the noise as being an intermittent banging which was masked by other ship-noise and muffled by the hatch covers. It was not unlike the noise of an anchor swinging against a hull; but it was not identified at the time as being from the doors. Finally, at about 0800 the morning of 13 November, the First engineer was on deck and saw the aft hatch cover lifted up about two feet by a gush of water out of the well. Then it plunged down into the well and disappeared. Thereafter, it was discovered that both of the doors were missing; and water was surging out of the well and threatening the tie-downs of a nearby truck on the deck.

3.7 Underwater Inspection at St. Juliens Creek (16 November 1979): Commerical divers conducted an underwater inspection of the damage to SEACON using TV and some measuring equipment. The TV tapes and the preliminary report show that hinge-blades which were part of the doors were broken off; but they were still attached by their hinge-pins to the mating hinge-blades which remained intact on the fore and aft bulkheads of the well. The foreward bulkhead hinge blades and pins were straight and undamaged. The aft bulkhead hinge blades and pins were bent and had obviously seen great abuse. Also the port and starboard door-sills were bent and damaged near the aft end of the well. Inspection of the four hold-down mechanisms showed the two on the aft door were in the full-closed position; but of the two foreward mechanisms, one indicated itself to be full open, and one partially open. The TV tapes and inspection report are available at St. Juliens Creek.

4.0 <u>ENGINEERING INVESTIGATION</u> (20 November through 29 November 1979):

The two investigators travelled to St. Juliens Creek for inspection of the SEACON and interviews with C-Division personnel on 20 and 21 November. Mr. Robert Redmon (SEACON Captain) and Mr. George Phillips (OCEI Manager) provided most of the information in the above chronology. Mr. K. Edgar (Tracor) showed the TV tapes and explained them. He also arranged to get the divers back on the SEACON to recover the damaged door-hinge-blades from the hinge assemblies on the bulkheads of the well. Mr. W. Hudson (Design Engineer from J. J. Henry) came over from the office of J. J. Henry to look at the recovered hardware, to look at the TV tapes and to discuss design deficiencies and the fixes being considered by the investigators. The failure-mode analysis, based on the above information and a detailed review of the ship drawings is reported on below.

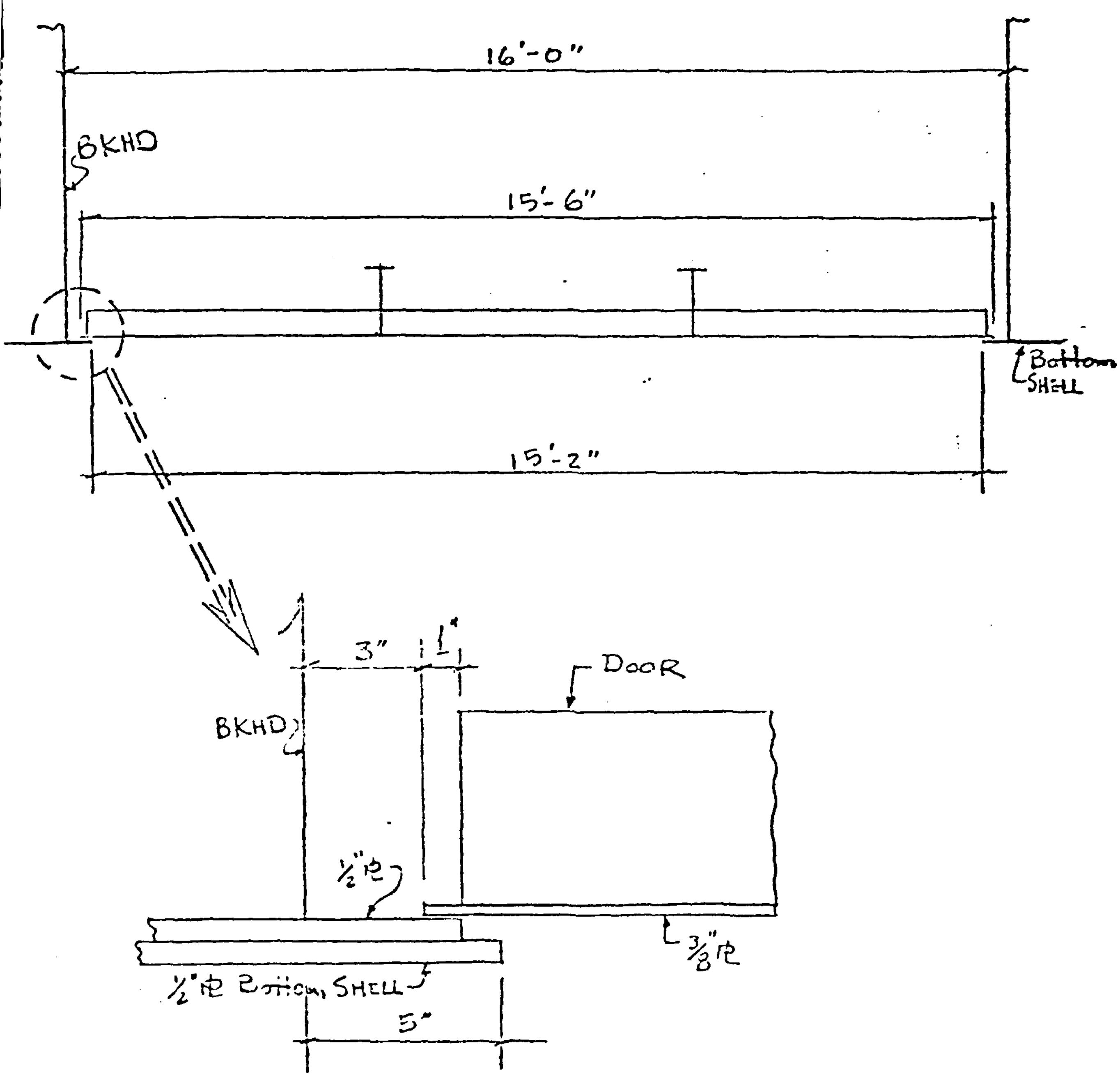


SK-01 CENTER WELL DOOR HINGES

4.1 Door Design: The door design was found to be structurally sound except for members which formed part of the door-hinges. Two 14" deep beams run longitudinally as stiffeners. These are spaced 1/3 of the door-width apart; and a portion of the web of each beam extends to form a door-hinge-blade as shown by the sketch SK-01. The beams are adequate as stiffeners; but the 1/4" web does not provide adequate material for this particular design application of a hinge.

4.2 Hinge Design: SK-01 shows some of the critical details of the hinge assembly design. The two hinge-blades welded to the bulkheads and lower sill of the well are large pieces of 1" plate which are well supported by the ship structure. On the other hand, there is only one door hinge-blade per assembly; and it is only 1/4" thick. The design provides a poor balance in both strength and stiffness between the bulkhead hinge and the door hinge blades. It provides an equal disparity between vertical load capacity of the hinge assembly and the side-load capacity of the door hinge-blade. This latter deficiency fails to accommodate side-loads on the door caused by ship roll, yaw and sway; yet no other provision was made for taking such loads at the hinge-ends of the two doors. The inability of the hold down mechanisms, at the opposite end of the doors, to help alleviate this is discussed below. These hinge elements accumulated several million cycles of side load-in the period between 1976 and the present. The condition exists whether the doors are in the up position, or in the down position. Even though this did not result in any noticeable permanent-set bending of the blades, they were certainly exposed to cyclic loads that under a combination of conditions could (and did) cause the failure of the door hinges. This design deficiency could only be aggravated by the omission of the spacer washers by the shipyard. Thus an increment of cyclic shock loading was added to the cyclic flexural loading on the hinge assembly (and the door hinge-blade in particular). The designer either overlooked this side loading condition, or he assumed that the hold down mechanisms at the opposite end of the doors would prevent side motion of the doors and side-loading of the hinge blades. In any case, the brilliance of hindsight shows that he was wrong in selecting this hinge configuration.

4.3 Door Sill Design: SK-02 shows the interface of the doors and the door side-sills based on nominal dimensions. It can be seen that if the side motion of the doors is not retrained by the hinges at one end, and the hold down mechanisms at the other, the door can escape the door sill and fall out. Note: there is no overlap between the doors and the fore and aft "sills". Thus the failure of the door hinges at one end, and



SK-02 DOOR SILL INTERFACE

inability of the hold downs to prevent side motion at the other end, can permit a door to drop out of the well (and it did). It should also be noticed that the bearing between the door and the sill is greatly weakened by the 1" setback between the doublers and the shell plating on the two parts. Also note that this discussion is without any consideration as to the unknown tolerances and fit-up of the ship and the doors.

4.4 Hold Down Mechanism Design: Forces to hold the doors in the down position were applied to the corners of the doors opposite to the hinges by four mechanisms. A spiral wedge-plate was mounted on the corner of the door. It could be engaged by a rotary dog which was fastened to a torque rod that reached up to nearly deck level. The crew applied drive - input torque to this rod by means of a large tee wrench. This input developed a vertical load on the door to hold it down on the door sill. The magnitude of the vertical load was function of the mechanical advantage of the wedge and the frictional torque restraint of the drive rod bearings and the dog-shoe on the wedge. It seems unlikely that crewmen would produce more than about 600 foot pounds of input torque at the tee wrench while standing on deck; and it is not likely that the friction coefficient of the dog on the wedge would be less than 0.1, nor greater than 0.5 under water with some ship vibration. Consequently with the mean radius of rotation for the dog-shoe of 0.5 feet, the vertical hold down force would be in the range of 2,400 -- 12,000 pounds per mechanism. This force is in the same order of magnitude as the distributed gravity force of a door. It is not in itself significant since the thrust bearings on the dog-shoe provide the ultimate hold down function for the doors. The interesting point is that this magnitude of bias force cannot generate the frictional resistance of the doors on the sills to resist side motion (when ship vibration, hydrodynamic turbulence of flow over the ship bottom and vertical surge forces through the door vents are considered). Roll yaw and sway accelerations of a fraction of a "G" will cause side motion that such a frictional clamp cannot restrain. The hold down mechanism should be looked on therefore as a means for placing and retracting a door stop -- and not as a clamp capable of restraining side motion.

4.5 Lift Cable Design: The lift cables were adequately designed and did not contribute to the loss of the doors. However all four cables had been broken; and the portions remaining attached to padeyes on the bulkheads revealed a great deal about the nature and sequence of the accident. The two foreward cables were broken off at about the same length, mostly by abrasion. The two aft cables had been damaged at about the same location; and one was broken at that spot. The other cable was broken off at a greater length which was a spot corresponding nearly to its point of attachment to the door. Polaroid prints document these findings.

5.0 FAILURE MODE SCENARIO

The investigators believe that the following failure - mode scenario is sufficiently realistic to guide the establishment of sound engineering recommendations for correcting the design deficiencies which caused the loss.

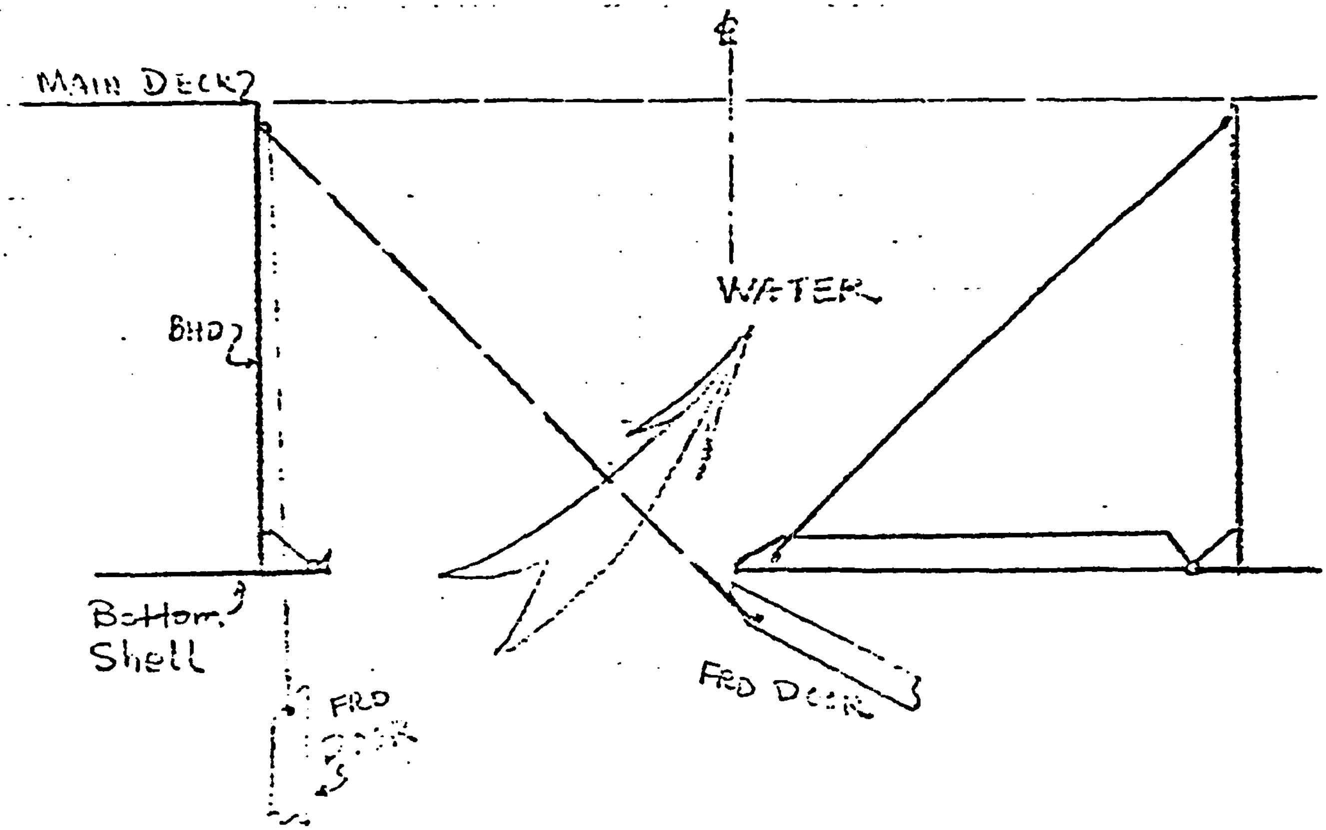
5.1 Loss of Forward Door: The door hinge-blades of both doors had suffered progressive deteriation due to cyclic side loads during past operations; so that while under tow in fairly high following seas the foreward door hinge blades broke off. The hold downs did not have sufficient clamping power to restrain the side loads on the hinges; and when the hinges broke, the clamping action was not sufficient to restrain the door from sliding sidewise, escaping the sills and falling out of the well. The falling door was restrained by its' two lift cables and brought up against the leading edge of the aft door as shown in SK-03. Here the two lift cables were abraded and broken away and the door was released and lost.

5.2 Loss of the Aft Hatch Cover: Loss of the foreward door left the aft door in the down position and facing foreward as a water scoop. This put very heavy hydrodynamic loads on that structure and sent a surge of seawater up against the aft bulkhead of the well and up against the underside of the aft hatch cover. This lifted the hatch cover up off of its shelf, relieved the hydraulic pressure and allowed the cover to fall down into the well and onto the lift cables of the aft door. The hatch cover was then washed out of the well either alone, or together with the aft door. This scenario assumes the former; but it is not significant.

5.3 Loss of the Aft Door: The falling hatch cover damaged both lift cables and broke one. The door may have become buckled and partially driven through the aft end of the two side sills. It had lost support from one lift cable and was under large hydraulic forces (as it twisted both hinge assemblies before breaking off the door hinge-blades). The door then escaped the sills of the well restrained only by one lift cable which broke off, or had broken off, near its attachment to the door.

6.0 ENGINEERING RECOMMENDATIONS

Preliminary discussions were held between the investigators, the FPO-1 C-Division, and Tracor as the work progressed; and it had been determined that a cofferdam could be constructed in the available time.

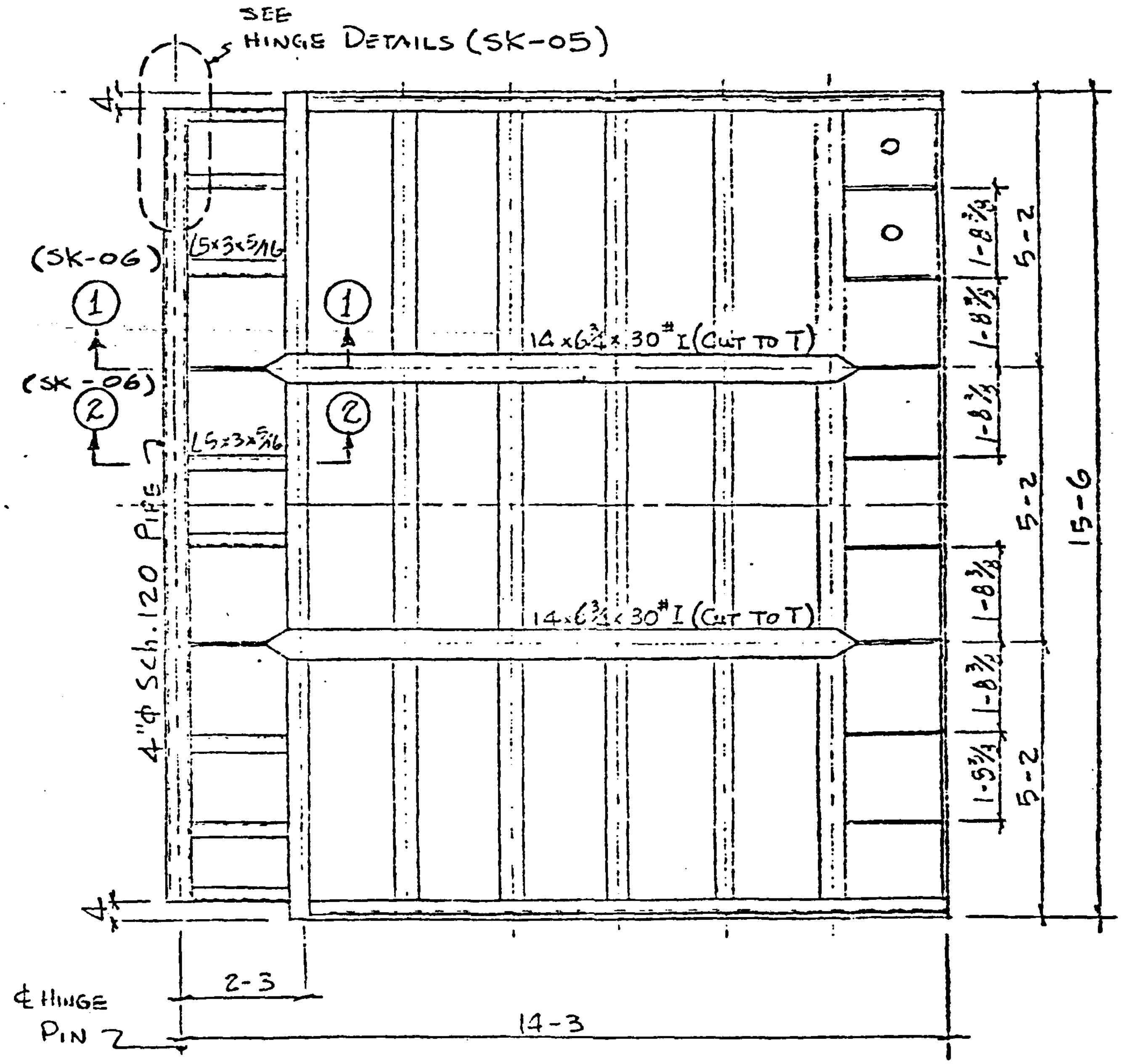


SK-03 FOREWARD DOOR FALL-OUT

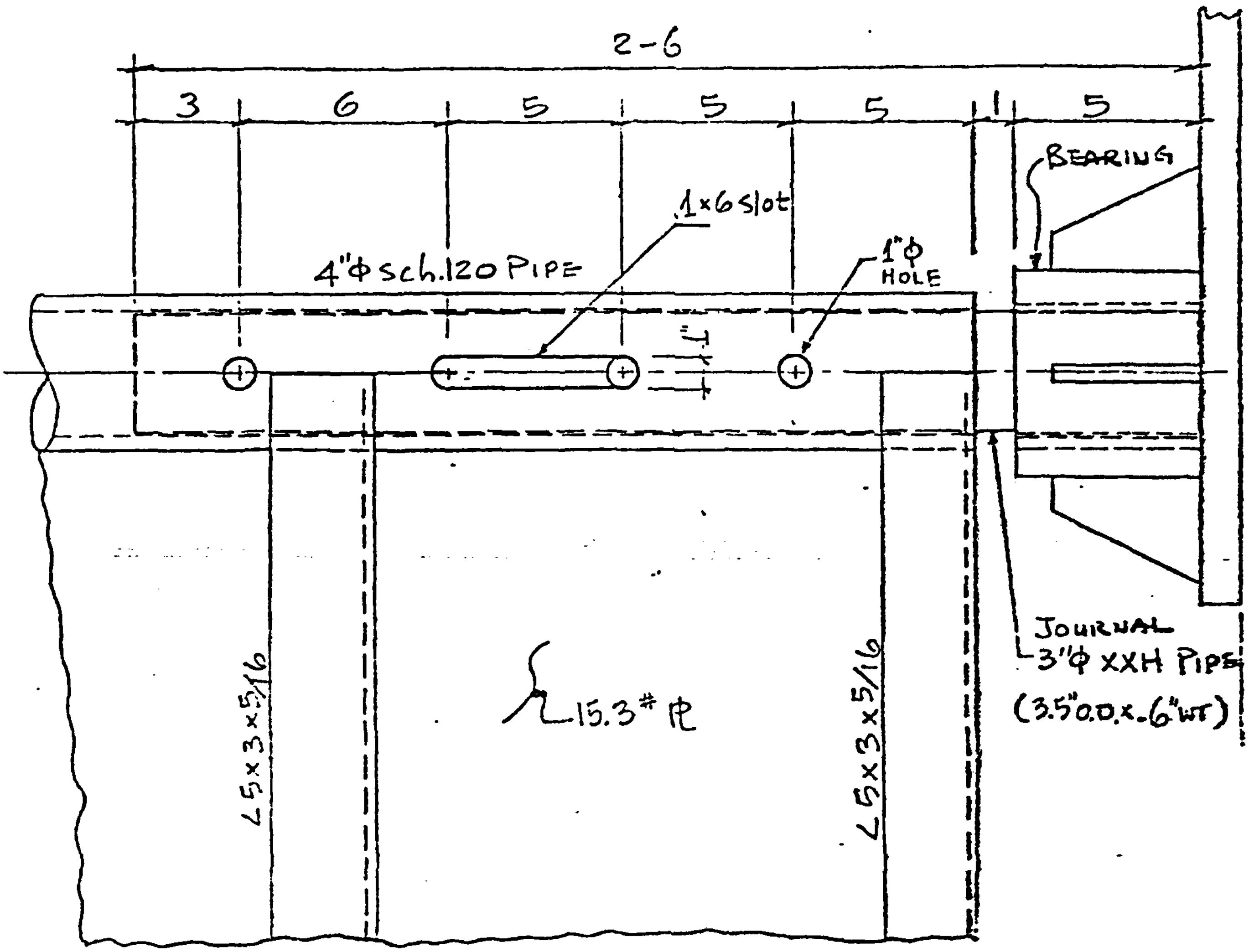
Also the contemplated permanent fix redesign and fabrication could be accomplished early January. A preliminary design study was conducted by Mr. C. Bodey and Dr. C. Chern and the following recommendations were presented on 29 November 1979:

6.1 Door Hinges: The door hinge design is changed to a journal and bearing design so as to provide a thrust bearing to restrain side motion of the doors and to eliminate the improper use of blade-flexure to accomplish this function. This is done by replacing the 3" x 5" angle iron at the hinge edge of the door with a thick walled section of 4.5" O.D. pipe as shown in SK-04 and SK-05. The section modulous of this pipe is more than enough greater than that of the 3 x 5 angle which it replaces to compensate for the fact that the bending moment on the door (with the hinges outboard of the door) is greater than it was with the blade-hinges at the one-third spacing. The hinge journals are slideably disposed inside of the pipe leading edge of the door to provide for side-play adjustment and for installation/removal of the doors. SK-06 shows interface of the pipe-structure with the original design details of the longitudinal beams and the 3 x 5 framing around the door. Except for the piping leading edge, there are essentially no other changes in the door design. SK-07 shows the journal bearing design. The design transfers the bearing loads suitably into the side-wall structure of the well; and it provides bronze brushings with lubrication tubing accessible from deck level for servicing. This design eliminates the flexural fatigue problem and controls side-play so that door motion cannot cause escape from the door-sills at the hinge ends. It involves minimum changes in the door design; and it can be installed and fitted up by use of cofferdam.

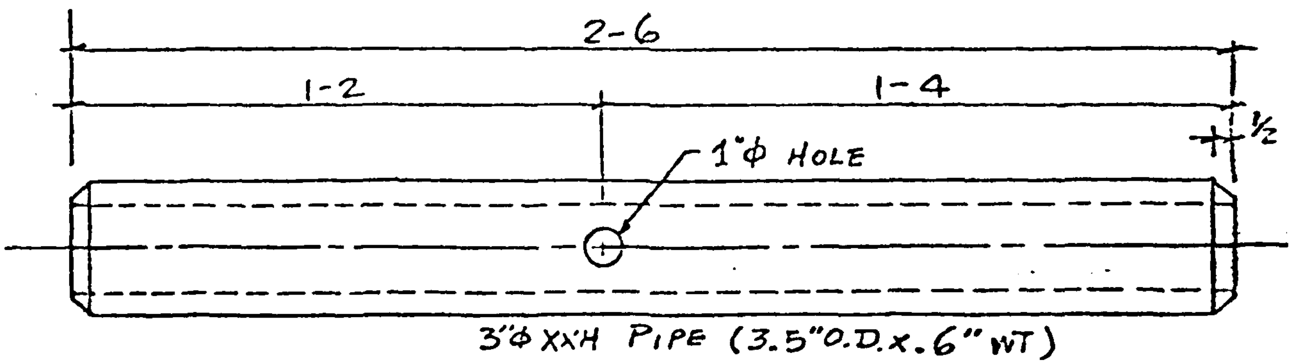
6.2 Door Sills: The original door sills were found deficient in design and were so battered up that they had to be straightened and/or replaced. Considering the difficulties involved and the availability of the cofferdam, it was recommended that the side-sills be cut away and replaced with a heavy-wall 6 x 6 angle iron section as shown in SK-08. By raising the angle base leg up about 1/2", the welding can seal the crack between the shell-plate and the doubler, as well as weld the heel of the angle iron to the sidewall of the center well. Since a sustantial discontinuity already existed between the shell plating and the undersurface of the doors, an additional 1/2" of so was of no matter. Considering all of the ventilation holes in the doors, and the large gaps at their foreward, middle and aft edges, the doors were obviously only effective as surge-dampers and were not intended to be even approximately flush with the ship plating for hydrodynamic reasons. This



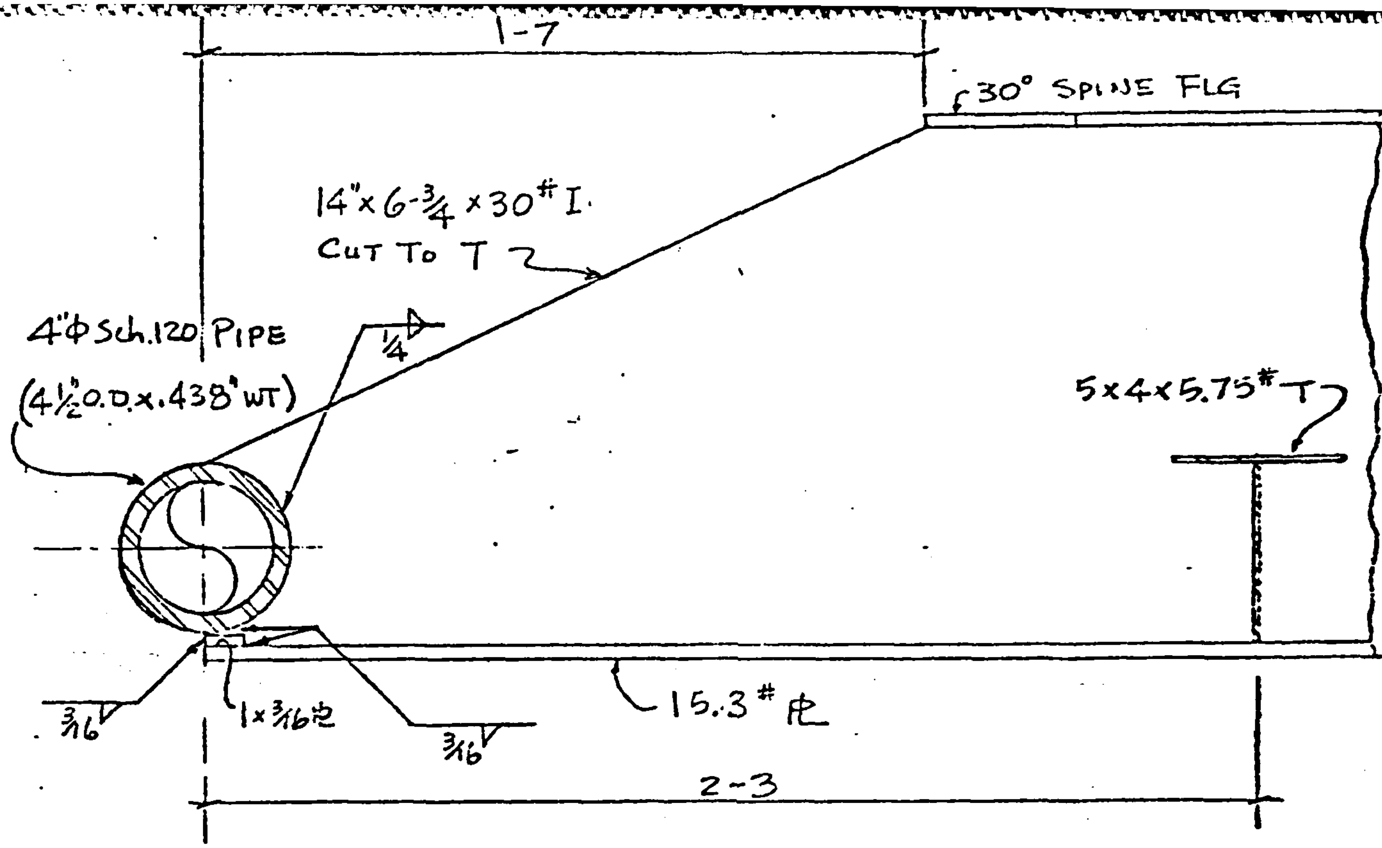
SK-04 PIPE LEADING-EDGE MODIFICATION FOR DOOR



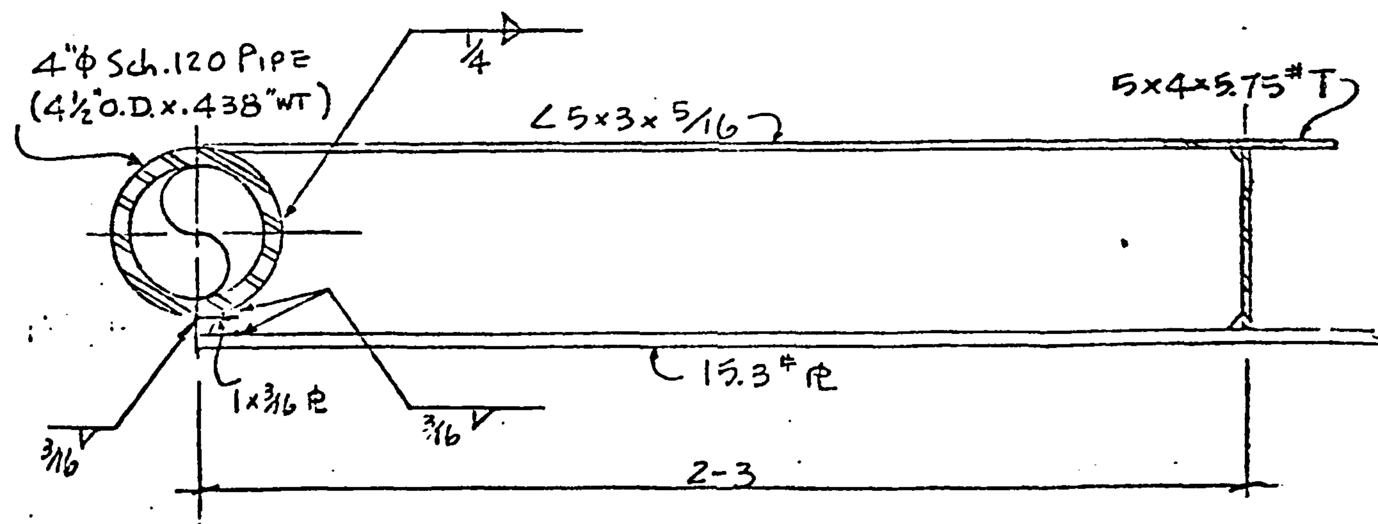
HINGE DETAILS



SK-05 JOURNAL BEARING HINGE FOR DOOR

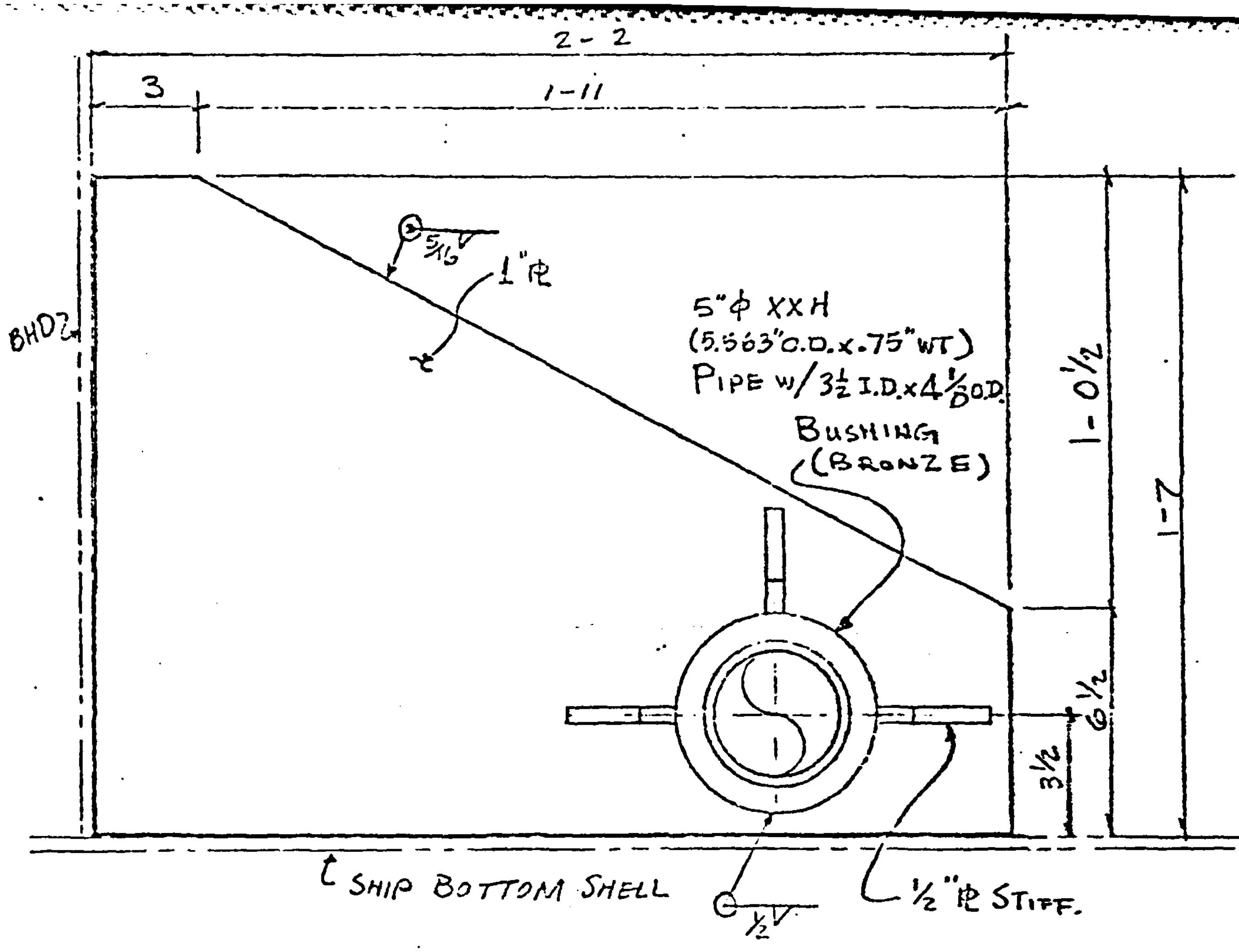


VIEW (1)-(1) (SK-04)

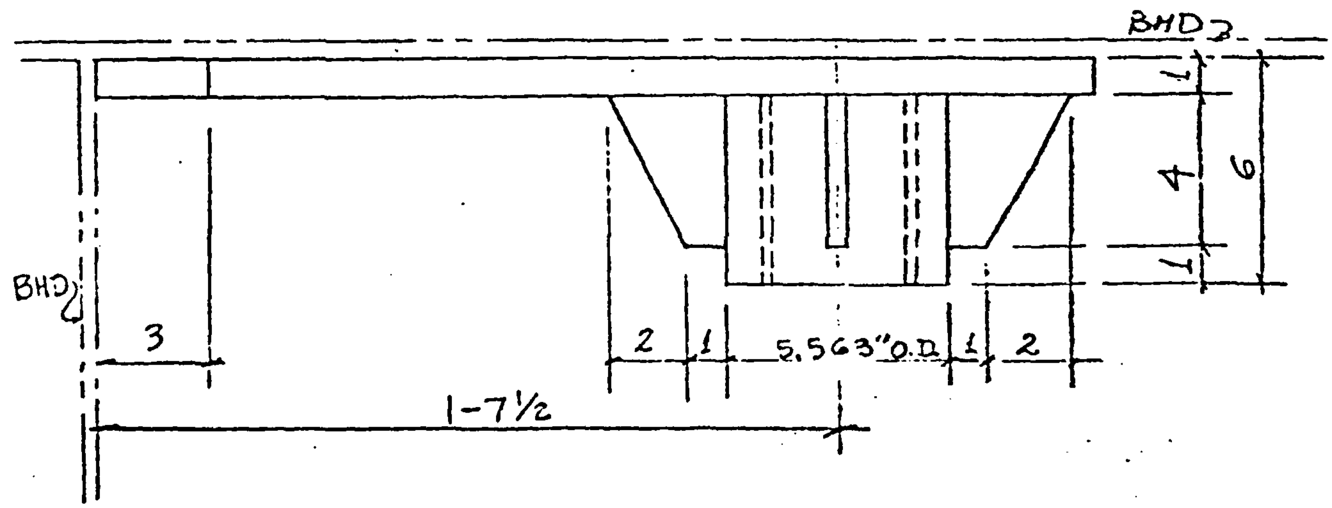


VIEW (2)-(2) (SK-04)

SK-06 INTERFACE OF PIPE WITH DOOR STRUCTURE

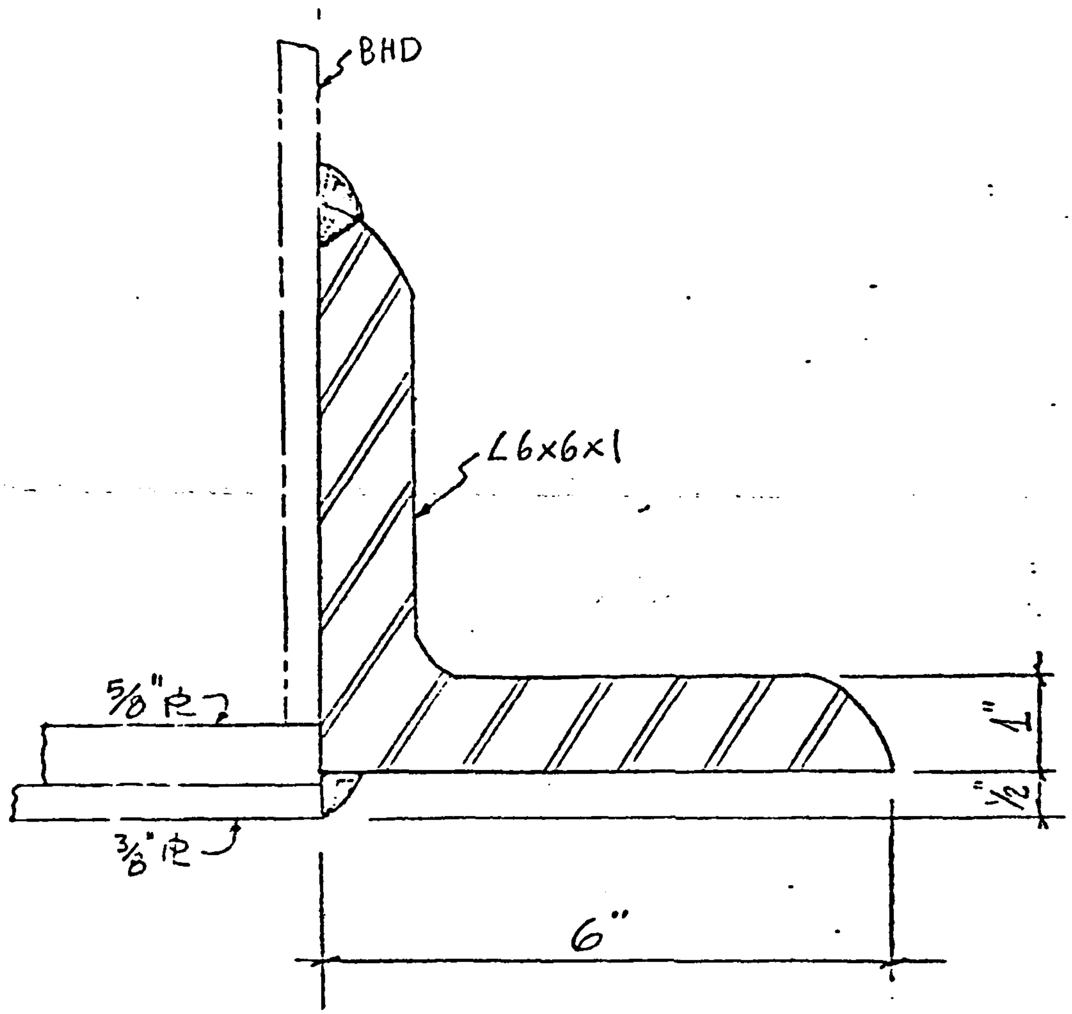


FRONT VIEW -- BEARING



TOP VIEW -- BEARING

SK-07 JOURNAL BEARING



SK-08 REPLACEMENT SIDE DOOR-SILL

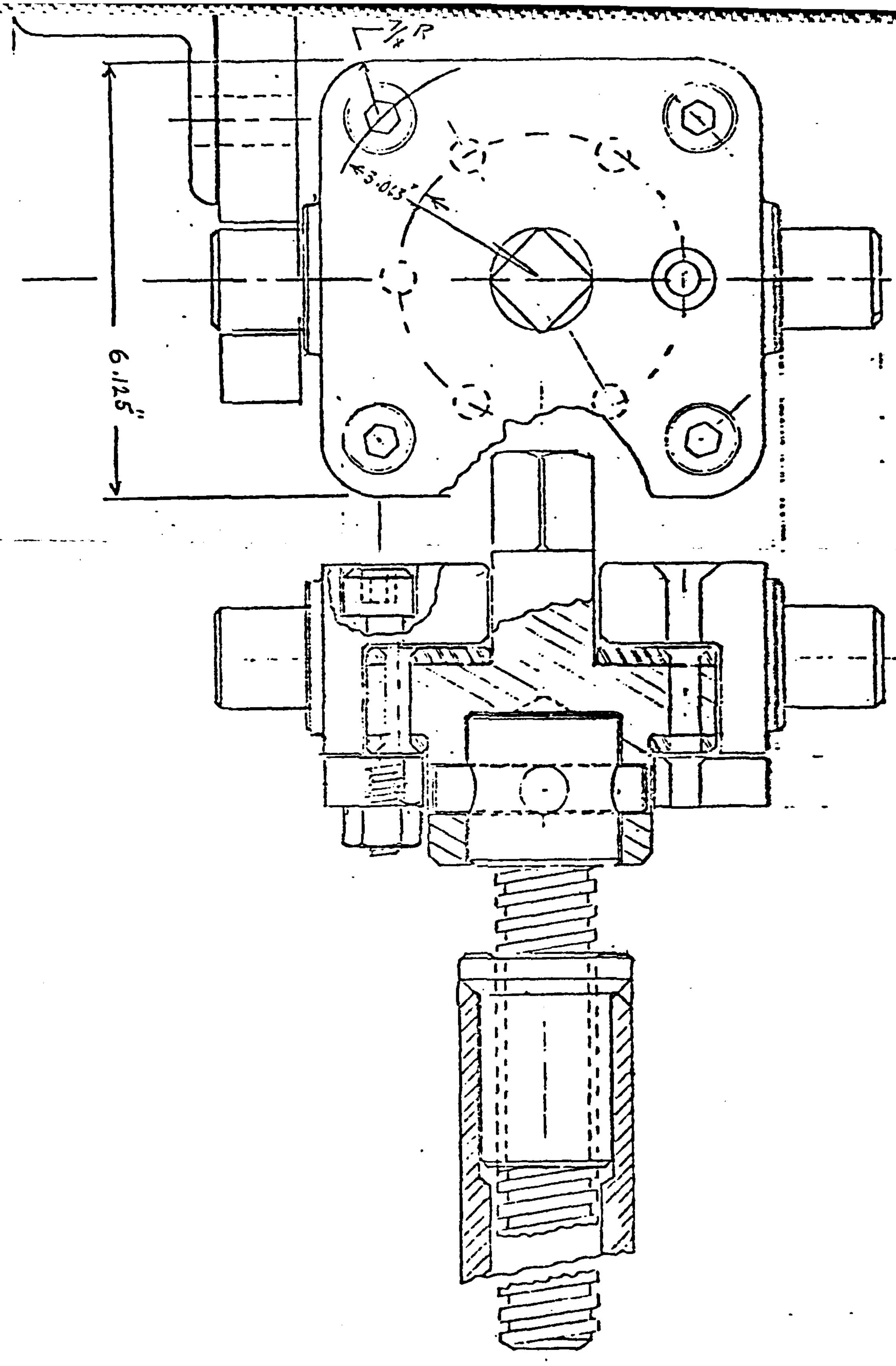
recommendation provided a practical means to repair the damaged door sills and to improve the design deficiency by eliminating the underlap that permitted escape of the doors from the sills.

6.3 Hold Down Mechanism: The deficiencies in the design of these mechanisms were that they were not capable of providing enough added friction of the door against their sills to protect the hinge blades from flexural fatigue loading; the ability to provide vertical clamping of the door to the sill varied widely depending on friction between the hold-down shoe and the wedge on the door. Side motion of the door could twist and loosen the shoe and the torque shaft assembly. With the new hinge design, it is possible to come up with a new mechanism which is interchangeable with the old one. It is shown in SK-09 and SK-10. The element is above the water level in the well. It is provided with a lubrication accessible from deck level; and it uses a safety lock-pin which is not dependent on friction to maintain the up/down settings. The interface with the door is a rocker arm which is actuated by the jackscrew and strut mechanism. The cam-plate on the door could be designed to develop both vertical and side-motion resistance; however, the final decision was to use a flat plate for vertical resistant only. This eliminates the rollers on the rocker arms. Lubrication of the rocker arm assembly from the deck level is specified. Since the function of this mechanism is only to provide a remotely actuated hold-down vertical-stop, and because of its high mechanical efficiency, it is not necessary to try to brute force it into the down position. A sufficient force can be developed and controlled by use of a preset torque wrench; and any discrepancies between torque release and the jackscrew "down" position indicator will show that a malfunction exists.

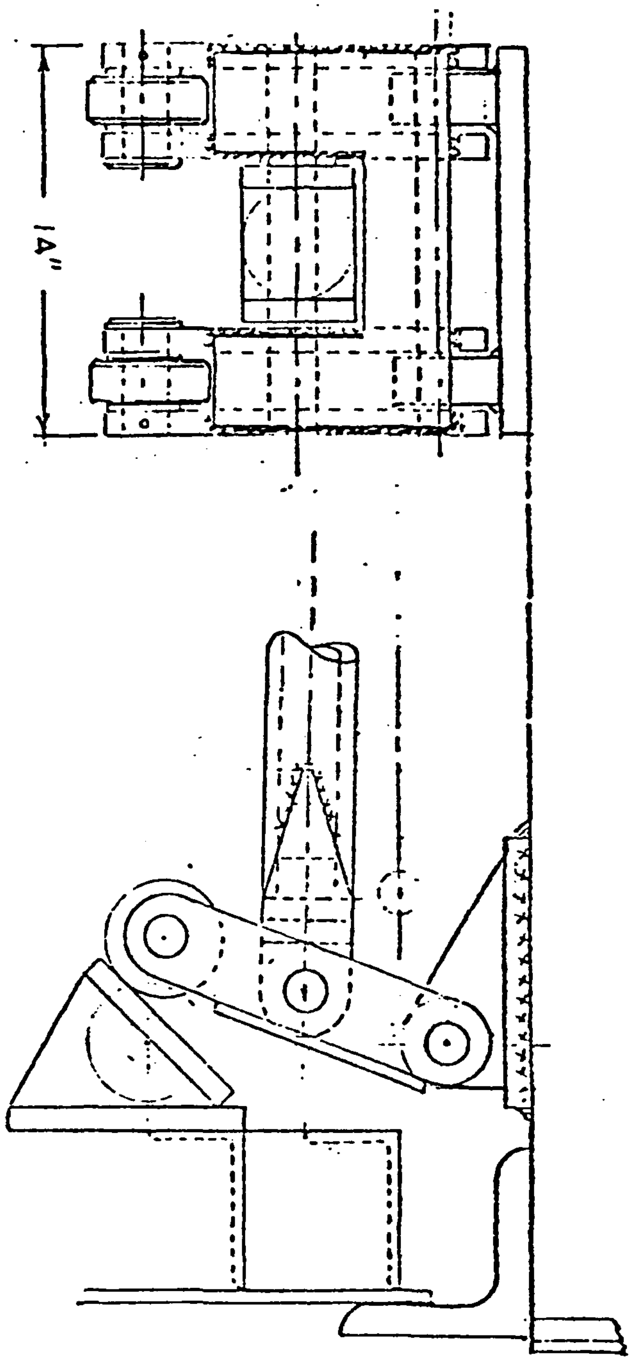
6.4 Acceptance of Recommendtions: The above engineering recommendations were presented to Mr. E. B. Spencer (FPO-1C, Director, Construction Division) and Mr. K. Egar and Mr. E. Clausner (Tracor) on 29 November 1979. They were accepted with the decisions to add the side-motion guide wedges, eliminate the horizontal restraint option of the rocker arm (and eliminate the need for the rocker arm rollers); and to make the jackscrew drive accessible through openings in the hatch covers.

7.0 SUMMARY AND CONCLUSIONS

This engineering investigation was completed on time with the assistance and full cooperation of all parties concerned. The Tracor responsibility to acquire underwater inspection support, locate sources for fabrication and detailed design, etc., was accomplished in parallel



SK-09 JACK SCREW HOLD DOWN ASSEMBLY



SK-10 HOLD DOWN ROCKER ARM

with this study effort and contributed largely to successfully meeting the deadlines set by FPO-1C. The findings and recommendations are summarized as follows:

7.1 Cause of Loss: The principle causes for the loss of the SEACON's center well doors and aft hatch cover were design defficiencies in the door hinges, door side-sills and the hold-down mechanism. A contributing factor was the replacement of the thinner hinge spacer washers by the shipyard. The result was progressive deteriation of the hinges which culminated in their failure and the loss of the hatch cover during the tow at night in fairly heavy following and quartering seas.

7.2 Engineering Recommendations: The engineering failure mode analysis was sufficient to develop a reasonable insight as what happended, how it happened and why it happened. This led to preliminary design analyses and recommendations for eliminating the deficiencies and restoring SEACON to service within the groundrules and constraints established by FPO-1C. Preliminary designs for the door modifications, redesigned hinges, door side-sills, and hold-down mechanisms were produced.

7.3 Follow on Status: Mr. C. Bodey and Mr. E. B. Spencer traveled to St. Juliens Creek to review progress of the work on 17 through 19 December 1979. The cofferdam had been fabricated and was being installed. The doors had been detailed, fabricated and inspected. Hinge assembles were completed. Hold-down mechanism parts were on order, detailed drawings were in process and completion dates appeared to support the installation requirement dates.

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