6

TECHNICAL EVIDENCE

CHAPTER SIX TECHNICAL EVIDENCE

An extensive program of scientific investigation was undertaken into the structural, electrical and mechanical design of the *Ocean Ranger*. This program was carried out under the supervision of Dr. Ewan Corlett, Chief Technical Advisor to the Royal Commission. The results of this work provided the technical evidence on which the analysis of the cause of the loss has been based.

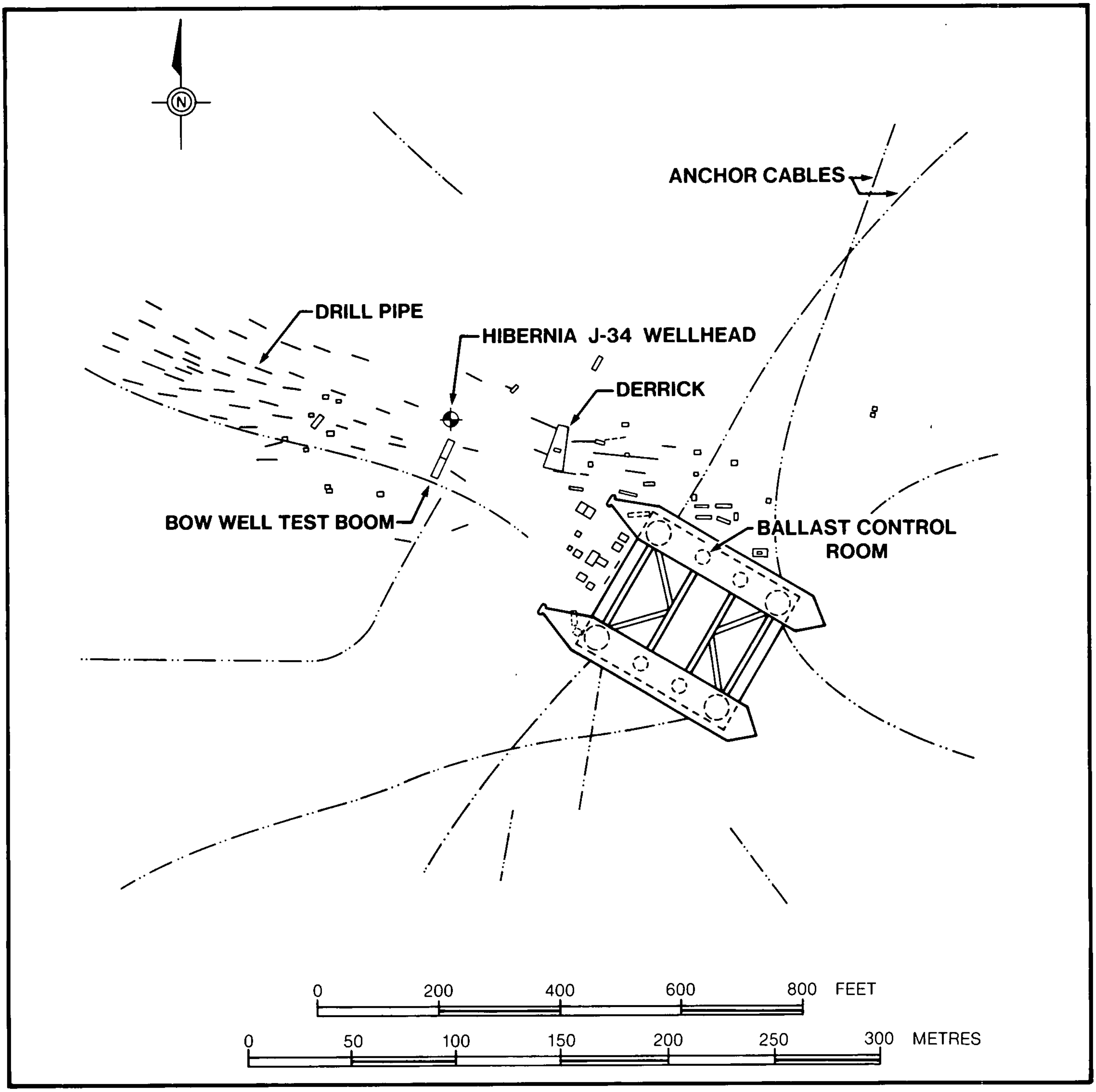
During July and August 1982, an underwater survey of the wreck and its site was carried out. The results of the diving program have provided important information on the condition of the rig and the circumstances contributing to the capsize. The Aviation Safety Engineering Facility (ASE) of Transport Canada carried out a technical examination of equipment recovered from the ballast control room and undertook a number of simulations to determine the cause and effects of the damage discovered. They identified features of the rig's electrical and mechanical systems that may have inhibited the crew's attempts to counter the problems leading to the loss.

It was apparent from the outset that an examination of the *Ocean Ranger's* stability and its behaviour in storm conditions would be necessary. Very little information was available regarding the rig's response to environmental forces and it was considered difficult, if not impossible, to develop adequate mathematical simulations to deal with the many factors involved. It was concluded, therefore, that a program of scale model testing supported by mathematical analyses would be the most effective method of assessing the effects of environmental forces, ballast transfers and downflooding on the rig's stability, as well as the behaviour of the rig at large trim angles. Analyses were also carried out on the ballast control panel and the pumping systems.

DIVING SURVEY

A series of sonar and underwater surveys conducted by Mobil Oil Canada Ltd., in February and March 1982, located the wreck in an inverted position, approximately 500 feet to the southeast of the Hibernia J-34 wellhead at a seabed depth of 255 feet. The superstructure was crushed into the seabed and the rig was resting on its upper deck. An examination was carried out using a remotely controlled vehicle (RCV) equipped with a closed-circuit television camera. The Mobil survey team located four areas of structural damage on the accessible portion of the wreck: significant damage to the bows and anchor bolsters of both pontoons; a damaged side girder and an area of collapsed under-deck plating at the base of the third starboard column; and two broken portlights in the ballast control room located in the same column. No structural damage was found at the critical nodes which connected the pontoons, columns, upper hull and transverse braces. An RCV examination of the wellhead and blowout preventer (BOP) revealed a considerable amount of debris near the wellhead, including a piece of drill pipe lodged against the BOP itself which, however, was essentially undamaged. The well was properly secured. (The J-34 well was subsequently re-entered and suspended during June 1982. The results of this program are detailed in Appendix F, Item 1.)

Planning for the Royal Commission's underwater survey took place during the early summer of 1982. A review of the "as-built" plans of the rig was carried out in



combination with a study of the video tapes and sonar recordings from the earlier Mobil survey. A diving support vessel, the *Balder Baffin*, was engaged and equipped to act as the tender for the underwater operations. The purpose of the survey was to verify the information obtained by Mobil and to inspect the wreck for further indications of structural failure. In addition, a survey of the debris and of the mooring lines and soundings of the pontoon tanks were to be undertaken. Plans were made to enter the ballast control room, if possible, in order to retrieve documents and equipment relevant to the investigation.

The survey began in July 1982 with a thorough structural examination. A team of divers and an RCV survey confirmed the results of the Mobil survey. No additional damage was located. It was observed that the damage to the anchor bolsters and bows of both pontoons was similar, although the total area of damage was slightly greater on the bow of the port pontoon. It was concluded that the rig had hit the seabed while trimmed by the bow at a considerable angle and that the rig was also heeled to port at the time of impact. Both the port and starboard bow ballast tanks were punctured. The damaged longitudinal girder and the collapsed section of under-deck plating at the base of the third starboard column were re-examined during the survey. This area was identified as the forward outboard corner of the emergency generator room. On examination, the damage was concluded to be a consequence of, rather than a contributor to, the capsize of the rig.

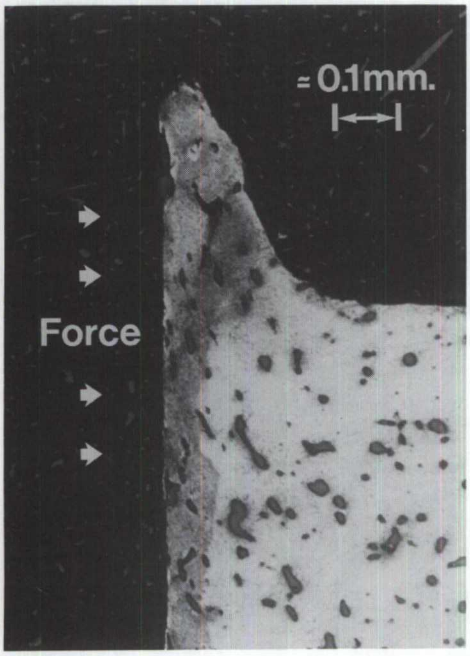
It had been reported on the night of February 14 that one portlight in the ballast control room had failed; at the time of the survey two were found to be broken. It was also noted that the deadlights on all of the four portlights were closed. The divers removed from the ballast control room both damaged portholes and a third that was undamaged. These were later forwarded to ASE for detailed examination and testing.

The debris and mooring lines on the seafloor were surveyed for indications of the exact manner of the capsize. The pattern of drill pipe to the northwest of the wreck and the position of the derrick and equipment from the foredeck were considered to be consistent with the rig attaining a severe bow trim while positioned over the wellhead. Although the survey was not sufficiently extensive to determine the exact condition of the twelve mooring lines and anchors, it would appear that through some combination of anchor dragging and line breakage the rig had moved directly above where the wreck was found. The force of the impact on the seabed completely destroyed the drill floor, the accommodations area and all other structures above the upper deck. The anchor windlasses were dislodged from their foundations and were found scattered on the seabed.

The divers found that both the port and starboard manual sea chest valves, which were normally left open at all times, had been closed. They also carried out soundings of the pontoon tanks in an effort to determine the tank contents immediately before the capsize. The volume of air remaining in each tank was determined and then extrapolated to obtain the equivalent air volume at the surface. Several investigators have attempted to reconcile the results of the tank soundings with the tank contents noted in the February 14 stability report which was recovered by the divers from the ballast control room. All attempts have been inconclusive. It would appear that during the capsize and the subsequent sinking of the rig the contents of individual tanks underwent considerable change due to flooding through the vent lines, transfer of contents through open or leaking ballast valves and possible damage to the internal bulkheads between the tanks. The tank soundings were not considered to be sufficiently reliable to form the basis for conclusions regarding the loss of the rig.

The diving team entered the ballast control room and recovered documents which included a working copy of the stability report for February 14. The entire

6.1 The location of debris at the Hibernia J-34 site, as developed from sonar and underwater surveys. The anchor cables are only shown to the limit of the area surveyed.



6.2 This photomicrograph shows the distinctive lip of metal discovered around the entire circumference of the locking ring from porthole #4. The lip and the pattern of deformation at its base indicate that the portlight was broken in the inboard direction by high impact loading evenly distributed over the entire glass surface.

mimic panel from the ballast control console and the 64 solenoid valves from beneath the lower portion of the console were also recovered. Eighteen of the solenoid valves were found to have a brass bushing and a rod inserted in the valve housing. The equipment was retrieved in an essentially intact condition, although some minor damage occurred during salvage. The divers did not recover the fuse and relay panels from the ballast control console nor did they ascertain the position of the electrical circuit breaker and air supply valve (Appendix F, Item 2).

PORTHOLE EXAMINATION

The two damaged portholes were examined to determine the cause of the failure of the portlights. The one intact portlight was tested to determine the breaking strength of the glass (Appendix F, Item 3). Both damaged portholes were disassembled and the locking rings which held the portlights in the frame were inspected for signs of deformation that might indicate the forces involved in breaking the glass. The locking ring from porthole #4 exhibited a pronounced "lip" of metal on the edge of the ring that had been adjacent to the portlight; the locking ring from porthole #1 was undamaged. It was concluded from a subsequent metallurgical examination of the deformation that the portlight in porthole #4 had been broken by wave impact of short duration and great force. The lack of a similar deformation in the locking ring from porthole #1 indicated that the portlight had been subjected to a slowly increasing pressure over a longer period and that it had been broken by static water pressure and possibly debris impact during the sinking of the rig.

The portlight was manufactured in Japan to meet the Japanese Industrial Standard JIS-F2410 (1955) (Appendix F, Item 3). It proved after examination to be 0.3 millimetres thinner than the "as-built" drawings. The intact portlight was found to be extensively pitted, a condition which is known to occur with use and which reduces the strength of tempered glass. In comparison with equivalent samples of new portlights purchased in Canada and Japan, the *Ocean Ranger* portlight exhibited a more uneven pattern of internal stresses when viewed through polarized lighting techniques. This variation in stress within the glass, caused by uneven cooling during the tempering process, was not considered a contributing factor.

To determine the pressure required to break the recovered portlight, ASE carried out a testing program using air pressure to exert force on one side of the glass. It was tested to failure at a pressure of 68 pounds per square inch (psi). According to the applicable Japanese Industrial Standard, the portlight should have been able to withstand a constant pressure of 99 psi. The Canadian and Japanese glass samples were also tested; the Canadian samples failed at an average pressure of 105 psi and the Japanese samples at an average pressure of 97 psi. Intentional pitting of one sample reduced its breaking strength to 54 psi. The reduced thickness and the surface pitting combined to reduce the strength of the *Ocean Ranger's* portlight to 30% below the allowable minimum. Not only did the portlight fail to meet the specification for thickness shown on the "as-built" drawing and the industrial standard for strength, but even if the portlight had met both, the requirements were still insufficient to withstand the wave forces that, under predictable extreme storm conditions, could reasonably be expected at the level and location of the ballast control room portholes on the *Ocean Ranger*.

SOLENOID VALVE EXAMINATION

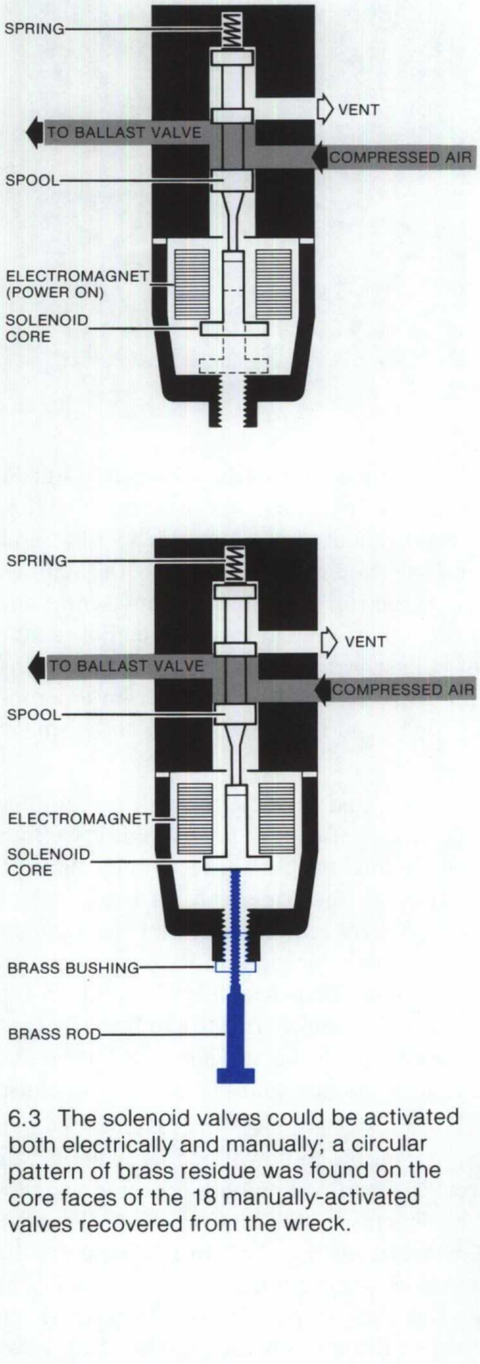
The 64 solenoid valves recovered from the ballast control room were forwarded to ASE for examination and testing (Appendix F, Item 3). They were arranged in six banks, each containing ten or eleven valves, and numbered sequentially with labels and small brass plates corresponding to the valve numbers on the mimic panel (Pl-

P32, S1-S32). The solenoid valves worked as follows: when power to an electromagnet at the front of the housing was turned on, it pulled in the core which moved the spool, depressed the spring and opened the valve. When the power was turned off, the core and spool were returned to the closed position by the spring. In the open position, the solenoid valve directed compressed air to a ballast valve in the pump room, causing the valve to open. In the closed position, the compressed air was vented from the ballast valve and a spring caused it to close. The solenoid valve could also be opened manually by pushing in the core and plunger with a tool inserted through the threaded hole in the front of the valve housing.

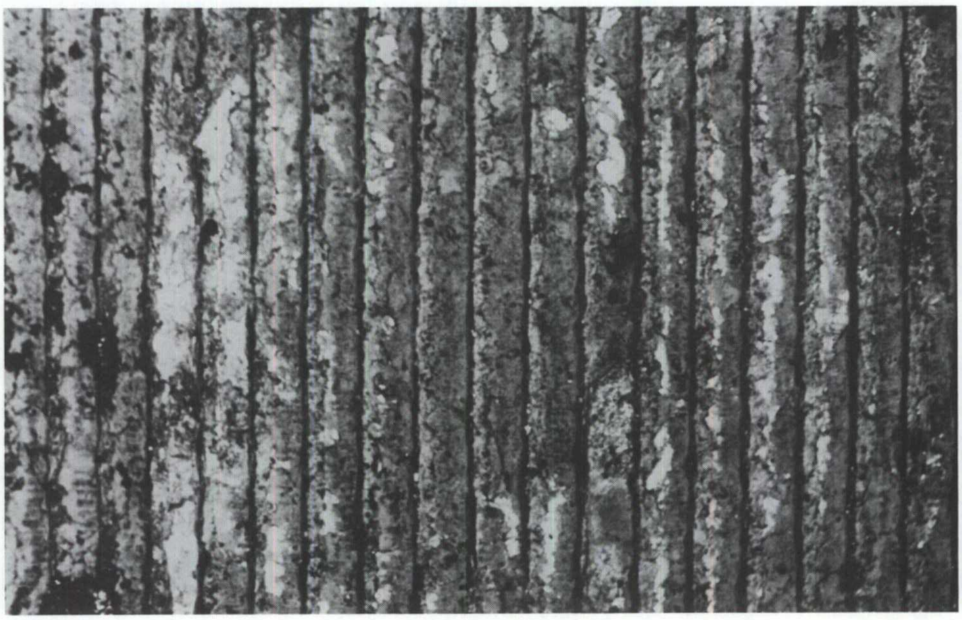
The divers found that 18 of the solenoid valves were fitted with a brass bushing and a brass rod. Many of the brass rods were bent or broken during salvage and four were inadvertently removed. Of the 64 valves received by ASE, 22 had rubber dust plugs inserted in the threaded hole of the valve housing and 24 were found to be empty. Measurements were made of the depth to which the brass rods were screwed in to determine whether the solenoid valves were opened or closed. It was found that all valves without the bushing or rod were closed. In contrast, all but one of the valves with the bushing or rod were open. The exception was valve P-13 which was half open, a condition which would probably have had the same effect as a fully opened valve.

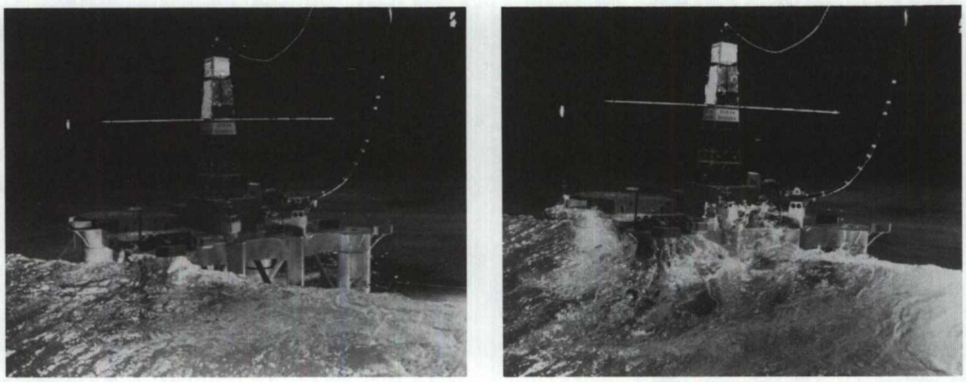
After the brass rods and bushings were measured and removed, the solenoid housings were opened to allow examination of the interior of each valve. In each case, the solenoid core and plunger were found to be stuck in position because the lubricant inside the housing had congealed while the valves were in the sea. All of the valves functioned normally when cleaned and re-lubricated.

The solenoid cores were examined. In each of the 18 activated valves the core face was marked with a circular deposit of brass corresponding to the diameter of the brass rods. Of the other cores, 4 showed circular indentations and deformations but did not exhibit any brass residue, indicating that a non-brass tool had caused the markings. It is probable that these marks were made during the construction and testing of the rig and were unrelated to the loss. The remaining 42 cores were not marked in any way. It is concluded that all 18 solenoid valves found with bushings had been opened with rods and that the brass rods had not been used to activate any other valves.



6.3 The solenoid valves could be activated both electrically and manually; a circular pattern of brass residue was found on the core faces of the 18 manually-activated valves recovered from the wreck.





6.4 The 1:40 model of the *Ocean Ranger* in the testing basin at the Norwegian Hydrodynamic Laboratories, Trondheim, Norway.

MODEL TESTING

The program of scale model testing at the National Research Council, Ottawa (NRC), and the Norwegian Hydrodynamics Laboratory, Trondheim (NHL), involved a series of 182 individual tests carried out between November, 1982 and September, 1983 (Appendix F, Item 5). The 1:40 scale models used at both facilities were manufactured from the "as-built" plans of the rig, and included representations of the chain locker openings and sections of the ballast system in order to allow simulations of the effects of downflooding and of ballast transfers. Both model test basins were equipped to simulate the wind[1] and the wave forces determined from environmental data recorded on board the *Zapata Ugland* and the *SEDCO 706* on February 14 and 15, 1982.

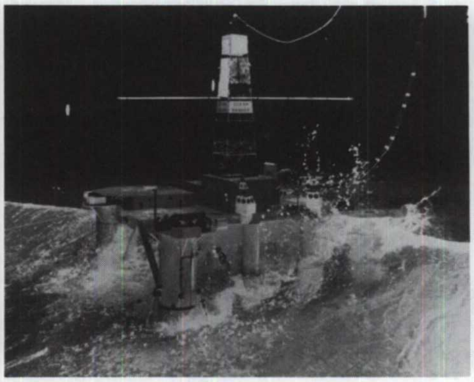
One of the main purposes of the program was to determine the rig's susceptibility to downflooding and the potential effect of downflooding on its stability. Both models were constructed to allow downflooding into the forward columns through the chain locker openings which were designated by the American Bureau of Shipping as the "first point of downflooding". It is an ABS requirement that the angle at which downflooding would first occur be calculated during the design process, in order to comply with its rules. It had been determined that the angle of downflooding for the *Ocean Ranger*, at the 80-foot draft, was a 27 degree trim to the bow. At that angle of inclination sea water would enter the chain lockers. This calculation was based on a still-water condition, without regard to the fact that heavy seas can cause downflooding at a much smaller angle.

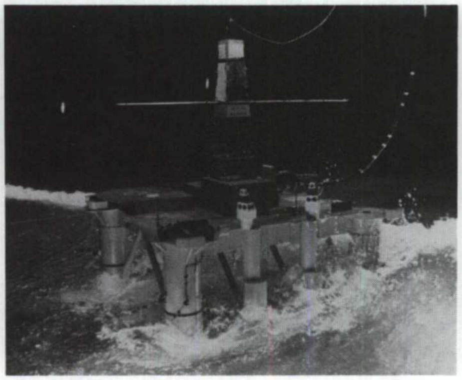
The tests showed that the rig was not susceptible to downflooding while it was substantially level at drafts as deep as 86 feet.[2] Downflooding only occurred at these drafts when the models were trimmed 10-12 degrees by the bow, or when the wave height was allowed to exceed the height recorded during the storm. These results established that the *Ocean Ranger* was capable of withstanding the storm conditions recorded at the site while level at the 80-foot drilling draft. During the tests at the 93-foot draft the models when level were subject to some flooding of the chain lockers but with bow trims in excess of 6 degrees rapid downflooding occurred.

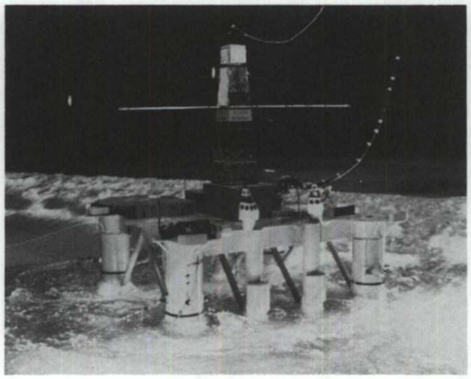
An additional series of tests was performed based on the ballast distribution that was assumed to have existed on the evening of February 14. The tests examined the effects that would have occurred if the manually activated solenoid valves had actually been used to operate the valves in the ballast system. The models were subjected to wind and wave simulations in the test tanks, and the relevant valves were

[1]Prior to the wave basin test, a 1:100 scale aerodynamic model was tested in the wind tunnel at the National Aeronautical Establishment of NRC in order to determine the rig's response to wind loads, and to develop data for the wind simulations used at NRC and NHL.

[2]A range of drafts from 72 feet to 93 feet were examined throughout the program, in order to allow for the possibilities that the rig had deballasted, or had increased its draft because of an unintentional ingress of ballast.







opened. In all cases the subsequent gravitational transfer of ballast, from the substantially full tanks at the stern to substantially empty tanks at the bow, resulted in bow trims in excess of 15 degrees and progressive downflooding into the chain lockers. Scaling difficulties in the models' ballast systems precluded an accurate assessment of the time required for full-scale gravitational transfer. The tests did, however, indicate the severity of unintentional ballast transfers and gave a realistic indication of the rig's motions and stability when trimmed by the bow.

One of the most difficult elements of the model testing program was the attempt to reproduce the capsize of the rig. The fact that the *Ocean Ranger*, with pontoons measuring 406 feet from bow to stern, had capsized in a water depth of only 255 feet created special problems in the model testing. In order to carry out a realistic simulation, the complex interaction between the ballast configuration, rig motions, environmental conditions, mooring system and flooding of the chain lockers and lower deck had to be considered; it was also necessary to make a number of assumptions in the absence of accurate knowledge of the condition of the rig before and during capsize. Furthermore, the models could not accurately reproduce the last phases of the capsize, because of the difficulties inherent in modelling the flooding of the lower deck space, the movement of the deck cargo and the ingress of water into the rig's void spaces. It was realized that, to simulate the capsize, considerable flooding of the lower deck and deckhouses, in addition to flooding of the chain lockers, would be necessary before the rig would reach the required degree of instability. It was apparent from the model tests that at significant bow trims the deck structure would be subjected to violent wave impact. The resulting damage to ventilators at the bow of the rig and to the superstructure in the accommodation area would have provided an unimpeded route for water to flood the sack storage area and, through the port bow stairwell, the accommodations areas of the lower deck.

Calculations of possible situations which would lead to capsize and analyses of the tests indicated that the probability of capsize diminished as the draft increased. The only model test that actually produced a capsize was performed at NRC, with a mean draft of 72 feet. Capsize at drafts in excess of 80 feet was considered to be unlikely, as the rig's trim in the final stage would be limited by the impact of the pontoon bows on the seabed.

A comparison of the model testing program results with the mathematical analysis produced for the U.S. Coast Guard by the David W. Taylor Naval Ship Research and Development Center revealed that the mathematical results made the rig appear less susceptible to downflooding in dynamic conditions. This simulation was affected by the limited ability of the computer program to model wave conditions in a realistic manner and by the many arbitrary assumptions that were necessary in setting up the program.

A number of studies were undertaken to verify the stability information contained in the *Ocean Ranger Booklet of Operating Conditions*. This information formed the basis for the day-to-day operational decisions affecting the stability of the rig and its accuracy was critical for safe operation. The ODECO stability data were found to be complete and generally accurate. Consideration was also given to the effects of the mooring system on stability and to the potential effect of "lightship growth"[3] on the rig. It was determined, however, that these factors did not play a role in the loss.

BALLAST SYSTEM STUDIES

From the outset it was suspected that the cause of the disaster was directly connected with a loss of control over the ballast system. The severe port bow list reported before the abandonment of the rig and the inability of the crew to restore it to level condition both indicate that a serious problem had occurred in this system. The results of the ASE solenoid valve examination served to strengthen this suspicion. An investigation was also undertaken by ASE of the electrical and mechanical components of the ballast control system (Appendix F, Item 3).

The port and starboard sections of the mimic panel were found to be essentially intact when recovered, although valve control switches P-2 and P-8, indicator S-35, and the lampholder from switch P-17 were missing and presumed to have been lost during the salvage effort. Four of the twelve green ("run") pump switch lenses and ten of the twelve red ("stop") pump switch lenses were also missing from the panel; the video tapes taken inside the ballast control room of the wreck showed that these lenses were missing before the recovery operation began. All of the valve control switches were found to have their original soldered connections. Apparently, no attempt had been made to open or replace them.

The mimic panel components were examined visually for any signs of damage that may have resulted from an electrical malfunction. Only one component, valve control switch P-19, was found to be damaged; the lower portion of its housing showed evidence of arcing and burning. This was consistent with short-circuiting of the 115-volt terminals at the base of the switch from an accumulation of sea water.

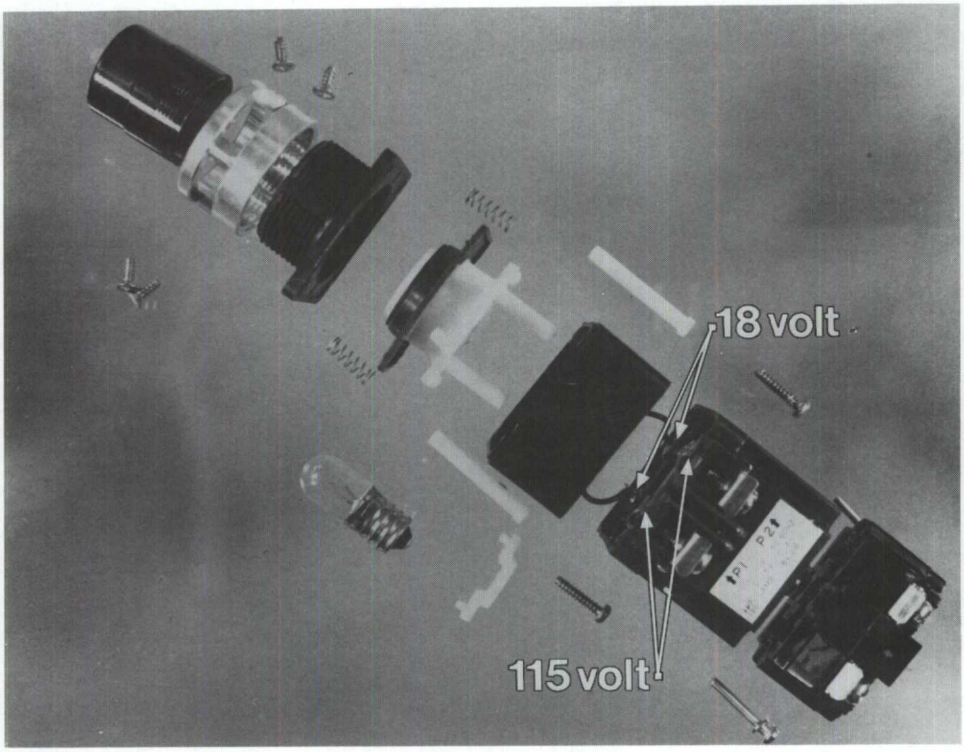
The second phase of the panel inspection was an optical and scanning electron microscope examination of all the indicator light bulbs. It was determined that of the 184 bulbs[4] recovered, 80 bulbs, or 43% of the total, were not functional because of broken filaments. Seventy-six of these showed evidence of failure due to exposure to excessive voltage. The failed bulbs were randomly distributed over the entire panel. All of the bulbs were found to be aged, indicating that none had been replaced during the night of the loss.

In assessing the damage to switch P-19 and the valve position indicator lights, the investigators noted that the 24-volt indicator circuit terminals and the 115-volt control circuit terminals were located close together at the base of the switch housing. They concluded that sea water entering switch P-19 had created a conductive bridge between the 24-volt and the 115-volt circuits[5], causing many of the indicator lights in the 24-volt circuit to fail because of overvoltage. The distribution of undamaged bulbs indicated that sea water had entered a large number of valve control switches, causing in some cases short circuits, *preventing* current from passing through the bulb filaments and consequently protecting them from damage. The result was a random distribution of damaged and undamaged bulbs.

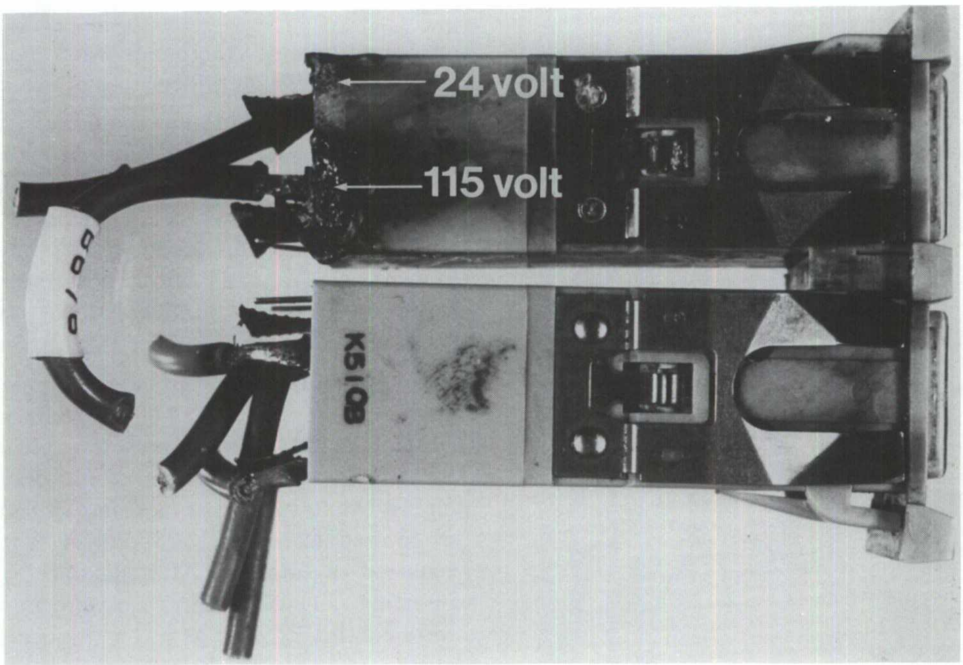
[3]"Lightship growth" is an unrecorded change in the weight of a vessel because of the gradual accumulation of paint, and other material. A vessel of the *Ocean Ranger's* size might be expected to have an annual lightship growth of up to 20 tons.

[4]The mimic panel included 168 valve position indicator bulbs and 24 pump switch bulbs. Eight valve indicator bulbs were lost during salvage.

[5]This effect may have occurred at more than one site in the mimic panel, although switch P-19 is considered to be the most likely location.

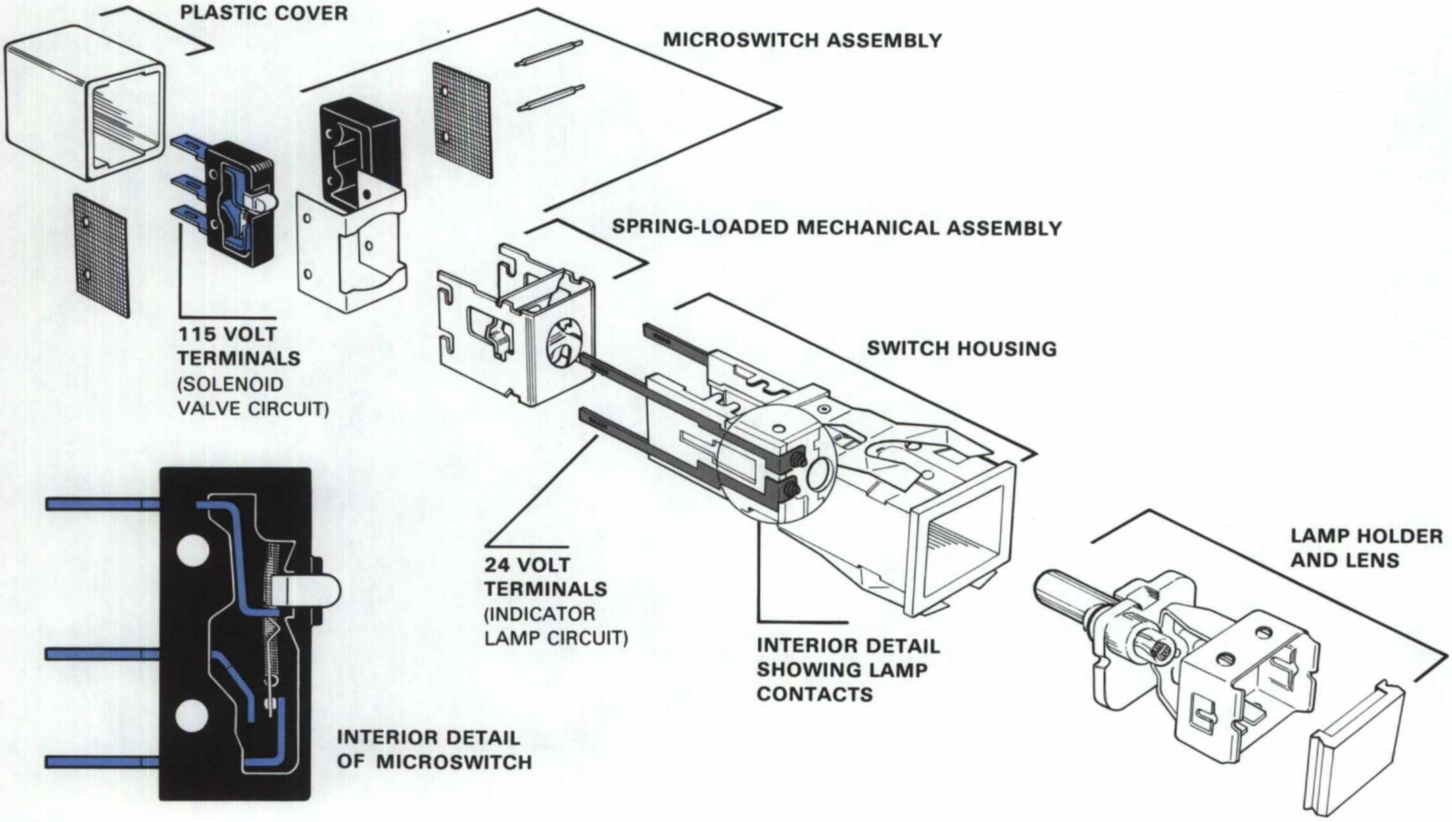


6.5 A disassembled pump switch identical to those used in the mimic panel. The failure of some of the indicator lamps in these switches was caused by sea water entering the transformer housing near the base of the switch, and short-circuiting the primary 115-volt and secondary 18-volt terminals.



6.6 Valve control switch P-19 was the only mimic panel component which was visibly damaged. The melted area near the base of the housing was caused by a short circuit between the 24-volt and 115-volt terminals.

The failure of the pump switch indicator lights, which were connected to a separate 115-volt circuit through a 115-volt/18-volt transformer in the body of each pump switch, was attributed to short circuiting of these transformer terminals. Each pump switch was equipped with a rubber gasket that prevented sea water on the surface of the mimic panel from entering the switch housing. Tests showed, however, that water could seep from the surface of the mimic panel through the valve switch



6.7 This illustration shows the components of the valve control switch used in the mimic panel. Short circuiting was found to occur: between the lamp contacts; between the leads connecting the lamp contacts to the base of the switch; between the 24-volt and the 115-volt terminals at the base of the switch; and within the microswitch itself.

openings and enter the pump switch housings, short-circuiting the transformers and causing the bulbs to fail because of excessive voltage.

In order to examine the effects of sea water on the electrical system of the mimic panel, ASE carried out a series of tests using identical new components purchased from the original equipment manufacturers in Japan. These tests demonstrated that sea water could readily enter the valve control switches. Even small amounts of sea water produced a dimming and flickering of the indicator lights and in some cases actually caused both the green and red lights to be illuminated simultaneously. In many of these tests, sea water was found to cause a short circuit capable of energizing the attached relay and solenoid valve.

A simulator of the original mimic panel was also tested in order to gauge the possible electrical effects of sea water on the panel. Sea water was poured over the simulator, but no attempt was made to duplicate the amount or velocity of the ingress of water on the night of the loss. The initial effect of the flooding was to short circuit the 24-volt valve position indicator circuit and cause the fuse to fail. It was discovered later that a 5-amp fuse had inadvertently been used instead of the required 10-amp fuse. Attempts to restore the circuit during the course of the test by inserting a new 10-amp fuse were unsuccessful, indicating that the short circuits were continuing even as water drained from the panel. During the first ten minutes of the test, 10 of the 32 valve control switches exhibited short circuits which activated the associated relays in the simulator. In the *Ocean Ranger's* system this would have caused the solenoid valves beneath the console to open and that in turn would have opened the remotely operated ballast valves in the pump rooms if the compressed air supply to the console was on. A subsequent examination of the affected switches in the test panel showed salt deposits inside the associated microswitches, confirming that sea water had entered the microswitches and caused an internal short circuit.

As the test progressed, many of the indicator lamps (both "open" and "close") were observed to flicker and light very brightly in a random pattern across the panel. This effect was accompanied by sparking in the interior of the panel. There was no 24-volt power source to the indicator light circuit at this time because of the earlier fuse failure. It was therefore concluded that the 115-volt and 24-volt circuits had become interconnected by sea water. An examination of the indicator light bulbs revealed that many had failed because of excessive voltage in a manner similar to those recovered from the wreck and that a number of switches exhibited damage similar to that of the recovered switch P-19. The extent of damage in the simulated panel was greater than that found in the recovered mimic panel. This was probably due to the fact that the power was left on for over an hour during the test, whereas on board the *Ocean Ranger* the power to the ballast control console was probably turned off shortly after the portlight failure.

The design and operational aspects of the *Ocean Ranger's* ballast control system were analysed in the technical investigation. One of the factors affecting the proper operation of this system was the signals provided to the operator regarding the status of the equipment through the ballast control console and its associated instrumentation. The mimic panel was designed to provide a means of allowing the operator to open/close valves and operate pumps (control) and to determine the current valve and pump status (monitor). The control and monitoring functions were not separated as is normally done so that each system operates independently. The *Ocean Ranger* system was designed with the valve control and monitoring systems interconnected through relays in the console[6]; while this arrangement operated properly under normal conditions, it created an unnecessary limitation of the information available to the operator and made both systems susceptible to common faults. The consequences of this design flaw will be examined in the next chapter.

The investigation of the ballast pumping system also revealed a number of limitations. The major limiting factor in the design of this system was the location of the pump rooms at the stern of the vessel. This factor made deballasting increasingly difficult as the rig assumed a trim by the bow because of the increasing vertical distance between the suction inlet in the ballast tank and the suction inlet at the pump (Appendix F, Item 4).

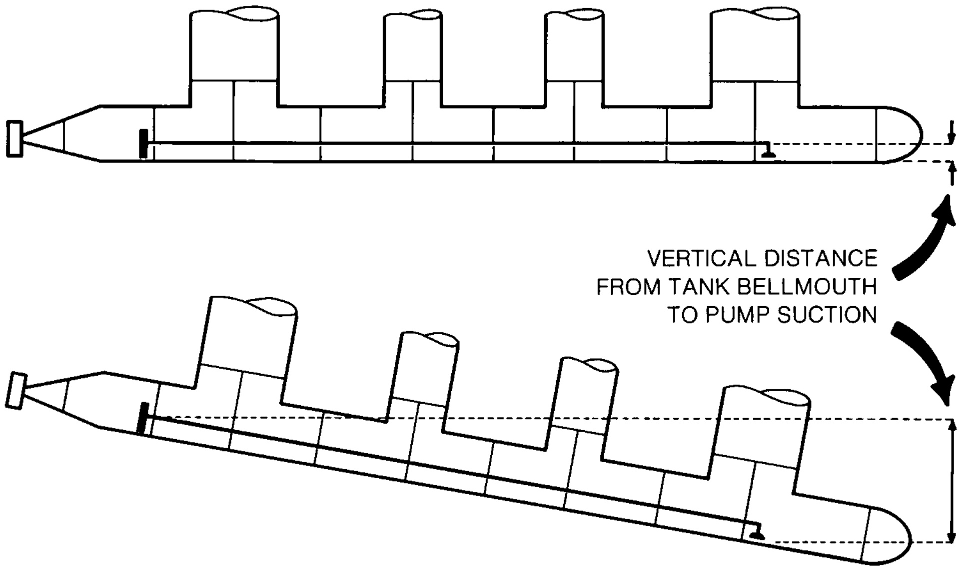
Conversely, trimming the rig to the stern would actually improve the performance of the system. Testimony indicates that the ballast control operators were not only aware of this effect, but were also accustomed to using a slight stern trim to aid in pumping out forward tanks. It is also evident that a port or starboard heel would not have an appreciable effect on the operation of the system.

Another limiting factor in the ballast pumping system resulted directly from its mechanical design. It violated the standard engineering practice of balancing the size of the pumps, the diameter and length of the suction lines and several other factors in order to guarantee reliable performance over the operating range[7] of the system. The use of very powerful, high capacity pumps combined with the relatively small diameter suction lines connecting the pumps to the ballast tanks severely restricted the operating range over which the ballast system could successfully function. Some method of "throttling" or reducing the flow through the ballast pumps would have greatly improved the efficiency of the system.[8] Although the requirement for a throttling mechanism was noted on the construction plans, it was never installed. Larger

[6]Current classification society rules do not allow this type of arrangement.

[7]In this context, the term "operating range"refers to the level of tank contents and the attitude of the rig which could reasonably be expected under normal or emergency conditions.

[8]Operation of the system could also have been improved by pumping from more than one ballast tank simultaneously, but this was not generally recognized by the ballast control operators who normally pumped from only one tank at a time.



6.8 As the rig trimmed to the bow the vertical distance between the suction inlet in the tank and the suction inlet at the pump increased, reducing the ability of the system to pump out the forward tanks.

diameter suction lines in the system would also have helped. ODECO has indicated that this consideration is included in all of their current designs.

The effect of these design weaknesses on the rig's ballast system would have seriously hampered any attempts to right the rig from the severe trim reported on the night of the loss. The rate at which ballast could be pumped from the bow tanks would be reduced to zero as the trim progressed. In normal operations, the rate of flow from a given tank is unimportant; under the circumstances which existed on the night of the loss, the flow rate from the bow tanks was a critical factor.

7

LOSS OF THE RIG

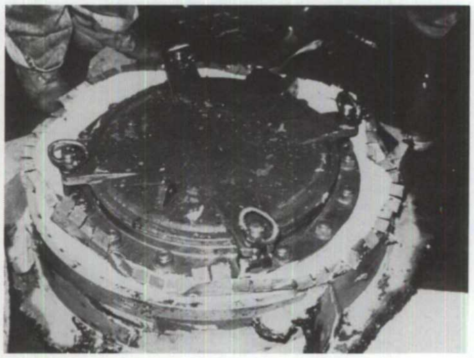
CHAPTER SEVEN LOSS OF THE RIG

In the course of its investigation the Royal Commission has gathered a great deal of technical evidence, inspected the ballast control room and pontoons of the sunken rig, and conducted a series of model tests designed to elicit information concerning the probable behaviour of the *Ocean Ranger* in various wind, sea, and loading conditions. It was recognized however that technical evidence alone would not explain the cause of the loss and, accordingly, many witnesses were called to provide information on the customary operating procedures aboard the *Ocean Ranger* and on the established patterns of behaviour of those in key positions. This evidence, combined with the technical data available, provided the basis on which conclusions were reached concerning the cause of the loss.

It was earlier concluded that the *Ocean Ranger* was still drilling at 4:30 p.m. on the afternoon of February 14, 1982, and that the hang-off and disconnect process was started shortly after that time and completed not later than 6:47 p.m. Testimony indicated that accepted practice on the Hibernia Field is to deballast a rig five feet or more following disconnect in order both to increase the air gap[1] and to reduce the likelihood of the marine riser damaging the blowout preventer on the seafloor. Testimony, however, also indicated that the *Ocean Ranger* had never followed this deballasting practice and had, in fact, demonstrated a capability to continue drilling in weather conditions too severe to permit other rigs to do so. Indeed the *Ocean Ranger* had disconnected due to weather conditions only once during its five-year operating history, on January 16, 1982. On that date, the maximum reported heave was 22 feet, maximum reported seas were 49 feet and maximum swell 25 feet. The maximum reported pitch and roll were 4.5 degrees and 5.5 degrees respectively. The *Ocean Ranger*, however, did not deballast but maintained its 80-foot draft throughout. Evidence indicated that the weather conditions and rig motions were not dissimilar on February 14.

Witnesses testified that, if more clearance between the marine riser and the blowout preventer were required after disconnecting to prevent damage to this equipment, the alternatives considered before deballasting would be to lift the riser with either the travelling block or the motion compensator. Although there were reported problems with the compensator hoses on February 14, the riser could have been raised by means of the travelling block. As the *Ocean Ranger* had never previously deballasted because of storm conditions and in the absence of any report that it did so then, it is concluded that the rig had not deballasted from its 80-foot draft before portlight #4 broke in the ballast control room.

[1]Air gap refers to the distance between mean sea level and the underside of the lower deck of the rig.



7.1 One of the three portholes removed from the wreck. The deadlight was closed and dogged.

PORTLIGHT BREAKAGE

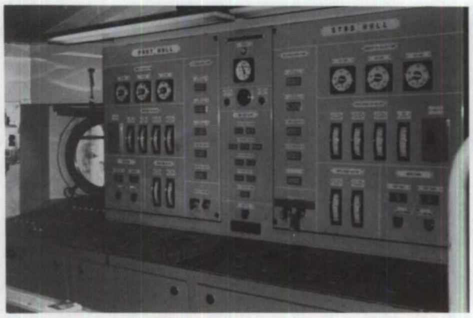
There is no doubt that the breaking of this portlight, sometime between 7:45 and 8:00 p.m., was the first link in the chain of events leading to the loss of the *Ocean Ranger*. Evidence indicated that the thickness of the glass, as specified on the plans furnished by the supplier of the portlight, was insufficient to withstand the wave forces under predictable extreme storm conditions and, moreover, that as the glass aged, pitting of its surface by water-borne or air-borne particles would diminish its strength. In addition, the installed glass failed to meet even the standard of thickness specified on the plans.

The size of the lip on the locking ring of portlight #4, which broke before the capsize, was approximately twice the size of the lip on portlight #2, which was recovered intact, after the latter was tested to glass failure at 68 psi. Testimony was given that the pressure necessary to produce a lip of the magnitude found on portlight #4 would be at least twice that amount. It was suggested by counsel for ODECO that the force of a wave alone was unlikely to approach that pressure and argued that the portlight was broken by heavy wave-borne debris. He argued that since the debris would necessarily be carried at or near the water surface, the portlight would not be subject to a large head of water and therefore, little water would enter the control room. The technical examination of the portholes recovered does not support this argument. Research on shock pressures generated by breaking waves indicates that dynamic pressures in excess of 140 psi are possible for short durations.[2] Examination of the recovered portlight confirmed that the glass was broken by the application of uniform pressure over its entire surface and not by debris impact.

Each porthole, as designed and installed, included on the inside a metal deadlight which could be lowered and secured over the glass when it was anticipated that waves might break on the portlight, but there were no instructions for the use of these deadlights and no standing orders that they be closed during storm conditions. Testimony indicated that appropriate instructions have now been included where relevant in all ODECO manuals. Notwithstanding the absence of instructions, if the crew, acting in accordance with good seamanship and common sense, had closed the deadlights in the ballast control room before 7:45 p.m. on February 14 the first link in the chain of events would not have been forged and the loss of the *Ocean Ranger* and its crew would have been prevented. It must be recognized, nevertheless, that if full consideration had been given in the design of the rig to the severe environmental conditions under which the rig might be operating, several other links in the chain of events which led to the capsize would not have been forged. For if the control console had been waterproof; or if it had been protected from any sea water that might come in through a broken portlight; or if the portlights themselves had been impregnable to the force of waves under predictable environmental conditions; or if the ballast control room had been located at a higher level on the upper deck and a system more sophisticated than draft marks attached to the columns had been provided for checking the draft, then, again, there would have been no chain of events and no loss.

Extensive evidence was presented with respect to the quantity of water that entered the ballast control room after the portlight was broken. The estimates ranged from half a ton to over 20 tons on the basis of various assumptions that may or may not be valid. Such unknown factors as the size, steepness and velocity of the wave, the attitude of the rig at the time of impact and the time taken to close the deadlight combine to allow considerable latitude in these estimates. But whatever the amount of water that entered the ballast control room, it was sufficient to wet the panel across its entire surface and thus initiate the sequence of events that followed.

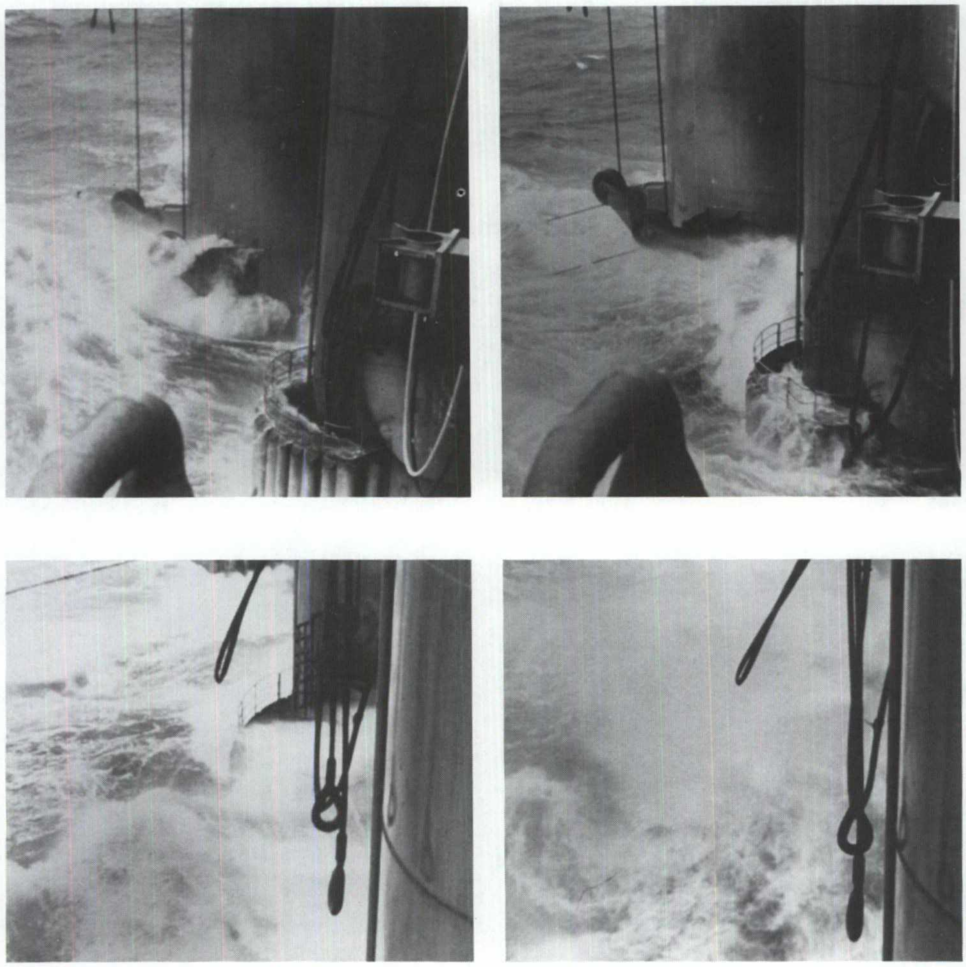
[2]Horikawa, K. *Coastal Engineering – An Introduction to Ocean Engineering* (University of Tokyo Press, 1978) pp. 97-100.



7.2 These photographs show the ballast control console and the view of the draft marks from porthole #3 at the extreme left.

Testimony indicated that, surprisingly, the failure of the portlight would not of itself be regarded as of sufficient importance to report to shore until the following day when it would be included as part of the daily routine commentary on equipment status. This may explain the complete absence of communication between the toolpusher and shore-based ODECO personnel. Similarly, Graham, when first advised by Jacobsen at 8:45 p.m. of the broken portlight, did not regard the event as significant, presumably because of the lack of concern expressed by Jacobsen. During a later conversation at 10:00 p.m. he was again reassured by Jacobsen that the *Ocean Ranger* was not in any difficulty as a result of the breakage. It is also surprising that at no time was there any mention of damage resulting from the incident, even though overheard VHF conversations indicated damage to or malfunctioning of the public address system and gas detection panel, and probably the ballast control panel. In fact, when the toolpusher requested a status report shortly before 10:00 p.m., the ballast control operator replied that "everything was okay", and this was relayed by Jacobsen to Graham as "all systems are functioning normally." The inaccuracy of these reports has been clearly demonstrated by the evidence. The differences between the reported and actual conditions can be attributed to an inaccurate assessment of the situation by the crew and to a lack of appreciation of the potential danger. The resulting lack of accurate and timely reports of the damage from those on board has hampered the investigation of the loss and led to a greater need for assumptions and deductions than would otherwise have been necessary.

The conclusions regarding the effect of the water on the equipment in the ballast control room are drawn from the VHF radio conversations overheard between 8:00 p.m. and 10:00 p.m., from the examination of the mimic panel and switches recovered from the wreck and from the ASE tests of new switches identical to those recovered. Of those who overheard portions of the VHF radio conversations, no one sensed any degree of urgency or felt any concern. Indeed nobody attempted to contact the rig to inquire about the problem. These conversations were all internal to the *Ocean Ranger* and represent communication between participants in the clean-up and the repair process and those in command. They provide a reliable indication of the thinking of those on board and, although the accuracy of testimony regarding the exact content and time of the conversations may be questionable, there is no doubt as to their general tenor.



7.3 This sequence of photographs shows the ballast control room portholes obscured by spray during relatively light sea conditions. The photographs were taken from the windlass control house at the mooring platform on the starboard bow.

The conversations dealt with the clean-up of the ballast control room and the condition of the equipment in the room. The participants stated that water and glass had to be cleaned up and that the gas detection panel and the public address system were not working. Reference was made to "the panel" being wet, and to the fact that someone, probably the electrician, was "working on it" and "had the cover off." Comments were made warning personnel of the potential for electric shocks and a request was made for maintenance personnel to come to the control room. There is no indication in these conversations that the crew felt any sense of danger. Clearly, they believed that whatever problems were being encountered had been defined and were under control.

It is manifest, however, that an inaccurate assessment by the crew played a significant role in the tragedy. While the crew were aware of the danger to those attempting to clean wet electrical equipment, they were unaware of the potential effect of sea water on the operation of the ballast control system. This ignorance of the workings of the ballast control equipment and of the unknown danger to the rig present within its components was, in all probability, the reason for the failure to report the damage to shore. In the final analysis, it was this ignorance which led to action which contributed to, rather than prevented, the loss of the rig.

DAMAGE TO THE BALLAST CONTROL CONSOLE

Examination of the recovered mimic panel and switches provided a reliable indication of the distribution of water and of the extent of damage to the ballast control panel. Testing indicated that those indicator light bulbs which did *not* fail survived because sea water elsewhere in the switch provided an alternate path for the 115-volt current, other than passing through the 24-volt bulb filament, thus protecting the filament from the effects of overvoltage. These intact bulbs were distributed randomly across the panel indicating a wide horizontal distribution of water. None of the damaged bulbs had been replaced, and the potential for continued short circuits within the switch housing indicates that the 24-volt indicator light circuit was never restored to normal operation. Another indication of the effects of sea water on the mimic panel was the burning and melting damage found at the plastic base of switch P-19 which controlled a remotely operated valve on the discharge side of the port drill water pump. This damage was caused by the collection of sea water at the base of the switch in a quantity sufficient to maintain a short circuit for the time necessary to cause the melting to the extent that was found. There was no indication of any attempt to replace this switch which, as recovered, was inoperable.

One 18-volt bulb in each pump switch pair was found to have failed, again because of an application of excess voltage, in this case, within the pump switch itself. Ingress of water into the affected pump switches required a wide horizontal distribution of water across the panel. Only 10 of the 24 individual pump switches were completely assembled when recovered and, of these, only the switch pairs controlling port pumps #3 and #5 were complete. Fourteen switches were without the coloured lens and in some cases the lens guard as well. The absence of the lens makes the switch difficult to operate. It is apparent from the condition of these switches that they had not been restored to normal operating condition before the abandonment of the rig.

The tests carried out by ASE on new valve control switches to determine their susceptibility to sea water demonstrated that the water would immediately affect the indicator light circuit. This effect would be caused either by a bridging of the contacts at the base of each light bulb, or by a bridging of the lower stems of those contacts located within the switch housing itself. Water could be removed from the bulb contacts at the base of the bulb by removing the push-button plunger and drying the switch cavity. It would be impossible, however, if a number of switches were affected, to remove water from within the switch housing itself in the time available to the crew. The soldered connections at the base of the switch were accessible with some considerable difficulty from the underside of the mimic panel. Without breaking these soldered connections, it was not possible either to lift the switch assembly away from the mimic panel or to disassemble the switch to remove water from inside the housing.

The ASE tests also confirmed that water can enter the microswitch located in the base of the valve control switch and cause a short circuit which will open the corresponding remotely operated valve if and when both the electrical and air supplies to the panel are activated. The opening of an appropriate combination of these valves would allow water to enter one or more ballast tanks from the sea or permit gravitation of ballast from one tank to another; for example, opening the remotely operated sea chest valve (#32) and the manifold valve (#20) in one pontoon plus any ballast tank valve in the same pontoon will permit sea water to flood into that particular tank. The opening of any two ballast tank valves in the same pontoon will permit gravitation between these tanks depending on the relative quantities of water in the tanks and the attitude of the rig.

Counsel for ODECO pointed out that the microswitches recovered from the rig showed no evidence of arcing, burning, or sea water shorting. He argued, as noted earlier, that little water had entered the ballast control room and that consequently no microswitches had ever been short-circuited by sea water. Although it was not possible to determine from an examination of the recovered microswitches if water had entered the switches before the capsize,[3] the ASE tests clearly indicated that water can readily enter and short-circuit these switches. It is concluded that water did in fact enter a number of microswitches in the mimic panel. Once water enters a microswitch, it is virtually impossible to remove the water without physically taking the microswitch out of the switch housing and subjecting it to prolonged drying. The evidence is clear that the microswitches were not removed from the switch housing nor disassembled in any way and that any water that entered the microswitches was still present at the time of the loss.

The susceptibility of the ballast control console and its components to sea water damage was, as indicated earlier, a deficiency in its design. Had all the components been sealed and designed for a marine application, the potential for water penetrating the switches would have been eliminated. The mimic panel was designed to allow the operator to control the valves and pumps by switches and to monitor their operation by the indicator lights. The damage to the panel affected the operation of both the monitoring and control circuits. Had these functions been designed to operate separately, the potential for human error would have been significantly reduced.

The testimony and technical evidence permit a number of firm conclusions to be drawn concerning the events of February 14 and 15, 1982. In the absence of direct evidence, however, some conclusions are based on assumptions derived from established patterns of behaviour and practice.

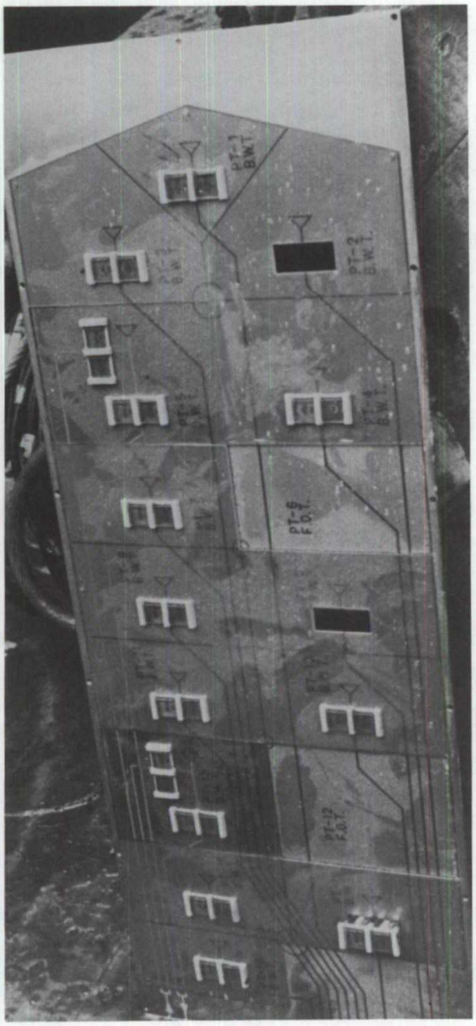
The probable immediate response of the ballast control operator to the portlight failure received a great deal of attention during the public hearings. All deadlights were found closed during the dive survey. It is generally agreed that the operator's first reaction would have been to close the deadlight on the damaged porthole to prevent more water from entering the room. He would probably have been immediately confronted with a ballast control panel that was unlit, with the exception of the 115-volt source light and possibly the lights in one or more of the pump switches. The sea water would have created immediate short circuits of most, if not all, of the lights by collecting either at the light contacts or in the switch housing. These short circuits would have increased the normal load up to 20 times and blown the fuse in the 24-volt light circuit[4].

It is unlikely that the operator on duty would have immediately turned off the electrical supply or the air supply to the panel, as both of these actions would have necessitated opening the ballast control console with the risk of touching wet electrical equipment. The operator would normally have called for assistance using the public address system, but it was disabled by sea water. The hand held VHF radio in the control room was used to report that there was water and glass in the room and the toolpusher, Thompson, ordered the crew "to get down there and get it cleaned up." The electrician would have quickly turned off the electric power to the panel, probably by means of the circuit breaker within the panel itself, or perhaps at the emergency switchboard located in the generator room at the lower deck level.

The overheard VHF radio conversations included reports to the toolpusher concerning the status of the equipment in the ballast control room. Reference was made to the malfunction of the public address system and the gas detection panel and to shocks, or the potential for shocks, from other equipment. One comment related to "valves opening by themselves." Other testimony indicated that there was a reference to valves "opening and closing." Because of the electrical circuitry of the ballast

[3]Examination of the tested switches which short-circuited revealed no evidence of arcing or burning damage and accordingly the condition of the recovered microswitches of itself neither confirms nor rejects the possibility of water entry.

[4]The 24-volt light circuit feeding the indicator lights was fused with a 20-amp fuse on each side of the line. Each bulb normally carried a current of .04 amps. A sea water short circuit creates a current load at each short circuit of .6 to .8 amps. Short circuits at approximately 30 sites would thus be sufficient to overload the circuit and blow the fuse.



7.4 One of four mimic panel sections recovered from the wreck. Several of the plexiglass insets from the panels were dislodged and lost during salvage.

control console, it is not possible for a valve to close electrically on its own after it has been opened by short-circuiting.[5] Under normal operations, the valve closes and stays closed once the "close" switch is momentarily depressed. After water has entered the microswitch in the "open" switch, however, the "close" switch must be manually depressed and held in place in order to close the valve. The valve would otherwise return to the open position as soon as the push button was released.

It is believed that, whatever the words used in relation to "the valves opening by themselves", the ballast control operator reacted to a random flashing or extinguishing of the valve position indicator lights. Within minutes he reported that "everything was okay." The statement that valves were opening could have been caused by either:

1. random flashing and dimming of bulbs as they failed due to overvoltage supplied from the 115-volt circuit, probably due to a short circuit at switch P-19, or

2. random microswitch shorting leading to the extinguishing of lights as valves commenced to open (only if the 24-volt circuit were operative).

Either of these effects is possible but the first is more probable. The immediate reaction of the operator, when he saw the indicator lights changing, would be to think that the valves were opening. The failure of any green ("open") light to come on within 20-40 seconds, perhaps coupled with shutting off the electric power to the panel, would lead the operator to report that the valves were okay. While one or more microswitches may have been shorted during this brief interval before the removal of electric power, there is no evidence of any change in the rig's attitude at this time. It is judged that if any remotely operated valves did open, they did not permit a significant amount of water to enter into or gravitate between the ballast tanks. It is, however, likely that in the few minutes before power was cut off a short circuit created by water at the base of switch P-19 caused 115 volts to leak into the 24-volt indicator light circuit resulting in the failure of 64 unprotected lightbulbs through overvoltage. George Granger, an *Ocean Ranger* electrician, testified that he believed that the crew would probably conclude that the problem lay with the indicator lights, caused by water collecting at the electrical contacts at the base of each light bulb.

According to the VHF conversation the crew were first occupied in cleaning up the water and glass and examining the condition of the equipment in the ballast control room. After an assessment of what was wrong with the ballast control console, the first action of the electrician would be to remove the covers from the 192 switches[6] and indicators on the mimic panel and dry each lamp holder and switch cavity, a task which would take several hours. The electronic technician would also be present in the control room, assessing and repairing as required the public address system and the gas detection panel. Since none of the indicator lamps was replaced and 14 of the 24 pump switches were found disassembled in the recovered panel, it is apparent that the maintenance operation was not completed by the time the rig was abandoned.

ODECO counsel suggested that in view of the report by Jacobsen at 10:00 p.m. that everything was functioning normally, the ballast control console had by then been restored to normal operation. This report, together with Jacobsen's comment that the anchor tensions were in the 240,000 lb. range, cannot be taken at face value. In the prevailing storm conditions the anchor tensions would differ widely, while the condition of the recovered panel clearly indicates that at no time following the portlight breakage was it restored to normal operating status.

[5]The microswitch in the "open" switch was wired in a "normally open" configuration. A short circuit in this microswitch would have the same effect as if the switch were pressed by the operator. The microswitch in the "close" switch was wired in a "normally closed" configuration. A short circuit in this microswitch would have made it impossible to close the associated valve by pressing the switch.

[6]The mimic panel included 168 valve position indicator lights and 24 pump switch lights.

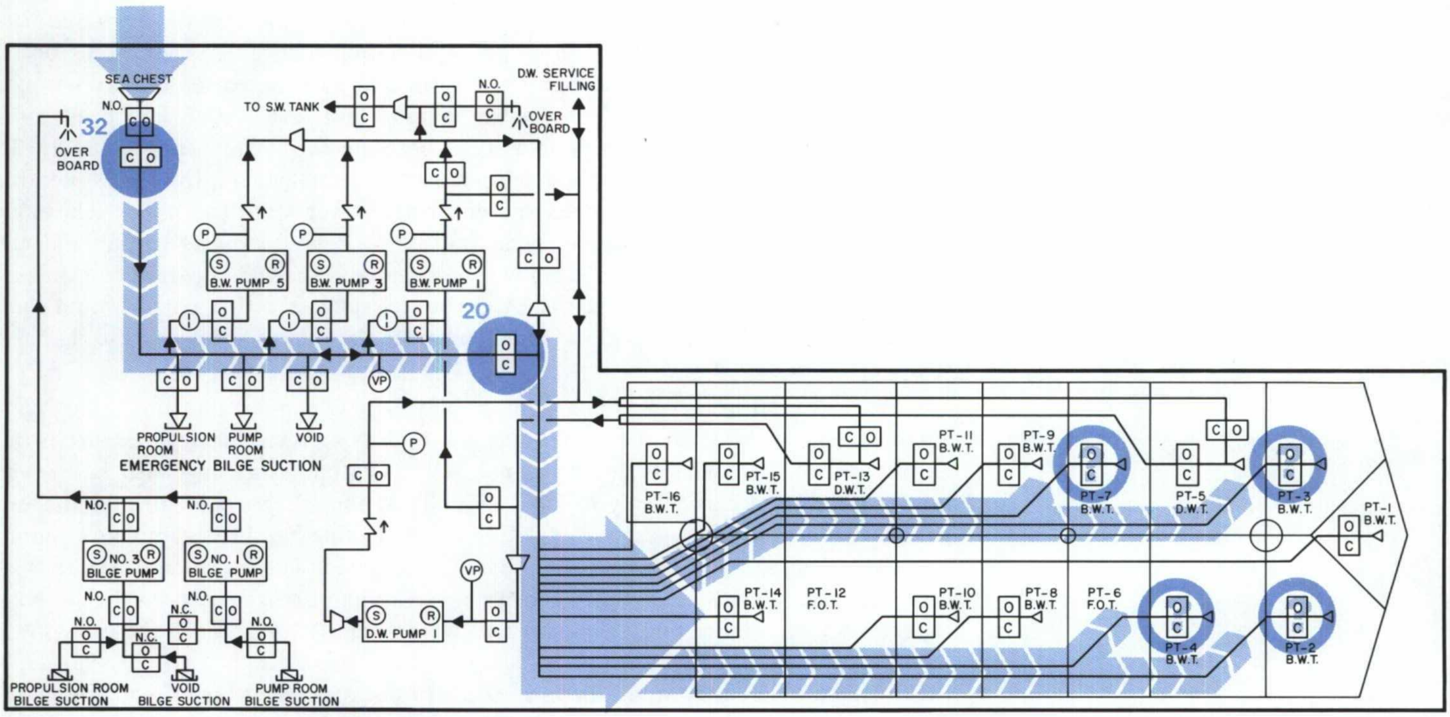
ODECO counsel went on to suggest that the *Ocean Ranger* was deballasted to a 72-foot draft sometime after 10:15 p.m. on February 14 in order to avoid further damage to the portlights in the ballast control room and to the upper deck structure and equipment, and that this deballasting which took approximately one hour was achieved by pumping out port and starboard tanks #10. The operation would have been carried out with the mimic panel functioning normally, although some or all of the indicator lights would not have been lit. He argued that this conclusion was based on the results of the model test program in which a capsize was only achieved from a 72-foot draft and on the tank soundings, particularly that of ballast tank PT-10.

Attempting to reproduce the capsize was one of the most difficult elements of the model test program and only one out of the 88 applicable tests resulted in the model capsizing (Appendix F, Item 5). It is determined that the rig was unlikely to have capsized at a draft greater than 80 feet. It would appear, therefore, that the capsize occurred at a draft between 80 feet and 72 feet. All attempts to reconcile the results of the tank soundings with the tank contents in the stability report of February 14 have, as noted earlier, been inconclusive. It would appear that during the capsize and subsequent sinking of the rig the contents of individual tanks underwent considerable change due to flooding through the vent lines or transfer of contents through open or leaking valves or possible damage to the bulkheads between the tanks. There is also evidence of some degree of error in the soundings themselves, either in the location of the air/water interface or in the measurement of the water depth to the keel. The possibility of error is particularly evident in the case of PT-10, since when the volume of air remaining in this tank was extrapolated to provide the equivalent air volume at the sea surface, the resulting volume was greater than the volume of the tank. It was decided on the basis of these factors that the tank soundings were not sufficiently reliable to form the basis for conclusions regarding the loss of the rig.

THE INITIAL LIST

It has been concluded that the electrical supply to the panel was restored between 12:30 and 12:45 a.m. The reason for doing this will never be known with certainty, but it is possible that it was done to permit an evaluation of the condition of the bulbs in both the valve switches and the pump switches. Testimony indicated that it is impossible to ascertain with the naked eye whether a bulb filament is broken or not. Accordingly, electric power would be required to evaluate the condition of the lights. It is also possible that the panel was reactivated, although without indicator lights, to deballast to a shallower draft in order to prevent damage to the subsea equipment as a result of increasing heave or to counteract the changing direction and intensity of the wind and waves. Documentary evidence indicates that, as recorded by the *Zapata Ugland*, heave continued to increase until midnight, while the recorded heave on the *SEDCO 706* reached its maximum at 11:00 p.m. It is possible that the *Ocean Ranger* may have been similarly affected but, as noted earlier, the rig had never previously deballasted for this reason. If the crew had slackened the leeward anchor lines, however, in response to increasing anchor line tensions, or if they had dumped or shifted any drilling mud, drillwater, fuel oil or deckload because of the severe storm conditions, it may have become necessary to operate the ballast system to counteract the shifting of these forces or weights.

Whatever may have been the reason behind the action, the restoration of power allowed random microswitch short circuits to open the corresponding remotely operated valves. It is known that the rig incurred a sudden port bow list, and it is concluded that the cause of this list was an ingress of water from the sea into the port



7.5 The accidental opening of ballast valves P-32 and P-20 allowed sea water to enter the common manifold leading to the port pontoon tanks. Open valves leading to one or more forward tanks rapidly lead to a 4-5 degree list by the port bow.

pontoon. For this to have happened, the short-circuited microswitches must have included at least P-32 (the remotely operated sea chest valve), P-20 (the cross-over or manifold valve) and at least one forward ballast tank in the port pontoon. The opening of these three valves would lead to an immediate ingress of water from the sea into a forward port ballast tank. The incident of February 6 involved inadvertent flooding from the sea during pumping and an adverse port heel of 6 degrees resulted within minutes.[7] Without the countervailing pumping the reaction of the rig to an ingress from the sea would of course be significantly faster.

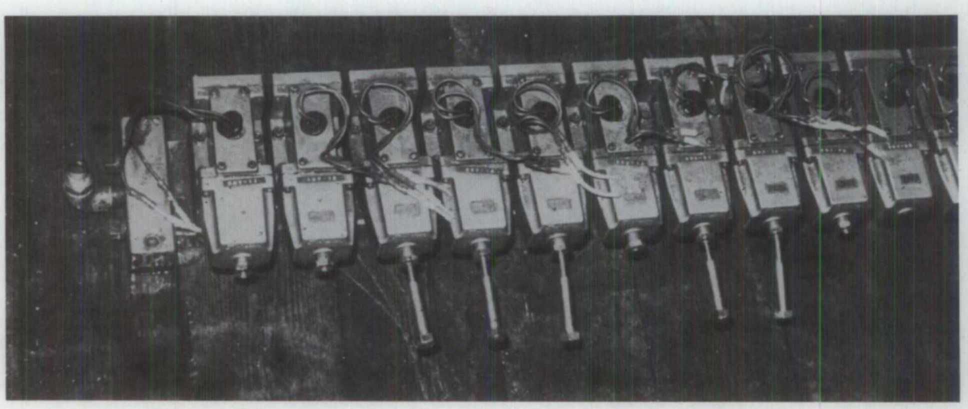
Observing the list, the ballast control operator would again have removed power from the panel, thus closing any open valves within 20-40 seconds. Before the removal of power, even if only minutes had passed, sufficient water would have entered the port pontoon to cause a port heel and probably a 4 or 5 degree trim by the bow. This trim, combined with the natural pitch and roll of the rig which probably exceeded 4 degrees in the prevailing sea and wind conditions, would give a maximum forward inclination of 8-10 degrees, the figures reported by Jacobsen to Graham at 1:00 a.m. The call by Jacobsen, however, was an "alerting" call only, with no reference to a Mayday or evacuation at that time, indicating that whatever the problem the crew believed that it could be isolated and rectified. Once power had been removed, any valves which had opened would close and the rig would appear to stabilize. Steps would then be taken to restore the rig to an even keel. The first and obvious remedy would be to try to pump out the port bow tank or tanks.

As previously noted, ODECO counsel argued that the microswitches did not in fact short-circuit. He suggested rather that at approximately 12:30 a.m. February 15, the ballast control operator inserted 18 manual control rods as a precautionary measure to ensure that the valves stayed closed. As previously discussed, the crew wrongly believed that insertion of a rod would close a valve. The reverse was true. Computer calculations prepared by Mr. Ralph Loomis, an ODECO engineer, indicate that after insertion of the brass rods gravitation between tanks would eventually

[7]A discussion of this incident is found in Chapter 4.

cause a severe bow trim of 18-22 degrees, at which point the chain lockers and forward upper hull spaces would be vulnerable to flooding. This gravitation would occur almost imperceptibly for approximately 20 minutes and thereafter the trim would progress at approximately one degree per minute until gravitation had been completed. A trim of 6-8 degrees would have been reached after approximately 30 minutes. Reacting to the inclination as soon as it became evident, the ballast control operator would then have removed the electrical power from the panel. The tank level gauges in the ballast control room would have been confusing as they did not give an accurate reading when the rig was trimmed and showed apparent transfers of ballast when none had occurred. ODECO counsel suggested that power would then have been restored to the panel in order to operate the pumps and bring the rig back to a level attitude.

It is difficult to accept the argument by ODECO counsel that the ballast control operator would insert the manual control rods as a precautionary measure if the ballast control console was operating normally. The operators on board had never used the rods and accordingly it is highly unlikely that they would have used them particularly when, as suggested by ODECO, deballasting had been completed and no further ballasting operation was required or anticipated. The insertion of the rods as a precautionary measure suggests a degree of planning and thought that is not consistent with the manner in which the rods were actually used. Since the crew must have recognized that there were not enough rods to complete the task, it is not logical to suggest that they would be used to carry out a planned operation. The insertion of three rods into solenoid valves affecting drill water tanks also suggests a hasty rather than a planned activity. Furthermore, the crew knew that the simple alternative of removing power from the panel would cause all valves to close. It was unlikely therefore that they would resort to a previously unused precautionary measure. If the rods had been inserted as a precautionary measure after the use of the panel for one hour to deballast, it would have been contrary to the established patterns of behaviour of the ballast control operators under normal conditions. Furthermore, since counsel for ODECO suggests the panel was functioning normally, the insertion of the rods would have been the only unusual action taken affecting the panel. It is likely, therefore, that the insertion of these rods would have been seen as contributing to the cause of the trim, in which case the crew would undoubtedly have removed them. The evidence shows that none of the rods was in fact removed and that the crew was "trying to isolate the problem." Insertion of the rods as found could result only in gravitation. This changes the longitudinal moment of the ballast but has no effect transversely; a forward movement of water in the port pontoon would cause a forward trim, but not a port heel. The reports of a port list are inconsistent with difficulties caused only by gravitation and no water ingress. The rig must, therefore, have been subject to ingress of water from the sea, not gravitation alone as suggested by ODECO.



7.6 One of the six banks of solenoid valves recovered from the ballast control console. Many of the brass rods were broken during salvage, leaving only the brass bushing and a section of the threaded rod at the front of the valve housing. The valve on the extreme right is fitted with a plastic dust cap.

THE CREW'S COUNTERMEASURES

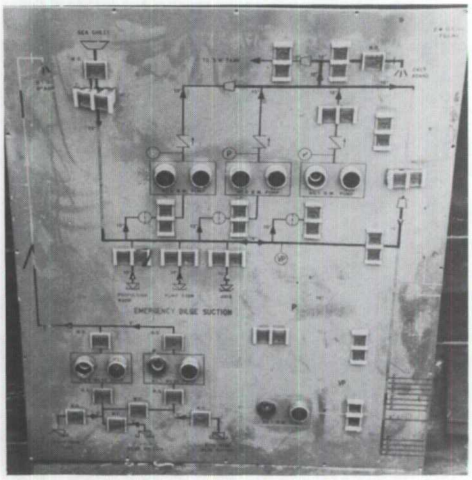
Considering the events that flowed from the restoration of power to the panel between 12:30 and 12:45 a.m., the crew may well have thought that an electrical malfunction had occurred in the switching system. With the February 6 incident fresh in their minds, their course of action would have been to prevent additional ingress from the sea and then pump out. Since the panel had malfunctioned and, in their opinion, valves had opened, the crew would have taken the prudent course of closing both manual sea chest valves before reapplying power to the panel to operate the pumps. The closing of these valves would have prevented any further ingress of sea water. The crew would have believed that the condition of the rig had been stabilized, and that no harm would result from reactivating the panel. While under other conditions the possibility of gravitation between tanks may have been considered, it is unlikely that this would have been considered possible if the pumps were running at the same time.

The absence of indicator lights would not necessarily have prevented the crew from reactivating the panel in order to pump out. An inclination reaching 8-10 degrees in bad weather would be a frightening condition and restoring the rig quickly to an even keel would be a priority.[8] Furthermore, the pumping operation was not complex, requiring only the opening of four valves to pump out of one tank with one pump. The other action taken would be to reassemble one or more pump switches. On the recovered panel, only the switches for pumps #3 and #5 on the port side were completely assembled. The crew apparently intended to pump from the port side of the rig. These switches were reassembled although the red or "stop" lights in both switches were broken. With the manual sea chest valves closed, power was restored and the appropriate valve and pump switches depressed to commence pumping from one or more forward port tanks, probably with the use of one pump initially. No indicator lights would be visible or lit, with the possible exception of the green "run" light for the pump. The restoration of power would once again allow short circuits in any affected microswitches to open ballast valves. The switches for the port aft tanks were in close proximity to the broken portlight and it is highly probable that the microswitches controlling the valves for one or more of tanks P-14,15 and 16 were short-circuited. On the morning of February 14, PT-15 and 16 were 100% full, while PT-14 was 67.9% full. PT-10 and 11, both aft of the centre line, were also 100% full.

With the rig inclined 8-10 degrees by the port bow and with the aft tanks being closer to the pump room than the forward tanks, any attempt to pump out of a forward tank would be futile as long as a full or partially full stern tank was open to the suction line. The water would be drawn from the stern tank first and the effect would be to increase the bow trim and raise the mean draft of the rig. The crew would observe that the pump suction and discharge gauges and ammeter were indicating a positive flow of water but that the bow trim was still progressing. The probable response would be to add another pump. This would increase the rate of pumping from the stern tanks and would accelerate the rate of trim.

The pumping rate would determine whether forward gravitation would occur in the port pontoon between tanks with open valves. There is no evidence of pumping from the starboard pontoon and accordingly gravitation between any inadvertently opened tanks in this pontoon was more likely. Any forward gravitation which did take place would of course serve only to accelerate the rate of forward trim. That pumping from the port pontoon was attempted and was to some degree successful is supported by the fact that when the *Boltentor* approached the stern of the *Ocean Ranger*, the rig appeared to be level transversely. The earlier port heel had apparently been substantially corrected and the only reasonable conclusion is that this was achieved by pumping water out of that pontoon.

[8]The incident of February 6 resulted in the crew being alerted to proceed to lifeboat stations.



7.7 One of the four mimic panel sections recovered from the ballast control console. Only the pump switches for port pumps #3 and #5 had been reassembled.

The pumping operation or planned pumping operation was perhaps relayed by Jacobsen to Graham at 1:00 a.m. In talking to SAREC immediately following his conversation with Jacobsen, Graham says:

> "Yes and they're down eight to ten feet. They are trying to ballas(t) – trying to isolate-ah-ah-what the problem is, but-ah-so far they haven't-ah-haven't been able to make it. Ah-they just don't know where-where the problem is."

While Graham had no recollection of his reference to "ballasting", since he repeats Jacobsen's reference to "feet" and "isolating the problem", it is more probable than not that Jacobsen had mentioned "trying to ballast." Since the countermeasures of closing the manual sea chest valves and pumping were proving ineffective, the *Seaforth Highlander* was called at 1:05 a.m. to come closer and as the trim progressed, the Mayday was issued at 1:09 a.m.

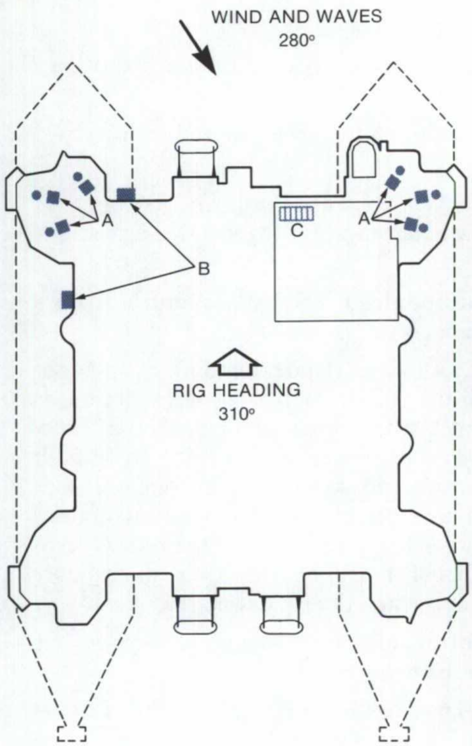
At this point the crew would have been at a loss to explain the increasing trim and would think perhaps of structural damage or valves being unintentionally opened. The pumps would be left running as the first line of defence and the brass manual control rods inserted in an effort to close valves which were thought to have stuck open. In fact, insertion of the rods opened the valves.

Many people have pondered the configuration of the inserted brass rods in an attempt to find some logic or evidence of the crew's intention. It is agreed generally that there is no explanation for the configuration found other than a last minute attempt to close any and all valves. The rods were inserted from the right side of the solenoid bank, where the box of rods was located, to the left side.

Another possible explanation is that as the crew thought that there were problems with valves "stuck open" they decided to leave open only those tanks necessary to pump out the port side. The insertion of the brass rods shows some confusion over the solenoid valves applicable to the drill water tanks, but generally the starboard ballast tanks are "closed" as are the majority of the port aft tanks. The reason for not "closing" all the port aft tanks may well be that there were insufficient rods. The rod inserted in port forward tank 2 is inexplicable.

In any event, the insertion of the manual rods would cause any relevant valves not already opened to open, thus adding to the potential for forward gravitation and an increasing trim. At or before 1:09 a.m., the crew would have observed that despite pumping, closing both manual sea chest valves and "closing" the majority of the ballast tank valves, the condition was worsening, and accordingly reported a severe port list of 12-15 degrees as "progressing." The model tests indicated that at this point chain locker flooding would commence, accelerating the rate of trim.

As the forward portion of the upper deck became lower, its cargo and deck fittings became exposed to the severe wave action. Drill pipe and storage huts were washed overboard and air vents leading to the sack storage area in the lower deck were broken, allowing water to flood into the lower deck area. One of these vents was located on the bow on the port side, while another was located on the port side forward. It is believed that one or both of these vents were broken off by wave action or by shifting deck cargo. It is also likely that water flooded from the lower deck into the column spaces above the chain lockers, into the accommodation areas through damaged portions of the superstructure and thence into the lower deck area, and into the lower hull tanks through exposed vent lines. Whether or not any of this damage and flooding occurred before the decision to abandon is unknown. The flooding would have created an unstable situation and the *Ocean Ranger*, dynamically assisted by wave motion, capsized and sank at approximately 3:15 a.m., February 15, 1982.



7.8 The illustration shows the location of the chain locker openings (A), the ventilators (B) and the accommodations area stairwell (C); the photograph shows one of the large bow ventilators which led to the sack storage area below. With a severe port bow list, drill pipe and deck cargo would have shifted, causing damage to the ventilator and allowing sea water to flood the lower deck.

CONTRIBUTING FACTORS

Of the three rigs operating on the Grand Banks on February 14, 1982, only the *Ocean Ranger* was lost. The individual factors contributing to the loss had lain dormant on the rig throughout its working life, but it was their unique active combination on February 14-15, 1982, which caused the tragic event. Various aspects of the *Ocean Ranger's* design made the rig more vulnerable than it should have been: the exposed location of the ballast control room; the weakness of the portlight; the lack of protection against sea water of the mimic panel; the lack of an adequate manual control system in the control room and the vulnerability of the chain lockers to flooding. Aspects of the management system were also contributory factors: lack of proper procedures for emergencies, lack of manuals and technical information relating to the ballast control console and lack of adequate training programs for key personnel. Human error, lack of knowledge of the vulnerability of the rig and its ballast system and a mistaken reaction to the malfunction of the equipment compounded these design shortcomings and led directly to the disaster. Closing the deadlights in the ballast control room before the storm intensified would clearly have prevented the loss. Even after the portlight had broken, knowledgeable action by the crew in dealing with the effects of the sea water on the ballast control console would have averted the tragedy.

Each event and action which contributed to the loss of the *Ocean Ranger* was either the result of design deficiencies or was crew-initiated. The disaster could have been avoided by relatively minor modifications to the design of the rig and its systems and it should, in any event, have been prevented by competent and informed action by those on board. Because of inadequate training and lack of manuals and technical information, the crew failed to interrupt the fatal chain of events which led to the eventual loss of the *Ocean Ranger*. It is, nevertheless, the essence of good design to reduce the possibility of human error and of good management to ensure that employees receive training adequate to their responsibilities.

The following is a summary of the contributing factors:

1. The design decision to locate the ballast control room in the third starboard column below the lower deck.

2. The failure to assess the potential loading on the portlight and to specify material of sufficient strength.

3. The failure in design to protect the ballast control console and its components for use in a marine environment where sea water ingress was a possibility.

4. The failure of the crew to close the deadlights in the ballast control room when confronted with the severe storm conditions.

5. The lack, on the part of the crew, of a sufficient understanding of and appropriate information on the way in which the ballast control system functioned to permit an accurate and timely assessment of the actual and potential effect of an application of sea water to the ballast control console. Shutting down both the air and electrical supplies to the console and then using only one of these power sources at any given time would have permitted the safe and temporary operation of the valves while the panel was being tested and repaired. A restoration of both sources of power to the panel shortly before 1:00 a.m. on February 15, 1982 created the initial trim from which the rig did not recover.

6. The interconnection between the control and monitoring circuits of the ballast system which caused problems for the operator.

7. Lack of a well understood alternate method for operating the ballast valves from the ballast control room. The brass manual control rods, if correctly used, provided an alternate means of controlling the ballast valves in the event of an electrical fault in the panel, but their use was not officially recognized nor was it documented.

8. The crew's misunderstanding of the operation of the manual control rods and lack of appreciation of the extent to which ballast water could transfer or gravitate from one ballast tank to another. The insertion of the manual control rods achieved an effect opposite to that intended by the crew and accelerated the progression of the bow trim.

9. Lack of an installed secondary communications system linking the ballast control room to the pump rooms which, in the event of a failure of the public address system, could have provided a means of co-ordinating the manual operation of the ballast system from the pump rooms.

10. Lack of appreciation by the ballast control operator that a forward trim would increase if one or more valves leading to the aft tanks were open while pumping from a forward tank was attempted.

11. Lack of protection for the chain lockers against ingress of sea water, lack of an alarm system to warn of any downflooding that did occur and lack of effective means of dewatering the chain lockers in that event.

12. Failure of the watertight integrity of the upper hull by reason of the vents and the light structure of the accommodation area.