USNS Chauvenet (T-AGS 29) Stranding Salvage Operations

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The salvage of the USNS CHAUVENET (T-AGS 29) was a classic stranding where the ship's stability in a grounded condition both restricted and dictated the salvors' options. The perseverance and tenacity of the USS BRUNSWICK (ATS 3) crew in successfully extracting the stranded ship from the coral reef, after several major setbacks, was typical of the professionalism of the Navy's salvage forces.

This case study of the CHAUVENET salvops is intended for ready reference by salvors when ship stability aground becomes a factor in future ship salvage operations. The knowledge and ability to accurately calculate and correctly influence a casualty's stability condition remains, as always, critical to success.

Finally, the scenario of the CHAUVENET salvops illustrates the importance to the Navy's mission of maintaining a fleet of fully capable, general purpose salvage ships. Ships capable of concurrently supporting diving operations, laying beach gear and/or deep water moors, carrying sufficient quantities of yellow gear, fabricating patches/shoring, etc., and pulling/towing are critical to success in remote locations and/or during wartime situations where external logistic support can be minimal or non-existent.

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USNS CHAUVENET (T-AGS 29)

SALVAGE OPERATIONS

MAY 1982

by
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FIGURE 1

USNS CHAUVENET (T-AGS 29) STRANDING

1. ABSTRACT

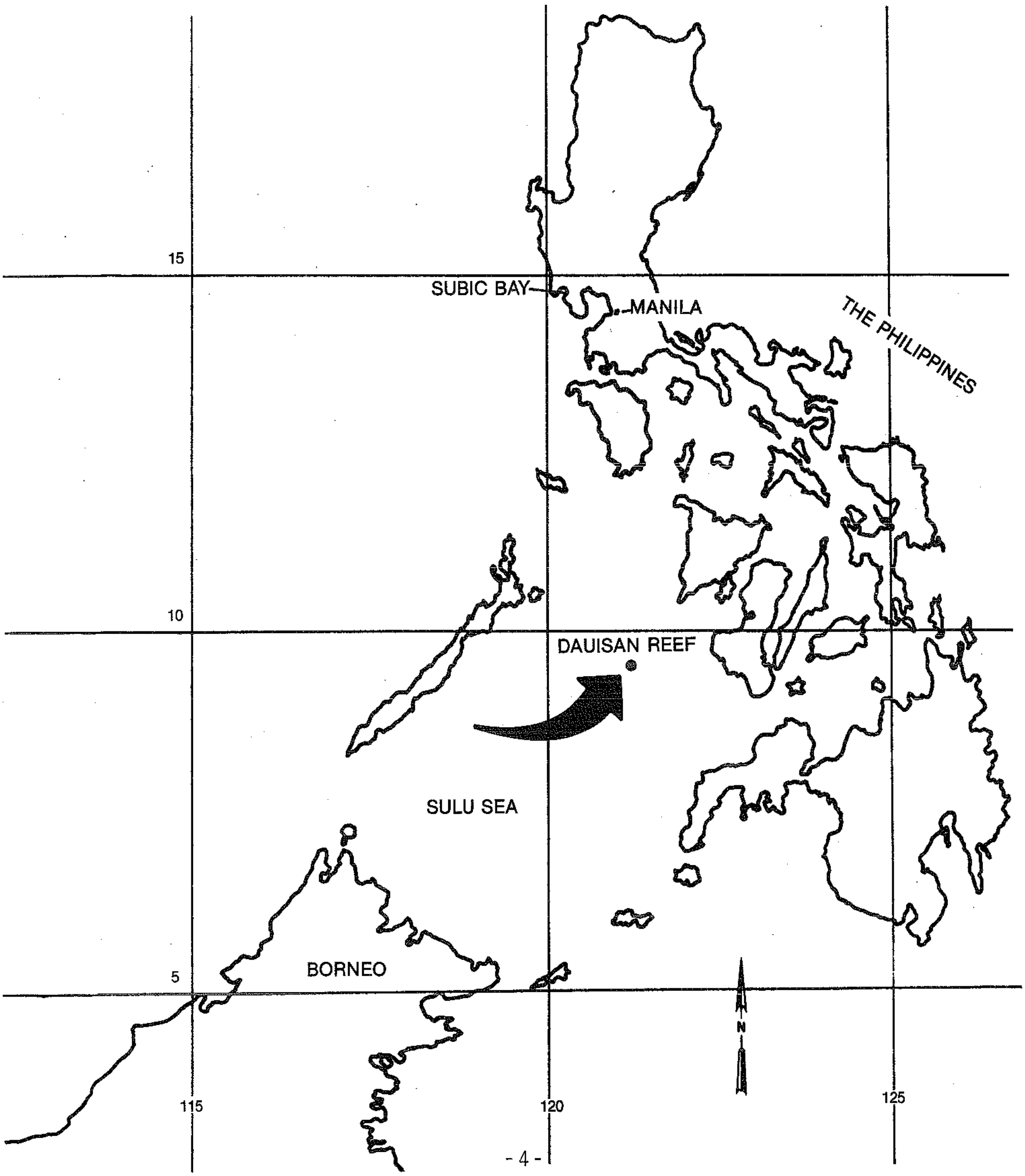
About two hours before midnight on 8 May 1982 while in transit from Subic Bay, Republic of the Philippines to survey grounds in Indonesian waters, USNS CHAUVENET (T-AGS 29) ran hard aground on Dauisan Reef (09 - 47N 121 -13.5 E) Cagayan Islands in the Sulu Sea. The ship sustained considerable damage to the stem and bottom plating, opening the fore peak, port diesel oil tanks, and other spaces to the sea. After approximately two and a half weeks of salvage efforts, the ship was refloated by U.S. Navy salvage teams and towed to the Ship Repair Facility in Subic Bay where damage assessment and temporary repairs were performed.

The refloating and return of the ship to the custody of the Military Sealift Command and the Naval Oceanographic Office represents one of the most ambitious and successful salvage operations conducted by fleet salvage units in recent years. Several problems involving stability, hull damage, temporary repair and logistical support under difficult geographical circumstances were encountered and overcome, rewarding the persistence of the fleet units tasked with the operation.

Significant lessons learned pertain to casualty analysis, stability aground, and methods of ballasting, pumping and counterflooding to permit extraction of a grounded vessel under circumstances which preclude the use of beach gear.

FIGURE 2

DAUISAN REEF, CAGAYAN ISLANDS, SULU SEA, THE PHILIPPINES



2. INTRODUCTION

Extraction of USNS CHAUVENET presented a problematic challenge to fleet salvage units and was the largest scale stranding salvage operation in recent years. The operation was prolonged by several complexities including the nature of the hydrographic features of the reef, the extent of the internal damage sustained in going aground, and the natural stability characteristics of the casualty. The successful refloating and tow of the oceanographic research vessel was the result of almost three weeks of determined work by the crew of the USS BRUNSWICK (ATS 3) supported by several higher commands.

As is normally the case in any significant salvage operation, a great amount of teamwork was critical to the eventual success. USS BRUNSWICK demonstrated its value as a fully capable salvage platform and towing vessel during this operation. USNS NARRAGANSETT (T-ATF 67), USS SAN JOSE (AFS 7), and USS KISKA (AE 35) provided limited logistical support. Key personnel were supplied by Commander-in-Chief Pacific Fleet, Commander Task Force 73, the Ship Repair Facility in Subic Bay, the Military Sealift Command, and the Supervisor of Salvage, Western Pacific Salvage Contractor in Singapore.

The bottom topography adjacent to the stranding precluded the use of ground tackle for hauling the casualty clear of the reef and therefore demanded a specifically designed ballasting, dewatering, and counterflooding plan to reduce ground reaction and enable the BRUNSWICK to apply the final retraction force. The movement of the required quantities of ballast water onto and off the ship at various phases of the refloating operation had a significant impact on the ship's stability characteristics. This effect was difficult to quantify and resulted in several severe alterations in the vessel's stranded attitude. Once all critical information was discerned and analyzed, successful refloating was accomplished.

After being refloated, the ship was towed to the Ship Repair Facility in Subic Bay where damage assessment and temporary repairs were effected to enable the ship to be safely towed to Sasebo, Japan for permanent repairs.

TABLE 1

SNAPSHOT SUMMARY

CONDITION	SITUATION
ALPHA	CONDITION BEFORE STRANDING
BRAVO	INITIAL STRANDING CIRCUMSTANCES
CHARLIE	CASUALTY CONDITIONS ON 19/20 MAY
DELTA	FORMULATION OF FINAL SALVAGE PLAN
ECHO	REFLOATING OPERATIONS

3. THE SALVAGE OPERATION

Overall, the problems to refloat USNS CHAUVENET are noteworthy in many respects. The routine daily operations to effect the salvage plan and its modifications were simple in execution yet subtle in application. In order to present a concise discussion of the material factors contributing to the important lessons learned in this case, the casualty condition is analyzed in this report at five discreet "snapshots" in time, as shown in Table 1. Key parameters are quantified by observation and calculation as appropriate, tabulated, and evaluated to present the pertinent details defining both the casualty circumstances and the rationale behind the development and conduct of the salvage plan.

3.1 Condition Alpha

The oceanographic research vessel USNS CHAUVENET was enroute to a hydrographic survey mission at the time of the casualty. In reports to the salvage team upon arrival at the casualty site, CHAUVENET officers reported the ship to be in a near full-load condition. This condition (Appendix 5.1) is found described in the ship's Trim and Stability Booklet and the information presented herein was established using that document and in conference with the casualty's officers.

FIGURE 3

USNS CHAUVENET (T-AGS 29)

TABLE OF PRINCIPAL CHARACTERISTICS

LENGTH, OVERALL	393′-2¼″
LENGTH, B.P.	357′-0″
BEAM (MOLDED)	54′-0″
BEAM (OVER BRIDGE WINGS)	56′-0″
DEPTH, MLD., TO MN. DK. AT SIDE ⊗	31′-0″
DEPTH. MLD., TO 01 LEVEL AT SIDE ⊗	40′-1-5/8″
BULKHEAD DECK	MAIN DECK
DRAFT, KEEL, FULL LOAD	17′-4¾″
DISPLACEMENT, FULL LOAD	4,830 TONS
LIGHTSHIP*	3,425 TONS
LIGHTSHIP V.C.G.*	26.56 FT.
LIGHTSHIP L.C.G. AFT F.P.*	185.95 FT.
FIXED BALLAST	61.0 TONS
CREW	70 PERS
SCIENTISTS/MIL. DEP. (MAX)	112 PERS
FUEL OIL (95%)	827 TONS
SALT WATER BALLAST (F.O. TKS)	1076 TONS
FRESH WATER	240 TONS
DRAFT TO IMMERSED PROPELLER TIP	12′-2″
SONAR DOME-MAX PROJ BELOW KEEL AT FR 56	1″-2″

*FROM STABILITY TEST DATA OF 8 JAN 1972

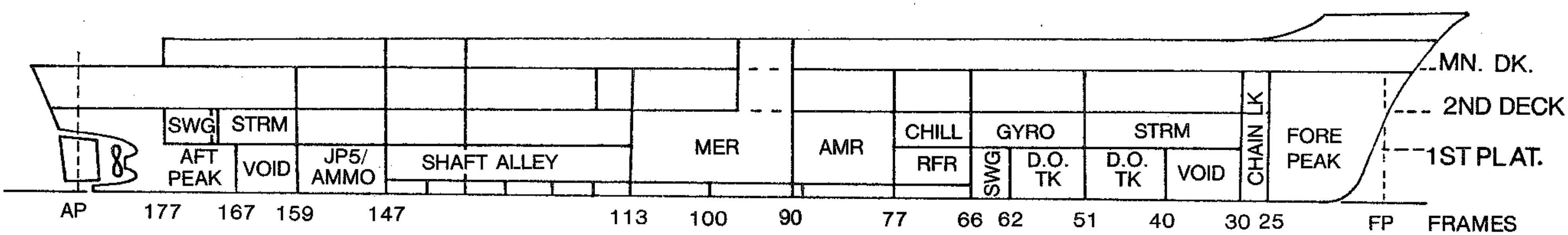
It is important to note at the outset that the casualty had a limited reserve stability characteristic in the full-load condition. As indicated in the Trim and Stability Booklet, this condition left a corrected metacentric height (GM) of only 2.8 feet. This provided only one foot reserve over the required design GM of 1.86 feet.

No hydrostatic curves of form were available to the salvors. However, the Trim and Stability Booklet included a deadweight scale which displayed displacement, transverse metacentric radius (KM), tons per inch immersion (TPI), moment to trim one inch (MTI), longitudinal center of flotation (LCF), and longitudinal center of buoyancy (LCB) versus "mean draft" (drafts between 10 and 18 feet). The ship's Booklet of General Plans was also on board and made available to the salvors. All dimensional information employed to calculate flood volumes and weights was extracted from the General Plans. CHAUVENET's General Arrangements are shown in Figures 4, 5, and 6.

CHAUVENET's afloat characteristics prior to going aground included drafts forward 16 feet 10 inches, and aft 17 feet 6 inches. The ship did not have midship draft marks. The mean draft afloat prior to the casualty was 17 feet 2 inches. From the Trim and Stability Booklet, this draft equated to a reported displacement of 4,725 tons.

FIGURE 4

Inboard Profile Noting Key Spaces

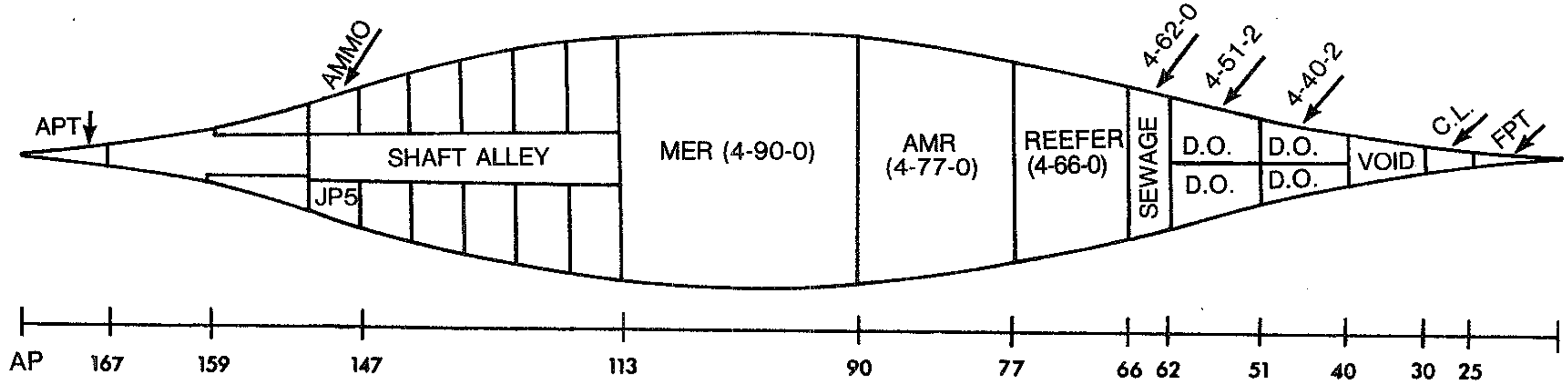


(ALL FRAME SPACING = 2 FEET)

(NO SCALE)

FIGURE 5

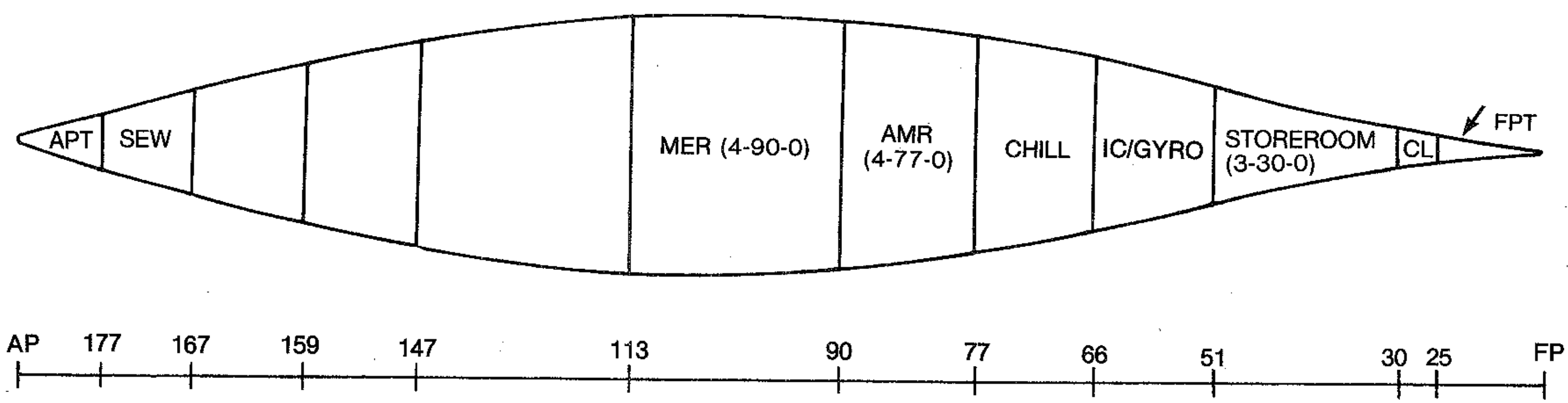
Hold Level



(NO SCALE)

FIGURE 6

First Platform Level



(NO SCALE)

(In this paper, all reference to tons is in terms of long tons of 2,240 lbs. All measurements are in feet and inches.)

3.2 Condition Bravo

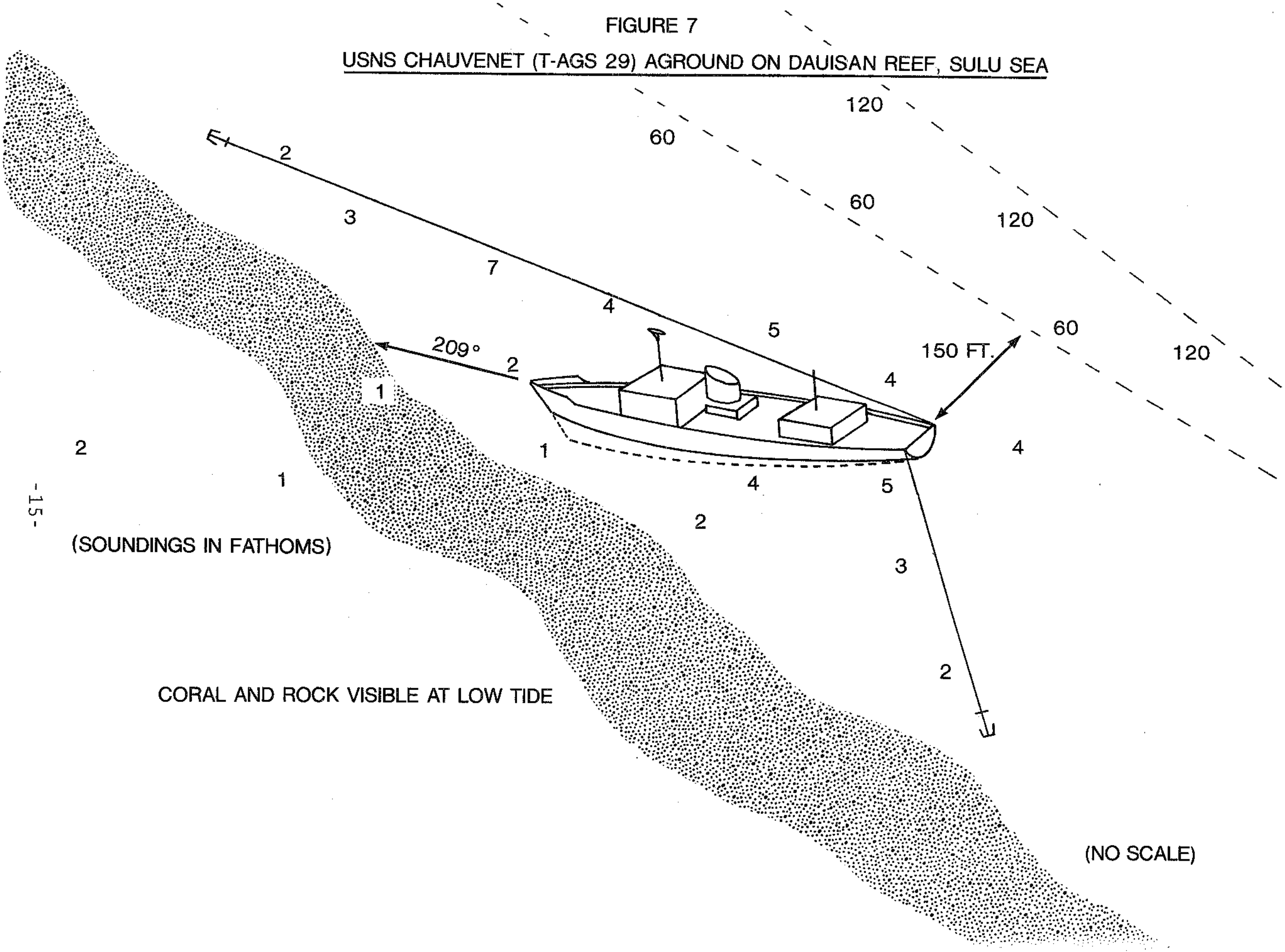
In going aground, the USNS CHAUVENET is speculated to have sideswiped the soft coral reef between the keel and the port bilge strake from frame 50 to 80 prior to driving her stem onto the reef. Flooding of several forward spaces ensued. The ship was unable to extract itself from the strand. Emergency assistance was solicited immediately.

At that time USS BRUNSWICK, in a maintenance availability status at SRF Subic Bay in the Republic of the Philippines, was tasked to depart as soon as possible for the stranding site and commence the salvage operations. Within eleven hours from initial notification, BRUNSWICK was underway towards the scene and arrived in the vicinity of CHAUVENET at 1000 local time on 10 May with six sets of beach gear rigged for immediate deployment. Only at that time was it determined that the extreme depth of water immediately adjacent to the grounding site would preclude the effective use of ground tackle in hauling the casualty clear of the strand.

The first evolution in the development of the salvage plan

FIGURE 7

USNS CHAUVENET (T-AGS 29) AGROUND ON DAUISAN REEF, SULU SEA



was the performance of an underwater survey of the casualty hull to determine the extent of damage, examine the relation of the hull to the ground, and identify any obstacles to extraction. CHAUVENET's general attitude on the reef is depicted in Figure 7. BRUNSWICK divers reported that the ship was aground from the forward perpendicular(FP) to frame 25 on soft coral, Figure 8. Amidships near frame 120, the ship was resting on a soft coral patch approximately 3 feet square. The hull aft of frame 120 was clear of the ground. At low tide the ship was observed to be more broadly aground with contact extending from FP to the vicinity of frame 50. Effective ground contact appeared to be entirely to port of the keel.

Damage observed was most noticeable by way of the forepeak tank where the forefoot was buckled, Figure 9, with some holing noted in the shellplate. A 60 foot gash was found in the hull inside and parallel to the port bilge strake extending from frame 50 to frame 80. This tear varied in width from 1 inch to a maximum of 18 inches and the contiguous shellplate was buckled and rolled inboard. The forward sonar dome was sheared off although no holing was found in that location.

Hull rupture from the impact on the coral reef had resulted in the flooding of the forepeak tank, the diesel oil deep tanks on the port side, the sewage tank between frames 62 and 66, the dry stores reefer compartment between frames 66

FIGURE 8

Flooding and Ground Contact - High Tide-May 10th Condition Bravo

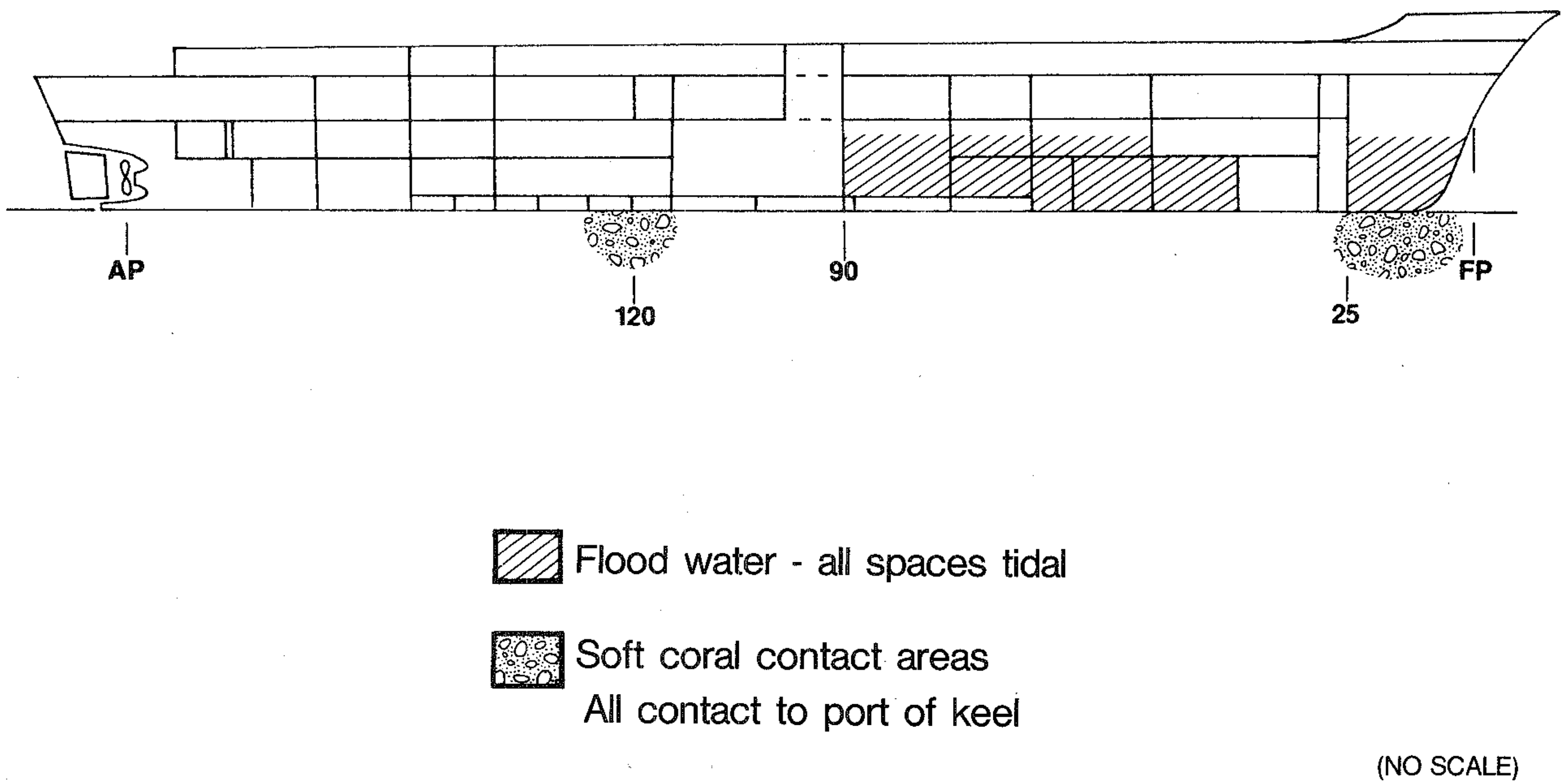
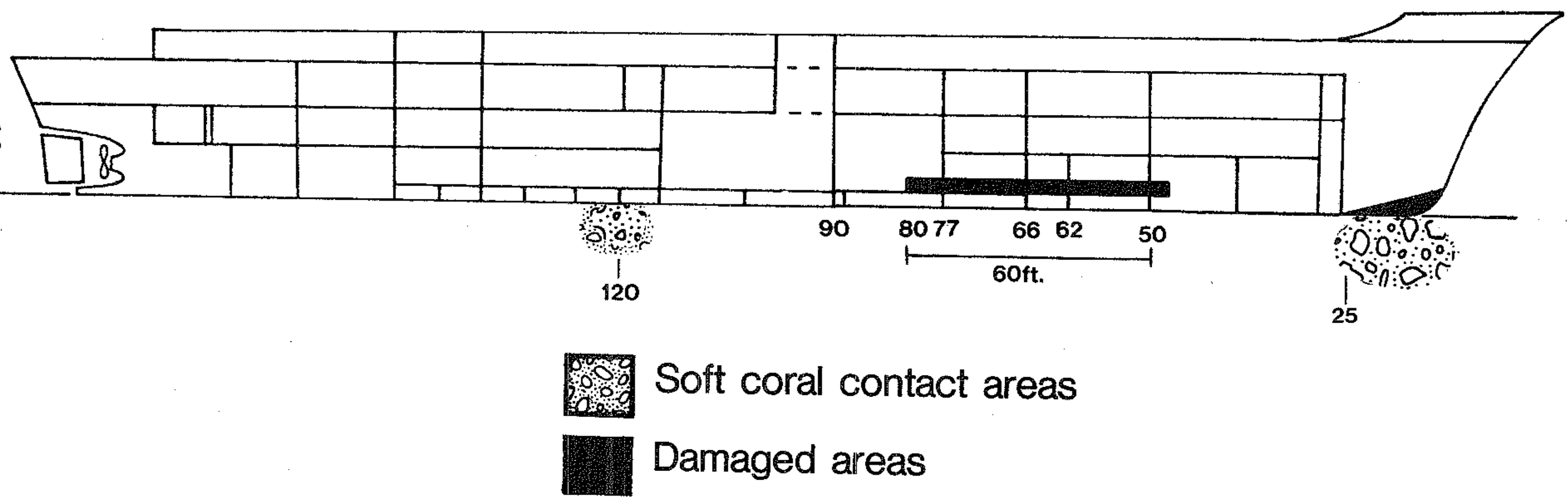


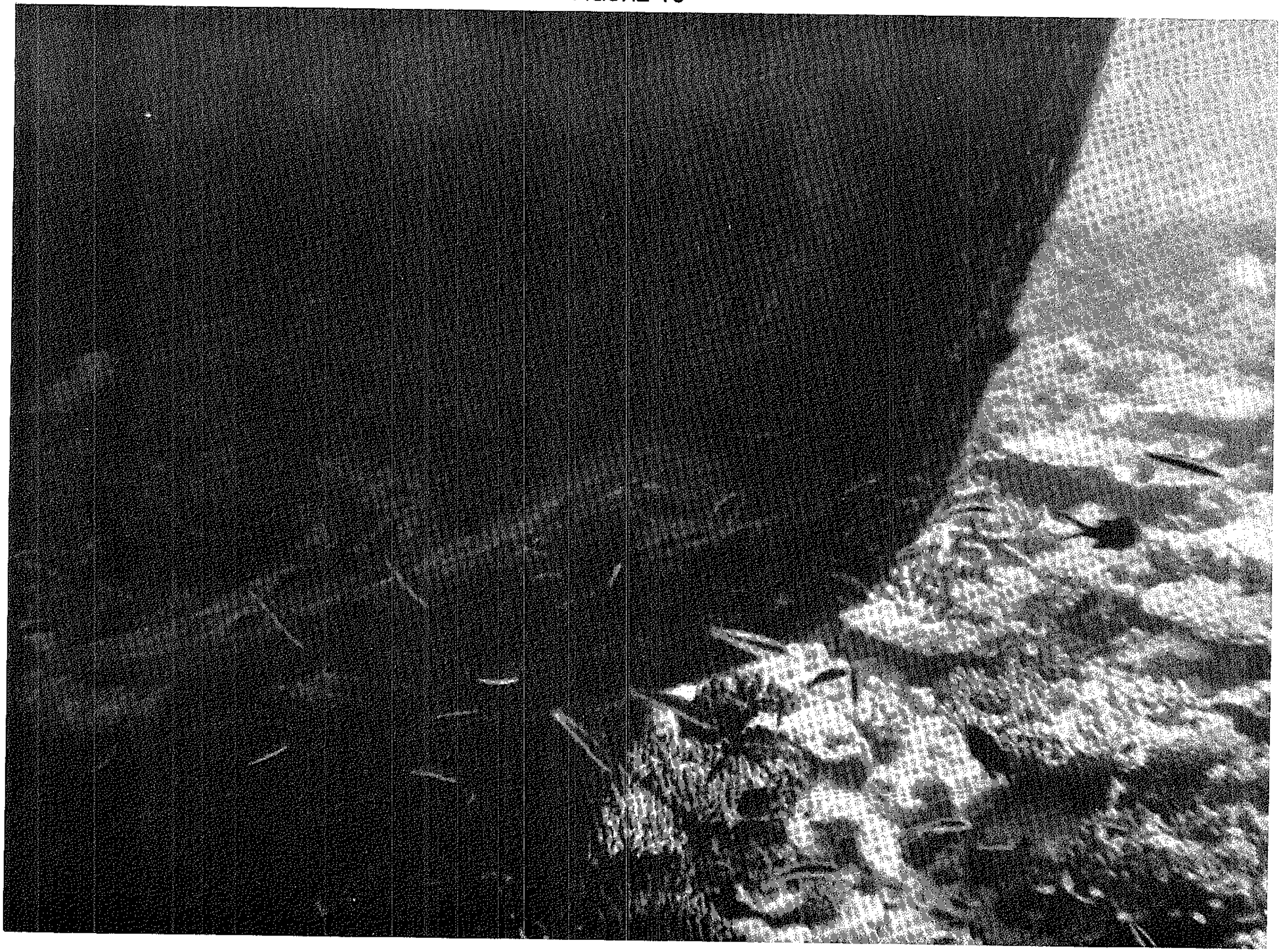
FIGURE 9

Damaged Areas



(NO SCALE)

FIGURE 10



Initial Bow Damage

and 77, and the auxiliary machinery room between frames 77 and 90 (Ref. Figures 4,5,6,8,9). Additionally, the spaces on the first platform over those compartments were also found to be tidal. All other spaces appeared to be watertight. The casualty lay approximately portside to the reef with a heading of 209 degrees True. At high tide an 8 degree port list was reported which decreased to 4 degrees to port at low tide. During the early phases of the salvops the list was somewhat variable and could actually be controlled by raising/lowering the ship's 10-ton survey boats in their davits, a clear indication of the instability of the casualty.

3.2.1 Ground Reaction

Drafts aground at low tide were noted to be 10 feet forward, 22 feet aft for a mean of 16 feet, indicating the stranded ship to be some 14 inches out of draft with a grounded displacement of approximately 4,300 tons. At high tide mean draft was 17 feet 9 inches for a displacement of 5,000 tons; clearly, the ship was heavier than when afloat, Table II.

If the hull had not sustained the damage as described and there had been no flooding, the maximum ground reaction indicated by the draft differentials would have been equal to the displacement before grounding minus the displacement after grounding or approximately 470 tons at low tide, and

TABLE II

DRAFT/DISPLACEMENT CHANGES IN GOING AGROUND

		CONDITION A	CONDITION B*
	FWD	16-10	15-01 / 10-0
DRAFTS (FT-IN)	AFT	17-06	20-06 / 22-0
	MEAN	17-02	17-09 / 16-0
DISPLACEMENT (LT)		4,725	5,000 / 4,300

*HIGH TIDE / LOW TIDE MAY 12

at high tide the ship would have had enough water to float clear. However, because of the added weight considerations due to flooding, a more rigorous calculation procedure to determine ground reaction was necessary.

It is noted that the displacement aground varies between two extremes: at low tide displacement aground is at a minimum and at high tide it is at a maximum. Ground reaction varies inversely to displacement aground being a minimum at high tide. The flooding and liquid load status of the forward spaces affected by the hull damage was reported by BRUNSWICK personnel as follows:

- forward peak tank (4-13-0) - tidal
- chain locker (4-25-0) - dry
- void unassigned space (4-30-0) - dry
- diesel oil tank (4-40-1) - full and intact
- diesel oil tank (4-40-2) - open to sea
- diesel oil tank (4-51-1) - full and intact
- diesel oil tank (4-51-2) - open to sea
- IC/Gyro and Chill spaces (1st platform, frames 50 and 77) - tidal-in free communication with lower compartments
- reefer space - open to sea
- sewage com't - open to sea

- auxiliary machinery room (4-77-0) - tidal
- aft diesel deep tanks and JP5 tank - full and intact
- afterpeak tank (4-167-0) - partially filled having been in use on the voyage

None of the stern tanks, that is, those aft of the main engineroom were damaged. The forepeak tank which had been full of fresh water prior to the casualty event had lost weight as the water level inside the tank was lowered to the water level outside the hull. Table III and Figure 11 consider the effect of flood water at low tide.

The weight of the flood water aboard had to be included in the ground reaction calculation. It was supposed that if the ship had been afloat with flooding to the level observed at low tide, its gross displacement would have been 5,586 tons for a mean draft of 17 feet 9 inches. Therefore, by subtracting the displacement aground (4,300 tons) from the displacement including the flood water (5,586 tons) (i.e. the estimated flooded weight of the ship), the true ground reaction at low tide was calculated and equal to approximately 1,286 tons, Figure 11.

TABLE III

WEIGHT CHANGES DUE TO FLOODING (AT LOW TIDE: D_M = 16 FT):

	WT	MOM(V)
FPT	-32	-544
IC/Gyro (50-66)	97	1,360
Sewage (62-66)	85	680
Reefer (66-77)	185	1,850
Chill (66-77)	91	1,272
AMR (77-90)	435	4,346
TOTAL	861 LT	8,964 FT TONS

KG* = CHAUVENET VCG AGROUND, FLOODED AT LOW TIDE

Kg = VCG OF FLOOD WATER MASS

$$KG = \frac{(\text{DISPLACEMENT AFLOAT} \times \text{KG AFLOAT}) + (\text{FLOOD WATER} \times Kg)}{(\text{DISPLACEMENT} + \text{FLOOD WATER})}$$

$$KG = \frac{(4{,}725 \times 21.86 + 8{,}964)}{(4{,}725 + 861)}$$

$$= 112{,}253/5{,}586$$

$$= 20.10 \text{ FT}$$

*EXCLUDING EFFECT OF GROUND REACTION

FIGURE 11

GROUND REACTION AND STABILITY FOR CONDITION BRAVO (LOW TIDE):

R = DISPLACEMENT AFLOAT + FLOOD WATER – DISPLACEMENT AGROUND

(DISPLACEMENT AFLOAT + FLOOD WATER = 4,725 + 861 = 5,586 LONG TONS)

AT LOW TIDE (MEAN DRAFT = 16-0 FT),

R = 5,586 – 4,300
= 1,286 LONG TONS

THEREFORE, SINCE KG = 20.10 FT
AND GG_1 = (R)(KG)/DISPLACEMENT
GG_1 = (1,286)(20.10)/4,300 = 6.0 FT

SO, AT LOW TIDE, KM = 25.5 FT (FROM THE TRIM AND STABILITY BOOKLET):

*GM = KM–KG
= 25.50–20.10 –6.0
= – 0.6 FT

*UNCORRECTED FOR FREE SURFACE.

At high tide, Figure 12, (mean draft 17-09 feet) the amount of flood water in the hull increased an estimated 175 tons to total 1036 tons. The theoretical afloat displacement (uncorrected for trim) becomes,

$$4725 + 1036 = 5{,}761 \text{ tons}$$

At the high tide mean draft, displacement aground (from the Trim and Stability Booklet) was read to be 5,000 tons. Therefore the casualty ground reaction at high tide was

$$5685 - 5000 = 761 \text{ tons}$$

Subsequent to the conduct of internal and external surveys, a salvage plan was outlined to include:

- patching hull damage by way of port bilge strake
- dewatering selected spaces to reduce ground reaction
- pulling with BRUNSWICK (50 ton bollard pull) on a rising tide

Assuming a coefficient of friction on the reef of 0.5, it appeared that complete dewatering of the AMR and IC/GYRO space would be sufficient weight reduction to enable the salvage tug to haul the casualty from strand.

FIGURE 12

GROUND REACTION AND STABILITY FOR CONDITION BRAVO (HIGH TIDE):

AT HIGH TIDE, MEAN DRAFT = 17-09 FT

AN ADDITIONAL 175 TONS OF WATER ENTERS THE BREECHED HULL,

$$R = (4{,}725 + 861 + 175) - 5{,}000$$
$$= 5{,}761 - 5{,}000$$
$$= 761 \text{ TONS}$$

THEREFORE, ADJUSTING FOR ADDED FLOOD WATER,

$$KG = \frac{(4{,}725 \times 21.86) + (861 \times 10.4) + (175 \times 16.9)}{(4{,}725 + 861 + 175)}$$

$$= 115{,}210/5{,}761$$
$$= 20.00 \text{ FT}$$

AND CONSIDERING DECREASED GROUND REACTION,

$$GG_1 = (761)(20.00)/5{,}000$$
$$= 3.04 \text{ FT}$$

SO, AT HIGH TIDE, KM = 25.05 FT

$$GM^* = 25.05 - 20.00 - 3.04$$
$$= 2.01 \text{ FT}$$

*UNCORRECTED FOR FREE SURFACE

3.2.2 Stability Aground

Observing that the ship had relatively fine lines and was reported to have had an afloat GM only slightly greater than the required design GM, calculation of the ship's stability aground was critical.

The measure of stability of a ship most commonly employed is metacentric height or GM which may be computed or tracked many ways. During the CHAUVENET salvage operation, the following basic equation was used:

$$GM = KM - KG - GG_1 - FS - FC$$

where GM = metacentric height;
(All figures in feet)

KM = metacentric radius or the height of the metacenter above the keel;

KG = the height of the vertical center of gravity above the keel of the ship corrected for weight changes (including flooding);

GG_1 = the virtual effect of ground reaction on KG;

FS = the virtual rise of KG due to flood free water surface;

FC = the virtual rise of KG due to off-center spaces in free communication with the sea.

Commonly in a non-casualty afloat condition, GM is the simple difference between KM, the height of the transverse metacenter above the keel, which is a function of the underwater hull form and obtained from the ship's curves of form, and KG. This is referred to as uncorrected GM. In reality, it is necessary to correct GM for free surface effect found in slack tanks aboard the afloat vessel.

KG, the height of the vertical center of gravity, is often a difficult value to ascertain. In this case, the similarity between the ship's actual load conditions immediately preceding the casualty incident and the Trim and Stability Booklet documented full-load conditions provided a convenient means for estimating the height of the vertical center of gravity. It was taken that KG in the full load condition was about the same as the casualty condition and equal to 21.86 feet (uncorrected for flooding and ground reaction).

The effect of the addition of flood water into a hull on the ship's center of gravity is similar to the effect of any weight added to the intact hull such as cargo, fuel or other liquids. The weight is treated as though it is brought on initially at the vertical center of gravity and subsequently moved to the flooded space. Normally in salvage calculations, the center of gravity of the flood water is taken as the centroid of the mass of flood water. This effect is calculated in Table III and included in KG figures referenced throughout this report.

On the other hand, the effect of ground reaction on the center of gravity is similar to the effect of removing a weight equal to the ground reaction at some point on the ship's hull which is the point of effective ground reaction. The virtual effect of ground reaction is included in the factor GG_1 in the above formula.

Of all the factors influencing the value of GM, the most significant in the case of the CHAUVENET were flood water and ground reaction. Figures 11 and 12 and Table IV show the combined effect of flood water and ground reaction on gross displacement and the height of the vertical center of gravity (KG) on the ship/deadweight system. Figure 8 shows the location of the flooded areas onboard the ship.

TABLE IV

CONDITIONS AFTER GROUNDING

CONDITION	DRAFT (FT)	DISPLACEMENT (TONS)	WEIGHT (TONS)	GROUND REACTION (TONS)	KM_T (FT)	KG[1] (FT)	GM[2] (FT)
BEFORE GROUNDING	17.2	4,725	4,725	0	25.20	21.86	3.34
AFTER GROUNDING							
W/FLOODING (HIGH TIDE)	17.8	5,000	5,761	761	25.05	23.04	2.01
W/FLOODING (LOW TIDE)	16.0	4,300	5,586	1,286	25.50	26.10	−0.6
AFTER BALLASTING CHAIN LOCKER & VOID							
AT HIGH TIDE[1]	17.8	5,000	5,883	883	25.05	23.33	1.72
AT LOW TIDE[1]	16.0	4,300	5,708	1,408	25.50	26.44	−0.94

[1] INCLUDING EFFECT OF GROUND REACTION
[2] UNCORRECTED FOR FREE SURFACE

Free surface is often considered a step function by salvors. If you have slack liquid in a space it is some maximum value. If the space is either fully pressed up or completely dry, the free surface is zero. While simplistic in approach and conservative in application, more rigorous calculations are normally beyond the degree of accuracy expected in a dynamic salvage situation. Free surface effect is defined as the moment of inertia (i) of the waterplane of a watertight space about the centerline divided by the ship's submerged volume (V); the resultant virtual rise in G for a rectangular space of beam B and length L is expressed

$$FS = i/V = B^3L/12/V$$

Although on CHAUVENET most of the flooded space waterplanes were trapezoidal in shape, the above equation was used. The beam and length dimensions were lifted from the Booklet of General Plans. For salt water, the equation reduces to:

$$FS = B^3L/12/35W = B^3L/420W$$

If the flooded space were flooded with a liquid other than salt water (e.g. diesel oil) the free surface should be multiplied by the ratio of densities.

A summary of the virtual rises in the center of gravity of the casualty due to flooding and free surface in key spaces is detailed in Table V.

Subsequently in this report metacentric height (GM) is presented uncorrected for free surface effect. Recalling that GM was marginal throughout the stranding and became negative at several junctures, it is noted that actual corrected GM was inevitably smaller than the already limited figures shown. For example, during Condition Bravo a maximum free surface degradation to GM of approximately 4 feet was estimated, making the corrected GM actually negative throughout the tidal range.

Only two off-center spaces were found to be in free communication with the sea, diesel oil tanks 4-40-2 and 4-51-2. Since both openings were subsequently patched by salvors, the effect of free communication was eliminated, so "FC" was considered to be zero and ignored throughout the salvage calculations.

Table IV compares conditions on board the ship with respect to ground reaction and stability before the grounding, after grounding at high and low tide with flooding, and at high and low tide in the ballasted and flooded condition. Ballasting implications are addressed in the following section. This table discloses that the ground reaction and

TABLE V

MAXIMUM FREE SURFACE EFFECT FOR KEY SPACES

SPACE	REDUCTION IN GM*
(HOLD LEVEL)	
SEWAGE	
(FRAME 62-66)	0.12 FT
REEFER	
(FRAME 66-77)	0.41 FT
AMR	1.73 FT
PORT D.O. TANKS	0.05 FT
TOTAL	2.31 FT
(FIRST PLATFORM LEVEL)	
AMR	1.73 FT
IC/GYRO	1.17 FT
CHILL	1.15 FT
TOTAL	4.05 FT

*F.S. EFFECT NOT ADJUSTED DOWNWARD FOR POCKETING OR SURFACE PERMEABILITY

water added to the ship during the casualty combine at low tide for approximately 1,400 tons of retaining force. At high tide, that force is reduced to less than 900 tons due to the added displacement consistent with tidal variation.

3.2.3 Salvage Operations and Effects

During periods of high tides and wind and swell conditions, salvors noted a certain liveliness in the grounded hull. CHAUVENET would pitch and yaw against the reef. Such movement was considered undesirable in the interests of preserving casualty status quo and preventing progressive hull damage while patching operations were underway. Two Eell's anchors were deployed to hold CHAUVENET on the reef and avoid premature refloating in the event of high off-reef winds; review Figure 7.

A decision was made to increase ground reaction by ballasting specific compartments forward in the ship over the effective point of ground reaction which had been determined to be in the area of frame 25 at high tide. Spaces selected for flooding were the chain locker and the unassigned void between frames 30 and 40 in the hull just aft of the chain locker. The additional weight and impact on the ship's vertical center of gravity stemming from this ballasting is shown in Table VI.

TABLE VI

BALLASTING BY SALVORS:

SPACE	WEIGHT (LONG TONS)	VCG (FEET)	V MOMENT (FOOT TONS)
CHAIN LOCKER	67	15	1,005
VOID (FR30-40)	55	9	495
TOTALS	122		1,500

The addition of 122 tons of weight into the hull was expected to increase ground reaction by a like number thereby achieving the purpose of retaining the ship harder aground and remove some liveliness. However, the stability impact of flooding the chain locker and void is negative, Table IV.

In this instance, adding weight albeit with a low center of gravity not only has the effect of lowering KG and thereby increasing GM, but it also concomitantly reduces GM. This contradiction can be easily explained. Typically, weight brought aboard the ship at some point lower than the vertical center of gravity of the ship and deadweight reduces KG, that is moving the vertical center of gravity toward the keel. However, as has been demonstrated, the accompanying increase in ground reaction is equal to the removal of the weight at the keel, that is, a weight whose vertical center of gravity (g) is at the keel, Kg = 0. By computing the effect this has on the moments defining the height of the overall vertical center of gravity (KG), one sees that the destabililzing effect of the increase in ground reaction is more excessive than the stabilizing effect of adding a low weight. Therefore, the net result is a reduction of metacentric height (GM) to the detriment of initial stability.

In the case of the CHAUVENET, the combined effect of

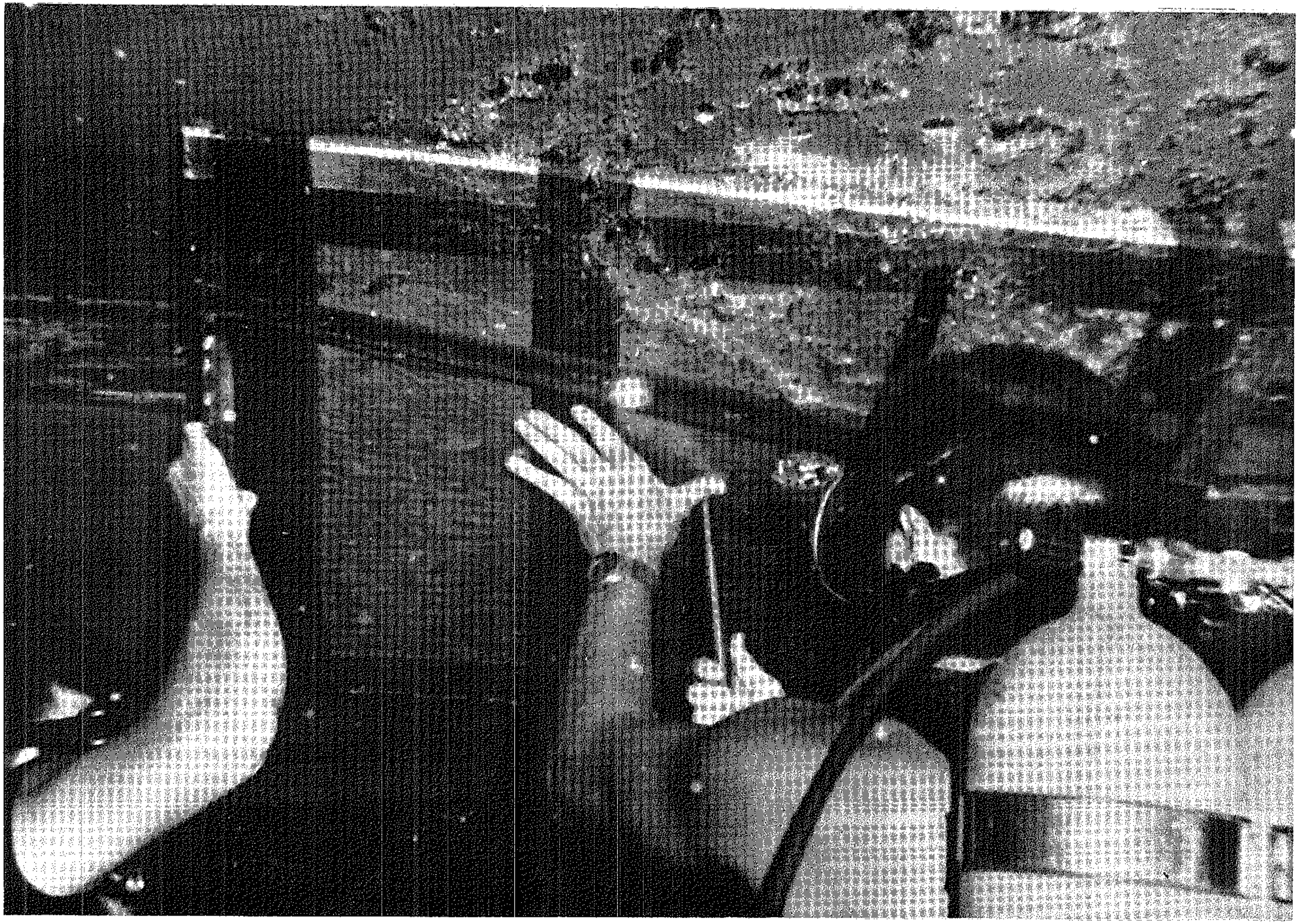
flooding and ground reaction significantly reduced GM. The greatest losses in GM were observed as the tide ebbed. Again directly attributable to increasing ground reaction, GM actually became negative at low tide. As noted earlier, correction for free surface indicates negative GM at all tidal ranges.

Characterized by negative GM, a hull is, to say the least, very tender and immediately responsive to any upsetting moments. Given the fact that CHAUVENET flooding and liquid load was basically symmetrical about the centerline, when the tide ebbed, the off-center effect of ground reaction tended to increase the list aground. Nonetheless, the cradling effect of the soft coral bottom against the hull tended to resist any significant ship rotation.

3.3 Condition Charlie

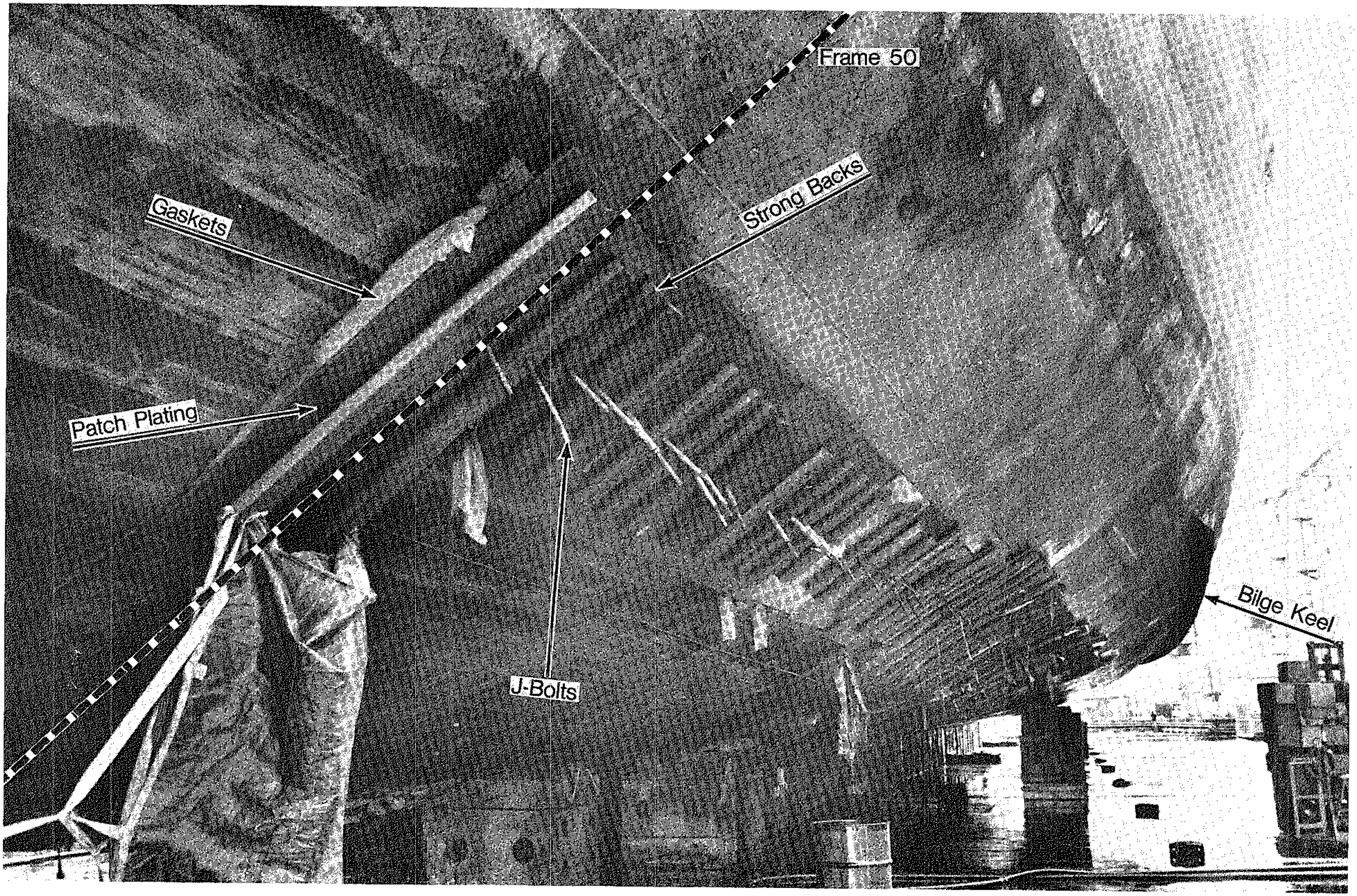
Following survey by BRUNSWICK on 10/11 May 1982, a salvage operation was directed toward patching the apparent hull damage externally, pumping to dewater selectively, and pulling to refloat the casualty. The 60 foot tear near the port bilge strake was closed using external patches tailored to fit the damage in the hull and held in place with a system of strong backs and J bolts. This was accomplished in the first week of operations and this patch is shown in Figures 13 and 14.

FIGURE 13



Patching the Port Side Tear

FIGURE 14



(Port side looking aft) Patch installed by Salvors

The quality of the patching, which proved to be quite high, was unknown until the first major pumping evolution was attempted. At that time, the unexpectedly slow rate of dewatering indicated that some leaking existed in the patching system. Two patches comprising the 60 foot long patch warped under hydrostatic load, buckled against the dished out hull plating, and prevented the planned dewatering of the auxiliary machinery room. New patches were fabricated and installed on 18 May and the dewatering continued.

The specific approach of the dewatering program aimed to control free surface while reducing ground reaction sufficiently to minimize the retaining force to be overcome by the pulling salvage ship. The pumping plan as laid out and executed by 18 May called for:

- Dewatering IC/Gyro space and subsequently rendering it watertight.

- Flooding storeroom on the first platform between frames 30 and 51.

- Dewatering the Chill spaces on the first platform.

- Reflooding the IC/Gyro spaces.

The final step in dewatering the auxiliary machinery room was never fully accomplished. By the morning of 19 May, the date of anticipated refloating, the water level in the AMR had been lowered to approximately 6 feet above the deck plates after prolonged and laborious pumping.

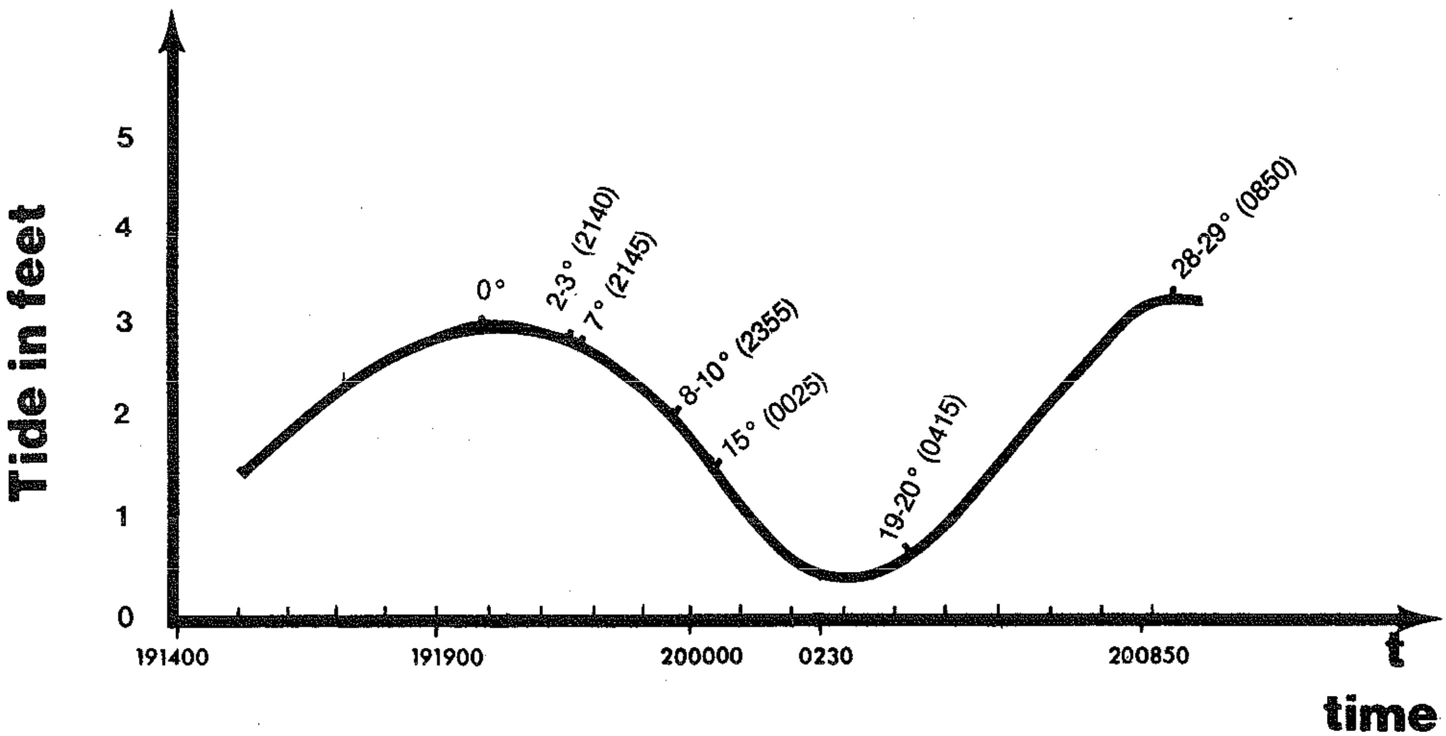
At approximately 2140 local time, CHAUVENET suddenly shifted to a 2 or 3 degree starboard list. Five minutes later the list had increased to 7 degrees; in the next 2 hours to 10 degrees. At 0025, 20 May, list reached 15 degrees, and by 0400, 20 degrees. In the intervening period, all fleet and CHAUVENET personnel save the casualty's master and three senior salvage officers were evacuated from the casualty to the U.S.S. BRUNSWICK and USNS NARRAGANSETT.

Eventually these last personnel were evacuated and by 0850, high tide, the list had increased to 29 degrees, Figure 15. Although winds of moderate force, 10-15 knots with gusts to 30 knots, and seas to 3 feet existed in the area at the time, these were not seen to be sufficient to increase the list so dramatically and sustain it. Although the situation was not clear, the salvors soon reboarded the ship and commenced shifting loose gear to port and removing topside weight starboard side until the list was reduced to about 20 degrees maximum.

In the immediate aftermath of taking the extreme list, bilge

FIGURE 15

STARBOARD LIST CONDITIONS MAY 19-20



water in the engineroom flooded the main switchboard and CHAUVENET lost main power. Operational requirements were satisfied using the emergency diesel generator for the remainder of the salvage operation.

3.3.1 Analysis of Events

The unexpected excessive list implied to the salvors that certain information had not been apparent to the initial survey. The immediate question related to the cause of the sudden change in the ship's attitude with the ebbing tide and continued increase in list as the tide turned to flood.

In anticipation of pulling efforts on a rising tide, pumping had been scheduled to coordinate the reduction in weight with the increased displacement at high tide for the greatest net reduction in ground reaction. Until the AMR was dewatered to the level of the first deck, all weight reduction was effected symmetrically about the centerline. First platform spaces remained pressed up and no heeling moments developed.

As the tide fell on the evening of 19 May, GM decreased. As AMR dewatering progressed below the first deck level, damage to transverse watertight bulkheads forward at frames 77, 66, 62, and 51 port side permitted fuel-contaminated flood water to flow aft. This resulted in the partial

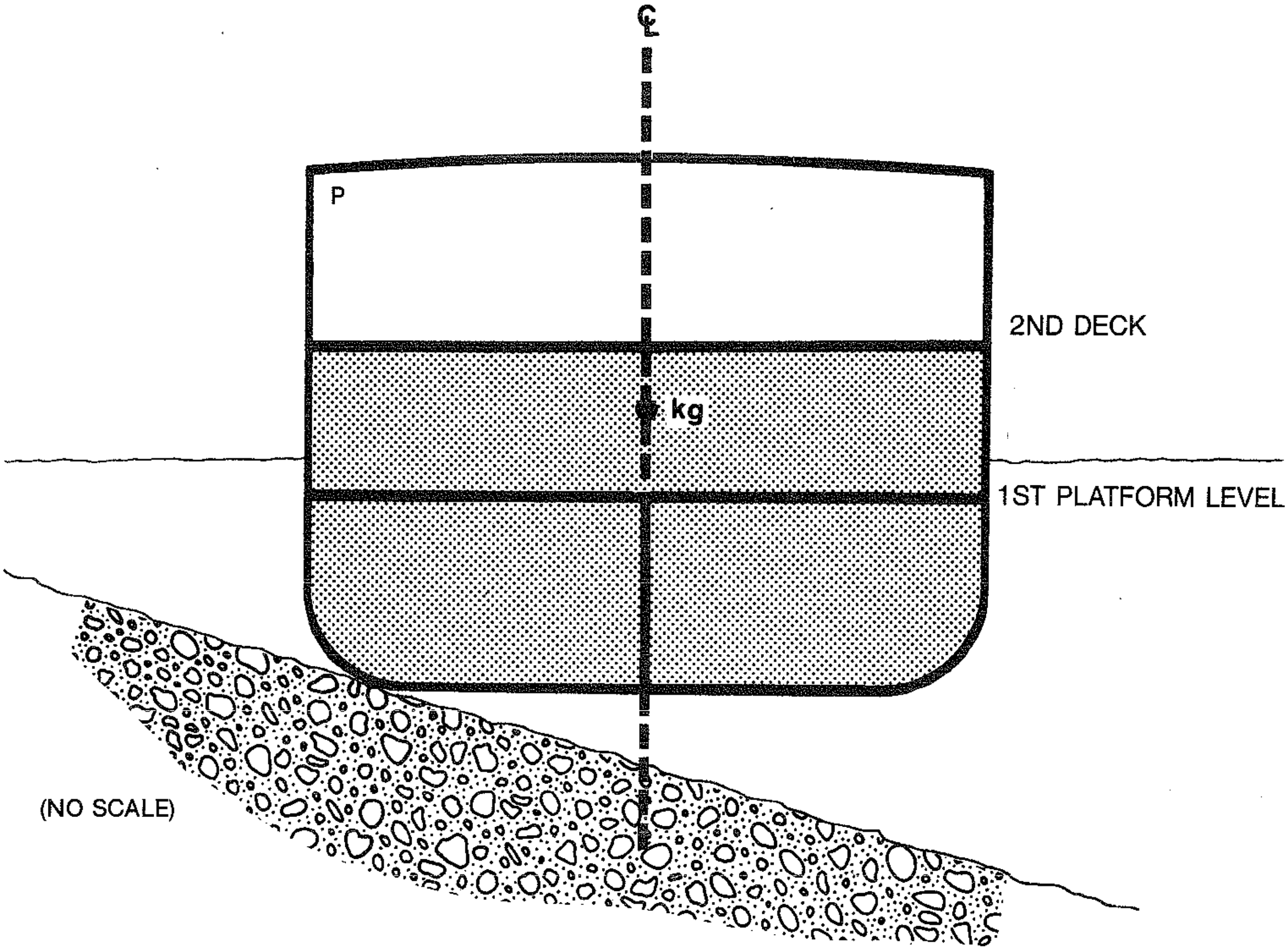
dewatering of the portside diesel oil tanks (4-40-2) and (4-51-2) which generated an inclining moment estimated st 350 ft.-tons to starboard. Since the ship had a negative GM, the effect of the moment was quick.

As the ebb continued, list increased and more flood water shifted to starboard. At low tide, the center of gravity of the flood water was substantially to starboard of the centerline. At this stage list stabilized, possibly because the hull at the starboard bilge keel was resting on the reef. With the flood tide, list continued to increase as the rising water increased displacement. During this sequence ground reaction had shifted from port toward the starboard side. Figures 15 thru 19 graphically display these events. Flooding in the athwartship spaces and significant loose gear below decks had shifted off-center to starboard. The list, though mitigated by the salvors' subsequent actions and the settling of the ship into the soft coral bottom, remained until the actual refloating on 29 May.

Table VII tracks the change in ground reaction and stability consequent to the dewatering operations up until the time the tide began to rise again. The declining trend of GM with ebbing tide is readily apparent. It is also theorized, though impossible to substantiate or quantify, that shifting the effective point and intensity of ground reaction with

FIGURE 16

SCHEMATIC DIAGRAM OF CHAUVENET SECTION



- FLOOD WATER TO SECOND DECK BETWEEN FRAME 30 AND FRAME 90
- MID TIDE
- GROUND REACTION ON PORT SIDE OF KEEL

FIGURE 17

AMR DEWATERED TO SIX FEET OVER THE TANK TOPS AT HIGH TIDE

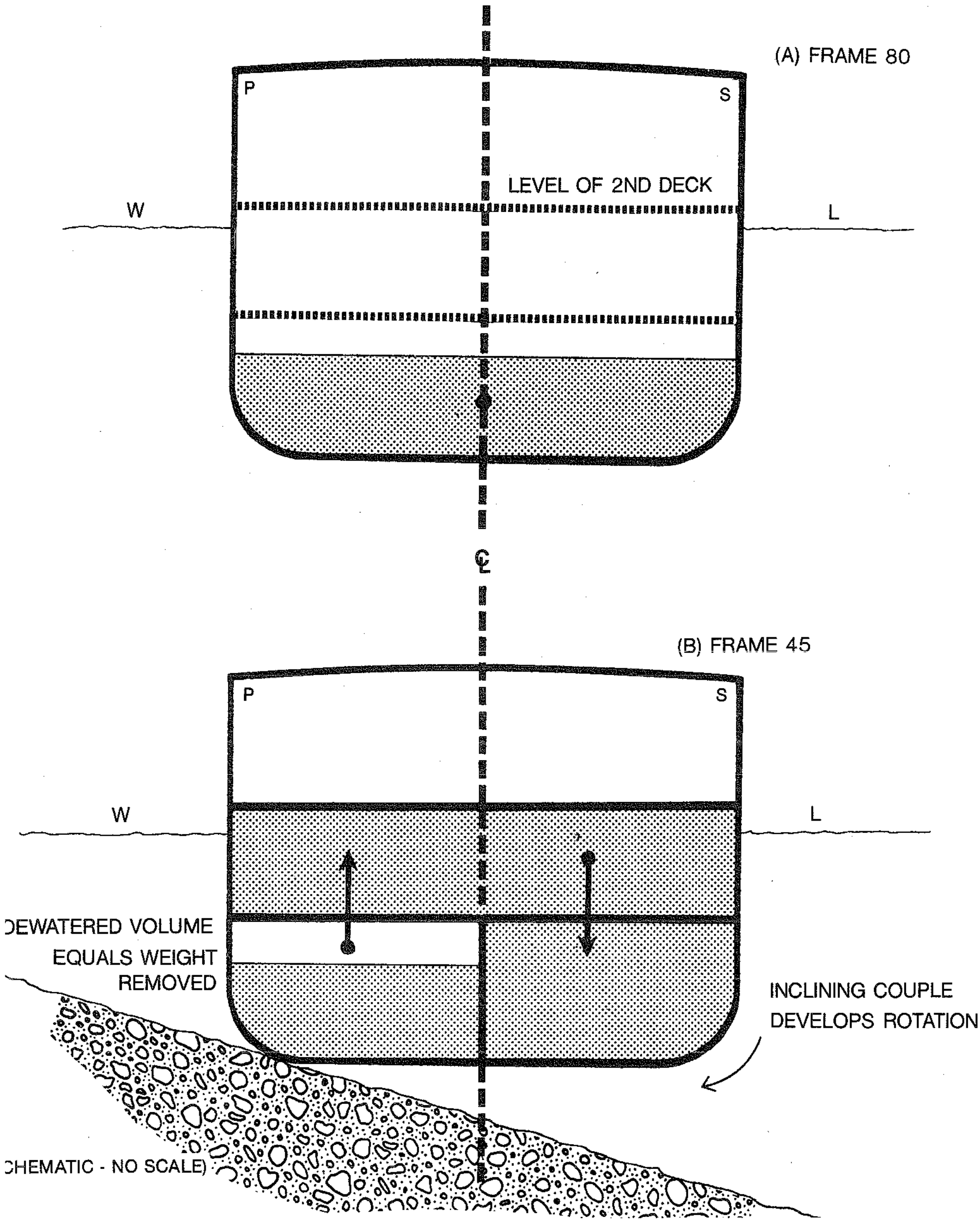


FIGURE 18

15° LIST CONDITIONS AT LOW TIDE

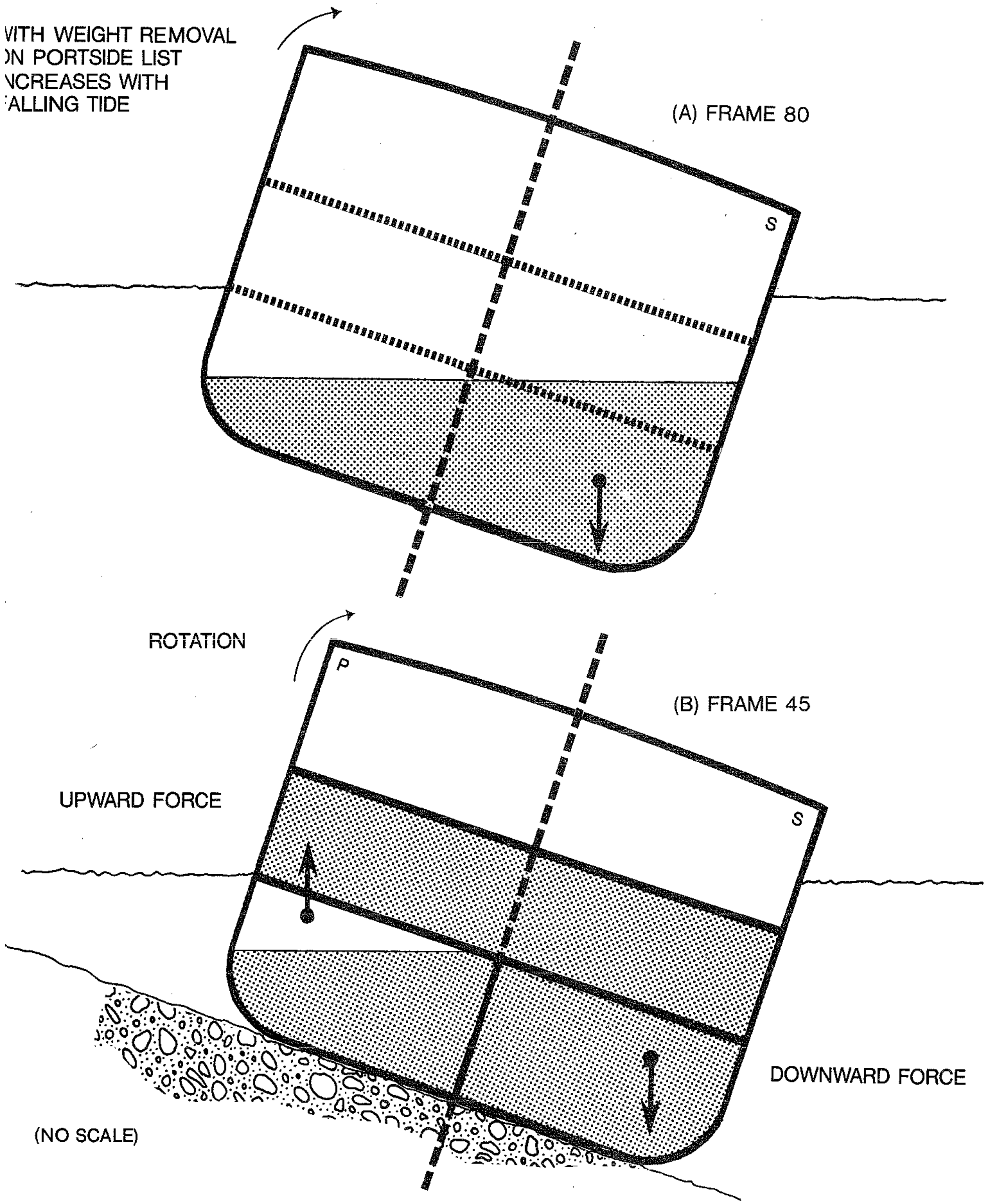
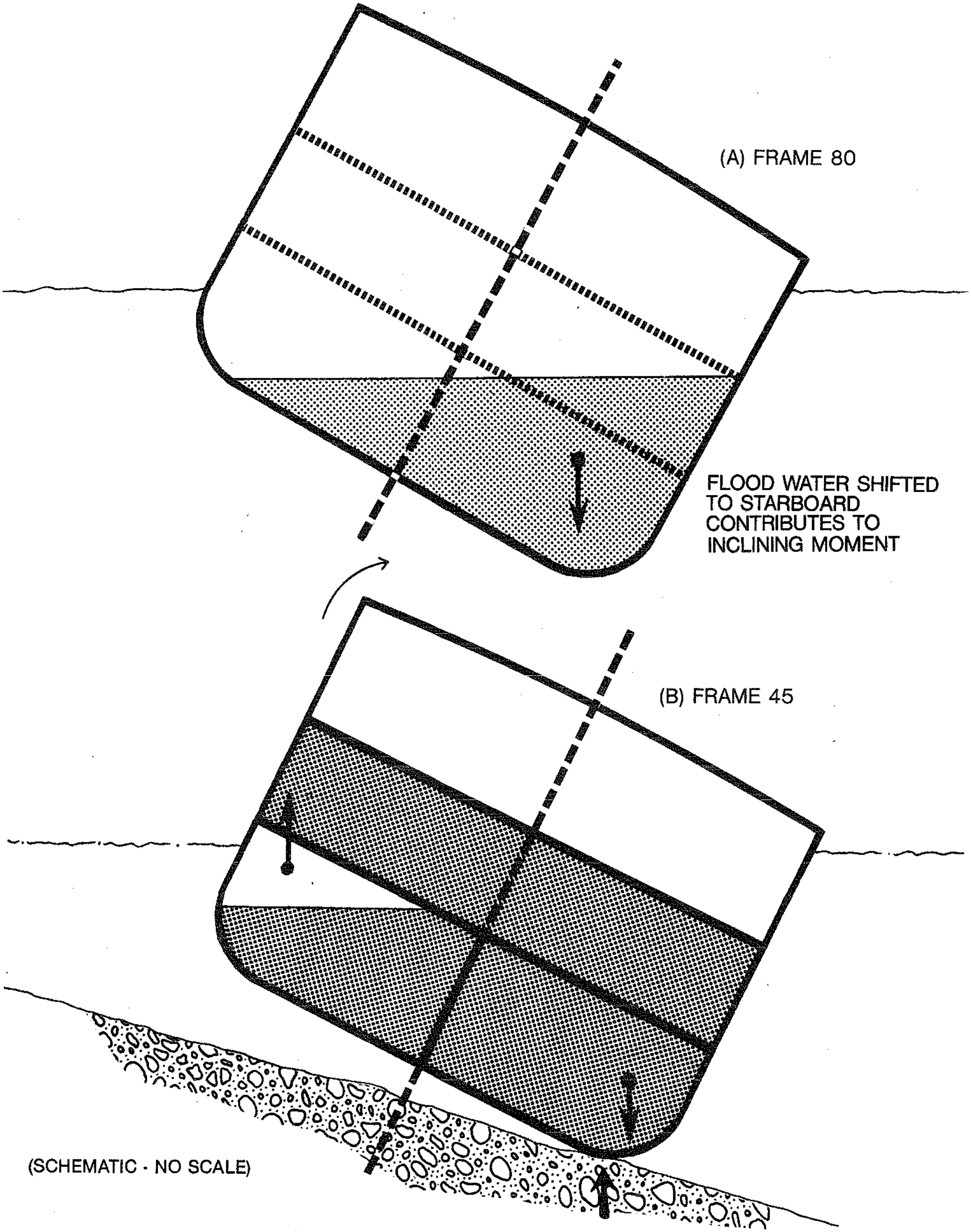


FIGURE 19

28° - 29° STARBOARD LIST AT HIGH TIDE (200850 LOCAL)



(SCHEMATIC - NO SCALE)

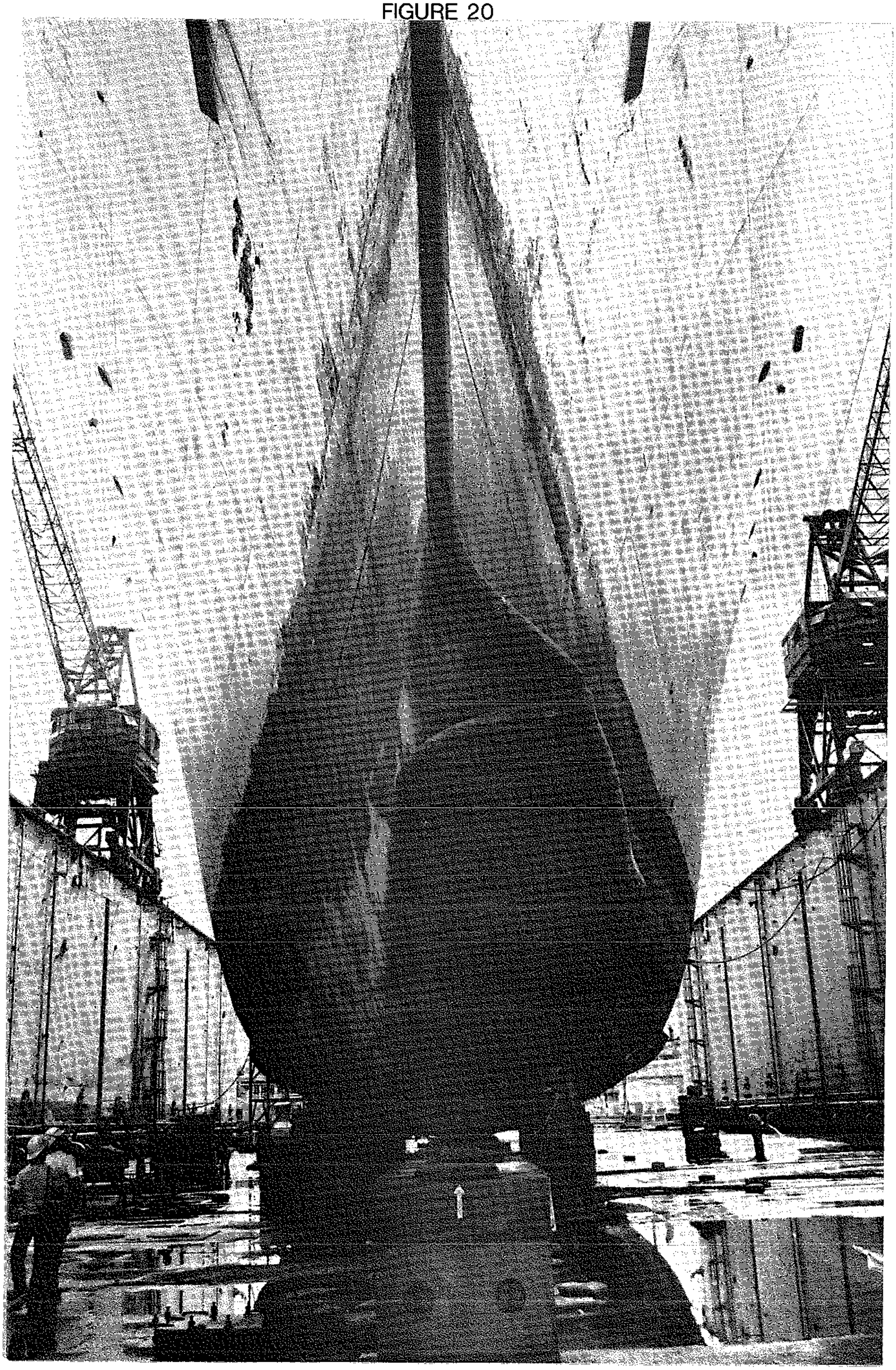
TABLE VII

EVALUATION OF CHANGES DURING CONDITION CHARLIE

LOCAL TIME	LIST (DEGREES)	DISPLACEMENT (TONS)	WEIGHT (TONS)	GROUND REACTION (TONS)	KM_T (FT)	KG (FT)	GM (FT)	GG (FT)	GM* (FT)
AT HIGH TIDE	0	4,800	5,316	516	25.10	21.1	3.91	-2.28	1.63
192140	2-3	4,700	5,316	616	25.20	21.1	4.01	-2.78	1.23
192355	8-10	4,500	5,316	816	25.35	21.1	4.16	-3.84	1.32
200025	15	4,400	5,316	916	25.40	21.1	4.21	-4.40	−.19
AT LOW TIDE	19-29	4,310	5,316	1,006	25.50	21.1	4.31	-4.94	−.63

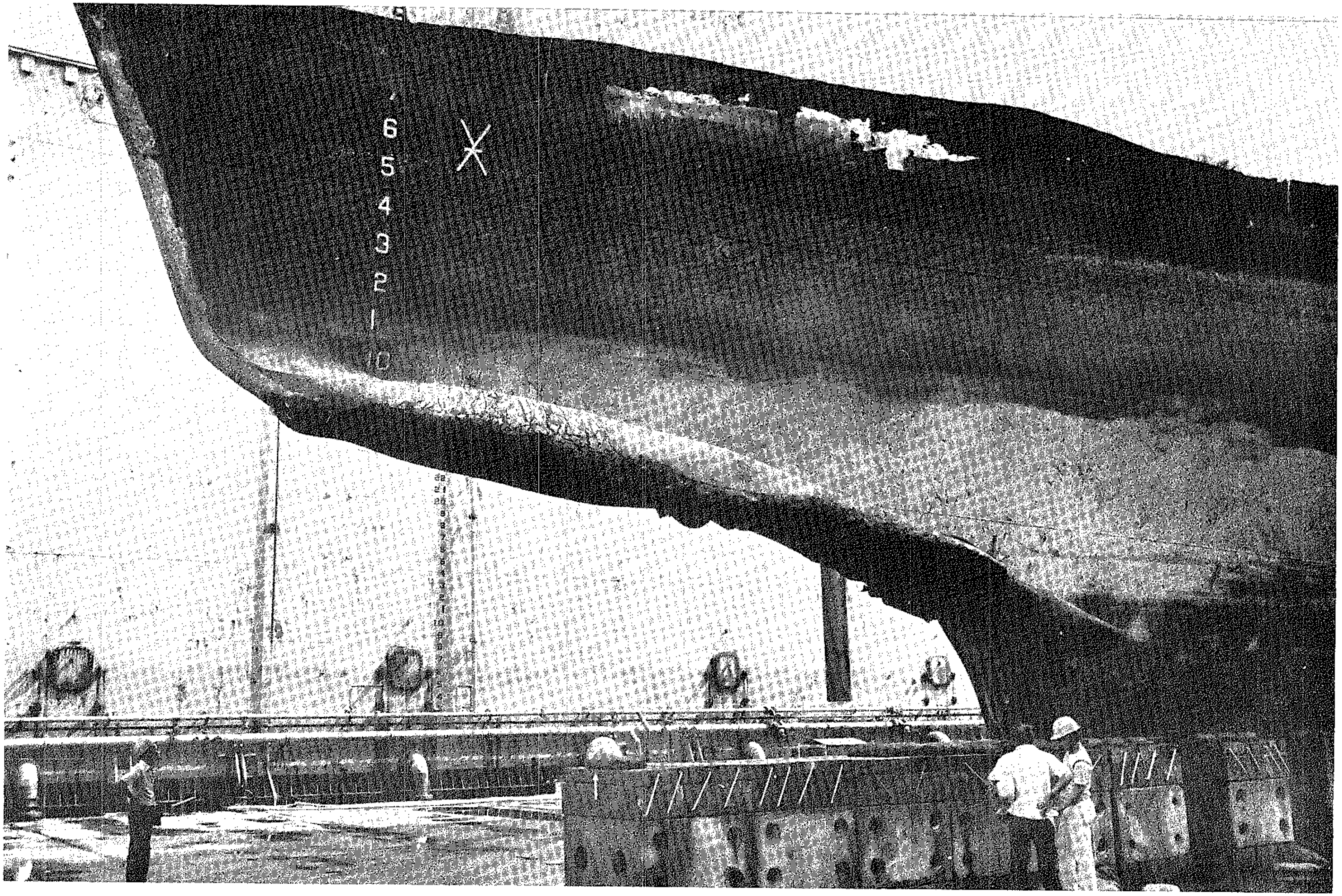
*UNCORRECTED FOR FREE SURFACE (ESTIMATED FROM TABLE V AT 2.31 FT.)

FIGURE 20



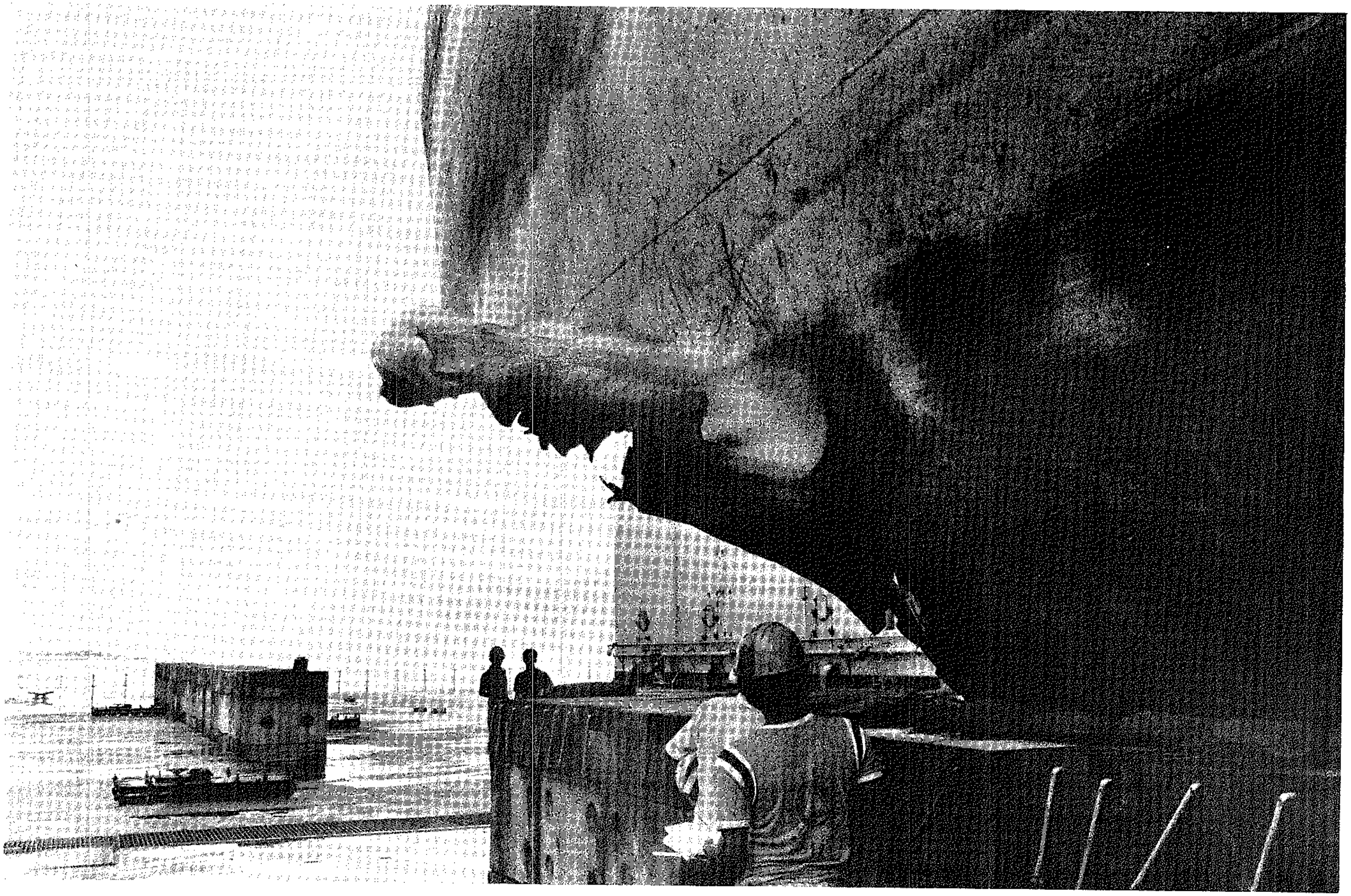
Bow Damage

FIGURE 21



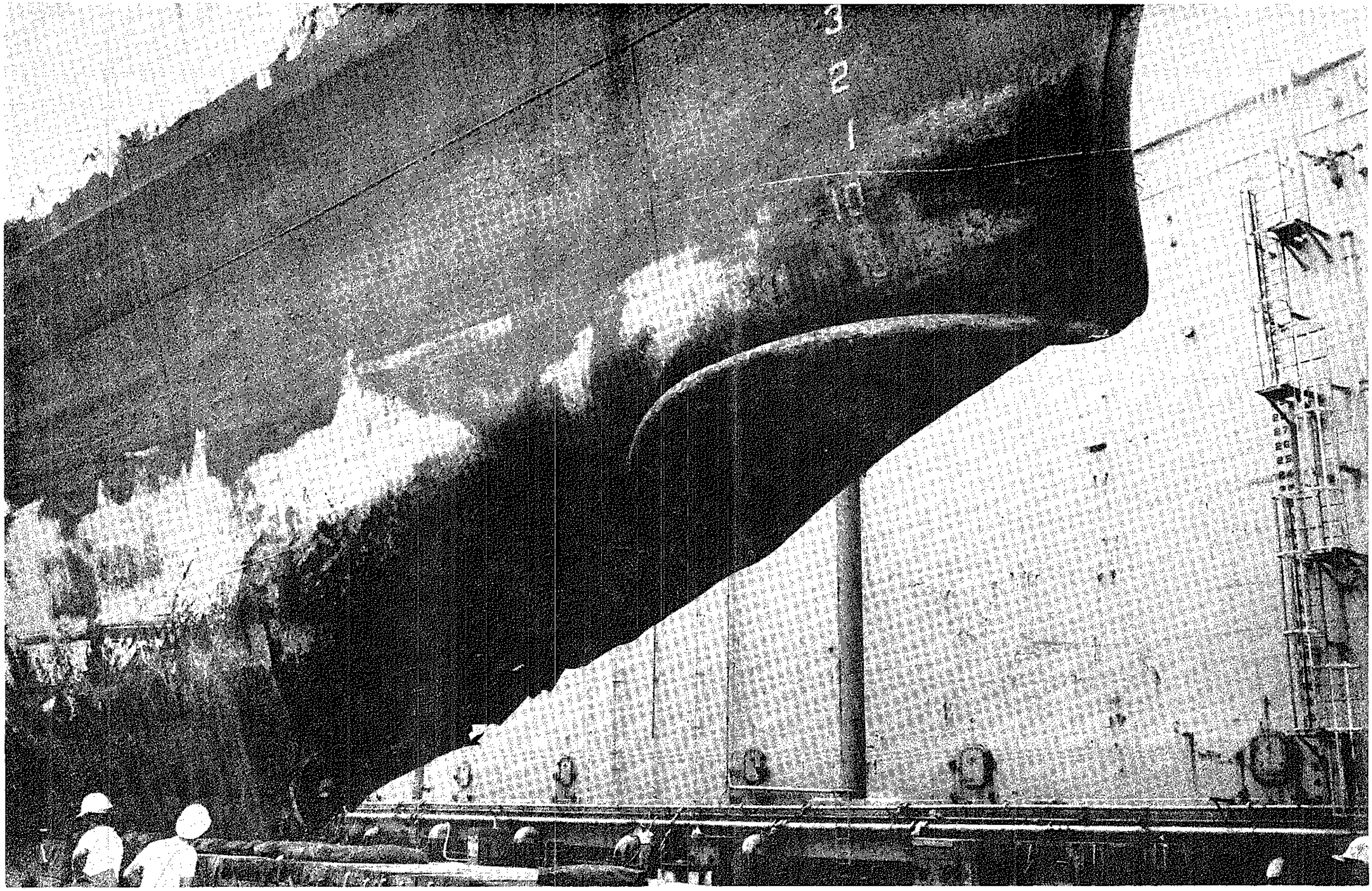
Bow Damage - Port Side

FIGURE 22



Bow Damage - Port Side Looking Forward

FIGURE 23



Bow Damage - Starboard Side

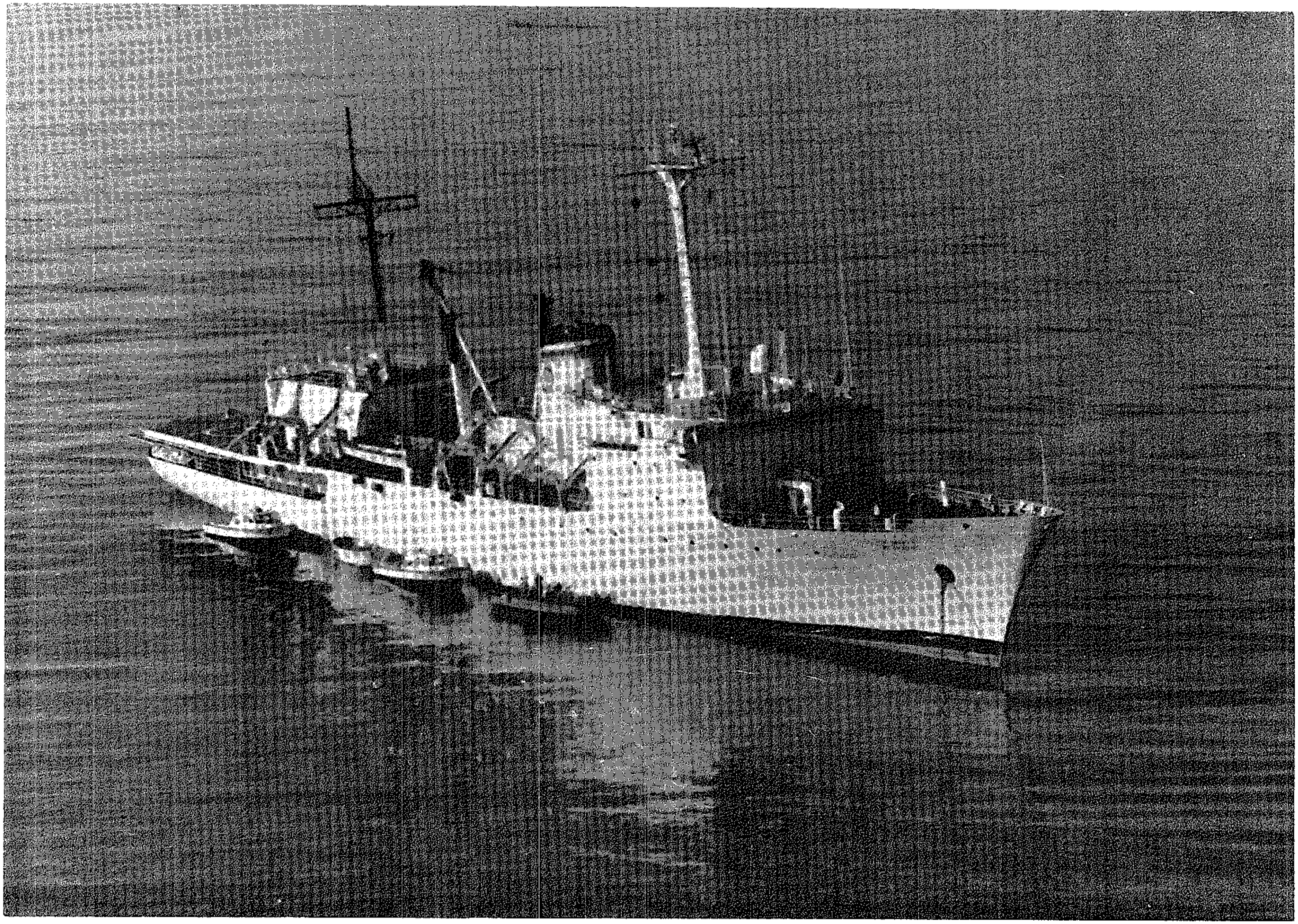
the development of the list crushed the ship's bow and buried it ino the soft coral reef. This resulted in a significant alteration in the hull to bottom interface and, consequently, a change in ground resistance to inclination. Figures 20-23 document the significant damage to the CHAUVENET's bow forward of frame 25.

Fears that the flooded casualty vessel would capsize while aground subsequent to taking the severe list were well founded. One of the lessons demonstrated in the CHAUVENET Salvops is that flooded, stranded ships may develop severe transverse stability problems. This factor is developed in Section 4, A Summary of Lessons Learned.

Section 3.4 Condition Delta

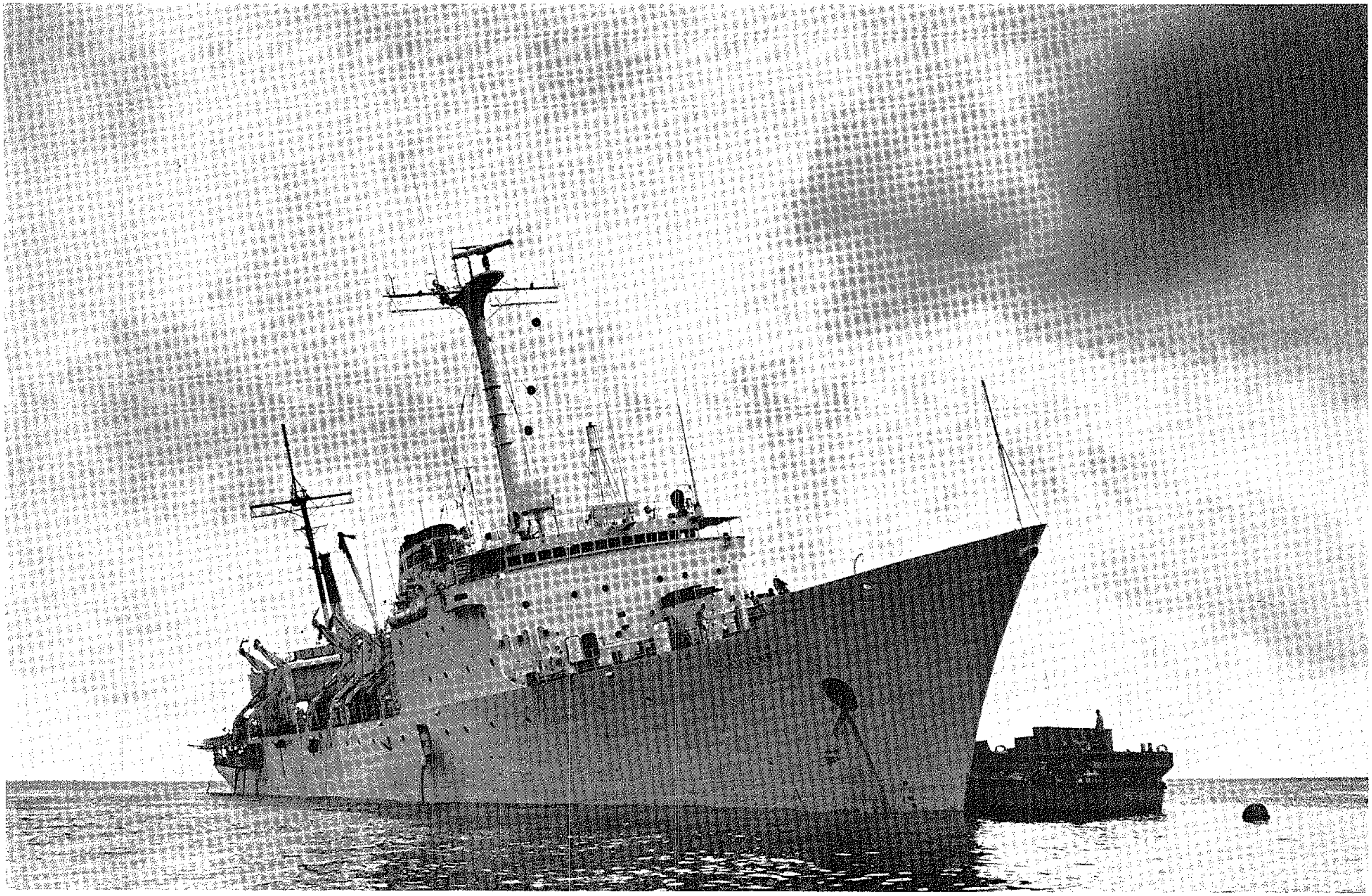
The failure of CHAUVENET's bow during the fall of the tide, May 19 - 20 time frame, caused a radical change in the trim conditions of the grounded ship. Whereas prior to this event the trim had averaged 6 feet by the stern, it shifted to average 1 to 2 feet by the bow. The before and after trim of the ship can be seen from Figures 24 and 25. This increased draft forward raised the water level in the AMR and chilled stores space to within one foot of the second deck level. Thus, in essence, CHAUVENET became fully flooded below the second deck from the forepeak to the forward bulkhead of the main engine room at frame 90, Figure 26.

FIGURE 24



Initial Casualty Condition

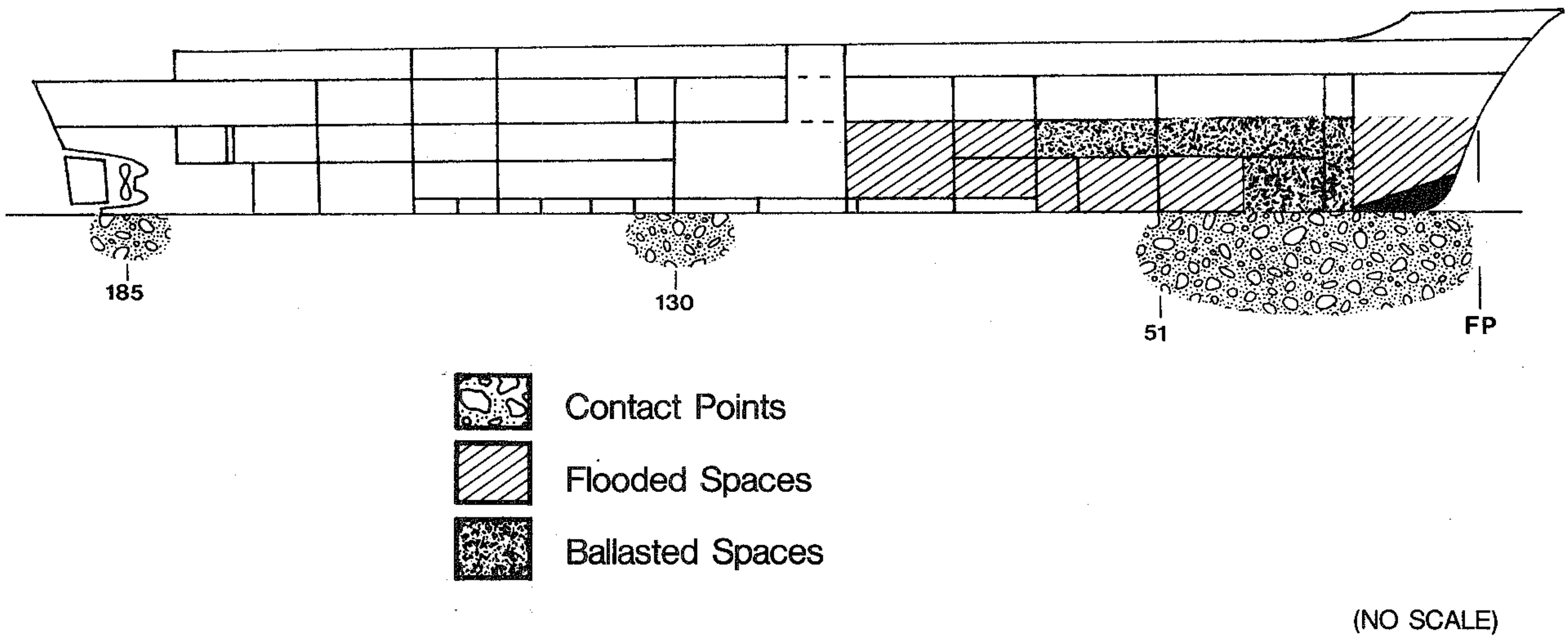
FIGURE 25



Casualty - Condition Delta

FIGURE 26

Casualty Conditions During Condition Delta



The fore and aft free communication between frames 40 and 90 along the port side prevented space by space dewatering below the first platform deck and necessarily had to be considered in the formulation of a modified salvage plan to effect refloating. On 25 May, the revised salvage plan was, in concept, established. This plan, as subsequently refined prior to refloating, is outlined below.

1. Flood and fully press up all intact fuel and water tanks to eliminate free surface in the ship.

2. Plug all second deck drains, vents and other openings to prevent any inadvertent flooding from spaces below.

3. Remove such topside weight as possible including all boats, anchor chain and 3 bow anchors. (Although consideration was given to toppling both masts, forward and aft, this was not accomplished due to the salvor's inability to control the fall of these structures.)

4. Rig submersible pumps assisted by 3 inch diesel pumps in the main engine room as a contingency against potential flooding.

5. Rig two 35-KW diesel generators as a contingency against loss of ship's emergency generator.

6. Rig low pressure air compressor and blow the fore peak tank down to 10 foot water line.

7. Dewater chain locker.

8. Rig fire main to press up AMR and Chill room to second deck level.(This was a theoretically noble idea to reduce the free surface in these two spaces since they could not be safely dewatered and the water level was already so near the overhead. It was of questionable success, however, since water not unsurprisingly leaked back out of the hull patches as fast as it was pumped in. Nonetheless, maintenance of a head of just a few inches would have made a positive, though unquantifiable, contribution to stability.)

9. Take a strain on the ship with USS BRUNSWICK via salvage tug's main tow wire while continuing steps to subsequently reduce ground reaction. These steps included:

   a) Counterflood and press up void space frame 159 - 167, hold level.

b) Counterflood and press up shaft alley frame 113 - 147.

c) Counterflood and press up JP5 and ammo spaces frame 147 - 149.

d) USS BRUNSWICK goes to full power (if necessary) heading 160 relative of CHAUVENET or approximately 000 degrees true.

e) Dewater first platform storeroom frame 30 - 51 and void frame 30 - 40 hold level using two 4 inch submersible pumps.

f) Dewater IC/Gyro space first level frame 51 - 66 using two 4 inch submersible pumps.

With BRUNSWICK taking a full strain at this time, extraction was predicted. However, if the ship failed to refloat at this juncture, the following additional steps were planned:

g) Counterflood and press up sewage tank space frame 171 - 177.

h) Hookup USNS NARRAGANSETT to BRUNSWICK'S bow to increase bollard pull from 50 tons to 100 tons total.

i) Counterflood and press storeroom frame 159 - 171 first platform level and continue pulling until well after high tide.

After extraction and when well clear of the reef, a visual survey was planned to inspect the hull to verify status and make final changes, if any, to towing rigging. Subsequently, CHAUVENET would be taken under tow to S.R.F. Subic at best possible speed. Subject to any last minute changes, it was planned to tow CHAUVENET stern first using the harness already rigged.

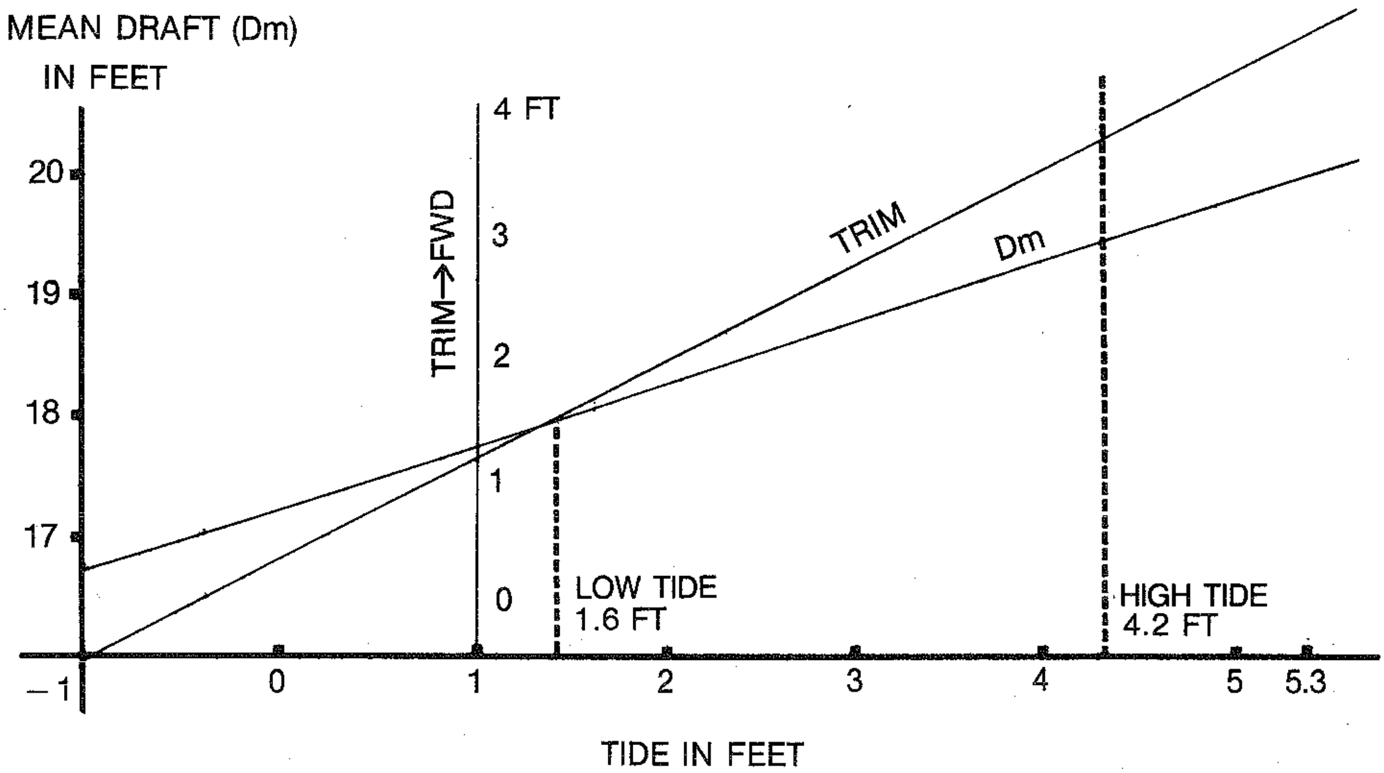
3.4.1 Salvage Analysis

In preparation for the target 29 May 1982 extraction attempt, it was important to predict what the casualty's minimum weight would be and the function of tide. The salvors had installed a tidal gauge near the ship on the reef shortly after arriving. This gauge had in the course of the period aground verified the accuracy of the locally available tide table predictions and provided real time tidal information (Appendix 5.3).

FIGURE 27

TIDE AND DRAFT INFORMATION

TIDE	DF	DA	Dm	TRIM
− 1.0 FT	16.5	17.0	16.75	− .5 (AFT)
+ 5.3 FT	22.2	17.6	19.90	4.6 FWD



AT LOW TIDE (290637 LOCAL)

Dm = 18.0 FT
TRIM = 1.6 FT BY BOW

AT HIGH TIDE (291416 LOCAL)

Dm = 19.3 FT
TRIM = 3.6 FT BY BOW

Sufficient draft readings were taken during the 25 - 28 May time frame to permit development of Figure 27 which plots mean draft and trim versus tide.

Extraction efforts were scheduled to commence at low tide 29 May (1.6 feet at 0637) and conclude at or near high tide (4.2 feet at 1416). From Figure 27, mean draft and trim at low tide were predicted to be 18 feet and 1.6 feet by the bow, respectively. Through reference to computer generated hydrostatics (Appendix 5.2) provided by Pearl Harbor Naval Shipyard for drafts exceeding 18 feet, low tide displacement was predicted to be 5,020 tons. High tide displacement, predicted to be 5,550 tons, indicated a gain of 530 tons of buoyancy with the tide change on that date.

The final step in evaluation of the salvage plan was the refinement of weight and stability data. The liquid load condition of the critical watertight compartments on CHAUVENET are shown in Figure 26 for the time of the salvage plan formulation; in Figure 29 for the condition following extraction and tow preparations.

It was recognized that counterflooding aft in the ship would necessarily increase total displacement. However, due to the location of this added weight, it was known that ground reaction forward would be decreased in the process. This deserves some discussion.

When a ship is aground at some point, there exists a longitudinal location away from that point where weight may be added or removed without changing ground reaction; this location is called the neutral loading point. Weight added to the ship between the neutral point and R results in parallel sinkage of the hull with an increase in ground reaction. Weight loaded aft of the neutral point or on the opposite side of the neutral point from R causes some parallel sinkage but also alters trim with the net effect of reducing ground reaction. For ships aground forward, as was the CHAUVENET, neutral point is located aft of the longitudinal center of flotation.

Neutral point may be determined with the following equation (See Figure 28):

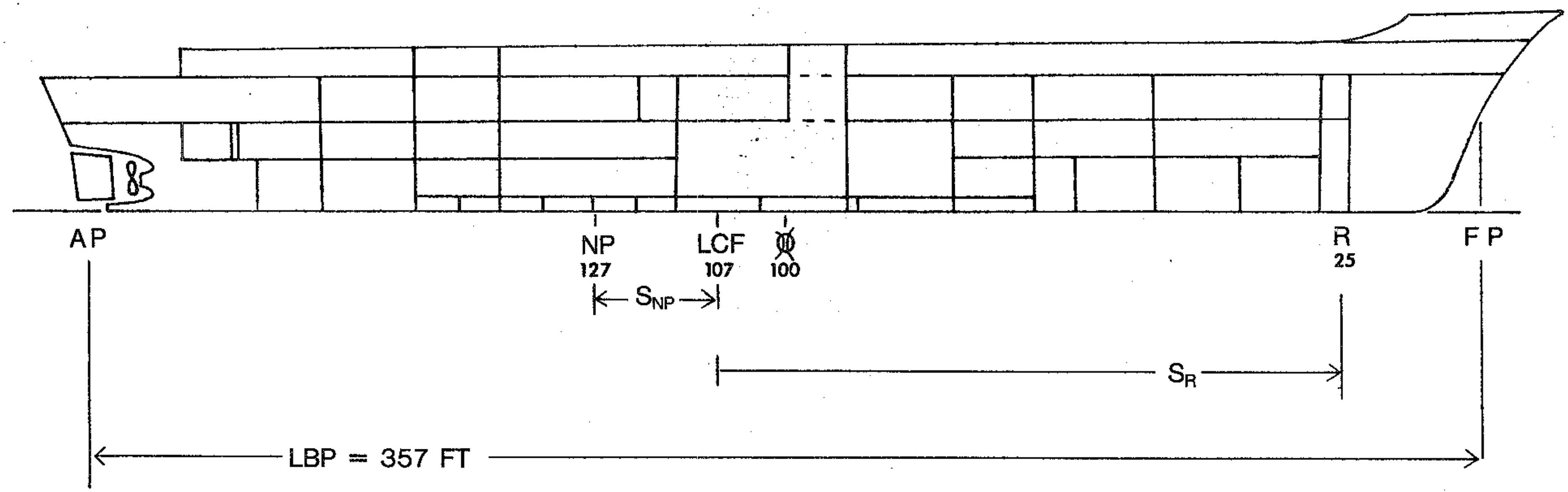
$$S_{NP} = (MTI)(LBP)/(TPI)(S_R)$$

Investigation of the CHAUVENET's condition on the reef indicates that the point of effective ground reaction, or R, was located in the vicinity of frame 25 under the transverse watertight bulkhead between forepeak tank and the chain locker. Although MTI, TPI and LCF varied somewhat as the ship conditions changed during the course of salvage operations, use of the design values found in the Trim and Stability Booklet and in the information generated by Pearl Harbor Naval Shipyard was of sufficient accuracy to be used in all calculations.

FIGURE 28

Determination of the Neutral Loading Point

$$S_{NP} = (MTI)(LBP)/(TPI)(S_R)$$



Referring to Figure 28:

S_{NP} = (597)(357)/(32.45)(163)

= 41 feet aft of the longitudinal center of flotation.

Therefore, NP is 204 feet aft of the point of effective ground reaction ($S_R + S_{NP}$).

To evaluate the net effect (ΔR) of counterflooding on ground reaction, a simple equation is employed.

$$(\Delta R)(S_R+S_{NP}) = (W)(S_W)$$

where W = the weight added (the amount of water used to counterflood a space)

S_W = the distance from the neutral point to the longitudinal center of gravity of the flooded space.

So,

$$\Delta R = (W)(S_W)/(S_R+S_{NP})$$

In counterflooding the three after spaces (JP5/Ammo, void at frame 159, and the shaft alley), 362 tons of ballast were added at an effective S_W of 44 feet. Therefore, the change in ground reaction was expected to be,

$$\Delta R = 362(44)/204 = 78 \text{ tons}$$

Table VIII shows weight and moment data indicating the contribution of all major weight changes to be accomplished during each discreet refloating evolution. The effect on ground reaction and stability during that period is tracked accordingly. Detailed calculations supporting development of Table VIII is presented in Appendix 5.4.

In formulating the ballasting plan for extraction, it was recognized that the weight of water added toward the aft perpendicular would combine with the flood water forward by way of the damaged hull to hog the casualty hull. This raised the issue of longitudinal bending stress levels and the hull girder's ability to sustain them during the tow after refloating.

A theoretical computer assisted strength analysis was performed ashore using a best estimate of the lightship load distribution curve, liquid weight distribution supplied by the salvors describing the predicted ballast configuration on refloating, and the 22,417 in.^2 ft. section modulus supplied by the Ships Hull Characteristics Program.

TABLE VIII

PREDICTED RUNNING CALCULATIONS DURING REFLOATING OPERATIONS

CONDITION	DISPLACEMENT (TONS)	WEIGHT (TONS)	GROUND REACTION (TONS)	KM_T (FT)	KG (FT)	GM (FT)	GG_1 (FT)	GM* (FT)
AFLOAT	4,725	4,725	0	25.20	21.86	3.34	0.	3.34
BASELINE CONDITION	5,020	6,443	1,423	25.00	19.91	5.09	5.64	−0.55
DEWATER CHAIN LKR	5,020	6,376	1,356	25.00	19.96	5.04	5.39	−0.35
REMOVE GROUND TACKLE	5,020	6,325	1,305	25.00	19.95	5.15	5.19	−0.14
BLOW FWD PEAK	5,020	6,277	1,257	25.00	20.00	5.00	5.01	−0.01
READY TO COMMENCE EXTRACTION PHASE								
COUNTERFLOOD THREE COMPARTMENT AFT	5,460	6,639	1,179	25.00	19.35	5.65	4.18	1.47
DEWATER STRM FR 30-51	5,417	6,379	962	25.00	19.44	5.56	3.45	2.11
DEWATER VOID	5,411	6,324	913	25.00	19.54	5.46	3.30	2.16
DEWATER IC/GYRO	5,308	6,024	716	25.00	19.66	5.34	2.65	2.69
TIDE FACTOR	5,838	6,024	186	25.00	19.66	5.34	0.63	4.71
FLOOD AFT SEWAGE	5,935	6,091	156	25.00	19.64	5.36	0.52	4.84
FLOOD AFT STOREROOM	6,176	6,269	93	25.00	19.60	5.40	0.30	5.10

*UNCORRECTED FOR FREE SURFACE

Even with substantial reductions for the effect of damage on section modulus (which was in reality minimal), these calculations revealed maximum stress levels of approximately five pounds per square inch or less. This was judged to be low enough to permit safe towage in all but the most extreme sea states.

3.5 Condition Echo

Due to a certain amount of operational inefficiency on the morning of 29 May 1982, deployment of the salvage team onboard the casualty was delayed. All hands were in position and all preparations completed well after the 0637 target time. Counterflooding operations finally commenced at 0842. The salvage plan was executed from that point exactly as outlined in Section 3.4 of this report. Actual events are recorded in Table IX, but at 1417, high tide, pumping of the IC/Gyro space was not yet completed and the CHAUVENET was still stranded.

In order to proceed quickly with the reduction of ground reaction, counterflooding of the aft sewage tank compartment was ordered even though the salvage plan called for completely dewatering the IC/Gyro space first.

This decision was made because it was felt that dewatering the IC/Gyro space would be more time consuming than flooding

TABLE IX

ACTUAL RUNNING CALCULATIONS
PERFORMED DURING REFLOATING OPERATIONS 29 MAY 1982

TIME	DISPLACEMENT (TONS)	WEIGHT (TONS)	GROUND REACTION (TONS)	KM_T (FT)	KG (FT)	GG_1 (FT)	GM* (FT)	COMMENTS
0842	5,250	6,277	1,027	25.03	20.00	3.92	1.11	COMMENCE COUNTERFLOOD AFT
1000	5,520	6,491	971	25.00	19.60	3.45	1.95	PARTIAL COUNTERFLOODING AFT
1100	5,800	6,639	839	25.00	19.35	2.80	2.85	COMPLETE COUNTERFLOODING AFT COMMENCE DEWATERING STRM & VOID
1300	5,880	6,324	444	25.03	19.54	1.48	4.01	COMPLETE DEWATERING STRM & VOID COMMENCE DEWATERING IC/GYRO
1430	5,910	6,024	114	24.97	19.66	0.38	4.93	CONTINUE DEWATERING IC/GYRO COMMENCE COUNTERFLOODING SEWAGE
1437	6,100	6,024**	0	24.95	19.66	0.00	5.29	AFLOAT
30 MAY	6,150	6,091**	0	24.95	19.64	0.00	5.31	AFLOAT, COUNTERFLOODING AND STRIPPING COMPLETE

*UNCORRECTED FOR FREE SURFACE (EST. MINUS ONE FOOT).
**CALCULATED WEIGHT. ACTUAL WEIGHT EQUALED AFLOAT DISPLACEMENT.

the after space and the tide was turning. By varying the relative angle of pull, BRUNSWICK managed to rotate the casualty about ± 10 degrees of compass heading. A cloud of white coral dust muddied the water around the ship indicating that the pivoting action was breaking down the reef.

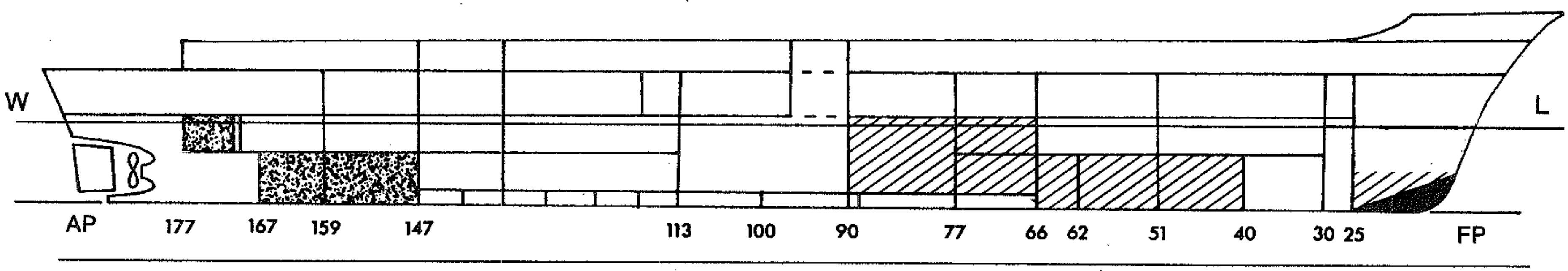
At 1437 aft motion was discerned and USNS CHAUVENET came off the reef very quickly. Tension energy accumulated in BRUNSWICK's tow wire imparted an extraction velocity estimated to have reached 5 or 6 knots. BRUNSWICK took control of the refloated ship and guided it to open water away from the reef.

Table IX documents the stability and weight changes during the salvage plan execution as developed from Appendices 5.5 and 5.6. Comparison of calculated versus actual weight and trim data shows very close correlation; well within the accuracy expected of a salvage operation of this complexity. The final ballast condition upon refloating is shown in Figure 29.

A brief underwater inspection verified that all external patches were still solidly in place and that damage to the bow warranted a stern first tow. U.S.S. BRUNSWICK laid a track for the three day tow to Ship Repair Facility, Subic Bay.

FIGURE 29

Ballast Condition upon Refloating
Condition Echo

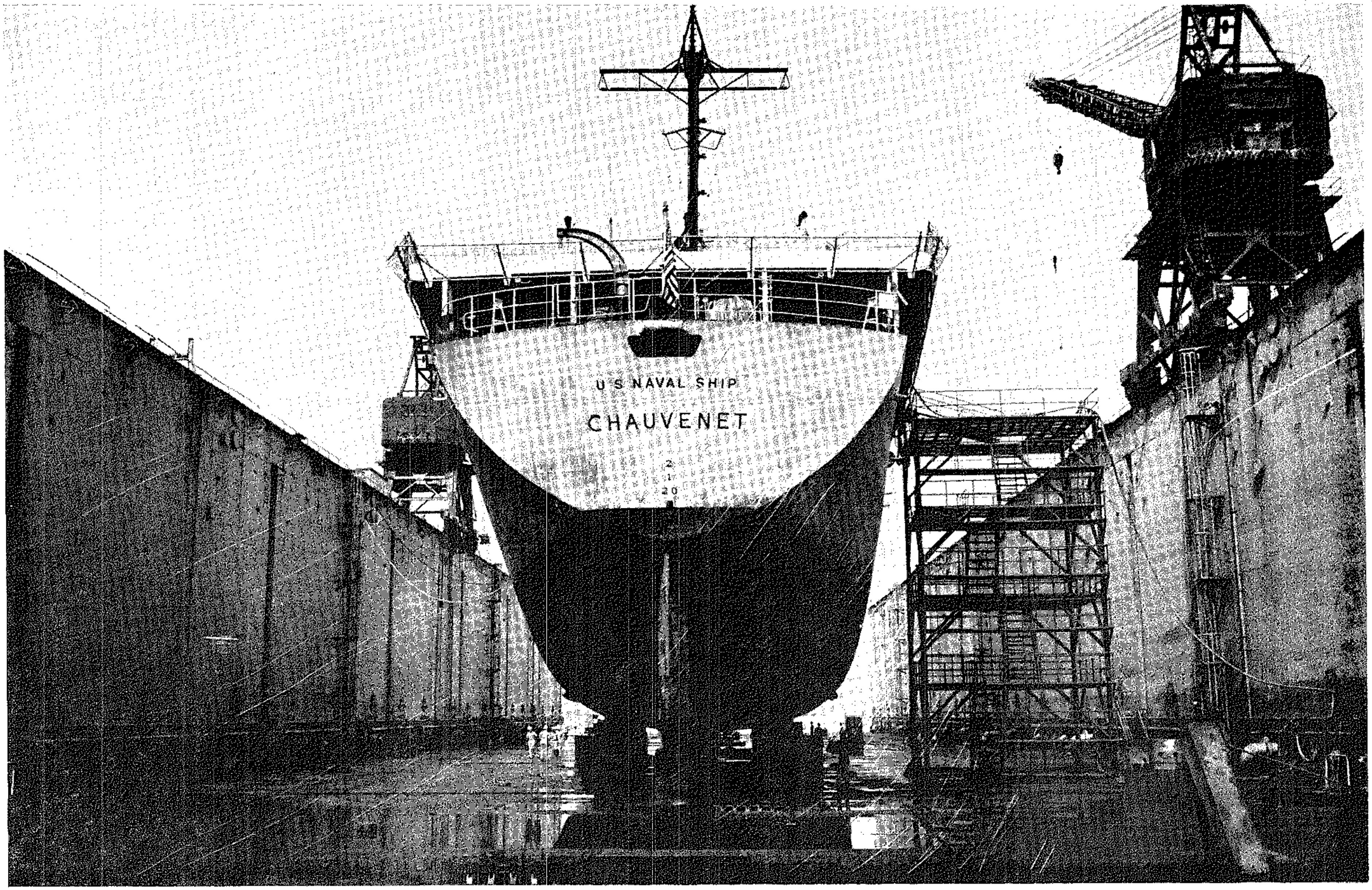


Flood water - all spaces except FPT pressed up

Pressed up with ballast water by salvors

(NO SCALE)

FIGURE 30



USNS Chauvenet on Dock, SRF Subic Bay

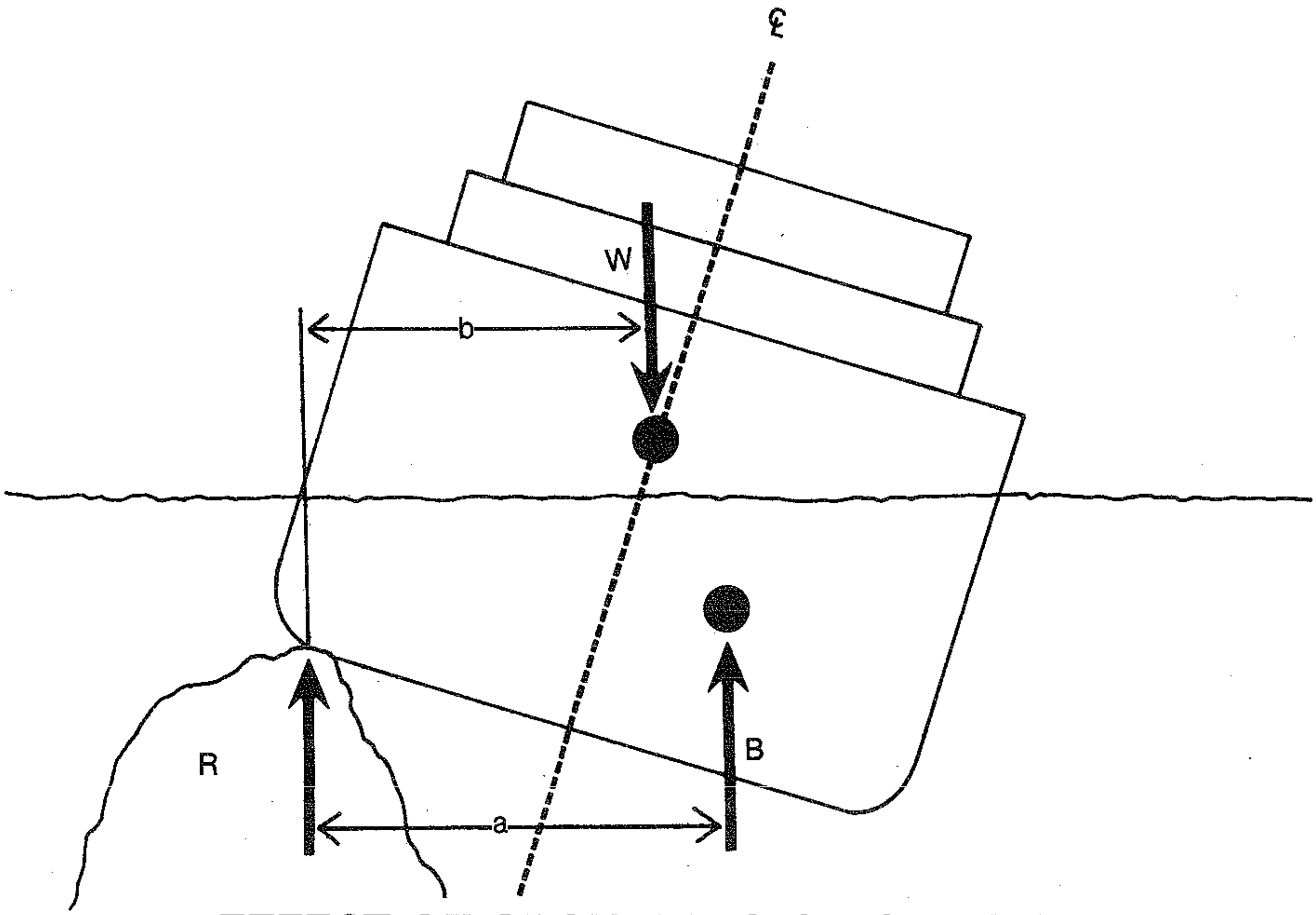
4. A Summary of Lessons Learned

The most dramatic event occurring during the operations to refloat the USNS CHAUVENET was the near capsizing of the stranded, flooded vessel on 19-20 May. While the details and events leading to this near loss are covered in the preceding report, a discussion of stability aground may be beneficial in clarifying the lessons to be found in this recent casualty. A concise discussion is presented in "Principles of Naval Architecture" published by The Society of Naval Architects and Marine Engineers and is quoted below.

"When a ship is stranded on a fairly flat bottom, there is no question of transverse stability.

"There is only a remote possibility of a stranded ship capsizing as the result of ebbing tide. For this to occur it would be necessary for the ship to be grounded on a bottom such that there is no restraint to heeling in one or both directions until a very large angle is reached as, for example, on a peak which was considerably higher than the surrounding bottom. When a ship is aground in this manner, as illustrated in Figure 31, the heel would increase as the tide ebbs. The attitude of the ship would always be such that the moment of buoyancy equals the moment of weight, or (W)(b) in Figure 31 would be equal to (B)(a). Before the

FIGURE 31



EFFECT OF GROUNDING ON STABILITY

WHERE W = TOTAL MASS ACTING THROUGH THE CENTER OF GRAVITY
B = DISPLACEMENT AGROUND (BUOYANCY) ACTING THROUGH THE CENTER OF BUOYANCY
R = EFFECTIVE GROUND REACTION

ship could capsize, leaving the point of support, the reaction R must be reduced to zero. Since R equals W - B, W and B would be equal when R is zero.

"Then, since (W)(b) equals (B)(a), a and b would be equal, or W would be directly above B in Figure 31. The situation would be the same as if the ship were heeled to its range (maximum angle) of positive stability and the angle of heel could be determined from the statical stability curve corresponding to the ship's weight, and position of its center of gravity. It can therefore be said that a stranded ship will not capsize in the absence of other upsetting forces until it reaches an angle of heel equivalent to its range of positive stability if it were afloat.

"The following conclusions may be drawn from the foregoing discussion:

- It is unlikely that a stranded ship will capsize unless its range of positive stability is much less than usual. Unless impaled, the ship would slide from the point of support when the tangent of the angle which the bottom of the ship makes with the horizontal exceeds the coefficient of static friction between the bottom of the ship and the support. This is generally much smaller than the range of positive stability.

- If the angle of inclination approached the range of positive stability, only a relatively small strain would be required to free the ship as the reaction of the support approached 0. The point of application of the towline should be low as only a small heeling moment would be required to capsize the ship.

- The likelihood of capsizing with the expected variation in tide can be evaluated by assuming the ship heeled to its range of positive stability drawing the waterline at the lowest expected level relative to the point of support and estimating the displacement below this waterline. If this displacement exceeds the weight of the ship, the range of positive stability will not be reached"

Relative to the foregoing discussion, it must be remembered that CHAUVENET was flooded when aground. The preceding discussion talks specifically of ships intact and stranded, but it does consider that the entire stability situation is more delicate in ship of reduced range of positive stability.

A ship with a reduced range of positive stability is one which has a negative metacentric height (GM), an off-center weight, or both. CHAUVENET, as discussed, developed both these conditions during the dewatering operations on 19 May.

As the tide ebbed on 19 May, the change in the center of gravity due to increased ground reaction was sufficient to develop a negative metacentric height. Consequently, the ship's initial resistance to heeling was eliminated. Because the ship was aground broadside to a sloping bottom, and because the port fuel tanks had been partially dewatered while pumping out the AMR, it responsively heeled as the tide ebbed. As this heeling occurred, shifting liquids and topside weight moved towards the starboard side, that is to say, off the centerline, leaving the ship with both conditions to impair stability aground - a negative metacentric height and off-center weight. Together, these combined to severely restrict the range of positive stability.

The weight shift progressed to starboard with increasing heel. Additionally, the patch by way of the portside bilge plate damage was known not to be 100 percent watertight. This probably meant that some flooding remained once pumping operations were ceased. If the ship had heeled further before the tide changed,(i.e. the bottom slope had been sharper) the weather deck might have passed the external waterline and the range of positive stability been exceeded. Consequently, rotation to capsizing would have continued with dire consequences to the eventual recovery of the ship.

This discussion may be considered a listing of lessons "re-learned". The subtleties involved in the behavior of a stranded ship while aground must be considered in the analysis of any stranding casualty and the implementation of any salvage plan. Proper understanding of the casualty circumstances is paramount to full analysis and confident implementation of salvage procedure. Such understanding is based on the complete detailing of the circumstances and conditions which define the casualty. Survey notes must consider conditions on board the vessel and those details which define the strand itself. The salvor must consider the relationship between the grounded hull and the bottom to be able to anticipate the likely movement of that hull on that ground.

Important details would include extensive soundings of the bottom under the hull, immediately adjacent to the hull, and in progressive distances away from the hull. Furthermore, a detailed record of draft, trim, list, and heading should be part of the daily notes kept on any casualty operation. Variations on these recorded figures may provide insight into the casualty circumstances and into the projected behavior of the casualty hull. Such information is especially crucial when the stranded hull has sustained damage and lies in a flooded condition.

The successful refloating of the CHAUVENET gave indications of the valuable assistance computer generated information may provide to field operating personnel. The hydrostatic information in CHAUVENET's Trim and Stability Booklet did not include that necessary for the evaluation of extreme values for displacement, trim, and list. With the help of information generated by Pearl Harbor Naval Shipyard using the Ship Hull Characteristics Program (SHCP), the Trim and Stability Booklet tables were expanded and augmented as required by onsite salvage engineering personnel to evaluate stranded behavior, the refloated casualty attitude, and suitability for tow to a safe port.

In future operations it is envisioned that salvage personnel will be equipped with a field computing capability for on site evaluation of casualty circumstances and salvage alternatives. Such a computing capability can be greatly expanded with the support of main frame computer capacity ashore assisted by information from cognizant commands.

In refloating CHAUVENET, field personnel were again reminded that salvage operations demand that responsible commands/personnel ashore be fully advised of conditions and intentions to permit analysis in advance of actual field personnel actions on the wreck. The implications and contingencies involved in any action taken by the salvage team must be fully analyzed to the same extent that the casualty is analyzed prior to the taking of any actions. Proceeding without a detailed understanding of the possible behavior of the casualty hull may generate unwelcome surprises to the detriment of operational success at best and jeopardizing the safety of personnel in the worst case.

In summary, CHAUVENET salvage operations reemphasized the need for on scene personnel to assemble and properly **disseminate a complete report** of all pertinent information defining the casualty circumstances in a thorough, timely, and accurate manner. All information must be continually reconfirmed as operations progress and reevaluated when necessary. SITREPS must endeavor to distribute, as directed, this information to all commands with a need to know. Only complete familiarity with the casualty enables higher authority to provide support to the operation and carry out its duties consistent with fleet responsibilities and the often high exposure given to the effort.

APPENDIX

5. APPENDIX

5.1 Deadweight Scale & Details of the "Full Load" Condition

5.2 Hydrostatics and Displacement Curves for Extreme Conditions

5.3 Summary of Watertight Compartment Parameters

5.4 Detailed Calculations for Predicted Refloating

5.5 Real Time Data Recorded During 29 May Operations

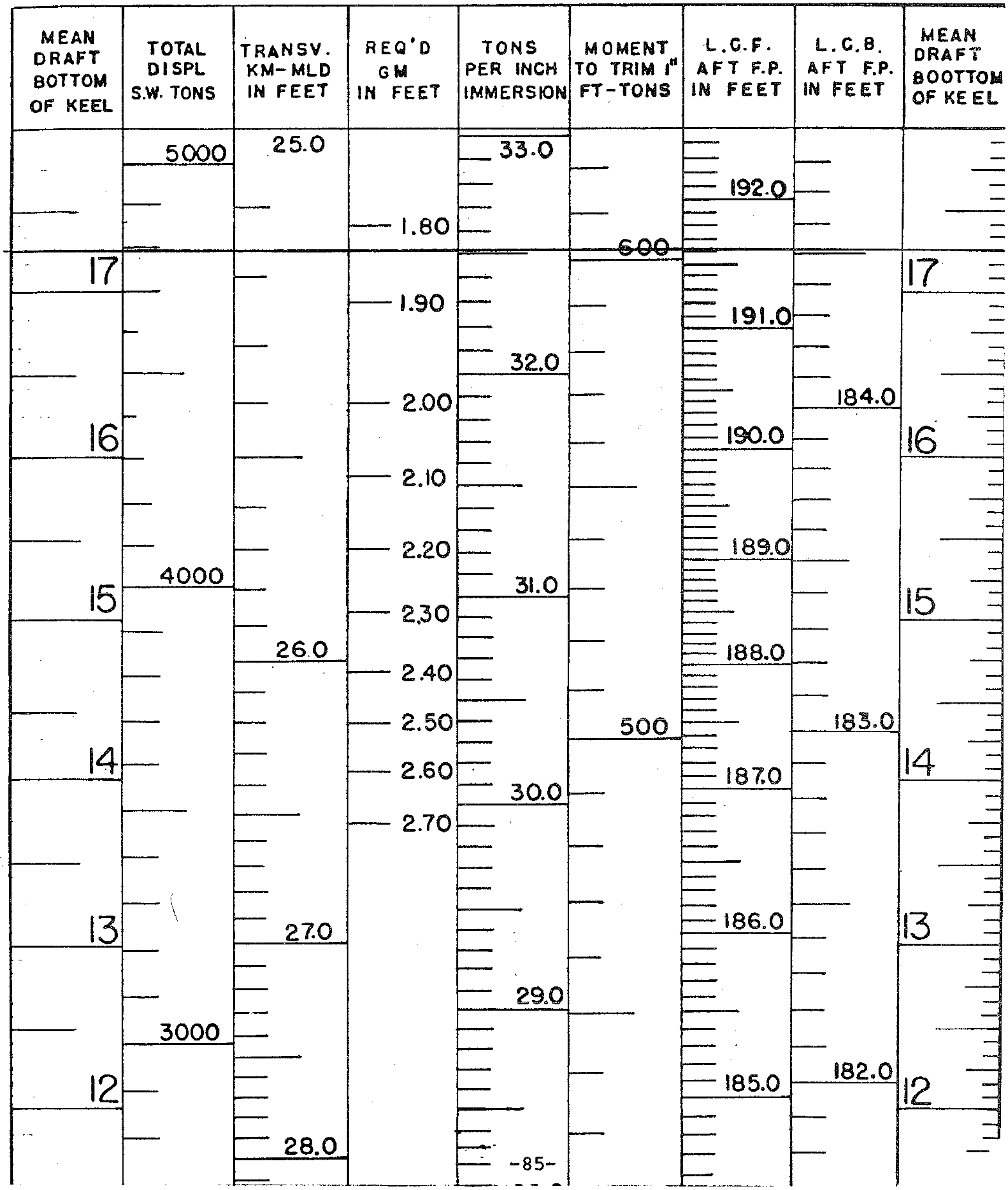
5.6 Running Calculations During 29 May Refloating Operations

5.1 Deadweight Scale

USNS CHAUVENET (T-AGS 29)

HYDROSTATIC PROPERTIES

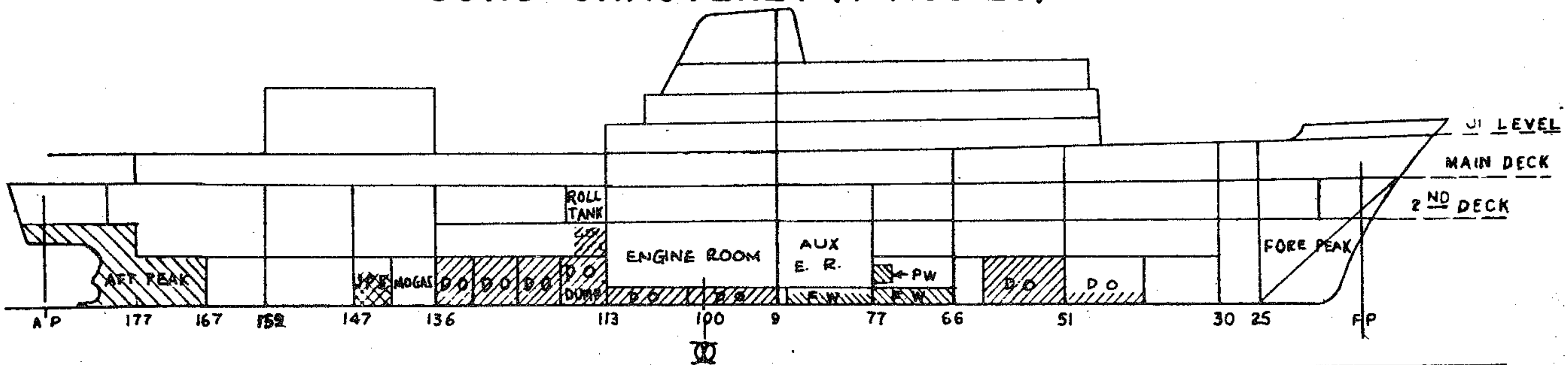
"SHEET 10"



"Full Load" Condition

LOADING DIAGRAM

USNS CHAUVENET (T-AGS 29)



ITEM	TONS	KG	MOMENT	L.C.G. F.P.	MOMENT	F.S.	SYMBOL
MEAN LIGHT OPERATING COND	3,447.70	26.61	91,746	185.76	640,447	—	
PROVISIONS & PERSONNEL STORES	46.20	12.16	562	112.20	5,184		
SHIP AMMUNITIONS	9.72	10.60	103	275.20	2,675		
HELICOPTER	4.46	49.00	219	272.50	1,215		
D.O. OR S.W. BALLAST TANKS	765.49		4,862		144,837	2,111	
FRESH WATER TANKS	236.17		2,484		60,258	170	
LUBE OIL TANKS	10.50		176		2,189	4	
JP-5 TANKS	55.00		413		14,705	225	
MOGAS TANKS	24.83	8.02	199	256.50	6,369	—	
CARGO	159.21	19.89	3,167	227.50	36,220	—	
TOTAL	4,759.28	21.84	103,931	192.07	914,099	2,510	

Details of the "Full Load" Condition (as taken from USNS CHAUVENET Trim and Stability Booklet).

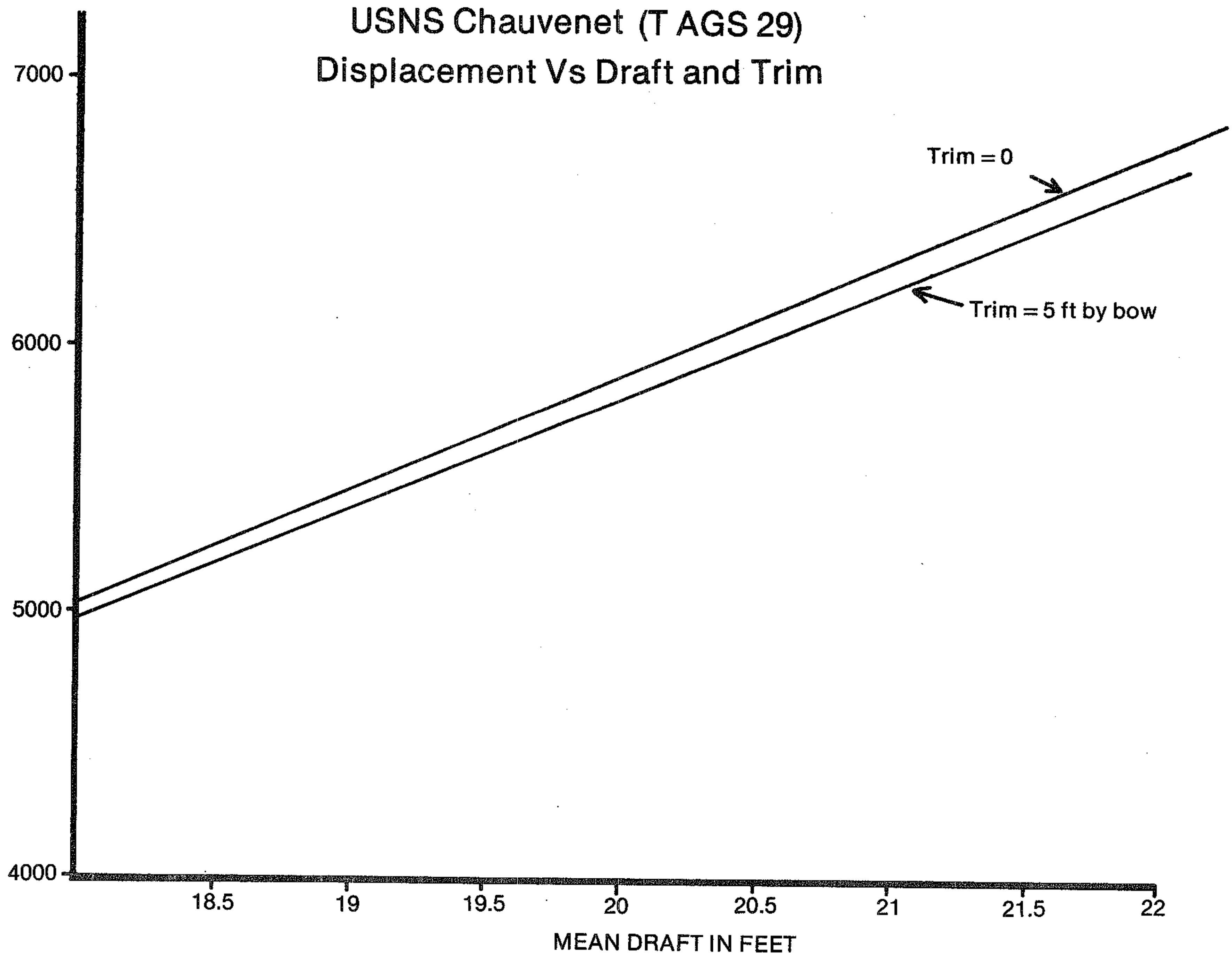
	(1) MEAN S.W. DRAFT (SHEET 10)	17.16'
	(2) KM (SHEET 10)	25.18
	(3) KG	21.84
	(4) GM UNCORRECTED = (2) - (3) =	3.34
	(5) F.S. CORR = $\frac{F.S.}{DISPL.} = \frac{2,510}{4,759.28}$ =	0.53
	(6) GM AVAILABLE = (4) - (5) =	2.81
	(7) GM REQUIRED (SHEET 11)	1.85
	(8) L.C.G.	192.07
	(9) L C B (SHEET 10)	184.46
*	(10) TRIM LEVER (~~FWD~~/AFT) = (8) - (9) =	7.61
	(11) MOMENT TO TRIM 1" (SHEET 10)	598.92
*	(12) TRIM IN INCHES (~~FWD~~/AFT) = $\frac{DISPL. \times (10)}{(11)}$ =	60.47
	(13) L C F (SHEET 10)	191.50
	(14) DRAFT AT F.P. = (1) - $\frac{(12) \times (13)}{357}$ =	14.46'
	(15) DRAFT AT A.P. = (14) + (12) =	19.50'

* POSITIVE VALUE SHOWS TRIM AFT
NEGATIVE VALUE SHOWS TRIM FWD

5.2 Hydrostatics and Displacement Curves for Extreme Conditions

TRIM + STERN	DRAFT FT	DISP TONS	LCB FM MID PLUS FWD	LCF FM MID PLUS FWD	TPI	MTI	KM (T) FT
1.0	19.0	5,495.5	-8.34	-17.33	34.17	680.3	25.10
	19.5	5,701.5	-8.67	-17.73	34.47	694.6	25.09
	20.0	5,909.2	-9.00	-18.05	34.75	708.1	25.09
	20.5	6,118.5	-9.31	-18.31	35.02	720.7	25.10
	21.0	6,329.3	-9.61	-18.50	35.26	732.5	25.11
	21.5	6,541.6	-9.90	-18.63	35.48	743.6	25.13
	22.0	6,755.1	-10.18	-18.69	35.68	753.8	25.14
0.0	19.0	5,476.2	-6.83	-16.39	34.05	674.7	25.03
	19.5	5,681.5	-7.18	-16.86	34.37	689.9	25.03
	20.0	5,888.6	-7.53	-17.25	34.66	704.2	25.03
	20.5	6,097.4	-7.87	-17.56	34.94	717.5	25.05
	21.0	6,307.9	-8.19	-17.81	35.20	730.1	25.00
	21.5	6,519.8	-8.51	-17.99	35.43	741.9	25.09
	22.0	6,733.1	-8.81	-18.11	35.65	752.8	25.11
-1.0	19.0	5,458.1	-5.32	-15.38	33.91	668.1	24.96
	19.5	5,662.6	-5.69	-15.93	34.25	684.4	24.96
	20.0	5,869.0	-6.06	-16.39	34.56	699.6	24.97
	20.5	6,077.3	-6.42	-16.77	34.85	713.7	24.99
	21.0	6,287.3	-6.77	-17.07	35.12	727.0	25.01
	21.5	6,498.8	-7.11	-17.31	35.38	739.5	25.04
	22.0	6,711.8	-7.44	-17.49	35.61	751.2	25.07
-2.0	19.0	5,441.2	-3.82	-14.30	33.76	660.6	24.90
	19.5	5,644.8	-4.21	14.93	34.12	677.9	24.90
	20.0	5,850.6	-4.60	-15.47	34.45	694.1	24.91
	20.5	6,058.2	-4.98	-15.92	34.75	709.2	24.94
	21.0	6,276.6	-5.35	-16.29	35.04	723.3	24.96
	21.5	6,478.7	-5.71	-16.59	35.31	736.6	25.00
	22.0	6,691.3	-6.06	-16.82	35.55	749.0	25.04
-3.2	19.0	5,425.6	-2.34	-12.76	33.52	646.3	24.83
	19.5	5,628.4	-2.75	-13.86	33.97	670.7	24.84
	20.0	5,833.3	-3.15	-14.47	34.32	688.0	24.85
	20.5	6,040.2	-3.54	-14.99	34.64	704.3	24.88
	21.0	6,249.0	-3.93	-15.42	34.95	719.4	24.91
	21.5	6,459.5	-4.31	-15.78	35.23	733.6	24.95
	22.0	6,671.07	-4.69	-16.06	35.49	746.9	25.00
-4.0	19.0	5,411.9	-0.89	-11.33	33.30	633.7	24.78
	19.5	5,613.2	-1.29	-12.33	33.73	656.4	24.78
	20.0	5,817.2	-1.70	-13.41	34.18	680.8	24.80
	20.5	6,023.3	-2.12	-14.01	34.52	698.1	24.83
	21.0	6,231.4	-2.52	-14.52	34.84	714.3	24.86
	21.5	6,441.4	-2.92	-14.94	35.14	729.4	24.91
	22.0	6,653.1	-3.31	-15.28	35.41	743.6	24.96

TRIM + STERN	DRAFT FT	DISP TONS	LCB FM MID PLUS FWD	LCF FM MID PLUS FWD	TPI	MTI	KM (T) FT
-5.0	19.0	5,399.9	0.53	-9.98	33.10	622.5	24.73
	19.5	5,599.9	0.13	-10.92	33.52	644.0	24.73
	20.0	5,802.5	-0.28	-11.91	33.94	666.7	24.74
	20.5	6,007.7	-0.70	-12.96	34.38	690.9	24.78
	21.0	6,215.0	-1.12	-13.55	34.72	708.2	24.82
	21.5	6,424.3	-1.53	-14.04	35.03	724.4	24.86
	22.0	6,635.4	-1.93	-14.45	35.33	739.6	24.92


USNS Chauvenet (T AGS 29)
Displacement Vs Draft and Trim
Trim = 0
Trim = 5 ft by bow
7000
6000
5000
4000
DISPLACEMENT IN TONS
18.5
19
19.5
20
20.5
21
21.5
22
MEAN DRAFT IN FEET

COMPARTMENT	L x H x B x μ	TONS (SW)	KG	V. MOM	LCG (FR)	ARM	+AFT MOM (L)	FS
Forepeak (open to sea)	Ship's Tables	-32	17	-544	18	-664	5,248	0.00
Forepeak (blown down)	Ship's Tables	-80	15	-1,200	18	-164	13,120	0.00
Chain Locker	10x21.5x8x0.9	67	15	1,005	28	-144	-9,648	0.00
Void FR30-40 (H)	20x8x12x1.0	55	9	495	36	-128	-7,040	0.04
Strm FR30-51 (1st)	42x9x26x0.9	260	17	4,420	42	-112	-29,120	0.42
IC/Gyro FR51-66 (1st)	30x9x42x0.9	300	17	5,100	60	-80	-24,000	1.17
IC/Gyro W/D_m=16 FT	30x3x42x0.9	97	14	1,360	60	-80	-7,760	1.17
Sewage FR 62-66 (H)	8x12x34x0.9	85	8	680	64	-72	-6,120	0.12
Reefer FR 66-77 (H)	22x9x36x0.9	185	10	1,850	72	-56	-10,360	0.41
Chill FR 66-77 (1st)	22x10x40x0.9	272	18	4,896	72	-56	-15,232	1.15
Chill FR W/D_m = 16FT	22x4x40x0.9	91	14	1,272	72	-56	-5,096	1.15
AMR FR 77-90	26x17x50x0.9	570	16	9,120	84	-32	-18,240	1.73
AMR W/D = 16 FT	26x13x50x0.9	435	10	4,346	84	-32	-13,900	1.73
AMR (hold only)	26x9x42x0.9	252	10	2,520	84	-32	-8,064	1.14
Main Engine Room	46x17x50x0.9	1,005	16	16,086	100	0	0	2.87
Damaged spaces - all half dewatered	Various	329	11	39,619	65	-70	-23,030	
Boats	5 @ 8 tons/boat	-40	45	-1,800	115	30	-1,200	N/A
Helo	- - - - - - - -	-4	50	-200	150	100	-400	N/A
JP5/Ammo FR147-159(H)	24x10x24x0.9	148	8	1,184	152	104	15,592	0.05
Void FR159 - 167 (H)	16x10x18x1.0	82	8	656	163	126	10,332	0.16
Shaft Alley FR113-159	92x8x7x0.9	132	8	1,056	136	72	9,504	0.00

5.3 Summary of W/T Compartments

COMPARTMENT	L x H x B x μ	TONS (SW)	KG	V. MOM	LCG (FR)	ARM	+AFT MOM (L)	FS
STRM FR 159-171(1st)	12 x 9 x 32 x .9	178	18	3,204	163	126	22,428	.70
Sewage FR 171-177(")	12 x 9 x 24 x .9	67	18	1,206	173	146	9,782	.23
Anchors & Chain	3+24 shots 2-inch	-51	21	-1,071	29	-142	7,242	N/A

5.3 Summary of W/T Compartments

5.4 Detailed Calculations For Predicted Refloating

1. Pre-Stranding Condition

Weight (Displacement) = 4,725 LT

KG = 21.86 FT

2. Changes In Weight To Establish Baseline Condition, Data From Appendix 5.3

Compartment	WT	MOM(V)	+ AFT MOM(L)
FOREPEAK	-32	-544	5,248
CHAINLOCKER	67	1,005	-9,648
VOID (30-40 HOLD)	55	495	-7,040
STRM (30-51 1ST)	260	4,420	-29,120
1C/GYRO (51-66)	300	5,100	-24,000
SEWAGE (62-66)	85	680	-6,120
REEFER (66-77)	185	1,850	-10,360
CHILL (66-71)	272	4,896	-15,232
AMR	570	9,120	-18,240
BOATS	-40	-1,800	-1,200
HELO	-4	-200	-1,200
TOTAL	1,718	24,972	-116,112

$$W = 4{,}725 + 1{,}718 = 6{,}443 \text{ LT}$$

$$R = 6{,}443 - 5{,}020 = 1{,}423 \text{ LT}$$

$$KG_1 = (4{,}725 \times 21.86 + 24{,}972)/6{,}443$$

$$KG_1 = 128{,}260/6{,}443 = 19.91 \text{ FT}$$

$$GG_1 = 1{,}423 \times 19.91/5{,}020 = 5.64 \text{ FT}$$

For purposes of this calculation, the free surface of all non-involved spaces is assumed to be zero. This is reasonable since all fuel and water tanks had been fully pressed up with salt water and the MER bilges were being maintained almost dry. While clearly the AMR and chill space did have significant free surface when the outgoing tide lowered the water level below the overhead, it was difficult to quantify. Since trends or changes to stability were the more critical issues and the free surface would diminish with incoming tidal flow, the AMR and chill space contribution to free surface was also zeroed for purposes of these calculations. During actual refloating operations, a free surface penalty of 1 FT was arbitrarily estimated.

3. The sequential effects of chain locker dewatering, ground tackle removal and fore peak tank blow are calculated as follows:

Chain Locker

$$KG_1 = (128,260 - 1,005)/(6,443 - 67)$$
$$KG_1 = 127,255/6,376 = 19.96 \text{ FT}$$

$$CG_1 = 1,356 \times 19.96/5,020 = 5.39 \text{ FT}$$

Ground Tackle

$$KG_1 = (127,255 - 1,071)/6,376 - 51)$$
$$KG_1 = (126,184/6,325 = 19.95 \text{ FT}$$

$$CG_1 = 1,305 \times 19.95/5,020 = 5.19 \text{ FT}$$

Peak Tank

$$KG_1 = (126,184 - 656)/(6,325 - 48)$$
$$KG_1 = 125,528/6,277 = 20.00 \text{ FT}$$

$$CG_1 = 1,257 \times 20.00/5,020 = 5.01 \text{ FT}$$

4. The following steps illustrate sequential planned actions to be followed. No attempt was made to incorporate effects of the incoming tide until after IC/Gyro space dewatering when the 530 tons was added at once. Calculations supporting these steps follow:

Counterflood Aft

	WT	MOM(V)	+ AFT MOM(L)
JP5/AMO	148	1,184	15,392
VOID (159-167H)	82	656	10,332
SHAFT ALLEY	132	1,056	9,504
TOTAL	362	2,896	35,228

$KG_1 = (125{,}528 + 2{,}896)/(6{,}277 + 362)$

$KG_1 = 128{,}424/6{,}639 = 19.35$ FT

LCG = 35,228/362 = 98 FT AFT Φ = FR 149

$S = (149 - 127)\ 2 = 44$ FT

$\Delta R = 44 \times 362/204 = 78$ Tons

$GG_1 = 19.35(1{,}179)/5{,}460 = 4.18$ FT

Dewater Storeroom FR 30-51

$KG_1 = (128,424 - 4,420)/(6,639 - 260)$

$KG_1 = 124,004/6,379 = 19.44$ FT

$S = (127 - 42)\ 2 = 170$ FT

$\Delta R = 170 \times 260/204 = 217$ Tons

$GG_1 = 962 \times 19.44/5,417 = 3.45$ FT

Dewater void FR 30-40

$KG_1 = (124,004 - 495)/(6,379 - 55)$

$KG_1 = 123,559/6,324 = 19.54$ FT

$S = (127 - 36)\ 2 = 182$ FT

$\Delta R = 182 \times 55/204 = 49$ Tons

$GG_1 = 913 \times 19.54/5,411 = 3.30$ FT

Dewater IC/Gyro

$KG_1 = (123,559 - 5,100)/(6,324 - 300)$

$KG_1 = 118,459/6,024 = 19.66$ FT

$S = (127 - 60)\ 2 = 134$ FT

$\Delta R = 134 \times 300/204 = 197$ Tons

$GG_1 = 716 \times 19.66/5,308 = 2.65$ FT

Tidal effect of 530 tons additional buoyancy

$GG_1 = 186 \times 19.66/5,838 = .63$ FT

Assuming extraction unsuccessful at this point, counterflood sewage tank FR 171-177.

KG_1 = (118,459 + 1,206)/(6,024 + 67)

KG_1 = 119,665/6,091 = 19.64 FT

S = (173 - 127) 2 = 92 FT

ΔR = 67 x 92/204 = 30 Tons

GG_1 = 156 x 19.64/5,935 = .52 FT

Assuming extraction unsuccessful at this point, counterflood storeroom FR 159-171.

KG_1 = (119,665 + 3,204)/(6,091 + 178)

KG_1 = 122,869/6,269 = 19.60 FT

S = (163 - 127) 2 = 72 FT

ΔR = 178 x 72/204 = 63 Tons

GG_1 = 93 x 19.60/6,176 = .30 FT

5. The predicted trim upon refloating was determined by summing the longitudinal moment contributions (MOM_L) of all added and subtracted weight as follows:

	+ AFT
Baseline	-116,112
Chain Locker	9,648
Ground Tackle	7,242
Peaktank	7,872
AFT Spaces (3)	35,228
STRM FR 30-51	29,120
Void FR 30-40	7,040
IC/Gyro	24,000
Moment ℄	+4,038 FT - Tons

LCG = 4,038/(6,024 - 4,725) - 4,038/1,299 =

3.11 FT AFT ℄

From the Pearl Harbor Naval Shipyard data of Appendix 5-2

MT 1 at 6,024 tons approximately 715 FT - Tons

Moment ARM from LCF = 16.0 - 3.11 = 12.89 FT

$$\text{TRIM} = \frac{\text{MOM}}{\text{MT1}} = \frac{(12.89)(1,299)}{715} = 23.4 \text{ IN down by bow}$$

5.5 Real Time Data -- 29 May Operations

RECORD READINGS EVERY 15 MINUTES

(MAG) HDG	TIME	DRAFT FWD STBD	DRAFT FWD PORT	DRAFT AFT MID	DRAFT AFT PORT	TIDE GUAGE	LIST STBD
198.50	0645	18-08	18-06	18-07	16-19	5-03	12.65
198.5	0715					5-03	12.5
198.5	0730					5-03	12.2
199	0745					5-06	12.0
199	0800					5-06	11.8
199	0815					5-09	11.8
199	0830					5-09	11.5
200	0845	19-00	18-00	17-00	18-00	5-09	11.1
200	0900	18-10	18-00	18-04	17-00	6-00	10.2
201	0915	18-10	18-06	18-10	17-00	6-00	10.0
201.5	0930	18-11	18-06	18-10	17-06	6-00	9.5
202	0945	19-03	18-10	18-06	17-09	6-03	8.9
202	1000	19-06	19-00	19-00	17-09	6-06	8.6
202.5	1015	19-10	19-00	19-02	17-11	6-06	8.1
202.5	1030	19-10	19-02	19-06	18-02	6-09	7.9
202.5	1045	19-10	19-00	19-08	18-06	6-09	7.6
203	1100	20-00	19-03	19-10	18-08	7-00	7.1
203	1115	20-02	19-08	19-10	18-10	7-00	6.9
203	1130	20-05	19-08	19-10	18-08	7-03	6.2
203	1145	20-03	19-10	19-08	18-06	7-03	7.0
203	1200	20-04	19-11	19-10	18-06	7-03	6.8
203	1215	20-06	20-00	19-08	18-06	7-03	6.4
203.5	1230	20-06	20-02	19-08	18-06	7-03	6.1
203.5	1245	20-06	20-02	19-08	18-06	7-06	5.9
203.5	1330	20-11	20-06	19-06	18-08	7-11	4.6
204	1345	21-00	20-06	19-04	18-11	8-00	4.0
204	1400	21-00	20-06	19-06	12-06	8-00	4.0
	1440	20-00	20-06	19-00		8-2	3.5
AFLOAT		21-09		19-06			

TIME	D_F	D_A	D_M	+ BOW TRIM	TIDE	DISPLACEMENT
0645	18.6	18.6	18.6	0	1.6	5,260
0845	18.6	18.4	18.5	+.2	2.1	5,250
0915	18.7	18.8	18.75	-.1	2.3	5,350
0930	18.7	18.8	18.75	-.1	2.3	5,350
0945	19.1	18.5	18.8	+.6	2.6	5,370
1000	19.3	19.0	19.15	+.4	2.9	5,520
1030	19.7	19.7	19.7	0	3.2	5,750
1100	19.8	19.8	19.8	0	3.3	5,800
1130	20.0	19.8	19.9	+.3	3.6	5,850
1200	20.2	19.7	19.95	+.5	3.6	5,870
1230	20.3	19.7	20.0	+.6	3.9	5,880
1300	20.3	19.7	20.0	+.6	3.9	5,880
1440	20.6	19.5	20.1	1.1	4.1	5,910
AFLOAT	21.75	19.5	20.6	2.25	--	6,100

Estimated Trim Afloat = 23.4 inches by bow

Measured Trim Afloat = 27.0 inches by bow

Variance = 3.6 inches trim

5.6 Running Calculations During 29 May Refloating Operations

1. Baseline Condition

$W = 6{,}277$ LT, $KG = 20.00$ FT

$D = 5{,}250$ LT (based upon 0845 draft readings)

$R = 6{,}277 - 5{,}250 = 1{,}027$ LT

$GG_1 = 1{,}027(20.00)/5{,}250 = 3.92$ FT

2. Flood Shaft Alley and Void FR 159-167

$KG_1 = (125{,}528 + 1{,}056 + 656)/(6{,}277 + 132 + 82)$

$KG_1 = 127{,}240/6{,}491 = 19.60$ FT

$R = 6{,}491 - 5{,}520 = 971$ LT

$GG_1 = 971(19.60)/5{,}520 = 3.45$ FT

3. Flood JP5/AMMO FR 147-159

$KG_1 = (127{,}240 + 1{,}184)/(6{,}491 + 148)$

$KG_1 = 128{,}424/6{,}639 = 19.35$ FT

$R = 6{,}639 - 5{,}800 = 839$ LT

$GG_1 = 839(19.35)/5{,}800 = 2.80$ FT

4. Pump Storeroom FR 30-51 and Void FR 30-40

KG_1 = (128,424 - 4,420 - 445)/(6,639 - 260 - 55)

KG_1 = 123,559/6,324 = 19.54 FT

R = 6,324 - 5,880 = 444 LT

GG_1 = 444(19.54)/5,880 = 1.48 FT

5. Pump IC/Gyro FR 51-66

KG_1 = (123,559 - 5,100)/(6,324 - 300)

KG_1 = 118,459/6,024 = 19.66 FT

R = 6,024 - 5,910 = 114 LT

GG_1 = 114(19.66)/5,910 = 0.38 FT

6. Flood Sewage FR 171-177

KG_1 = 118,459 + 1,206/6,024 + 67

KG_1 = 119,665/6,091 = 19.64 FT

R = 0 (afloat)

Actual W = D = 6,150 LT

Computed W = 6,091 LT

Variance = 59 LT --- Correlation Good