ENVIRONMENTAL AND MOTION DATA OBTAINED DURING THE JLOTS II RO/RO
PHASE TRIAL CONDUCTED WITH THE MV CYGNUS

DTNSRDC/SPD-515-04

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

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by

Grant A. Rossignol

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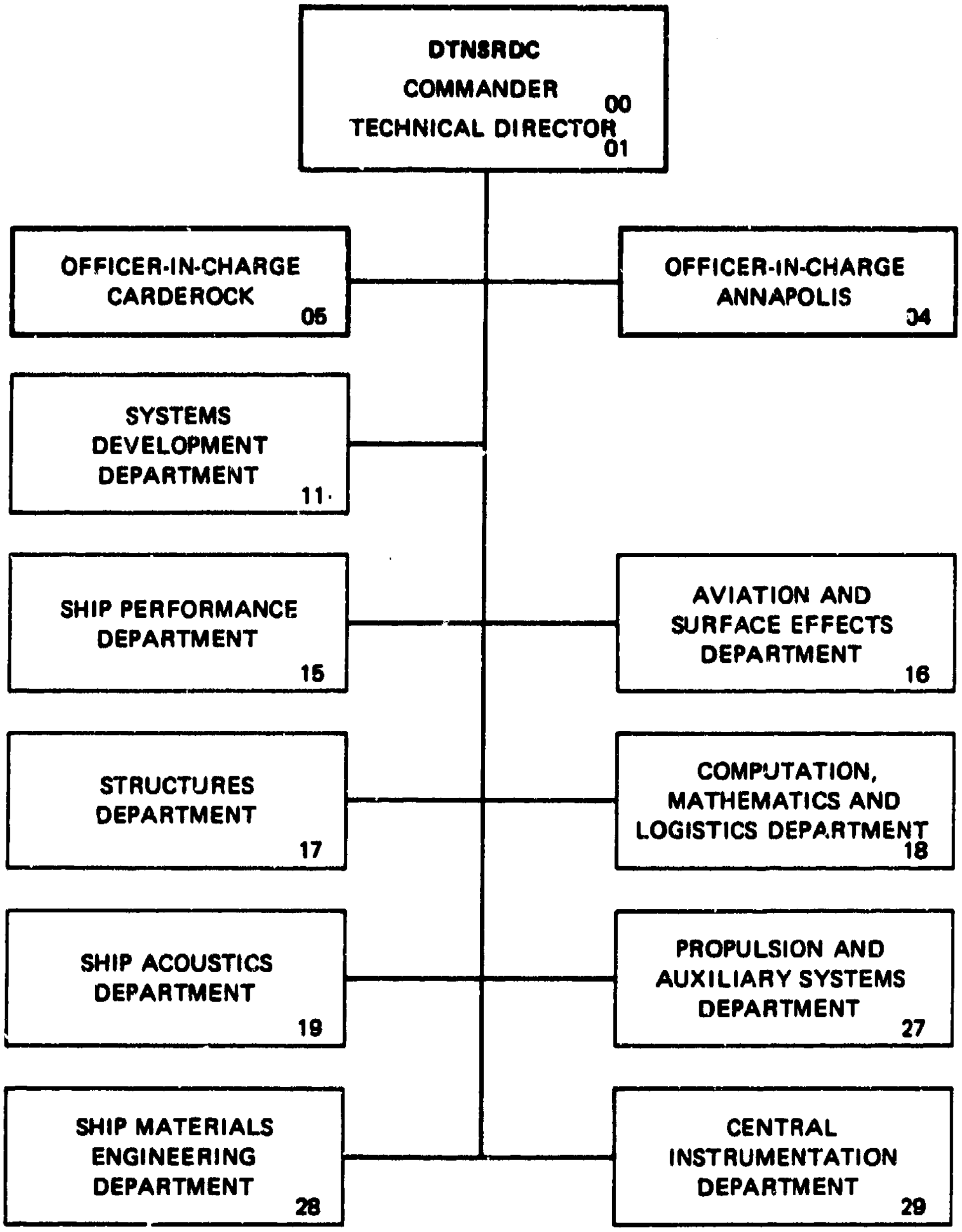

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the measurements show that the heading of the ship will oscillate ±180 degre
(in light winds) as the tide changes from high to low and back.

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NOTATION

B	Maximum beam at the design waterline
LOA	Length overall
$S_\zeta(\omega)$	Wave height spectral density ordinate
T	Draft
T_o	Modal wave period
Δ	Displacement (weight)
$(\zeta_w)_{1/3}$	Significant wave height
ω	Angular frequency of the waves

ABSTRACT

This report presents environmental and ship motion data obtained during the JLOTS II RO/RO Phase Trial conducted with the MV CYGNUS, a self-sustaining RO/RO ship.

The operating environment, from 12 to 16 July 1983 in the Chesapeake Bay off Fort Story, was quite calm and hot. The waves were 1.5 feet (0.5 meters) and less with light and variable winds. The results obtained from the measurements show that the heading of the ship will oscillate ± 180 degrees (in light winds) as the tide changes from high to low and back.

ADMINISTRATIVE INFORMATION

This work was authorized by the Mobile Support Systems Office (Code 1190) of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Systems Development Department and funded by the Office of the Under Secretary of Defense (OSD/OUSD/ODDTE) NIPR-DTAM20005. The work was performed under DTNSRDC work unit number 1190-160-30.

INTRODUCTION

Joint Logistics Over-the-Shore (JLOTS) II is a program sponsored by the Director, Defense Test and Evaluation to evaluate the joint Services' capabilities to provide sustained throughput of containerized, breakbulk, and bulk petroleum cargo across an austere beach. The program is designed to determine the Services' ability to discharge large commercial ships offshore with equipment that has been developed by the Army, Navy, and Marine Corps to meet this difficult and demanding mission. To help satisfy the objectives of JLOTS II, a series of trials are planned for 1983 and 1984. These trials consist of three phases: RO/RO, Deployment, and Throughput. The RO/RO Phase planning consists of trials with two commercial RO/RO ships: one equipped with a ramp (self-sustaining) and one not so equipped (non self-sustaining).

Future major amphibious operations conducted by the Department of Defense (DoD) will, in many cases, rely extensively on United States flag commercial shipping. The Roll-On/Roll-Off (RO/RO) ship seems to be particularly well suited to serve the needs of rapid deployment of military rolling stock such as tanks, trucks, and artillery in support of any major DoD operation. However, these operations usually occur over undeveloped beaches, while RO/RO ships require complete pierside facilities for offloading and backloading. To meet this need, the Navy has developed a RO/RO Discharge Facility for the offshore offloading and backloading of rolling stock between commercial RO/RO ships and military lighterage.

The RO/RO Discharge Facility Causeway Platform consists of six Navy causeway sections linked together by flexor side and end connectors to form a platform which is three causeway sections wide and two long. The overall platform is 65 feet (19.7 meters) wide and 180 feet (54.5 meters) long. Auxiliary equipment includes ship fenders, dunnage, and a portable ramp for RO/RO ships not equipped with their own ramps. Causeway ferries (strings of causeway sections end connected only) and LCU's represent the lighterage used in moving the rolling stock between the Causeway Platform and the beach. The causeway ferries (CWF's) link directly to the end of the Causeway Platform opposite the ship, but the LCU's require that a causeway B section (with a rhino horn in place) be first linked to the Causeway Platform end opposite the ship.

The JLOTS II RO/RO Phase Trial (self-sustaining ship) was conducted with the MV CYGNUS, a commercial RO/RO ship equipped with a slewing, stern ramp. The trial took place from 12 to 16 July, 1983 in the Chesapeake Bay off the beach of Fort Story (Virginia Beach), Virginia (Figure 1). The trial began with a pierside loadout of the CYGNUS at the Naval Operations Base in Norfolk, Virginia; with approximately 100 vehicles representing some of the largest, heaviest, and most unusual possessed by the Army and Marine Corps. Upon completion of the loading, the ship transited to an anchorage off Fort Story. Each day of the trial, the Causeway Platform was moored to the stern of the CYGNUS, the ramp was lowered, and operations would begin. Figures 2 and 3 show the CYGNUS to Causeway Platform interface configuration. The vehicles were moved from the ship to a staging area on the beach at Fort Story using a combination of lighterage. Both day and night operations were conducted using either only causeway ferries, only LCU's, or a combination of both. A complete offload and backload evolution was accomplished during each day of the trial, with the order reversing daily. Warping tugs were used to power the Causeway Platform and causeway ferries. Preliminary trials were conducted from September to November of 1982 in preparation for this trial. Included in these trials were vehicle evolutions with the CYGNUS and the Causeway Platform.

The DTNSRDC Ship Performance Department (Code 1561) was tasked by the DTNSRDC Systems Development Department (Code 1190) to define the prevailing environmental conditions and measure ship (and Causeway Platform) motions during the trial. Near the end of each day of the trial, a summary of that day's environmental conditions and a prediction of the next day's weather (including tides) were reported to the JLOTS II Directorate. The results of all environmental conditions and motions obtained during the trial are presented in this report.

OBJECTIVES

The primary objectives of the DTNSRDC (Code 1561) effort during the trial were to:

a. Define the prevailing environmental conditions during each trial day;

b. Measure the motions of the ship and Causeway Platform;

c. Provide daily summaries of the environmental results;

d. Provide daily weather predictions.

DESCRIPTION OF PARTICULARS

The principal characteristics of the CYGNUS, 1610 Series LCU (both Army and Navy), warping tugs, and a single causeway section are given in Table 1. The CYGNUS is a RABENFEL's Class merchant RO/RO ship operating under contract to the Military Sealift Command (MSC). A report* covering the 1982 trials conducted with the CYGNUS and the Causeway Platform describes the physical characteristics of all vessels and platforms involved in this trial in detail. Figures 4 and 5 show photographs of the CYGNUS, a warping tug, a causeway B section, a causeway ferry, and a 1610 series LCU.

INSTRUMENTATION

The DTNSRDC Portable Data Collection Center (PORDACC) trailer was used as a central site for monitoring, collecting, and processing the data during the trial. PORDACC was installed on the Army LCU 1586 (TUNISIA) along with a leased (30 KW, three-phase, diesel) generator. The TUNISIA was tied along the port side of the CYGNUS for the duration of the trial. Figures 6 and 7 show the TUNISIA alongside the CYGNUS and details of the arrangements of PORDACC

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*Rossignol, G.A., "MV CYGNUS, SS AMERICAN TROJAN, and Causeway Platform Facility Relative Motion Evaluation," Report DTNSRDC/SPD-515-03 (Feb 1983). (This report has a restricted distribution and is not available to the general public.)

and the generator on the deck, respectively. Some of the features and equipment which make PORDACC ideally suited for all (but fairly small) trials where sufficient deck space exists are:

a. The air conditioned space maintains peak instrumentation performance (especially the computer);

b. The interior space accommodates all needed signal conditioning;

c. 440 volts of electricity is plugged into PORDACC (available on most ships or supplied by a portable generator) and then stepped down by a transformer to provide ample 220 and 110 volts for all trial requirements;

d. Many incoming signals to PORDACC are connected to monitors which provide immediate data displays in engineering units;

e. The computer in PORDACC not only stores the data in digital form but also provides real time analysis, word processing, and program development capabilities;

f. A marine radio serves as a ship-to-shore radiotelephone, a means of communication with other vessels (including the one on which PORDACC is located), and a monitor of marine weather forecasts;

g. The table/desk top and bench area in PORDACC provides the project engineer with space to write and reduce data during a trial.

Figure 8 shows the interior of PORDACC.

Measurements were made of environmental conditions and ship motions. The ship motions measured were pitch, roll, vertical acceleration, and heading. A weather tight box housing a pitch/roll gyroscope and vertical accelerometer was installed on the outboard edge of the main deck (portside) of the CYGNUS at approximately amidships. Pre-trial planning included a similar motion package to be installed on the Causeway Platform, but trial configuration changes precluded that installation. Initially, the Causeway Platform was to stay moored to the CYGNUS for the duration of the trial and the TUNISIA was to be located further aft. Unfortunately, the maximum motion package cable length could not accommodate the changes. Figure 9 shows the motion package as installed on the CYGNUS and also with the top removed. The heading of the ship was obtained by taking readings from the gyrocompass on the TUNISIA.

The environmental conditions measured were open water wave height (near the ship), surf zone wave height (near the beach), wind speed, wind direction, current speed, precipitation, visibility, water temperature, and air temperature. Figure 10 shows photographs of the wave buoys and the mooring line arrangements used during the trial. Figures 11 and 12 show sketches and photographs, respectively, of both buoys as they were actually deployed. The locations of both buoys are shown in Figure 1. The buoy near the ship was in approximately 40 feet (12.1 meters) of water, while the water depth at the surf zone buoy location was 12 feet (3.6 meters). The ship buoy is an ENDECO directional buoy which is capable of providing wave direction data in addition to the vertical wave displacement. The surf buoy is a Waverider displacement buoy. Both buoys have double integrating circuitry which converts vertical wave acceleration to wave height, prior to transmitting signals back to PORDACC. To prevent ship blockage of the wave buoy signals, the receiving antennas were located high above the ship's superstructure, as shown in Figure 13. To check the results of the surf zone wave buoy, surf sleds were constructed and deployed in between the buoy and the beach. The sleds were positioned such that neither low nor high tides could prevent readings from being taken. Figure 14 shows the surf sleds. The scales are marked off in feet from the bottom.

The wind speed and direction were measured by a wind meter installed above the CYGNUS superstructure (Figure 13). The current speed was measured by a current meter hung over the side of the TUNISIA. The current direction was not necessary to measure as the direction changed only from ebb to flood with the tide changes. Figure 15 shows the current meter and digital display. The tide changes were obtained using the standard NOAA National Ocean Survey tide tables. Figure 16 shows a rain gage and temperature probes which were used to monitor precipitation, water temperature, and air temperature. The rain gage and air temperature probe were installed on the roof of PORDACC, while the water temperature probe was hung over the side of the TUNISIA. Barometric pressure was monitored using a barometer in PORDACC. The visibility was estimated periodically each day using a combination of the TUNISIA's radar, nautical charts, and observations of known land references. Table 2 summarizes the measurements made, the type of transducer used, and the location of each transducer.

MEASUREMENTS AND DATA REDUCTION

Time histories of the following signals were recorded in analog form on strip charts and analog tapes and in digital form on disks:

a. CYGNUS pitch;

b. CYGNUS roll;

c. CYGNUS vertical acceleration;

d. Wind speed;

e. Wind direction;

f. Wave height (surf zone);

g. Wave height (ship);

h. North/South tilt (wave direction);

i. East/West tilt (wave direction).

The following variables were tabulated from a variety of monitoring devices:

a. Water temperature;

b. Air temperature;

c. Precipitation;

d. Visibility;

e. Times of high and low tides;

f. Current speed;

g. Current direction

h. Heading;

i. Wave direction;

j. Barometric pressure.

A PDP 1123 minicomputer system installed in PORDACC was used to collect and reduce the data during each day of the trial. This computer system consists of a central processor, analog-to-digital converter, CRT display, keyboard, dual floppy disk drive, and a printer. Figure 17 shows the computer system components as installed in PORDACC. The signals were sampled at a rate of 5 samples per second using one hertz filters. When possible, 15 minutes of data were collected every hour during the trial operations. Real-time data reduction was accomplished during the trial to provide time history statistics, thus enabling daily reports to be made to the JLOTS II Directorate. The wave height time histories were spectrum analyzed using the FFT program at DTNSRDC after the trial to provide wave spectra. The computer program in the PORDACC PDP 1123 is capable of providing the following types of analysis:

a. Time history statistics (mean, minimum, maximum, range, significant amplitude, root-mean-square, standard deviation);

b. Time history printout (amplitude in engineering units versus time);

c. Time history plot (amplitude in engineering units versus time);

d. Spectral analysis;

e. Relative motion analysis (generates relative motion time history from a pair of like measurements);

f. Histogram (frequency of occurrence versus amplitude for the instantaneous amplitude values of a given signal).

A description of the equations used in the data reduction for the trial data is given in the appendix.

TRIAL CONDITIONS AND PROCEDURE

The trial operations (OPS) area ranged from the CYGNUS anchorage in the Chesapeake Bay to the beach at Fort Story (Virginia Beach, Virginia). The CYGNUS was anchored (Figure 1) one nautical mile (1.8 kilometers) from the Fort Story beach in approximately 40 feet (12.1 meters) of water. Each day of the trial (12 to 16 July 1983), LCU and causeway ferry lighterage moved vehicles in a round trip between the CYGNUS and a staging area on the beach. Both day and night operations were conducted using either only LCU's, only causeway ferries, or a mixture of the two.

The sea and wind conditions were quite calm during the trial. The significant wave height (near the ship) varied from 0.4 to 1.5 feet (0.1 to 0.5 meters), while the surf zone significant wave height ranged from 0.3 to 0.9 feet (0.1 to 0.3 meters). The wind speed varied from 1 to 14 knots, but was around 6 to 8 knots the majority of the time and variable in direction. The weather conditions were hot, humid, and hazy during the entire trial, with no precipitation. The current speed and direction were a function of the tide changes, with a maximum current speed of 1.9 knots (ebb). Table 3 summarizes the environmental conditions which prevailed during the trial.

The wave buoys and surf sleds were deployed on the day before the trial began and left in the water for the duration of the trial. The buoys were moored to anchor weights. The technique used in mooring the buoys was not well established and initially, both buoys drifted somewhat. The buoys were retrieved, the mooring configuration was modified, and the buoys were redeployed. The buoys then stayed in place for the duration of the trial.

The ENDECO directional buoy was moored near the ship in about 40 feet (12.1 meters) of water, while the depth was 12 feet (3.6 meters) at the surf zone buoy location. The surf sleds were held down on the bottom of the water by their weight (the wooden one had weights tied on). The surf sleds were intended to provide a check on the accuracy of the surf zone wave buoy or even provide data should the buoy fail to operate. Two sleds were used to allow for readings through high and low tides.

PRESENTATION OF RESULTS

Figures 18 through 22 present wave spectra for each day of the trial. A comparison is shown between the open water spectra and the surf zone spectra. These spectra represent the wave conditions which were the largest during each trial day. Since the remaining wave conditions not spectrum analyzed were milder than these, the presentation of those spectra would not be very informative. As can be seen the modal wave period for the seaway was in the 2.5 to 4.2 second range with swells occasionally appearing as low frequency spikes (periods ranging from 4 to 10 seconds). The energy (and thus the significant wave heights) associated with the surf zone wave height is consistently less than that of the open water wave height. Although some differences are present in the significant wave heights (for both buoys) between the spectra results and those in Table 3, these differences are slight and are due mostly to the small wave heights. As the wave heights increase, the time history values will agree better with the spectral values.

Figure 23 presents one of the most useful and interesting results of the trial measurements. The ship and Causeway Platform interface motion most predominant was the changing heading of the ship. Every time the tide began to change (flood in or ebb out), the corresponding tidal current would change direction and cause the CYGNUS to swing about the anchor. This swing would continue until the ship's heading changed 180 degrees and the ship headed directly into the current. The ship then stayed at this heading (either due East or due West) until the next tide change. The only deviation from these swings seems to be when the winds are strong enough to oppose the tidal currents. Further data would have to be obtained during periods of higher wind speeds than occurred during this trial to establish the nature of the relationship. The swinging of the ship could be of real concern to future RO/RO interface operations. Knowledge of the ship swinging times can enable better planning of lighterage to Causeway Platform marriages. This planning may prove to be especially important under more adverse sea and wind conditions than were encountered during this trial. One attempt at measuring the rate of ship swinging during a tide change resulted in a value of 2.6 degrees per minute. This means that the ship (and Causeway Platform) could swing 90 degrees from an initial position in 35 minutes. An approaching causeway ferry with its slow speed (around 4 knots) could actually end up having to "chase" the Causeway Platform as it swings around with the ship.

Figure 23 and 24 present a graphical summary of the rest of the environmental data. As can be seen there was little variability in the wave data at both locations, with the wave direction being primarily influenced by the wind direction. The winds are shown to have been generally light and variable. The water temperature seemed to vary with the tide changes as the cooler sea water came into the bay during the incoming tides. Tables 3, 4, and 5 summarize all environmental data; while ship motion data are included in Tables 4 and 5. As can be seen, the motions of the ship were almost nonexistent. The most meaningful statistic to be presented for a particular measurement depends on the variable being measured. Quantities such as wave height and ship motions, which oscillate about a mean value from cycle to cycle, lend well to the use of statistics such as significant amplitudes. Others such as ship's heading, temperature, wind speed, wind direction, and current speed do not vary as fast and not so cyclic, so time averaging yields the best result (mean value). In all cases, the difference between the largest and smallest values measured (range value) will tend to bound the results. For oscillatory (cyclic) measurements, the range will be a limiting value for the maximum double amplitude.

Future motion measurements during JLOTS II should concentrate more on lighterage and Causeway Platform motions and less on ship motions. Large ships, such as RO/RO ships and others to be used during JLOTS II trials, should not experience much motion in the seas likely to be encountered at the trial OPS area.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the measurements made during the trial, the following conclusions are drawn concerning the environmental conditions and ship motions:

a. The sea and wind conditions were extremely mild during the trial. The significant wave height was 1.5 feet (0.5 meters) and less, while the winds were light and variable (mostly 6 to 8 knots).

b. The weather conditions were hot, humid, and with hazy visibility.

c. The ship and Causeway Platform (moored to the ship) swung periodically with the periodic variations in tidal current and tide changes. By accurately tabulating the upcoming tides and currents, the times that the ship will begin to swing about its anchor can be estimated.

The following recommendations are made regarding measurements during future JLOTS II trials:

a. The motions of lighterage when alongside ships or married to the Causeway Platform should be measured and compared to the ship (or Causeway Platform) motions. The relative motions can then be determined. The relative motions between Causeway Platform sections should also be calculated.

b. Pre-trial visits should be made by representatives of DTNSRDC (Code 1561) to the ships involved so as to provide optimum planning for the measurements.

c. Tide and tidal current data should be used in the planning of daily events during future trials. Scheduling lighterage activities around anticipated ship swinging (changing heading) times may prove to be quite beneficial, particularly under slightly adverse weather conditions.

APPENDIX

FORMULAS AND EQUATIONS

I. Time history analysis.

The mean value, $\bar{y}_i$, and the root mean square value, $(RMS)_i$, for a particular measurement are calculated by

$$\bar{y}_i = \frac{1}{N}\sum_{j=1}^{N} y_j$$

and

$$(RMS)_i = \left[\frac{1}{N}\sum_{j=1}^{N} y_j^2\right]^{1/2},$$

where y_j is the instantaneous value of the particular time history, $y(t)$, and N is the number of samples digitized. The standard deviation, σ_i, for a particular measurement is calculated by

$$\sigma_i = [(RMS)_i^2 - \bar{y}_i^2]^{1/2}.$$

The significant amplitude, $(\tilde{i}_A)_{1/3}$, for a particular measurement is calculated from the standard deviation by

$$(\tilde{i}_A)_{1/3} = 2\sigma_i.$$

For a given time history segment of a particular measurement, $y(t)$, the minimum and maximum values are $y_{j_{max}}$ and $y_{j_{min}}$. These values are used to calculate the range R_i, by

$$R_i = |y_{j_{max}} - y_{j_{min}}|.$$

Since the largest double amplitude cannot be greater than the range, the range is used to represent a limiting value for the maximum double amplitude.

II. Spectral analysis.

The Fast Fourier Transform (FFT) method was used to obtain spectra for the wave height signals. The wave height spectral ordinate is represented by

$$S_{\zeta}(\omega), \text{ in feet}^2 \cdot \text{sec (meter}^2 \cdot \text{sec)},$$

where ω is the angular wave frequency in radians per second. By taking the area under the spectrum, A, significant wave height was calculated by

$$(\tilde{\zeta}_w)_{1/3} = 2\sqrt{2}\sqrt{A}.$$

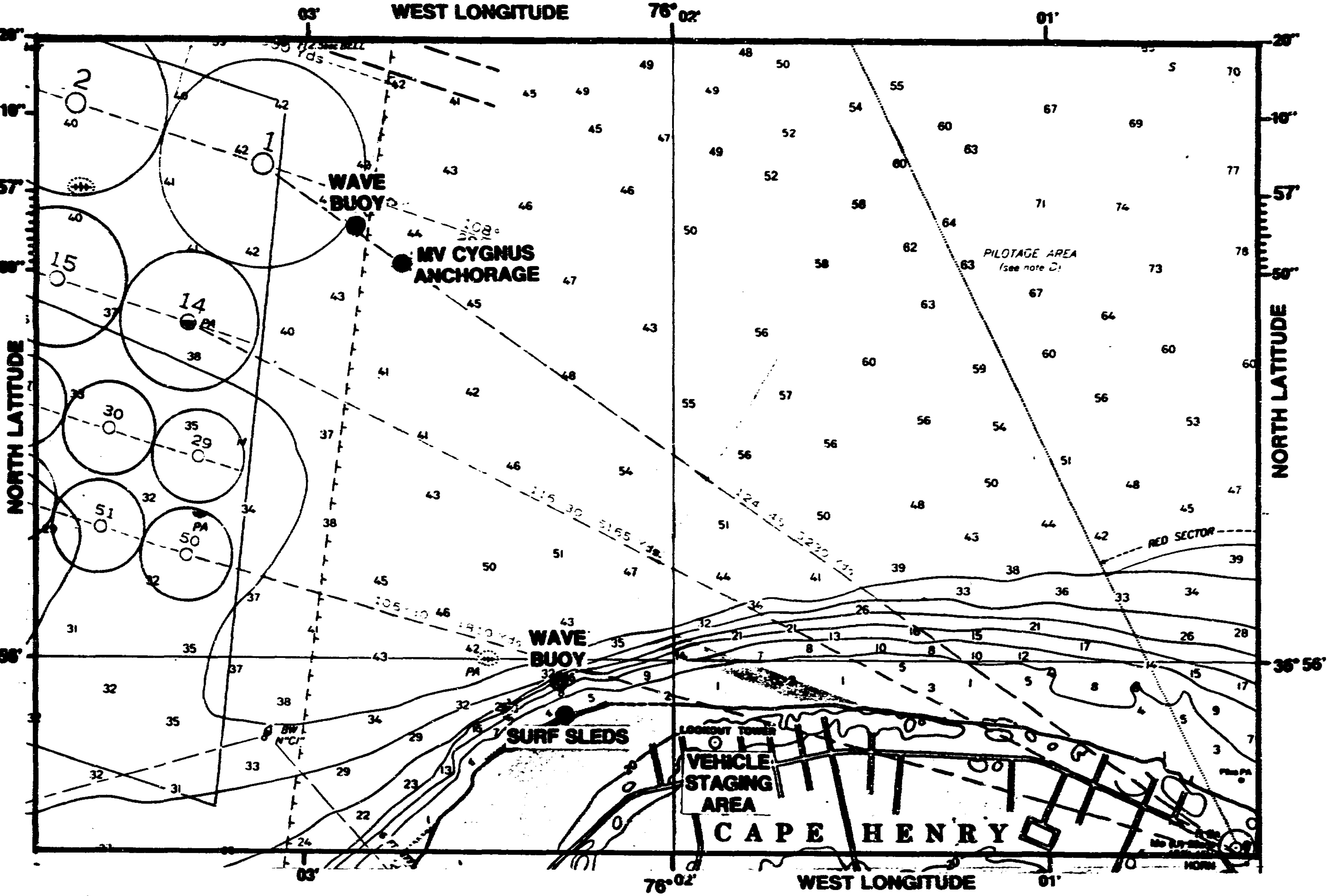


Figure 1 - Nautical Chart of the Trial Operations Area Located in the

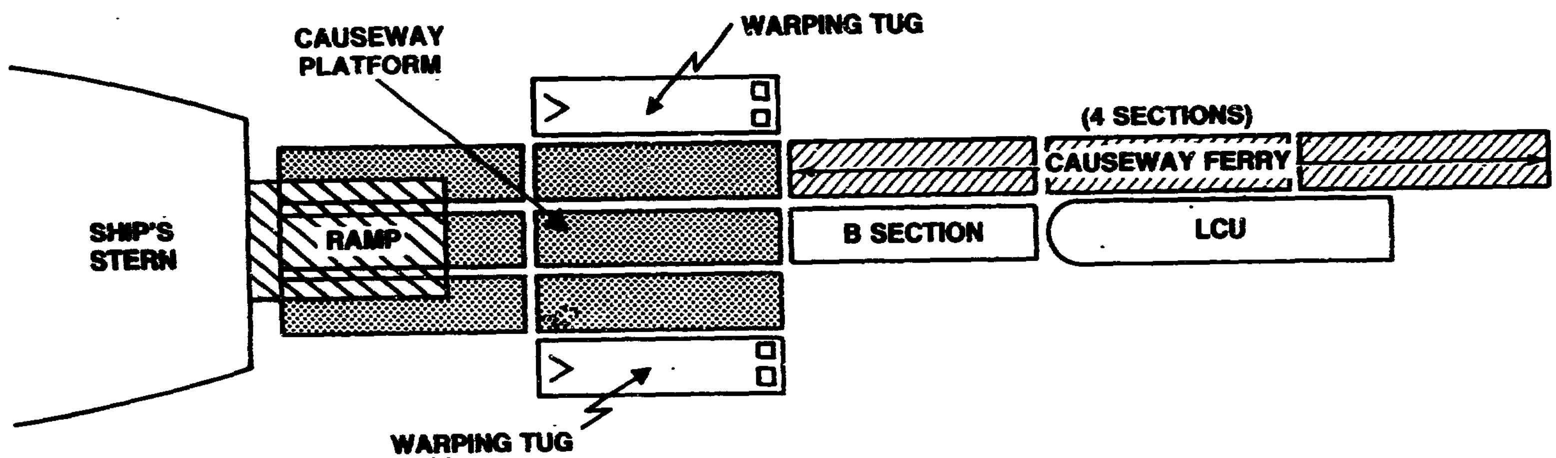


Figure 2 - Sketch of Configuration used during MV CYGNUS Interface Showing Relative Positions of Causeway Platform, Ship's Stern, Ship's Ramp, Warping Tugs, B Section, Causeway Ferry, and LCU

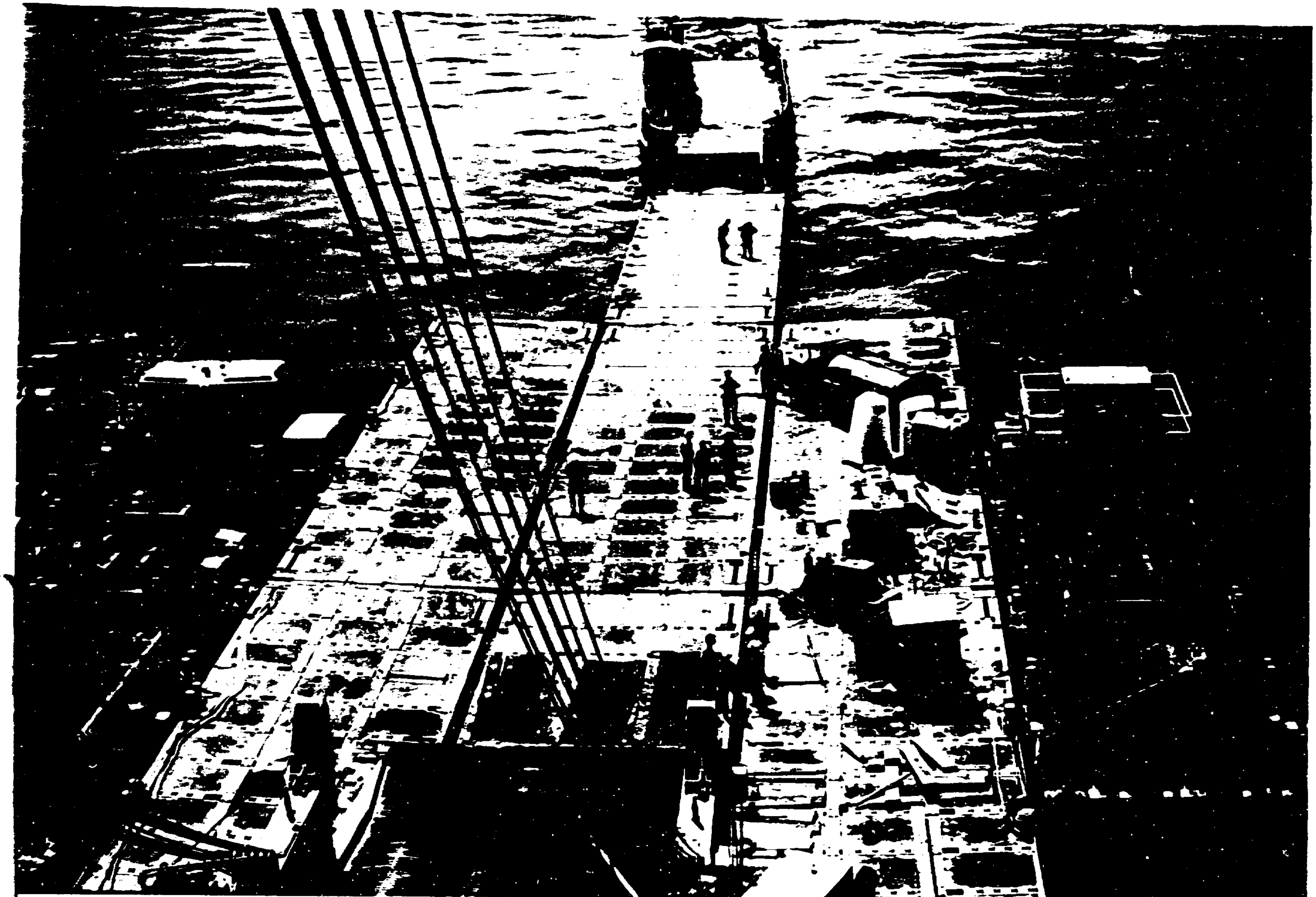


Figure 3 - Photograph of the Causeway Platform in Position at the Stern of the MV CYGNUS

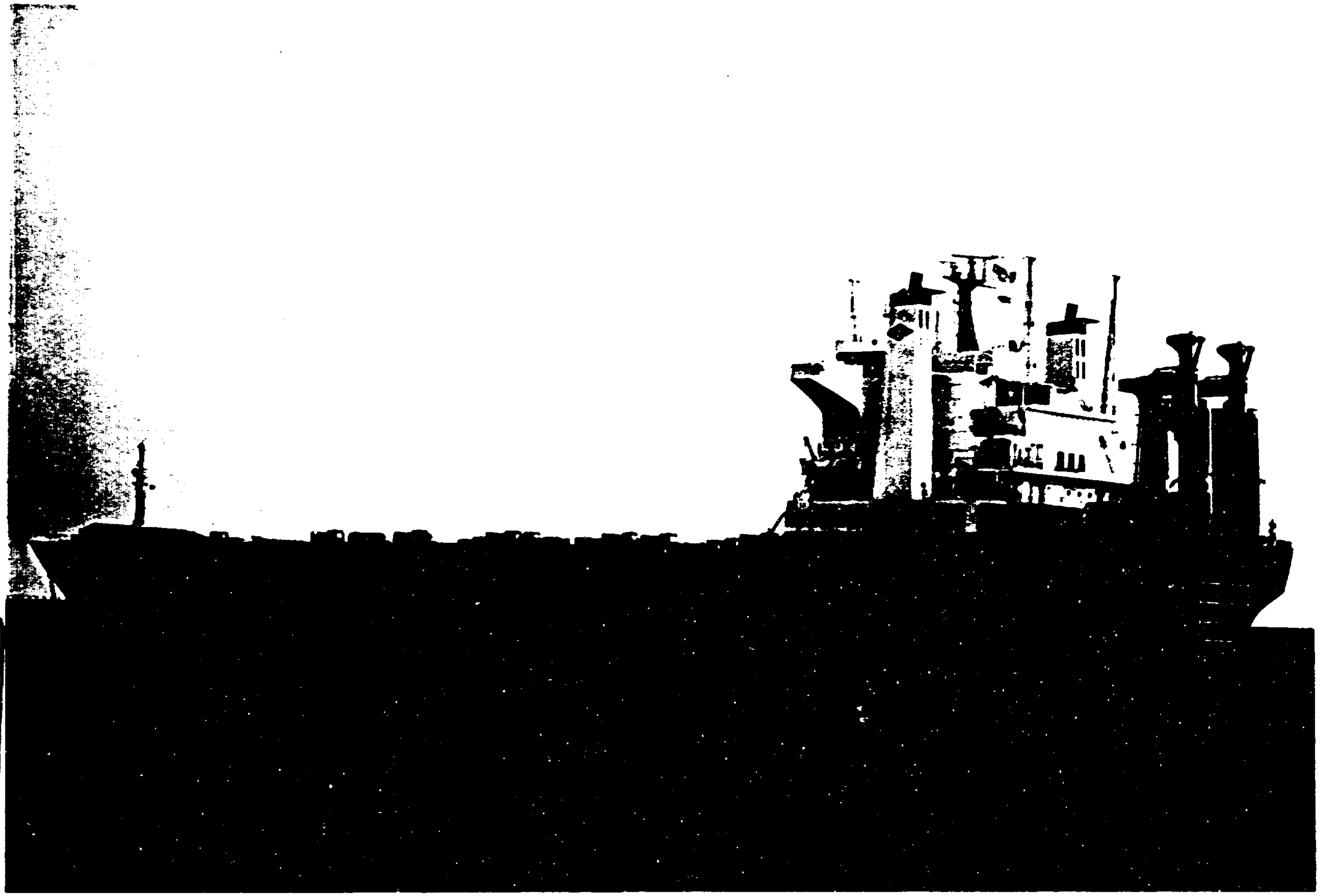
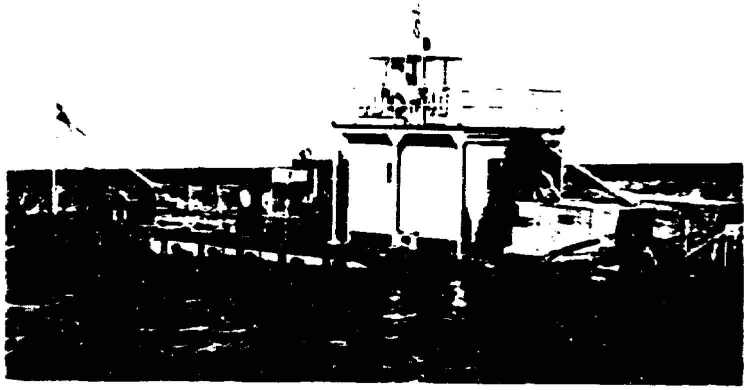
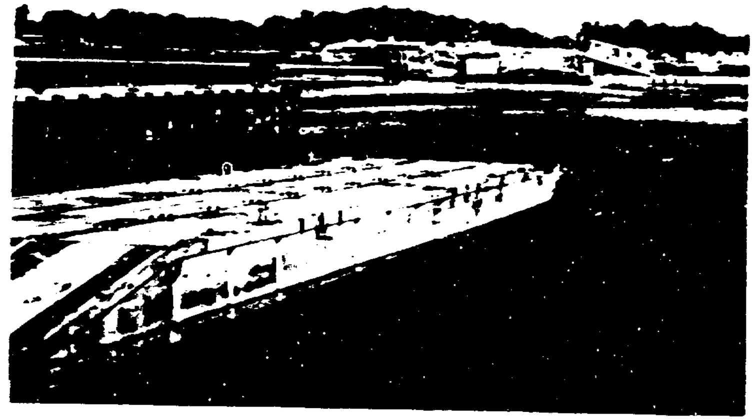


Figure 4 - Photograph of the MV CYGNUS

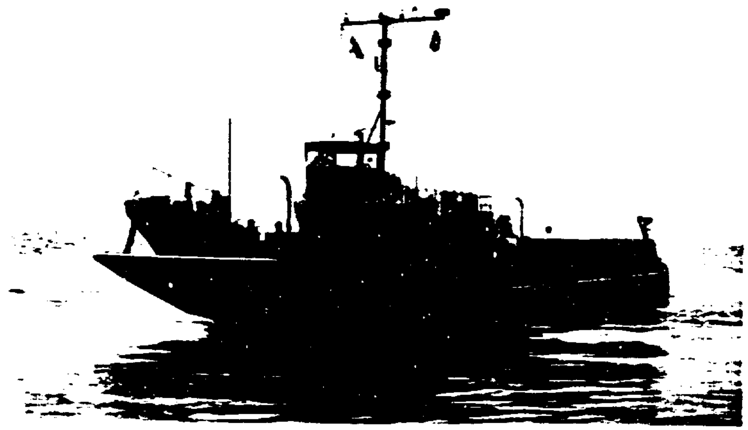


WARPING TUG (WT)
HOME PORT TYPE



CAUSEWAY SECTION (B)

CAUSEWAY FERRY (CWF)



LCU (1610 SERIES)

Figure 5 - Photographs of a Warping Tug (WT), Causeway Section (B), Causeway Ferry (CWF), and LCU (1610 Series)

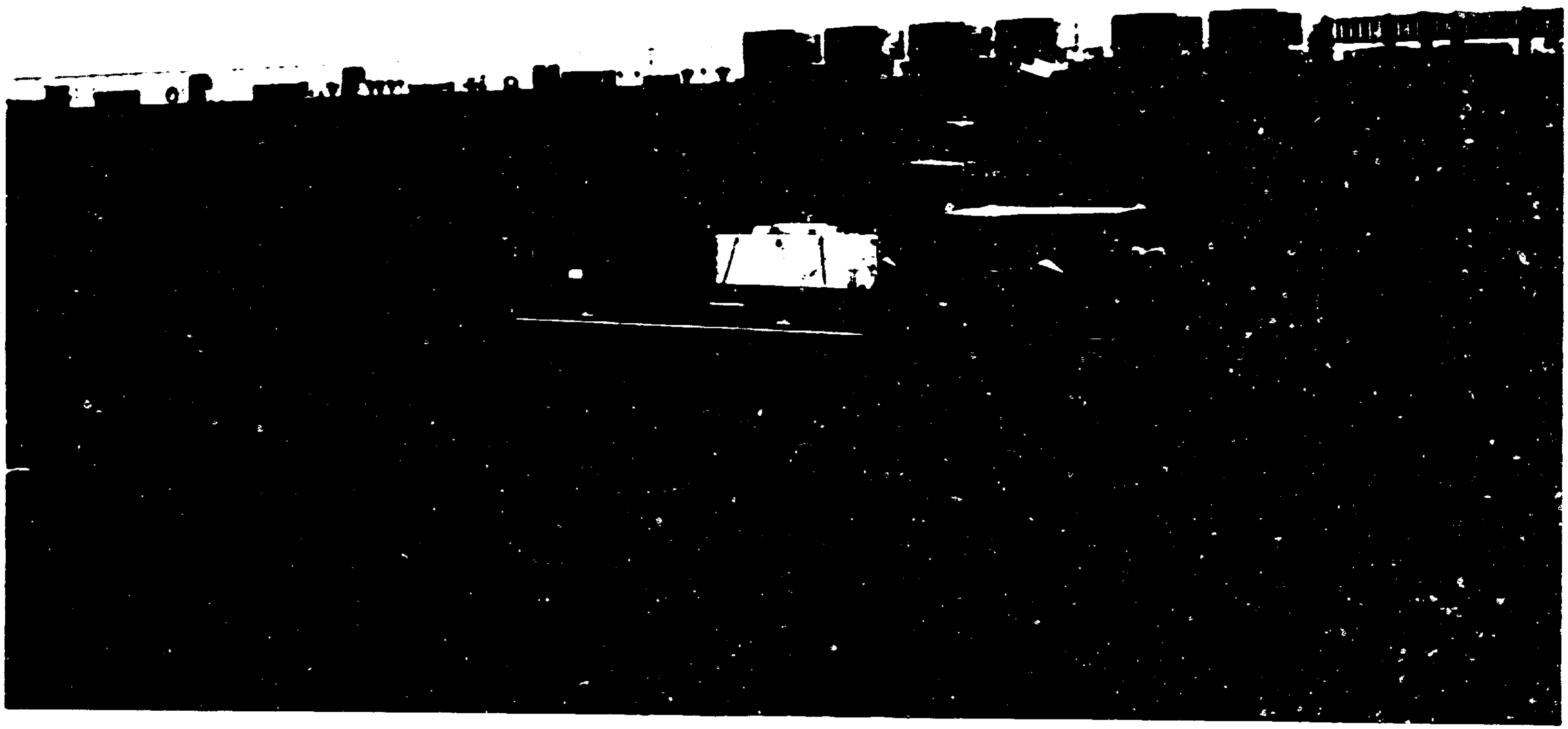


Figure 6 - Photograph of the Army LCU 1586 (TUNISIA) Tied Alongside the MV CYGNUS with the Portable Data Collection Center (PORDACC) Trailer on Board

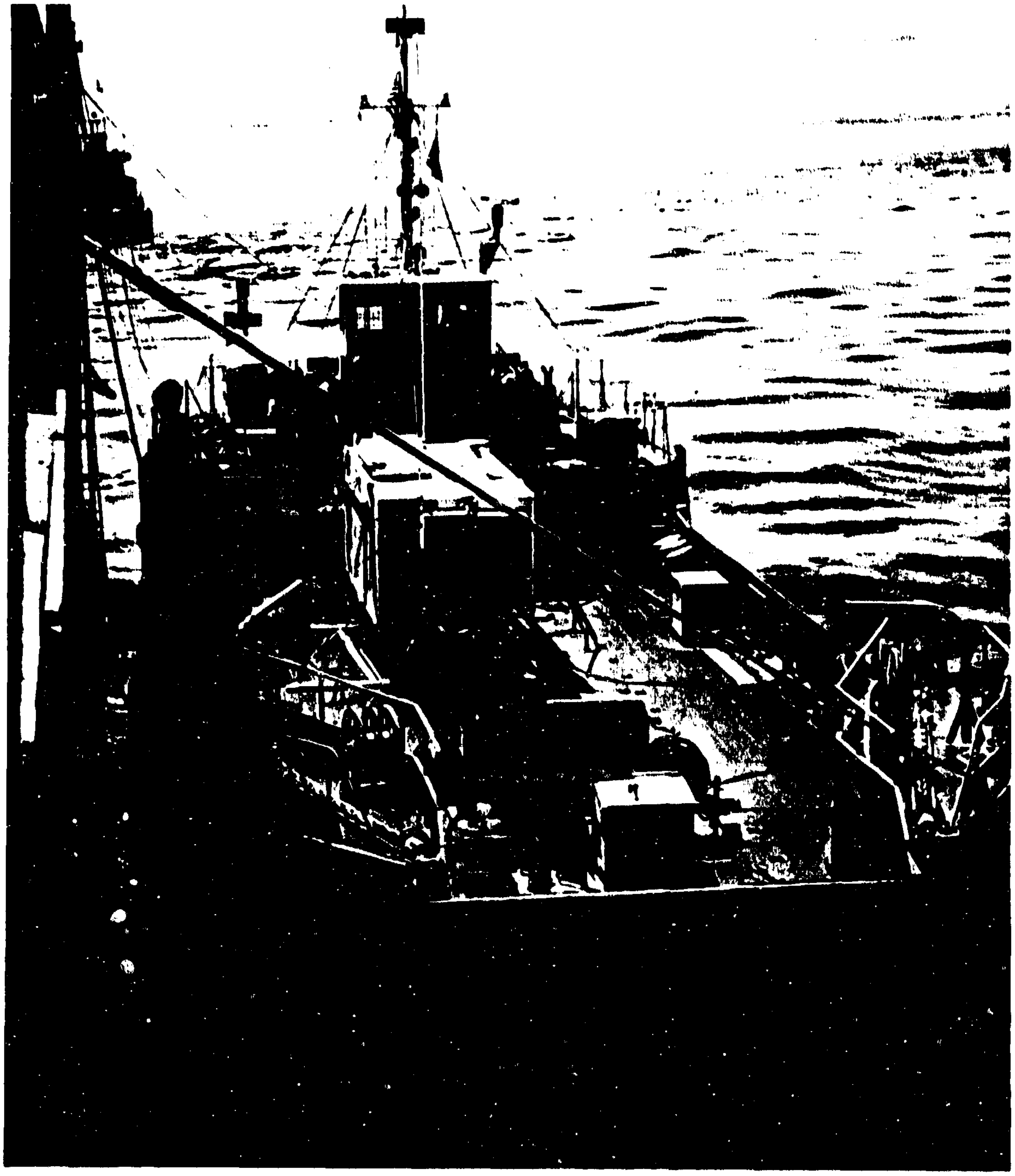
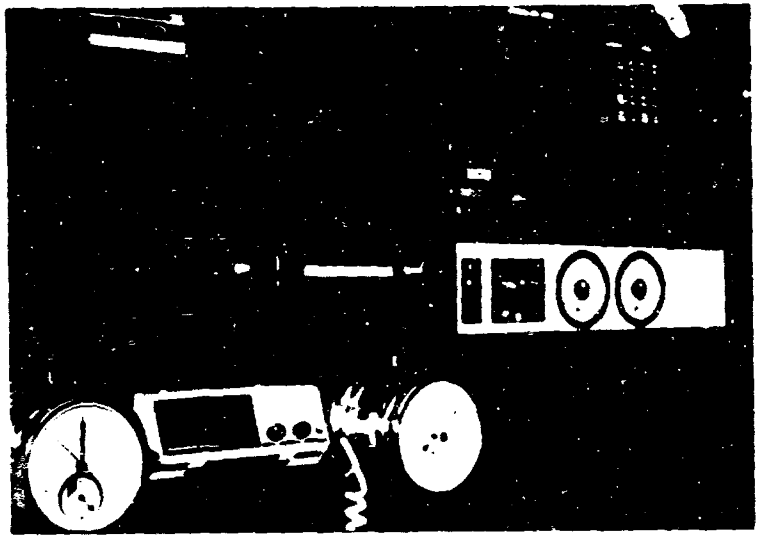


Figure 7 - Photograph of the Details of the PORDACC and Generator Installation on the Army LCU 1586 (TUNISIA)



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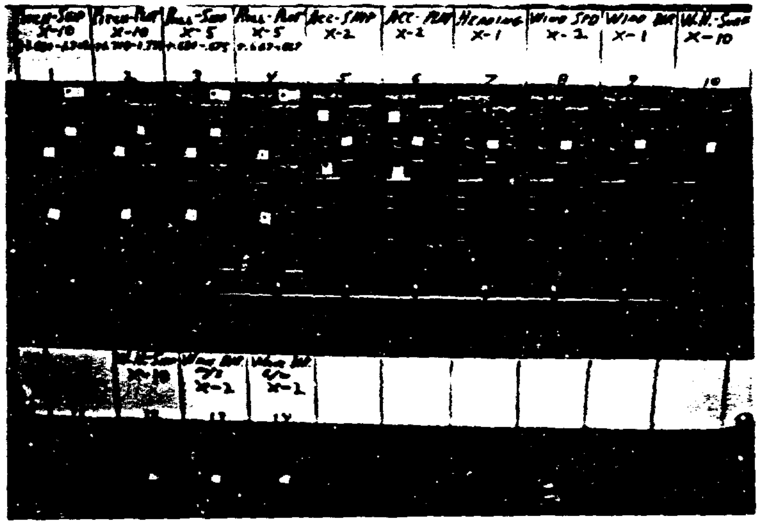

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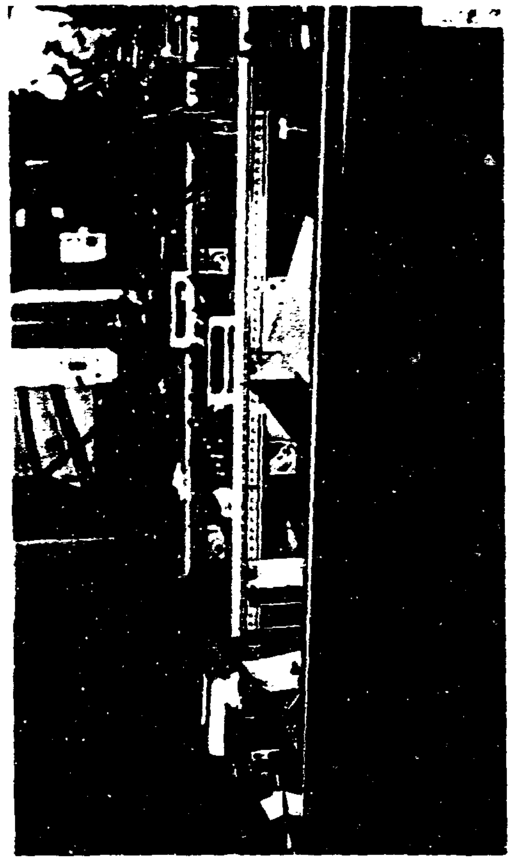
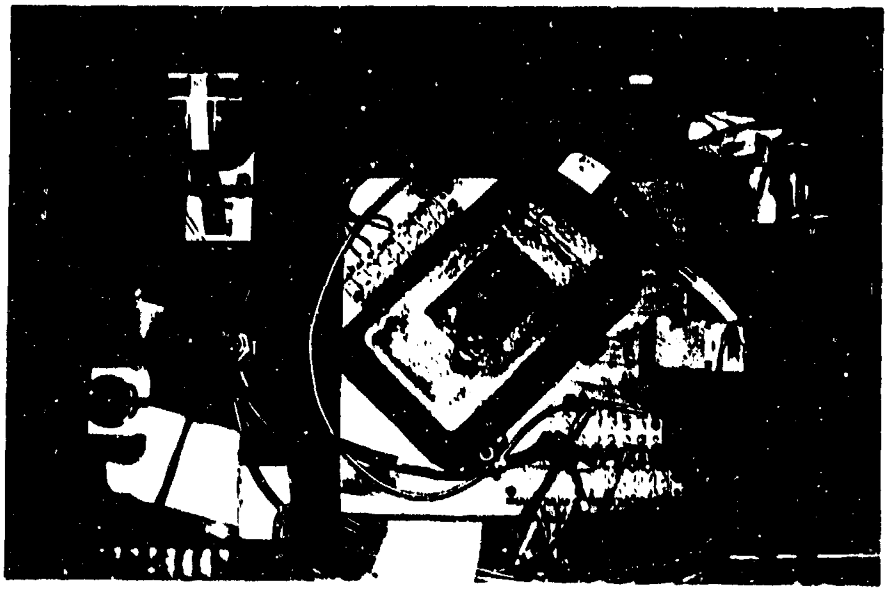
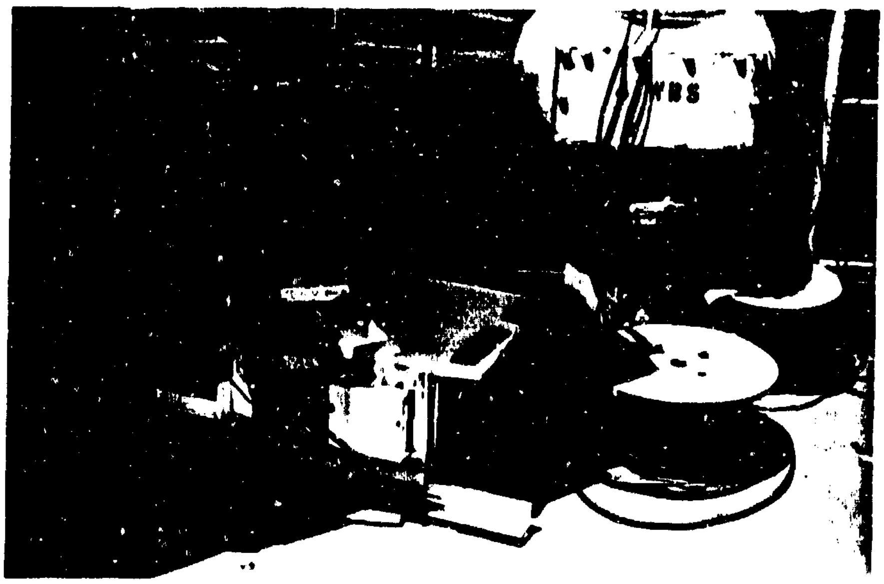


INSTRUMENTATION RACKS

Figure 8 - Interior Photographs of PORDACC Showing Some of the Equipment/Instrumentation used during the Trial

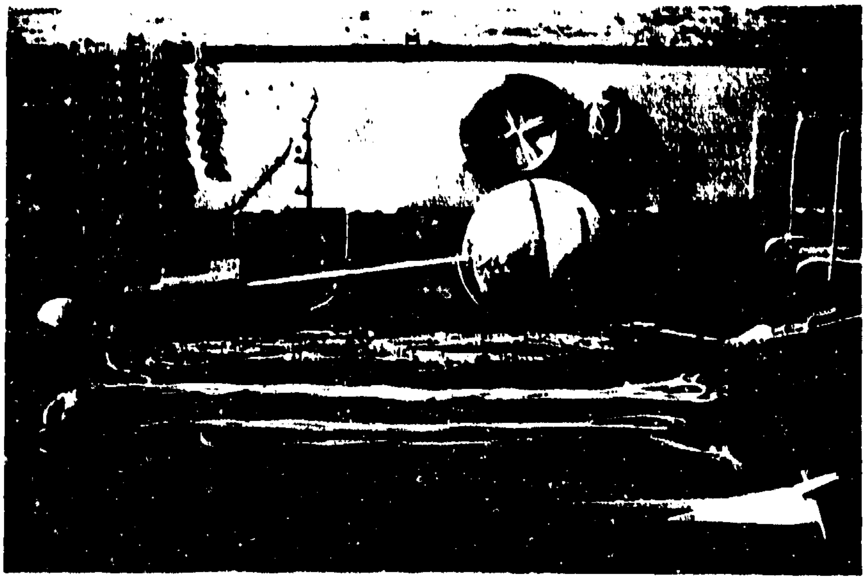


COVER REMOVED TO SHOW GYRO AND ACCELEROMETER



PACKAGE IN POSITION

Figure 9 - Photographs of the Motion Measurement Package Installed on the MV CYGNUS



ENDECO BUOY (SHIP)

WAVERIDER BUOY (SURF)

Figure 10 - Photographs of the Wave Buoys and Mooring Line Arrangements

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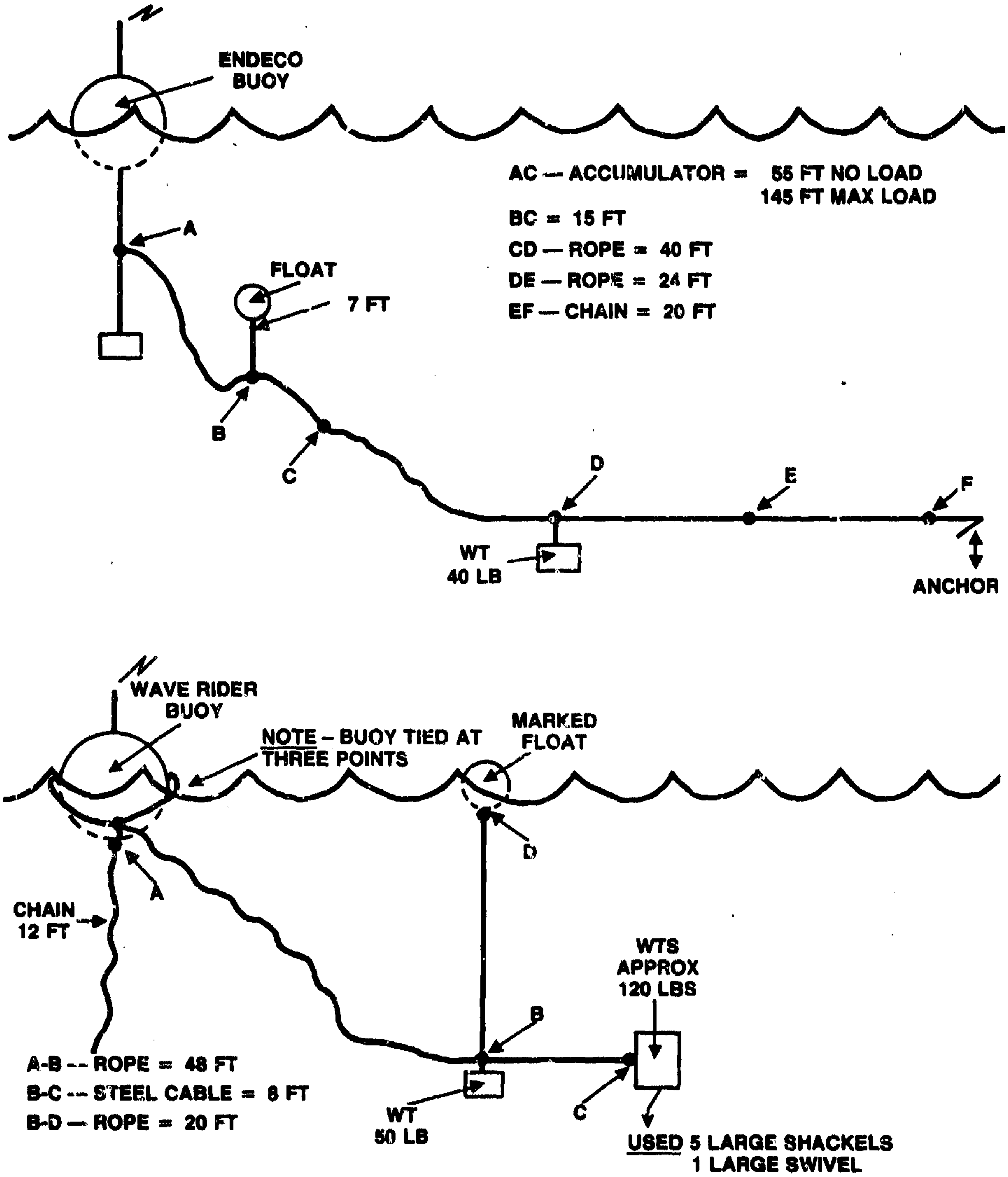
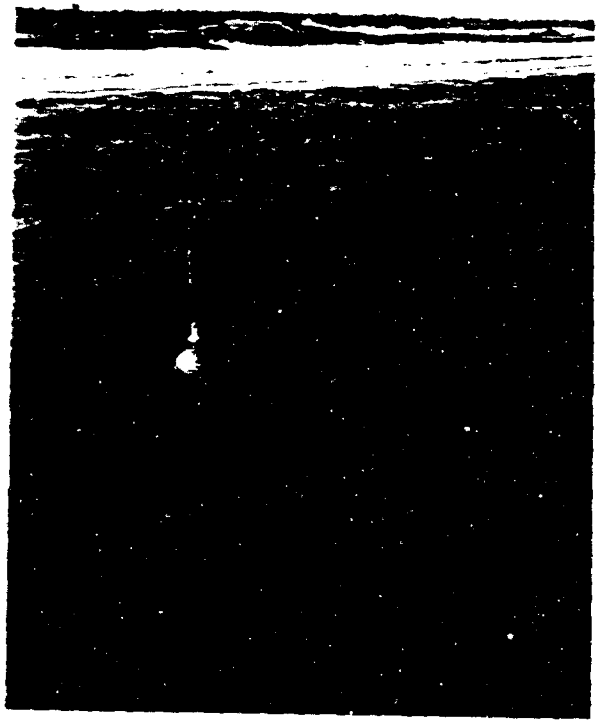
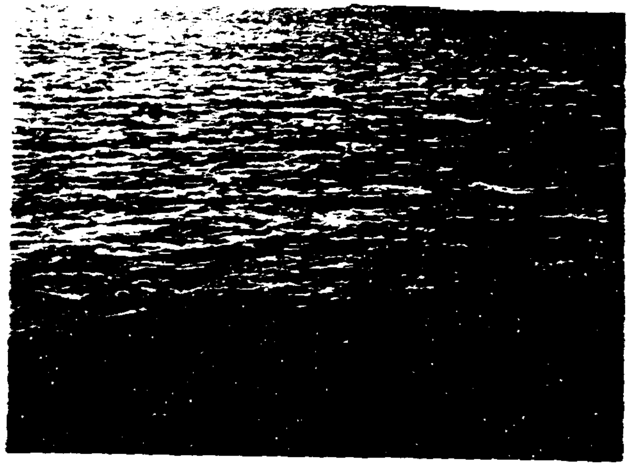


Figure 11 - Sketches of Wave Buoy Mooring Configurations

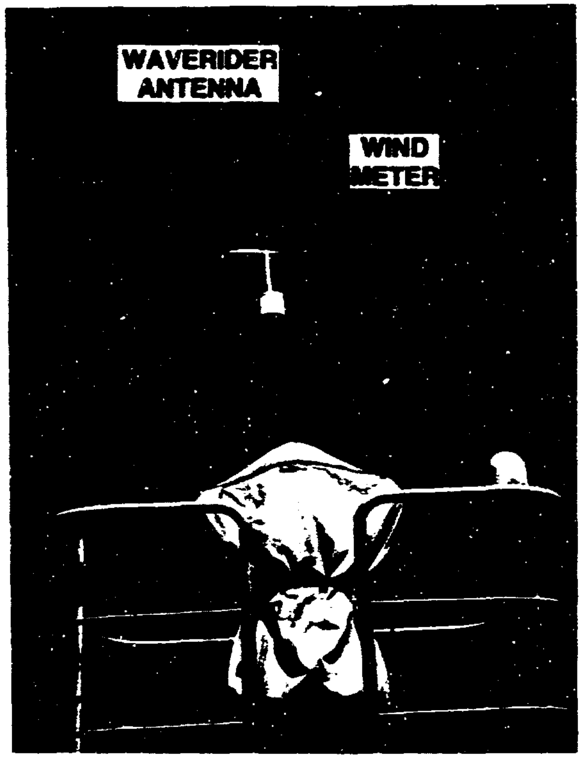


WAVERIDER BUOY (SURF)



ENDECO BUOY (SHIP)

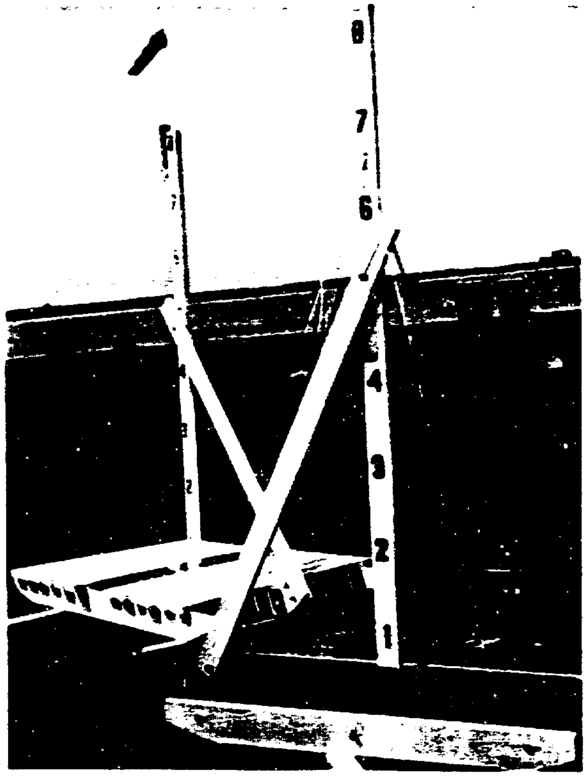
Figure 12 - Photographs of the Wave Buoys as Deployed in the Trial OPS Area



WIND METER AND WAVERIDER BUOY (SURF) ANTENNA

ENDECO BUOY (SHIP) ANTENNA

Figure 13 - Photographs of the Wind Meter and Wave Buoy Receiving Antennas



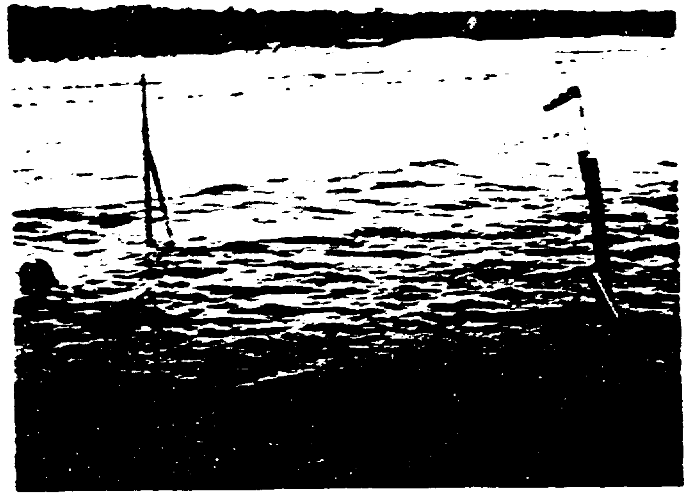


Figure 14 - Photographs of the Surf Sleds

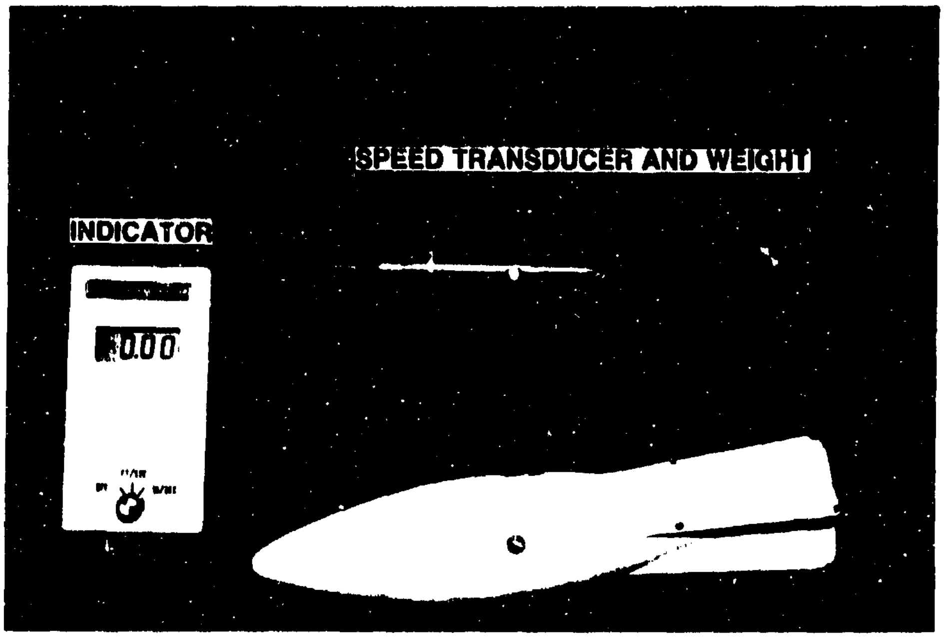
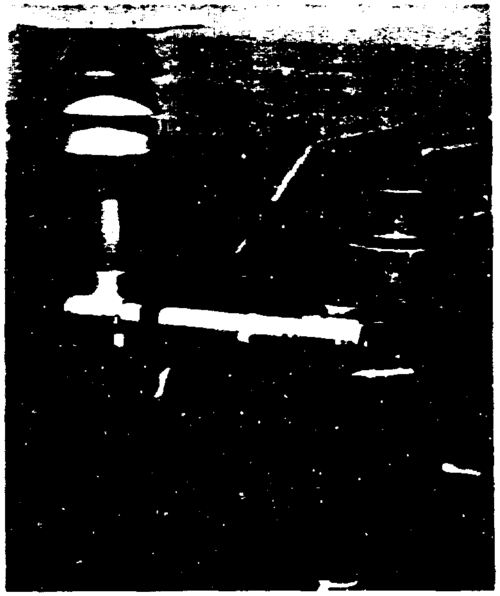
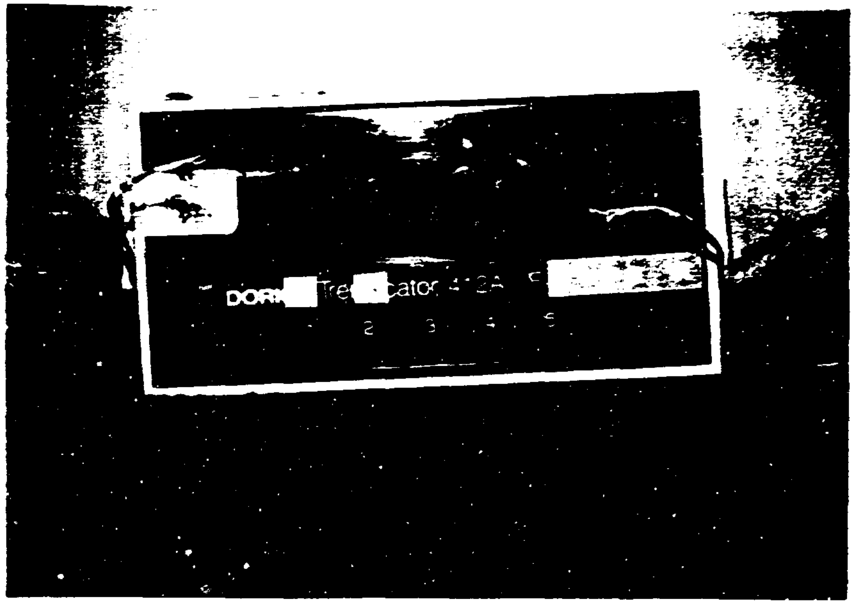


Figure 15 - Photograph of the Current Meter

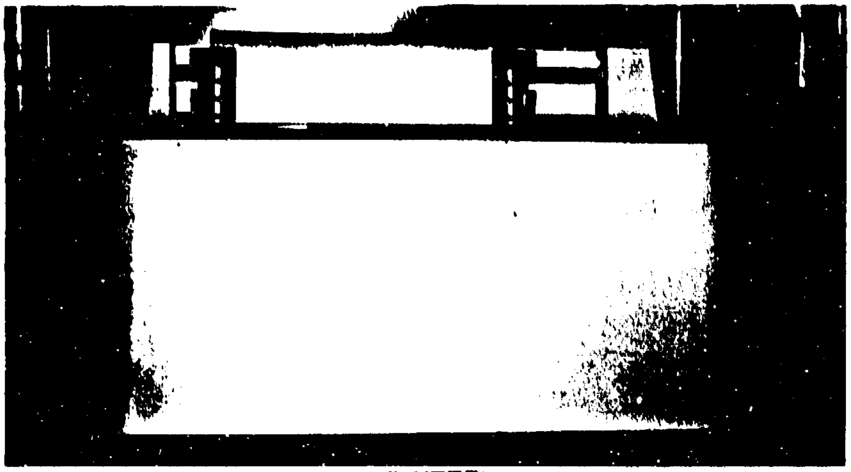


RAIN GAGE AND AIR
TEMPERATURE PROBE

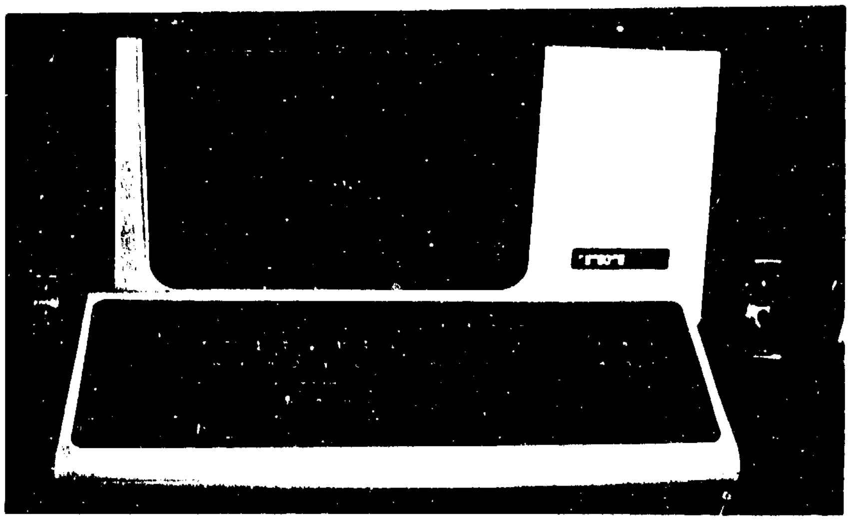


WATER TEMPERATURE PROBE (COILED UP)
AND TEMPERATURE INDICATOR

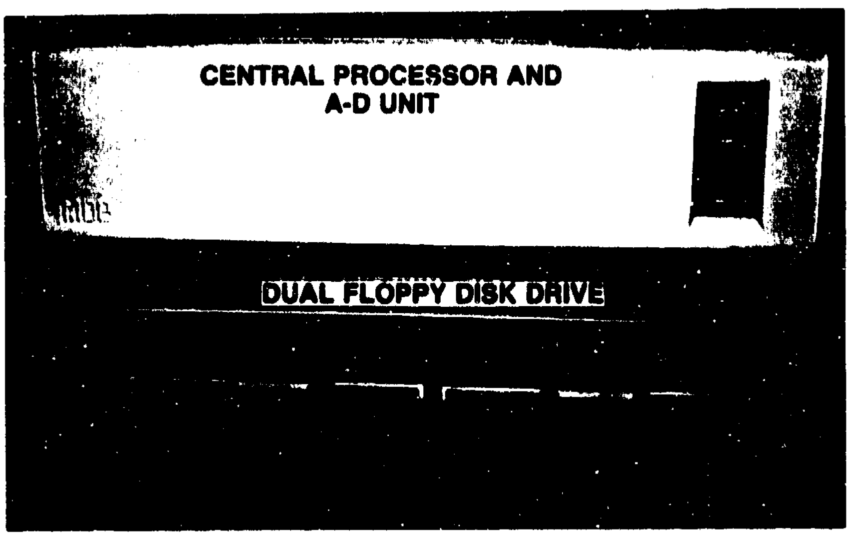
Figure 16 - Photographs of the Rain Gage and Temperature Probes



PRINTER



CRT DISPLAY AND KEYBOARD



CENTRAL PROCESSOR/A-D UNIT AND DUAL FLOPPY DISK DRIVE

Figure 17 - Photographs of the PDP 1123 Computer System as Installed in PORDACC

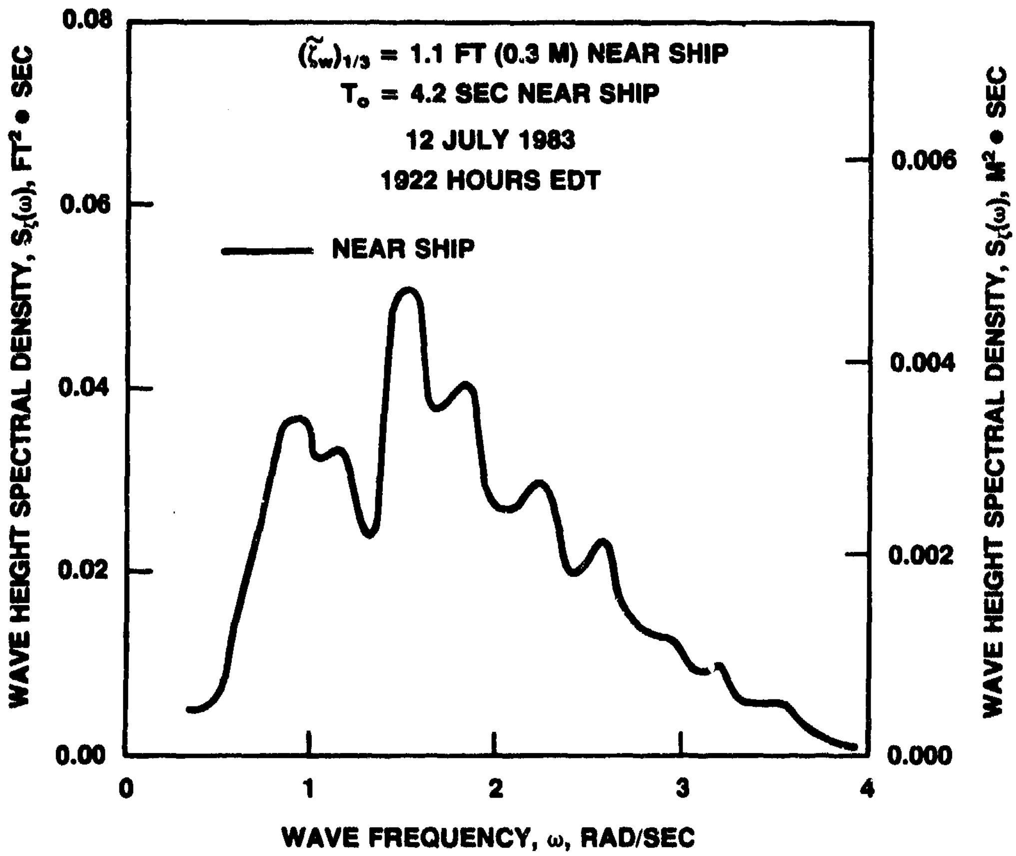


Figure 18 - Wave Spectrum Representing the Maximum Wave Conditions Encountered during the First Day of the Trial (12 July 1983)

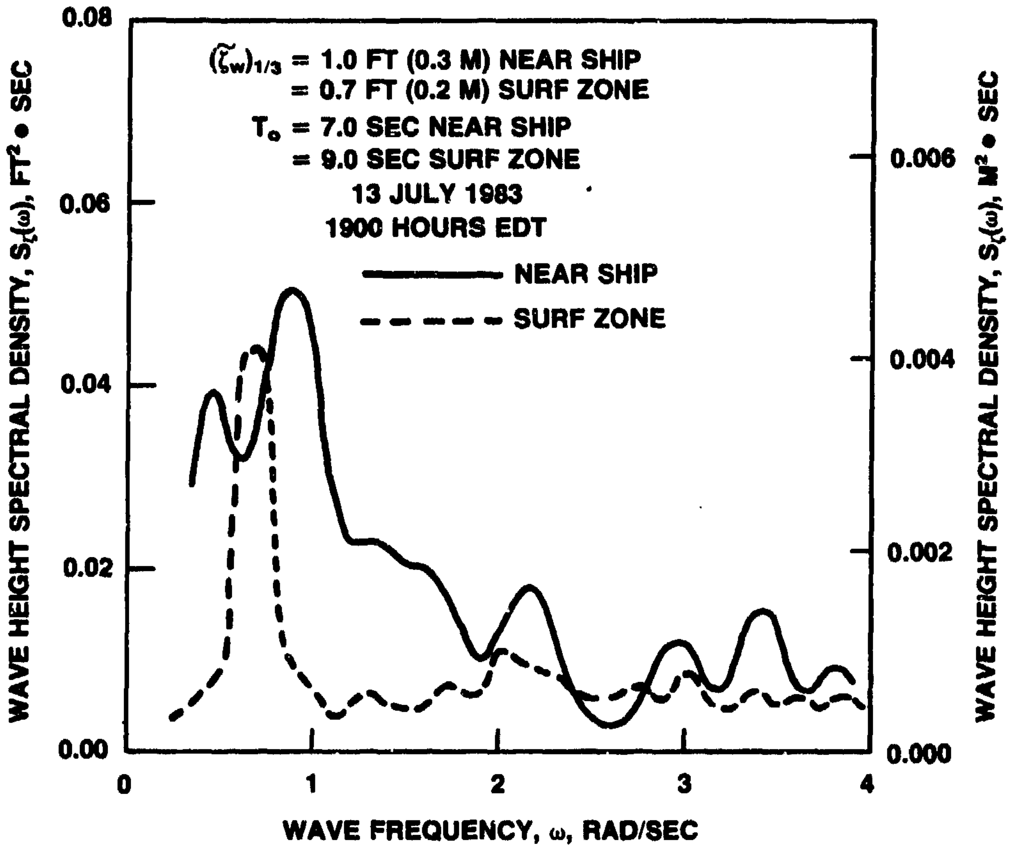


Figure 19 - Wave Spectra Representing the Maximum Wave Conditions Encountered during the Second Day of the Trial (13 July 1983)

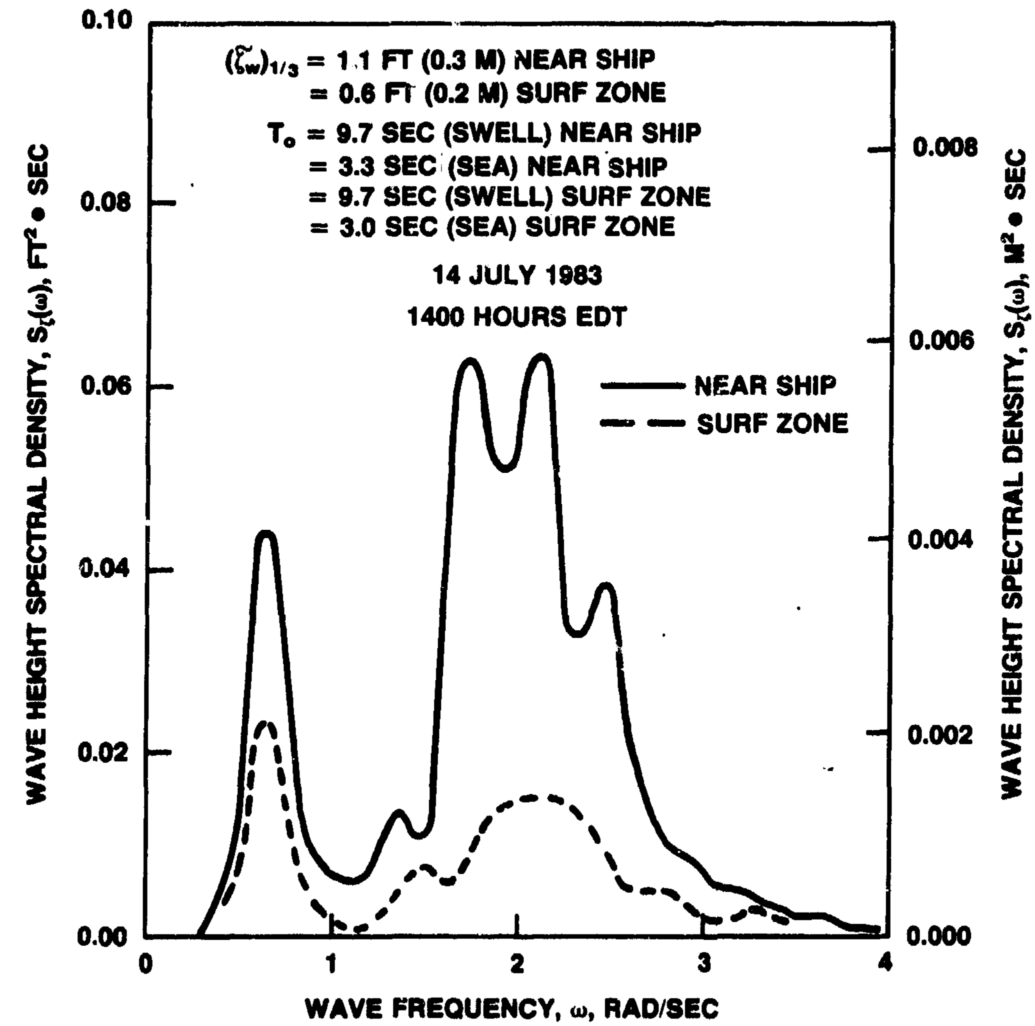


Figure 20 - Wave Spectra Representing the Maximum Wave Conditions Encountered during the Third Day of the Trial (14 July 1983)

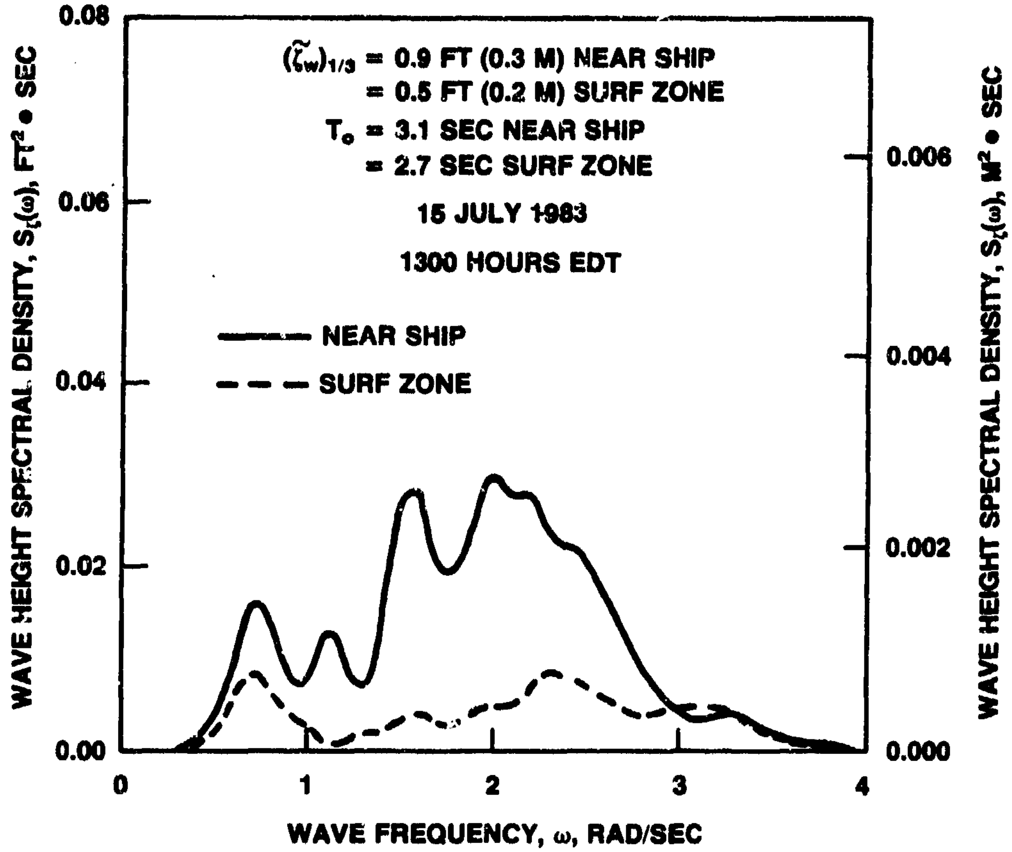


Figure 21 - Wave Spectra Representing the Maximum Wave Conditions Encountered during the Fourth Day of the Trial (15 July 1983)

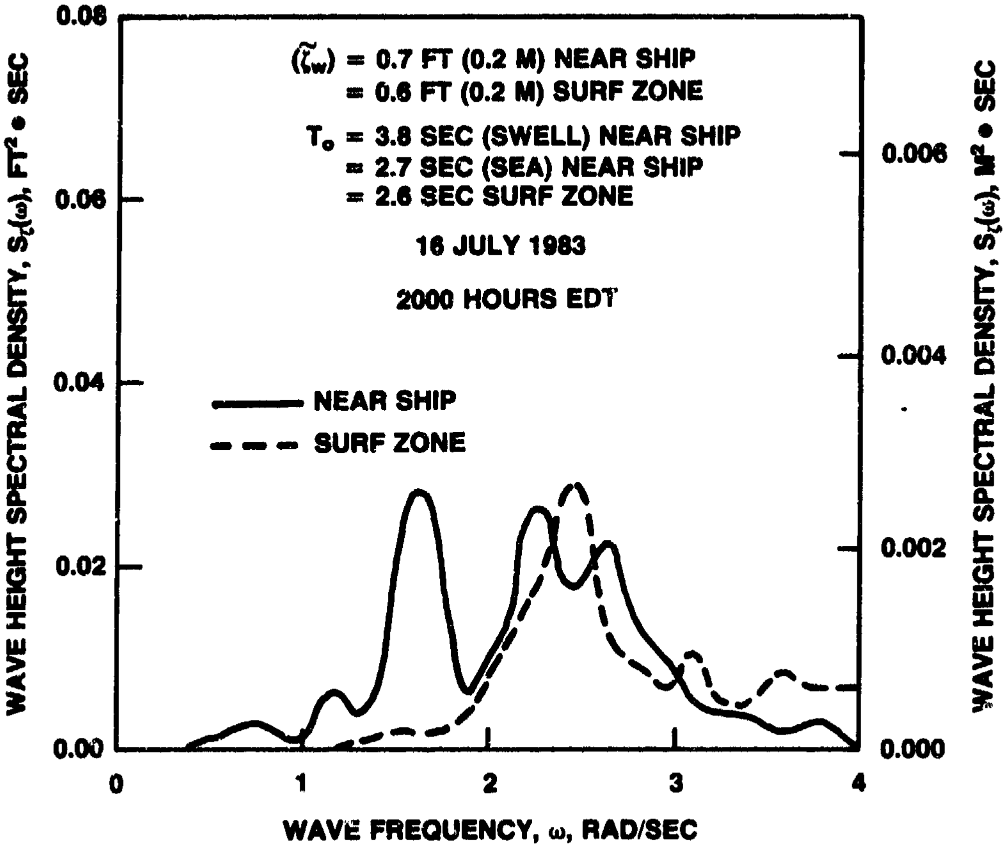


Figure 22 - Wave Spectra Representing the Maximum Wave Conditions Encountered during the Fifth Day of the Trial (16 July 1983)

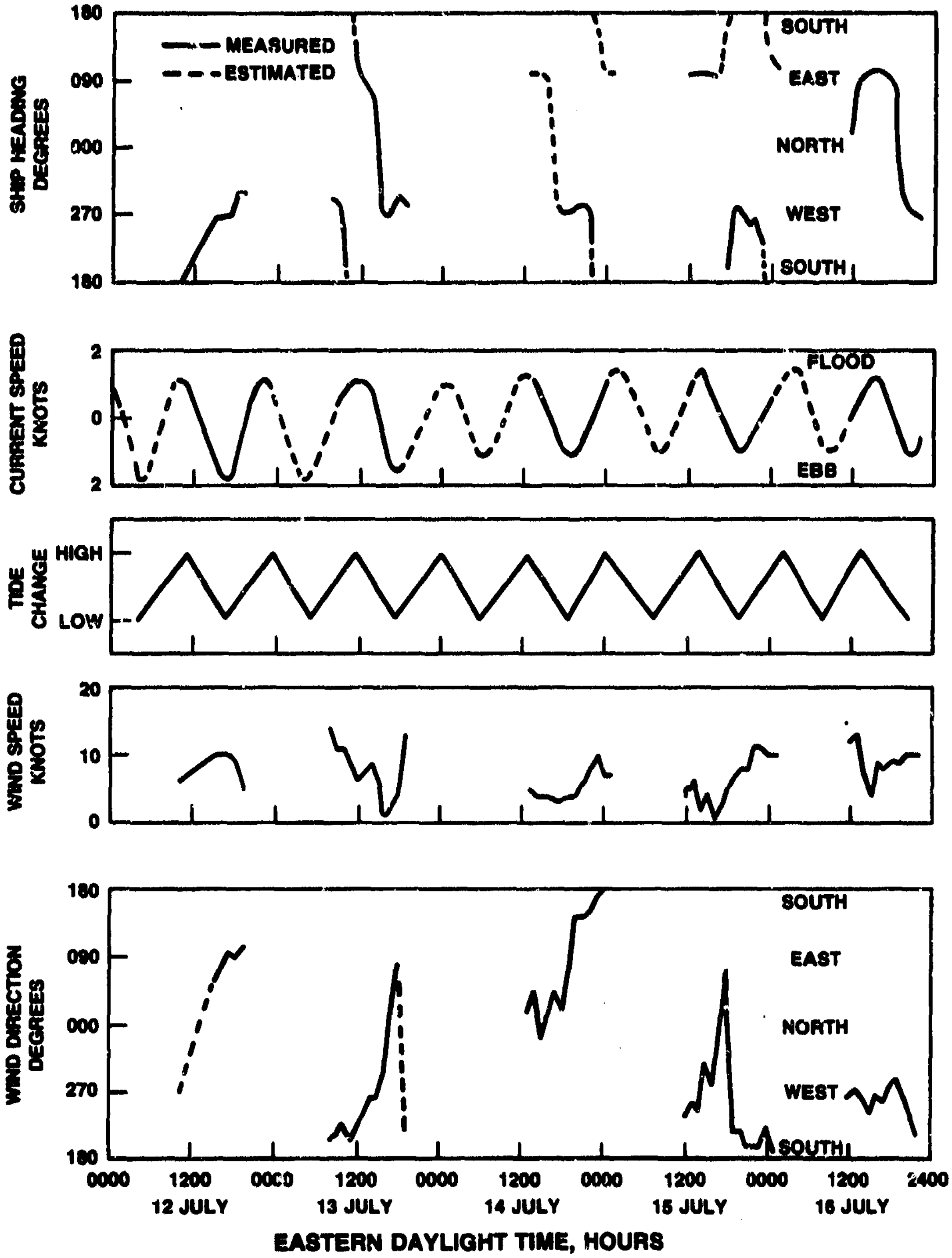


Figure 23 - Ship Heading Variations and Influencing Environmental Conditions versus Date and Time Obtained during the Trial

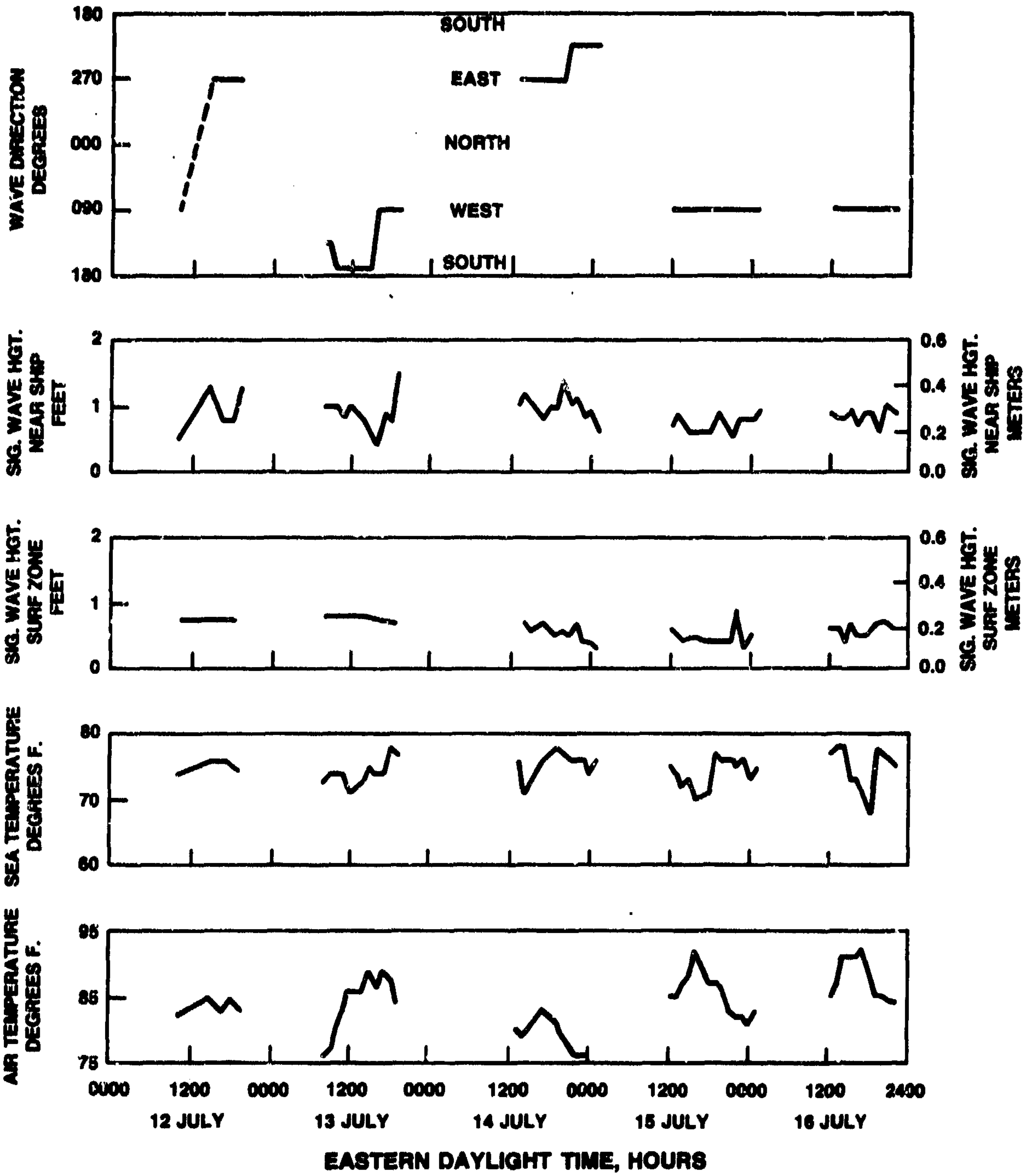


Figure 24 - Wave and Temperature Variations versus Date and Time Obtained during the Trial

TABLE 1 - PARTICULARS OF THE MV CYGNUS, LCU, WARPING TUG, AND A TYPICAL CAUSEWAY SECTION

Particular	MV CYGNUS	LCU	Warping Tug	Causeway Section
Class	RABENFELS' RO/RO	LCU 1610	LWT (Home Port Type)	C, B
LOA, ft, m	637.6 (193.2)	134.9 (41.1)	92.9 (28.3)	90.0 (27.4)
B, ft, m	89.1 (27.0)	29.0 (8.8)	23.0 (7.0)	21.0 (6.4)
T, ft, m	30.0 (9.1)	6.1 (1.9)	6.5 (2.0)	1.65 (0.5)
Δ, LTSW, tonnes	26,457.0 (26,880.0)	375.0 (381.0)	120.0 (122.0)	80.0 (81.4)

TABLE 2 - SUMMARY OF MEASUREMENTS DURING THE TRIAL

Measurement	Location	Transducer
Wave height	Near the ship	ENDECO directional buoy
North/South tilt	Near the ship	ENDECO directional buoy
East/West tilt	Near the ship	ENDECO directional buoy
Wave height	Near the beach	Waverider buoy
Wind speed	Top of ship's superstructure	Anemometer
Wind direction	Top of ship's superstructure	Anemometer
Current speed	Side of TUNISIA	Current meter
Water temperature	Side of TUNISIA	Temperature probe
Air temperature	Top of PORDACC	Temperature probe
Precipitation	Top of PORDACC	Rain gage
Barometric pressure	Inside of PORDACC	Barometer
Ship heading	TUNISIA pilot house	Gyrocompass
Ship pitch	Portside, main deck,	Gyroscope
Ship roll	Portside, main deck,	Gyroscope
Ship vertical acceleration	Portside, main deck,	Vertical Accelerometer

TABLE 3 - SUMMARY OF ENVIRONMENTAL CONDITIONS DURING THE TRIAL

Date	Time hours, EDT	Temperature deg F.		Wind Speed knots	Wind Direction deg	Ship Significant Wave Height and Direction ft (m)	Surf Significant Wave Height ft (m)	Current Speed and Direction E-Ebb, F-Flood knots	Visibility nm (km)	Barometer Reading
		Water	Air							
12 July	1000	74	82	6	270	0.5 (0.2)W	0.6 (0.2)	--	Haze 4 (7.2)	30.32
	1502	76	85	10	054	1.3 (0.4)E	0.6 (0.2)	1.2 E		30.29
	1651	76	83	10	097	0.8 (0.2)E	0.6 (0.2)	1.8 E		30.25
	1805	75	85	9	092	0.8 (0.2)E	0.6 (0.2)	1.4 E		30.25
	1922	74	83	5	110	1.3 (0.4)E	0.6 (0.2)	0		30.24
13 July	0808	73	76	14	204	1.0 (0.3)SW	0.8 (0.2)	0.4 F	Extreme Haze 3 (5.4)	30.30
	0900	74	77	11	214	1.0 (0.3)SW	0.8 (0.2)	0		30.30
	1000	74	80	11	230	1.0 (0.3)S	0.8 (0.2)	--		30.30
	1100	74	83	8	204	0.8 (0.2)S	0.8 (0.2)	--		30.30
	1200	71	86	6	210	1.0 (0.3)S	0.8 (0.2)	1.1 F		30.30
	1400	73	86	9	263	0.8 (0.2)S	0.8 (0.2)	—		30.26
	1500	75	89	6	260	0.6 (0.2)S	0.8 (0.2)	0.4 F		30.23
	1610	74	87	1	298	0.4 (0.1)W	0.8 (0.2)	1.1 E		30.21
	1700	74	89	2	033	0.9 (0.3)W	0.8 (0.2)	1.3 E		30.20
	1800	78	88	4	080	0.8 (0.2)W	0.7 (0.2)	1.6 E		30.20
	1900	77	84	13	220	1.5 (0.5)W	0.7 (0.2)	1.4 E		30.20
14 July	1300	76	80	5	021	1.0 (0.3)E	--	1.3 F	Slight Haze 7 (12.6)	30.28
	1400	71	79	4	047	1.2 (0.4)E	0.7 (0.2)	1.1 F		30.26
	1500	73	80	4	345	1.0 (0.3)E	0.6 (0.2)	0		30.26
	1700	76	83	3	042	0.8 (0.2)E	0.7 (0.2)	0.6 E		30.25
	1800	77	82	3	018	1.0 (0.3)E	0.6 (0.2)	0.8 E		30.24
	1900	78	81	4	071	1.0 (0.3)E	0.5 (0.2)	1.0 E		30.24
	2000	77	79	4	144	1.4 (0.4)D	0.6 (0.2)	1.1 E	Dark	30.24
	2100	76	77	6	143	1.0 (0.3)D	0.5 (0.2)	0.5 E		30.23
	2200	76	76	8	153	1.1 (0.3)D	0.7 (0.2)	0		30.25
	2300	76	76	10	171	0.8 (0.2)D	0.4 (0.1)	0.4 F		30.24
	2400	74	75	7	179	0.9 (0.3)D	0.4 (0.1)	1.1 F		30.24
	0100	76	75	7	185	0.6 (0.2)D	0.3 (0.1)	1.4 F		30.23

D - Dark, could not see waves.

TABLE 3 (Continued)

Date	Time hours, EDT	Temperature deg F. Water	Temperature deg F. Air	Wind Speed knots	Wind Direction deg	Ship Significant Wave Height and Direction ft (m)	Surf Significant Wave Height ft (m)	Current Speed and Direction E-Ebb, F-Flood knots	Visibility nm (km)	Barometer Reading
15 July	1205	75	85	4	238	0.7 (0.2)W	0.6 (0.2)	0.6 F	Slight Haze 6 (10.8)	30.20
	1300	74	85	6	256	0.9 (0.3)W	0.5 (0.2)	1.1 F		30.20
	1400	72	87	2	243	0.7 (0.2)W	0.4 (0.1)	1.4 F		30.18
	1500	73	88	4	317	0.6 (0.2)-	0.5 (0.2)	1.0 F		30.16
	1600	70	92	1	279	0.6 (0.2)-	0.5 (0.2)	0.2 F		30.15
	1700	--	--	2	--	0.6 (0.2)-	0.4 (0.1)	0		--
	1800	71	87	5	067	0.6 (0.2)-	0.4 (0.1)	--		30.12
	1900	77	87	7	218	0.9 (0.3)-	0.4 (0.1)	0.9 E		30.10
	2000	76	86	8	216	0.7 (0.2)-	0.4 (0.1)	1.0 E	Dark	30.12
	2100	76	83	8	199	0.5 (0.2)D	0.4 (0.1)	0.7 E		30.13
	2200	75	82	11	202	0.8 (0.2)D	0.9 (0.3)	--		30.13
	2300	76	82	11	200	0.8 (0.2)D	0.3 (0.1)	0		30.13
	2400	73	81	10	219	0.8 (0.2)D	0.5 (0.2)	0.2 F		30.10
	0100	75	83	10	191	0.9 (0.3)D	--	0.7 F		30.10
16 July	1205	77	85	12	265	0.9 (0.3)W	0.6 (0.2)	0	Extreme Haze 2 (3.6)	30.14
	1300	78	87	13	276	0.8 (0.2)W	0.6 (0.2)	0.6 F		30.12
	1400	78	91	7	261	0.8 (0.2)W	0.4 (0.1)	0.6 F		30.11
	1500	73	90	4	240	0.9 (0.3)W	0.7 (0.2)	1.2 F		30.10
	1600	73	90	9	268	0.7 (0.2)W	0.5 (0.2)	1.2 F		30.08
	1700	71	91	8	258	0.9 (0.3)W	--	0.5 F		30.06
	1800	68	88	9	280	0.9 (0.3)W	0.5 (0.2)	0		30.06
	1909	78	85	9	293	0.6 (0.2)W	0.7 (0.2)	0.2 E		30.04
	2000	77	85	10	258	1.0 (0.3)D	0.7 (0.2)	1.0 E	Dark	30.06
	2100	76	84	--	--	--	--	1.1 E		30.07
	2200	75	84	10	211	0.9 (0.3)D	0.6 (0.2)	0.6 E		30.08

TABLE 4 - SUMMARY OF SIGNIFICANT AMPLITUDES OF MEASUREMENTS

Date	Time hours, EDT	Ship Pitch deg	Ship Roll deg	Ship Vertical Acceleration g's	Wind Speed knots	Surf Wave Height* ft (m)	Ship Wave Height* ft (m)
13 July	1610	0.1	0.1	0.001	0.8	--	0.4 (0.1)
	1700	0.2	0.1	0.001	1.6	--	0.9 (0.3)
	1800	0.1	0.5	0.002	1.3	--	0.8 (0.2)
	1900	0.1	0.2	0.002	1.6	--	1.5 (0.5)
14 July	1300	0.2	0.4	0.001	1.5	--	1.0 (0.3)
	1400	0.1	0.1	0.001	1.0	0.7 (0.2)	1.2 (0.4)
	1500	0.1	0.1	0.001	0.9	0.6 (0.2)	1.0 (0.3)
	1700	0.1	0.1	0.002	1.7	0.7 (0.2)	0.9 (0.3)
	1800	0.1	0.1	0.001	1.8	0.5 (0.2)	1.0 (0.3)
	1900	0.1	0.1	0.001	1.4	0.5 (0.2)	1.0 (0.3)
	2000	0.2	0.2	0.001	1.8	0.6 (0.2)	1.4 (0.4)
	2100	0.2	0.2	0.001	3.0	0.5 (0.2)	1.0 (0.3)
	2200	0.1	0.2	0.002	2.0	0.8 (0.2)	1.1 (0.3)
	2300	0.2	0.1	0.001	1.8	0.3 (0.1)	0.8 (0.2)
	2400	0.1	0.2	0.001	5.4	0.4 (0.1)	0.9 (0.3)
	0100	0.1	0.1	0.001	6.0	0.3 (0.1)	0.6 (0.2)
15 July	1200	0.1	0.2	0.002	2.0	0.6 (0.2)	0.7 (0.2)
	1300	0.1	0.1	0.001	2.5	0.5 (0.2)	0.9 (0.3)
	1400	0.1	0.2	0.001	1.3	0.4 (0.1)	0.7 (0.2)
	1500	0.1	0.1	0.001	1.0	0.5 (0.2)	0.6 (0.2)
	1600	0.2	0.2	0.001	1.0	0.5 (0.2)	0.6 (0.2)
	1700	0.1	0.1	0.002	1.0	0.4 (0.1)	0.6 (0.2)
	1800	0.1	0.1	0.001	1.5	0.4 (0.1)	0.6 (0.2)
	1900	0.1	0.3	0.001	1.0	0.4 (0.1)	0.9 (0.3)
	2000	0.2	0.7	0.002	0.5	0.4 (0.1)	0.7 (0.2)
	2100	0.1	0.2	0.001	0.4	0.4 (0.1)	0.4 (0.1)
	2200	0.2	0.3	0.001	0.6	0.9 (0.3)	0.8 (0.2)
	2300	0.1	0.1	0.001	0.7	0.3 (0.1)	0.8 (0.2)

*These values are significant double amplitudes.

TABLE 4 (Continued)

Date	Time hours, EDT	Ship Pitch deg	Ship Roll deg	Ship Vertical Acceleration g's	Wind Speed knots	Surf Wave Height* ft (m)	Ship Wave Height* ft (m)
	2400	0.1	0.1	0.001	3.0	0.4 (0.1)	0.8 (0.2)
	0100	0.1	0.1	0.001	3.8	1.2 (0.4)	0.9 (0.3)
16 July	1200	0.1	0.2	0.003	1.5	0.7 (0.2)	0.8 (0.2)
	1400	0.6	0.9	0.026	0.2	0.8 (0.2)	0.7 (0.2)
	1500	0.1	0.5	0.001	3.3	0.7 (0.2)	0.9 (0.3)
	1600	0.1	0.4	0.002	4.7	0.5 (0.2)	0.7 (0.2)
	1700	0.1	0.1	0.001	2.5	--	0.9 (0.3)
	1800	0.1	0.1	0.001	3.1	0.5 (0.2)	1.0 (0.3)
	1900	0.1	0.2	0.001	0.9	0.7 (0.2)	0.6 (0.2)
	2000	0.1	0.1	0.001	0.8	0.7 (0.2)	1.0 (0.3)
	2200	0.2	0.7	0.001	0.6	0.6 (0.2)	0.9 (0.3)

TABLE 5 - SUMMARY OF RANGE VALUES OF MEASUREMENTS

Date	Time hours, EDT	Ship Pitch deg	Ship Roll deg	Ship Vertical Acceleration g's	Wind Speed knots	Surf Wave Height ft (m)	Ship Wave Height ft (m)
13 July	1610	0.2	0.4	0.003	1.7	--	0.6 (0.2)
	1700	0.3	0.4	0.003	4.0	--	1.8 (0.5)
	1800	0.4	1.1	0.004	3.6	--	1.3 (0.4)
	1900	0.3	0.4	0.006	3.8	--	--
14 July	1300	0.5	0.8	0.006	4.4	--	1.7 (0.5)
	1400	0.3	0.4	0.004	3.6	1.3 (0.4)	2.4 (0.7)
	1500	0.4	0.5	0.004	2.4	1.1 (0.3)	1.7 (0.5)
	1700	0.2	0.3	0.006	10.7	1.2 (0.4)	1.4 (0.4)
	1800	0.2	0.3	0.003	4.7	0.9 (0.3)	1.6 (0.5)
	1900	0.3	0.3	0.004	5.1	0.9 (0.3)	1.6 (0.5)
	2000	0.4	0.7	0.004	4.9	1.1 (0.3)	--
	2100	0.4	0.4	0.005	9.3	0.8 (0.3)	1.7 (0.5)
	2200	0.3	0.4	0.005	5.2	1.0 (0.3)	1.9 (0.6)
	2300	0.4	0.3	0.004	4.7	0.6 (0.2)	1.2 (0.4)
	2400	0.4	0.5	0.004	13.1	0.8 (0.3)	1.5 (0.5)
	0100	0.3	0.4	0.004	14.4	0.5 (0.2)	1.0 (0.3)
15 July	1200	0.3	0.4	0.005	6.0	1.1 (0.3)	1.1 (0.3)
	1300	0.3	0.3	0.004	6.6	1.6 (0.5)	2.8 (0.9)
	1400	0.3	0.5	0.003	3.3	0.7 (0.2)	1.3 (0.4)
	1500	0.3	0.4	0.003	3.5	1.1 (0.3)	1.2 (0.4)
	1600	0.4	0.4	0.004	2.2	0.9 (0.3)	1.3 (0.4)
	1700	0.3	1.3	0.006	2.7	0.8 (0.3)	1.1 (0.3)
	1800	0.3	0.4	0.006	3.6	0.6 (0.2)	0.9 (0.3)
	1900	0.3	0.7	0.003	2.7	0.8 (0.3)	--
	2000	0.5	1.6	0.006	2.9	0.7 (0.2)	1.1 (0.3)
	2100	0.3	0.5	0.003	1.5	0.7 (0.2)	0.8 (0.3)
	2200	0.4	0.8	0.005	1.8	1.3 (0.4)	1.4 (0.4)
	2300	0.2	1.5	0.005	2.3	0.6 (0.2)	1.1 (0.3)

TABLE 5 (Continued)

Date	Time hours, EDT	Ship Pitch deg	Ship Roll deg	Ship Vertical Acceleration g's	Wind Speed knots	Surf Wave Height ft (n)	Ship Wave Height ft (m)
	2400	0.3	0.4	0.004	9.5	0.8 (0.3)	1.2 (0.4)
	0100	0.2	0.4	0.005	10.6	1.4 (0.4)	1.4 (0.4)
16 July	1200	0.3	1.5	0.008	4.3	1.2 (0.4)	1.6 (0.5)
	1400	1.3	1.9	0.093	0.6	1.5 (0.5)	1.2 (0.4)
	1500	0.3	2.0	0.004	0.9	1.5 (0.5)	2.1 (0.6)
	1600	0.3	0.8	0.056	12.9	0.9 (0.3)	1.2 (0.4)
	1700	0.2	1.5	0.004	6.8	1.9 (0.6)	1.4 (0.4)
	1800	0.3	0.3	0.004	9.0	0.9 (0.3)	1.7 (0.5)
	1900	0.3	0.5	0.004	2.5	1.1 (0.3)	1.2 (0.4)
	2000	0.3	0.3	0.004	1.5	1.3 (0.4)	1.5 (0.5)
	2200	0.5	1.3	0.004	1.4	1.1 (0.3)	1.5 (0.5)