NAVY DEPARTMENT

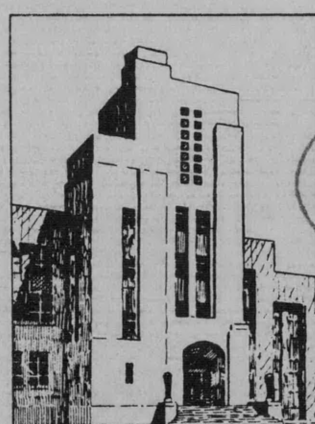
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

SEA TESTS OF THE USCGC UNIMAK
PART 1 - GENERAL OUTLINE OF TESTS AND TEST RESULTS

by [redacted]

Norman H. Jasper and John T. Birmingham



RESEARCH AND DEVELOPMENT REPORT

March 1956

Report 976

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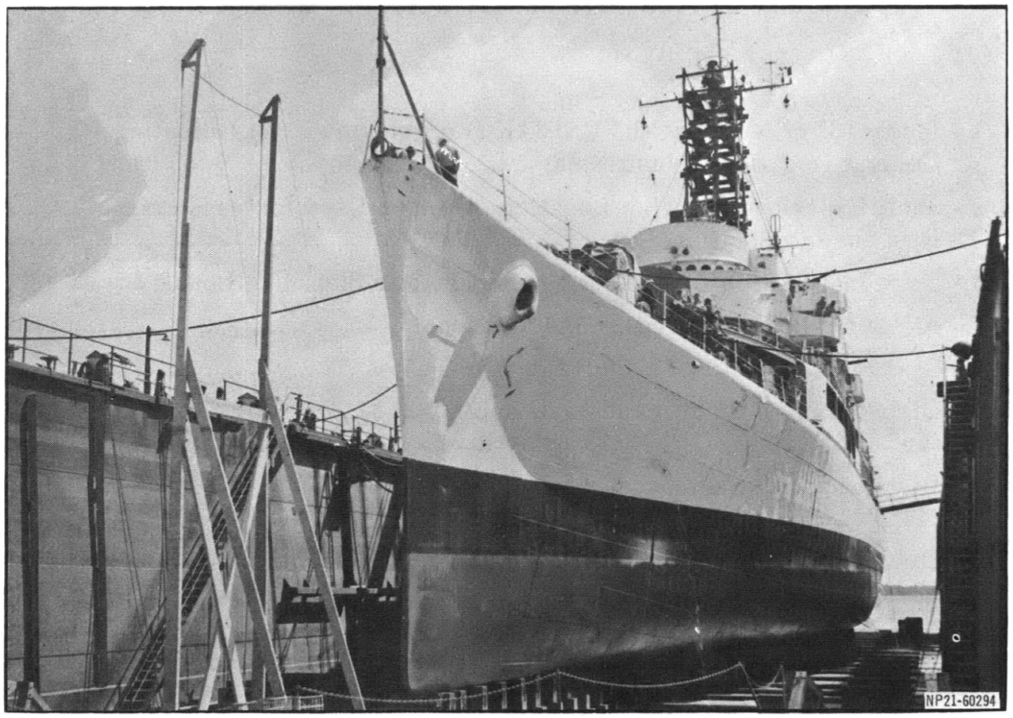
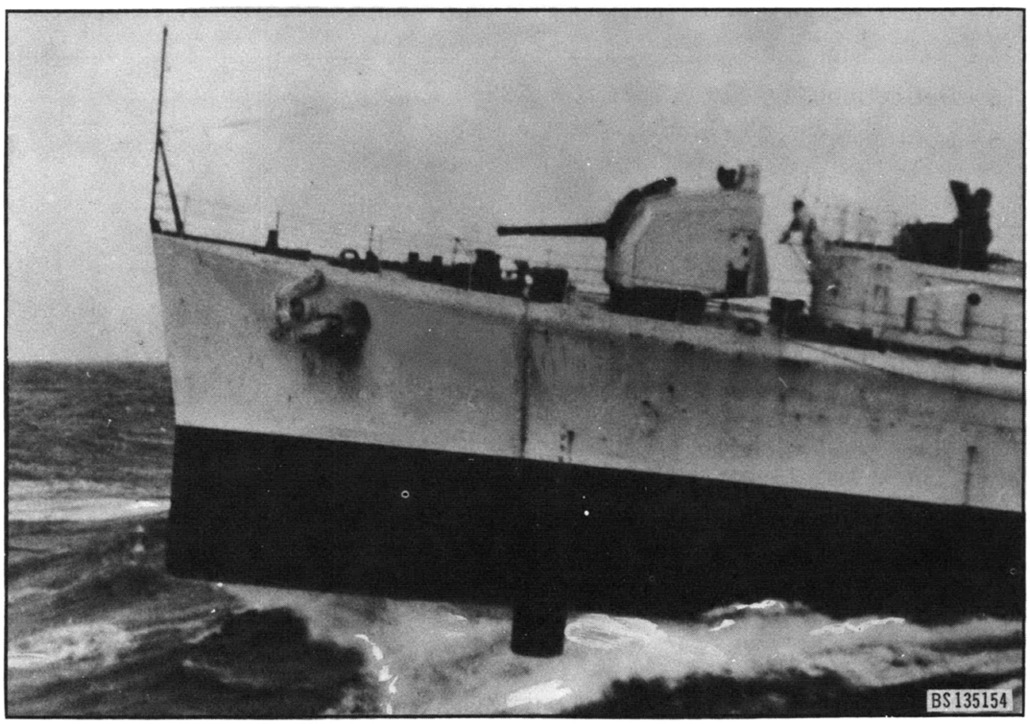


United States Coast Guard Cutter UNIMAK



Coast Guard Cutter Slamming

ABSTRACT

Sea trials of the USCGC UNIMAK were conducted in the North Atlantic Ocean during the winter of 1954 and 1955. Measurements of ship motions, hull girder stresses, bottom pressures, stresses in the bottom structure incident to slamming and stereophotographs of the sea were obtained under a wide variety of sea conditions, ship speeds, and headings relative to the waves. This report outlines the scope of the tests and presents the data in some detail in order to expedite their use by other investigators. Sample oscillograms are included.

During the entire tests, the maximum magnitudes recorded for slamming pressures were between 200 and 300 psi; for variation in roll angle, 40 deg; for variation in pitch angle, 18.5 deg; for variation in heave acceleration, 0.55 gravity units; and for variation in hull girder stress at main deck amidships, 5900 psi. Statistical gages, which were operative continuously, indicated that on a few occasions the oscillographic values were exceeded.

INTRODUCTION

The David Taylor Model Basin is conducting a long-range research project[1] to evaluate present methods of ship structural design and to suggest improvements based on a more realistic knowledge of the loads, stresses, and motions which ships experience in service. Instrumentation developed for the purpose of collecting service data was installed on the USCGC UNIMAK during a voyage in the North Atlantic. A similar installation had previously been made on a sister ship, the USCGC CASCO.[2] At that time it was observed that the water pressures acting on the ship's bottom near the forward quarter point during slamming of the bow against the waves were much larger than those assumed for the design of bottom plating. The indication was that these pressures are of the order of several hundred pounds per square inch. The pressure gage and the recording equipment were not adequate to give an accurate pressure-time history, nor was it possible to assess the area of bottom plating over which these high "slamming" pressures were acting. One of the main objectives of the UNIMAK tests was to measure the magnitudes and extent of these slamming pressures and the corresponding plate stresses and deflections. From these data the severity of this type of loading can be evaluated and theoretical methods which have been developed[3,4] for possible application to a more realistic design of bottom plating subject to these intense loads can be checked.

Another main objective of the UNIMAK trials was the collection of sufficient data on ship motions and longitudinal hull girder stresses (bending moment) to determine the frequency distribution of these quantities for different combinations of sea conditions, ship's speed, and ship's heading relative to the waves. These frequency distributions are to be used to establish the service stresses and motion that this type of vessel may be expected to experience during any portion of her service life. These data will also be utilized to test the theories that amplitudes of ship motions and of hull girder stresses experienced over long periods of time (years) follow a statistical distribution pattern which may be approximated by a log-normal distribution[5] whereas the distribution of sea waves and ship motions for a given set

[1]References are listed on page 36.

of environmental conditions, assumed stationary in time, are expected to follow a one-parameter distribution.[6, 7]

Secondary objectives of the UNIMAK tests were as follows:

1. To determine the "power spectra" of the ship motions in order to help test the validity of a statistical theory of ship motion (for a given sea condition and ship's heading and speed) proposed in Reference 7.

2. To provide experimental data on the simultaneous time variation of slamming pressures at several selected points in a transverse section of the ship in order to provide a basis against which theoretical methods of computing such pressure variations[8] may be evaluated, at least qualitatively.

3. To indicate the approximate maximum hull girder stresses that are experienced under severe sea conditions and compare them with the static stresses ordinarily computed on the trochoidal wave.

4. To determine the severity of the hull girder stresses incident to severe slamming in rough seas and to compare these with the ordinary wave-induced stresses.

5. To determine the maximum angles of roll and pitch that this type of vessel is likely to experience.

6. To provide observations and measurements of wave heights and wave lengths for comparison with estimates of Weather Bureau personnel on board the UNIMAK.

7. To provide experimental data on ship's motion, hull girder stresses, and wave characteristics which may serve as an experimental check for the evaluation of present and future theories and model test procedures dealing with these aspects.

The sea trials were made during two weather patrols of the USCGC UNIMAK in the North Atlantic Ocean. The first patrol assignment was to Station D (lat. 44° 00′ N, long. 41° 00′ W) from 11 October 1954 to 12 November 1954. The second patrol assignment was to Station B (lat. 56° 30′ N, long. 51° 00′ W), from 8 January 1955 to 6 February 1955.

It is the purpose of this report to give an outline of the scope of the tests and of the results. There will be a tabulation or index of the type of data obtained. Several sample oscillograms will be reproduced, and the magnitudes of the largest measured hull girder stresses, motions, and slamming pressures will be given. This report will list the data in some detail, and the conditions under which they were obtained in the hope that other researchers will utilize some of these available data.

It is intended to publish several reports which will deal with particular aspects of this study:

1. A report on slamming[9] will treat the pressures acting on the bottom near the bow incident to slamming as well as the resulting plate stresses and deflections. This report will

compare the measured values of stress and deflection with those computed on the basis of theoretical considerations.

2. A report on distribution patterns[10] of hull stresses and motions will apply the methods of statistics to the presentation, prediction, and specification of the service stresses (bending moments) and motions of vessels similar to the UNIMAK (formerly a U.S. Navy AVP) for the North Atlantic service.

TEST INSTALLATION

In general, the shipboard instrument installation consisted of two distinct groups of equipment, one to study the transient response of the structure due to loads incident to slamming and another to measure the slow variations incident to the rigid-body motion of the ship; see Figure 1.

Instruments in the first group must be able to follow faithfully the rapid variation in signals proportional to the strains, pressures, and ship motions which are a consequence of the slamming phenomenon. The pressure, strain, and deflection gage signals had flat responses from zero to approximately 500 cps. The output of the accelerometer at the bow was flat to about 100 cps. In order to resolve the time variation of the measured signals, high recording speeds had to be used; this, in turn, made it desirable to provide special arrangements*

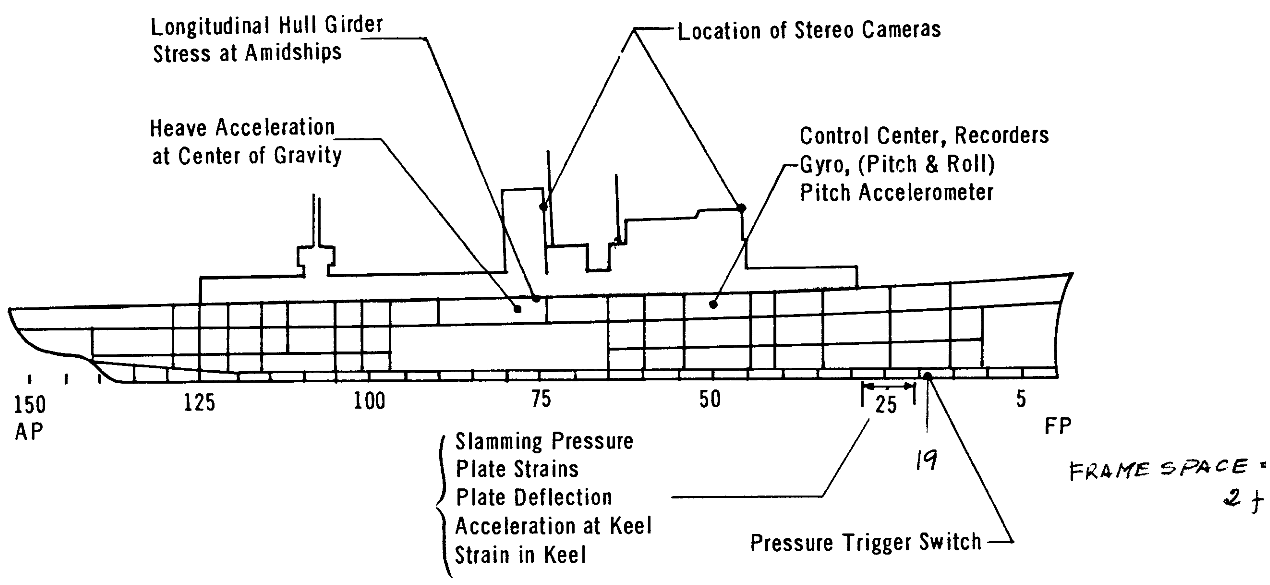


Figure 1 - Inboard Profile of USCGC UNIMAK (Formerly AVP 31) Indicating General Location of Instruments

Length Between Perpendiculars = 300 ft; Extreme Beam = 41 3/4 in.; Design Draft = 11 ft 7 1/16 in.

*This was accomplished by installation at Frame 19 of a trigger mechanism, consisting of a relay actuated by a pressure gage located near the bow. Whenever the pressure gage emerges from the sea (pressure falls below a preset value), the relay closes and starts a recording cycle which lasts for a preset interval of time of the order of 20 sec.

so that the desired data were recorded for a time duration long enough for the required analysis but not longer than necessary.

The second group of instruments are intended only to determine the "rigid-body" stresses and motions. Here the variations in stress and motion are quite slow, with periods of the order of 7 sec, and it is desirable to record at very slow speeds and over a sufficiently long period of time so that a good representative sample of data is obtained for the particular environmental conditions encountered.

SLAMMING

Most of the equipment which was installed to measure the response incident to slamming was located between Frames 23 and 24; see Figure 2. This location was chosen because (a) the vessels of this class had evidenced damage to bottom plating in this area and (b) the pressure gage on the USCGC CASCO[2] had been installed in the same area (15 in. forward of Frame 24) and had often indicated slamming pressures subsequent to emergence of the keel from the sea. Thus it was expected that slamming pressures of appreciable magnitudes could be recorded near Frame 24. The gage locations (for transient response) are listed in Table 1 and shown in Figures 2 and 3.

Four pressure gages were installed along a transverse line running from the keel to Longitudinal 1 on the starboard side. Four additional pressure gages were installed next to the keel along a longitudinal line extending from Frame 21 to about Frame 29. It was thus

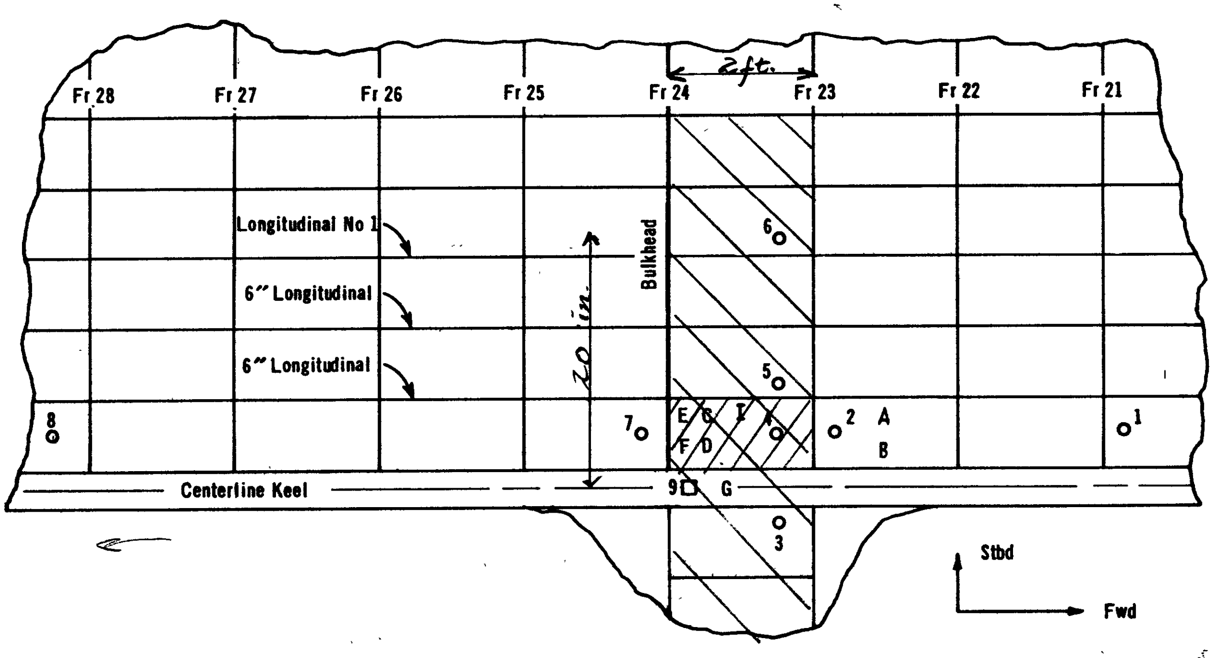


Figure 2 - Shell Expansion Showing Location of Gages Used for Measuring Response to Slamming Loads

The frame spacing is 24 in.

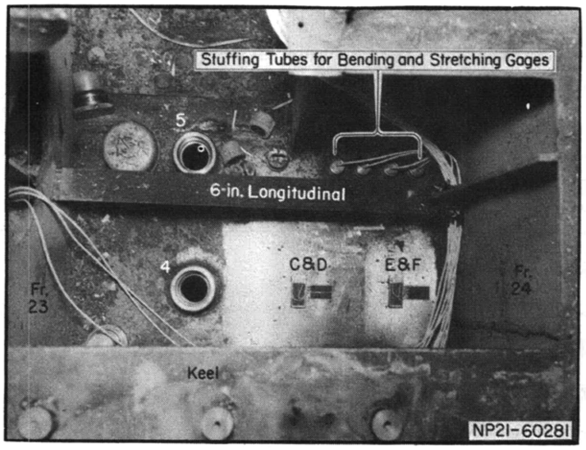


Figure 3a - Test Panel

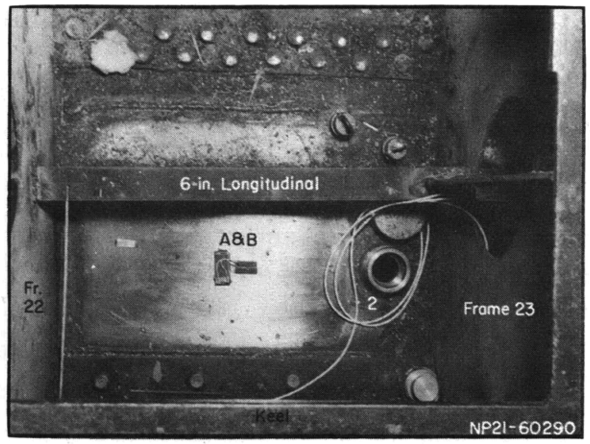


Figure 3b - Panel Just Forward of Test Panel

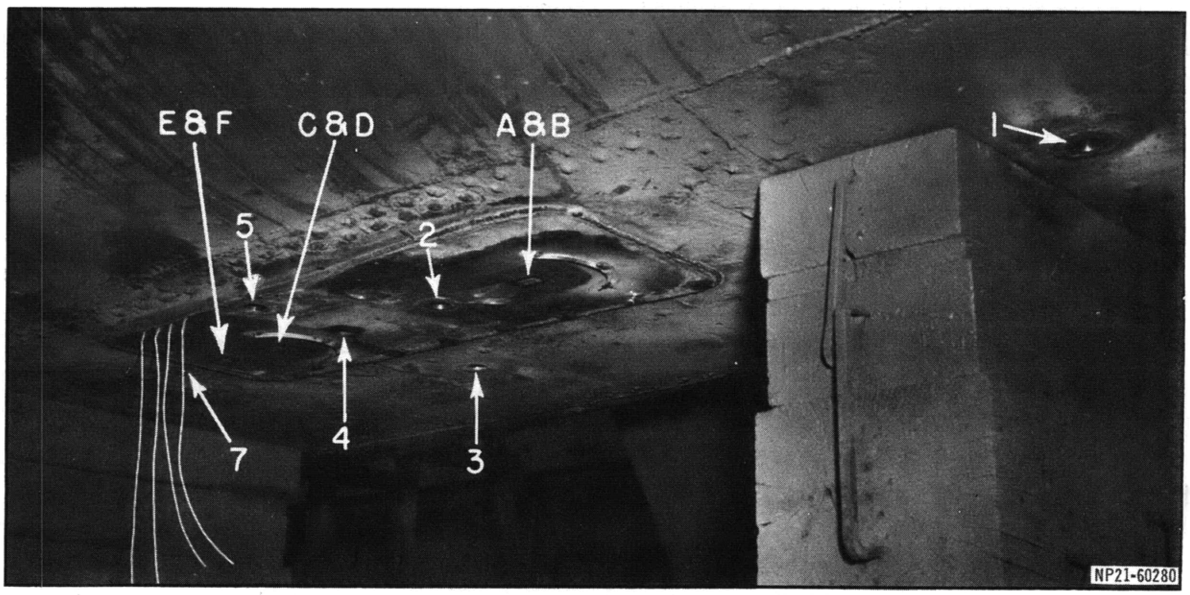


Figure 3c - Test Installation Looking from Outside of Hull

Figure 3 - Gage Installation for Measuring Response to Slamming Loads

possible to observe the time sequence and the spatial distribution of the slamming pressures over a portion of the ship's bottom affected by the pressures. One panel adjacent to the keel, between Frames 23 and 24, was instrumented to permit simultaneous measurements of the pressure on the panel, the resulting bending and tensile stresses and deflection of the panel, and the hull girder stresses and accelerations of the keel at a point adjacent to the panel. The output of all these gages was recorded on a Consolidated Engineering Company oscillograph.

TABLE 1

Location of Gages Used for Measuring the Response to Slamming Loads

All dimensions are taken from the edge of the plating stiffeners. For sketch of instrument locations see Figure 2.

Gage	Location	Quantity Measured
1	3 in. forward of Frame 21, 8 1/2 in. starboard of centerline	Pressure
2	3 in. forward of Frame 23, 8 1/4 in. starboard of centerline	Pressure
3	7 5/8 in. aft of Frame 23, 8 1/4 in. port of centerline	Pressure
4	7 5/8 aft of Frame 23, 8 1/4 starboard of centerline	Pressure
5	7 5/8 aft of Frame 23, 3 in. starboard of 6 in. longitudinal	Pressure
6	7 5/8 aft of Frame 23, 3 in. starboard of longitudinal No. 1	Pressure
7	3 in. aft of Frame 24, 8 1/4 in. starboard of centerline	Pressure
8	11 3/4 in. aft of Frame 28, 8 1/4 in. starboard of centerline	Pressure
9	2 in. forward of Frame 24, on centerline keel	Acceleration (range of instrument 5 g)
A	Center of panel Frame 22-23, 8 1/4 in. starboard of centerline	Longitudinal tensile strain in plate
B	Center of panel Frame 22-23, 8 1/4 in. starboard of centerline	Longitudinal bending strain in plate
C	15.9 in. aft of Frame 23, 8 1/4 in. starboard of centerline	Longitudinal tensile strain in plate
D	15.9 in. aft of Frame 23, 8 1/4 in. starboard of centerline	Longitudinal bending strain in plate
E	22.1 in. aft of Frame 23, 8 1/4 in. starboard of centerline	Longitudinal tensile strain in plate
F	22.1 in. aft of Frame 23, 8 1/4 in. starboard of centerline	Longitudinal bending strain in plate
G	15 in. aft of Frame 23, on centerline of keel	Longitudinal hull strain in centerline keel
I	Frame 23 1/2, 8 1/4 in. starboard of centerline	Deflection at center of plating panel

HULL GIRDER STRESS AND MOTIONS

The measurements of the quantities associated with the rigid-body motions of the vessel were recorded on the TMB automatic statistical recorder described in the appendix. Simultaneously, an automatic statistical analysis of the data resulted in a digital tabulation (on TMB cycle counters) of the number of times that the magnitudes of the variations of stress and motion had fallen within predetermined limits. On several occasions the motion data were also recorded on a special slow-speed, magnetic-tape recorder (frequency-modulated output) which is described in the appendix.

The sensing devices used for the measurement of hull girder stress and motion were:

1. A Minneapolis-Honeywell stable element, Type JG 7003A11, which gave signals directly proportional to the angles of pitch and roll.

2. A Schaevitz linear accelerometer for measuring the change in the apparent acceleration of gravity near the center of gravity of the ship.

TABLE 2

Location of Gages Measuring Waves and Rigid-Body Hull-Girder Response to Waves

Recorder Utilized	Quantity Measured	Type of Instrument	Location
Consolidated Oscillograph	Heave acceleration	Statham linear accelerometer range ± 2 g	Frame 78, 30 in. below second deck on centerline of ship
TMB Automatic Statistical Recorder	Heave acceleration	Schaevitz linear accelerometer range ± 1 g	Same as above
	Hull girder strain (longitudinal flexure)	SR-4 strain gages	One set of gages was mounted on each of two longitudinals 96 in. port and starboard of centerline of ship at a location 9 in. aft of Frame 76 and 23 ft 9 in. above baseline (approximately main deck amidships)
	Roll angle	Minneapolis-Honeywell Co gyroscope with potentiometer output	5 in. aft of Frame 50 2½ in. above second deck, 95 in. starboard of centerline
	Pitch angle	Same as above.	Same as above.
	Pitch acceleration	Schaevitz angular acceleration range $\pm$ ½ rad/sec^2	6 in. forward of Frame 50, 22 in. below main deck, 6 in. starboard of centerline
Consolidated Oscillograph (18 channels)	Roll angle	Minneapolis-Honeywell Co gyroscope with potentiometer output	6 in. forward of Frame 50, 22 in. below main deck, 12 in. starboard of centerline
	Pitch angle	Same as above.	Same as above.
	Sea surface configuration (Stereophotographs)	Type K24 Aerial cameras 7 in. focal length, Super XX film	Forward camera was located on the flying bridge near Frame 47 approximately 56 ft above baseline. After camera was located on the smokestack near Frame 73 approximately 55 ft above baseline. The distance between the cameras was 52 ft.

3. A Schaevitz angular accelerometer, which was especially developed for this project, to measure the angular roll or pitch accelerations of the ship.

4. SR-4 electric strain gages mounted on symmetrically located port and starboard main deck longitudinals 9 in. aft of Frame 76. These gages were electrically connected to give a signal proportional to the longitudinal hull girder stresses free of the effects of flexure in a transverse plane (normal to the centerplane fixed in the ship). The gage locations are given in Table 2 and are also shown in Figure 1. A portion of the instrument installation can be seen in Figure 4.

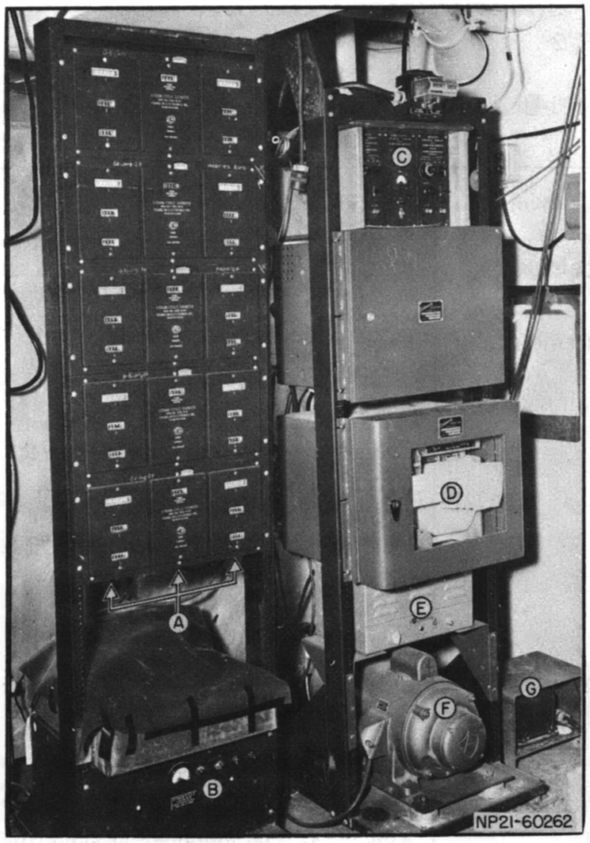


Figure 4a - Installation of Automatic Statistical Recorder and Cycle Counters

A - Cycle Counters
B - Stand-by Power Supply for Cycle Counters
C - Strain Amplifier
D - Automatic Statistical Recorder
E - Control for MG Set
F - MG Set
G - Roll and Pitch Measuring Gyroscope No. 1

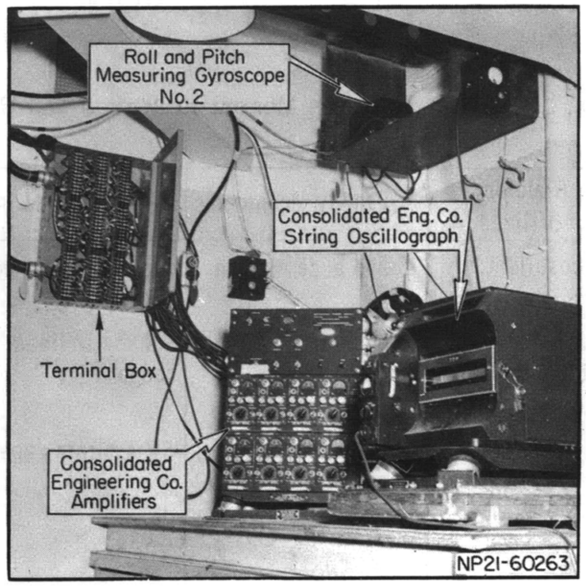


Figure 4b - Recorder and Equipment for Recording Information on Slamming

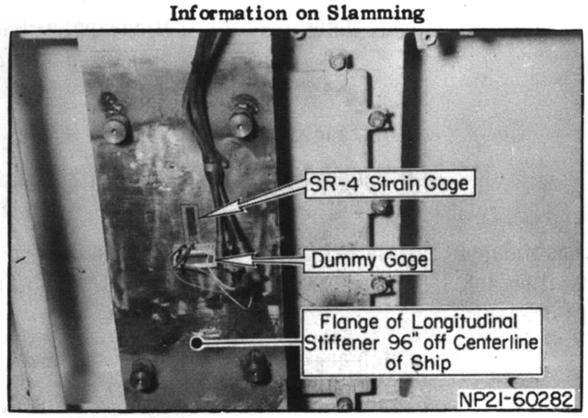


Figure 4c - Strain Gage, Located at Frame 76, for Measuring Hull Girder Stress (One Gage Installed on Port and Starboard Longitudinals)

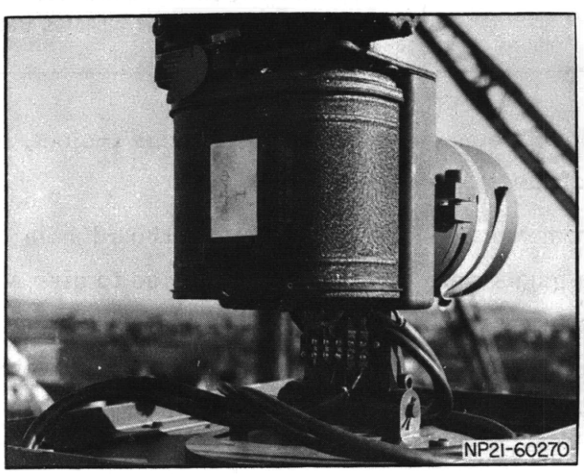


Figure 4d - Forward Stereo Camera on Flying Bridge (Protective Cover Removed)

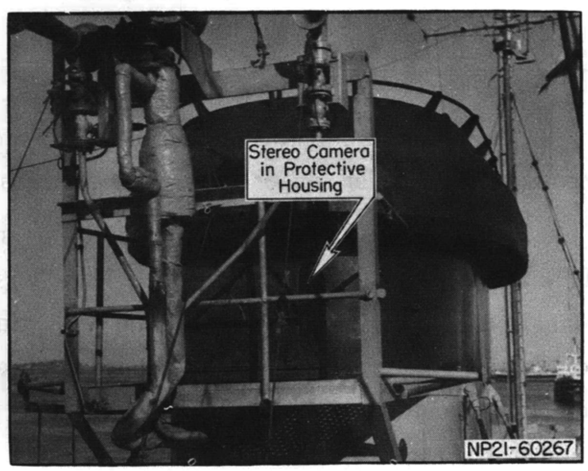


Figure 4e - After Stereo Camera on Smokestack (Protective Cover in Place)

Figure 4 - A Portion of the Instrument Installation

TEST PROCEDURES

The general procedure during the sea tests was as follows. The TMB automatic statistical recorder was set to record for periods of 2 min at 1-hr intervals at a chart speed of 1 in./min. The automatic statistical gages and digital counters (see Appendix) were active at all times whether records were taken or not. The digital counters were read twice a day. A copy was made of the weather observers' log which gives conditions of sea, weather, ship's speed, and course at intervals of 3 hr. Relevant data from the ship's log were also recorded.

Whenever the ship was subjected to appreciable slamming, a record was made of all the outputs of the gages connected to the Consolidated oscillograph. Whenever unusually severe conditions of slamming, ship motion, or stress were encountered, high-speed oscillograph records were taken at a paper speed of about 18 in./sec together with records on the TMB automatic statistical recorder. When possible, stereophotographs of the sea were also taken. Continuous records of ship motions and hull girder stress were made with the TMB automatic statistical recorder for 39 periods of ½ hr during each of which a given combination of sea condition, ship speed, and heading was maintained constant. Occasional records were also taken during each period with the Consolidated oscillograph. For some of these periods, continuous magnetic-tape recordings of ship motions were also obtained* (30-min minimum). The particular combinations of conditions for which the ship motion and hull girder stresses were recorded are listed in Table 3. Stereophotographs of the sea were taken during each condition for which it was practicable to do so.

Another special set of tests consisted of simultaneous visual estimation of wave heights by trained weather observers together with stereophotographic measurement of the wave heights. In addition a number of wave lengths were estimated by the observers and checked against a measurement obtained for the same waves by utilizing a marked line and buoy.

PRESENTATION AND DISCUSSION OF REPRESENTATIVE DATA

SLAMMING

The two oscillograms of Figure 5a indicate the variation of pressures on the bottom plating with time and the consequent strains and deflections in the plate. These particular oscillograms represent two of the most severe slams encountered throughout the tests at Station B in the North Atlantic. The type of measurement represented by each trace may be identified by reference to Table 1. The sensitivity scales are indicated directly on the oscillograms. The response to slamming is also indicated in the oscillograms of pitch acceleration and hull girder stress amidships in Figure 5e.

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*The magnetic-tape records will be useful for establishing the autocorrelation functions for the measured motions.

TABLE 3

Steady Conditions for Which ½-Hr Continuous Measurements of Hull Motions and Strains Were Made

Heading of Seas Relative to Ship's Course	Ship's Speed Knots (From Pat Log)	Sea State* and Significant Wave Height (Observed)**															
		State 2 - 6 Ft				State 3 - 7 to 9 Ft				State 4 - 16 Ft				State 5 - 21 Ft			
		ASR Rec No†	Consol Oscill Rec No	Stereo Photo No	Magnetic Tape Rec No	ASR Rec No	Consol Oscill Rec No	Stereo Photo No	Magnetic Tape Rec No	ASR Rec No	Consol Oscill Rec No	Stereo Photo No	Magnetic Tape Rec No	ASR Rec No	Consol Oscill Rec No	Stereo Photo No	Magnetic Tape Rec No
Head Seas	7-7½	-				-				Roll 4 675-706	4109-4111	549-550		Roll 2 9	3953-3954	515-517	
	10	Roll 3 362-392	-	528-529	4-5	Roll 2 3	3938-3939	-		Roll 4 709-741	4112-4113	551-552		Roll 2 3	3938-3939	-	
	14	Roll 3 330-362	-	525-527	4-5	Roll 2 2	3936-3937	-		Roll 4 741-771	4114-4116	553-554		Roll 2 2	3936-3937	-	
	17	-				Roll 2 1	3933-3935	-						Roll 2 1	3933-3935	-	
Quarter Head Seas	7-7½	-				-				-				Roll 2 5	3942-3943	507-509	
	10	Roll 3 258-295	-	-	4-5	Roll 1 944-972	3925-3927	-		-				Roll 2 6	3944-3946	510-512	
	14	Roll 3 295-327	-	522-524	4-5	Roll 1 884-914	3921-3922	-		-				Roll 2 7	3947-3949	513-514	
	17	-				Roll 1 788-825	3912-3915	-		-				-			
Beam Seas	7-7½	-				-				-				Roll 2 19	-	-	
	10	Roll 3 393-423	-	530-532	5-6	Roll 1 702-732	3905-3907	497-499		-				-			
	14	Roll 3 429-461	-	533-534	5-6	Roll 1 733-759	3908-3909	500		-				-			
	17	-				-				-				-			
Quarter Following Seas	7-7½	-				-				-				Roll 2 18	4002-4004	-	
	10	Roll 3 491-524	-	-	5-6	Roll 1 973-1003	3928-3939	-		-				Roll 2 17	3999-4001	-	
	14	Roll 3 462-491	-	-	5-6	Roll 1 914-944	3923-3924	-		-				Roll 2 16	3996-3998	-	
	17	-				Roll 1 827-858	3916-3918	-		-				-			
Following Seas	7-7½					-				-				Roll 2 13	3987-3989	-	
	10	Roll 3 524-558	-	-	5-6	-				-				Roll 2 14	3990-3992	-	
	14	Roll 3 562-594	-	-	5-6	-				-				Roll 2 15	3993-3995	-	
	17					Roll 1 859-882	3919-3920	-		-				-			

*The definition of sea state used here is given in Hydrographic Office Publication No 606e.

**The significant wave height is defined as the mean value of the one-third largest waves. The observations were made by U.S. Weather Bureau observers.

†ASR Record No identifies the record made on the automatic statistical recorder; see Figure 5 for a sample record.

Figure 5 - Samples of Records Taken During the Tests

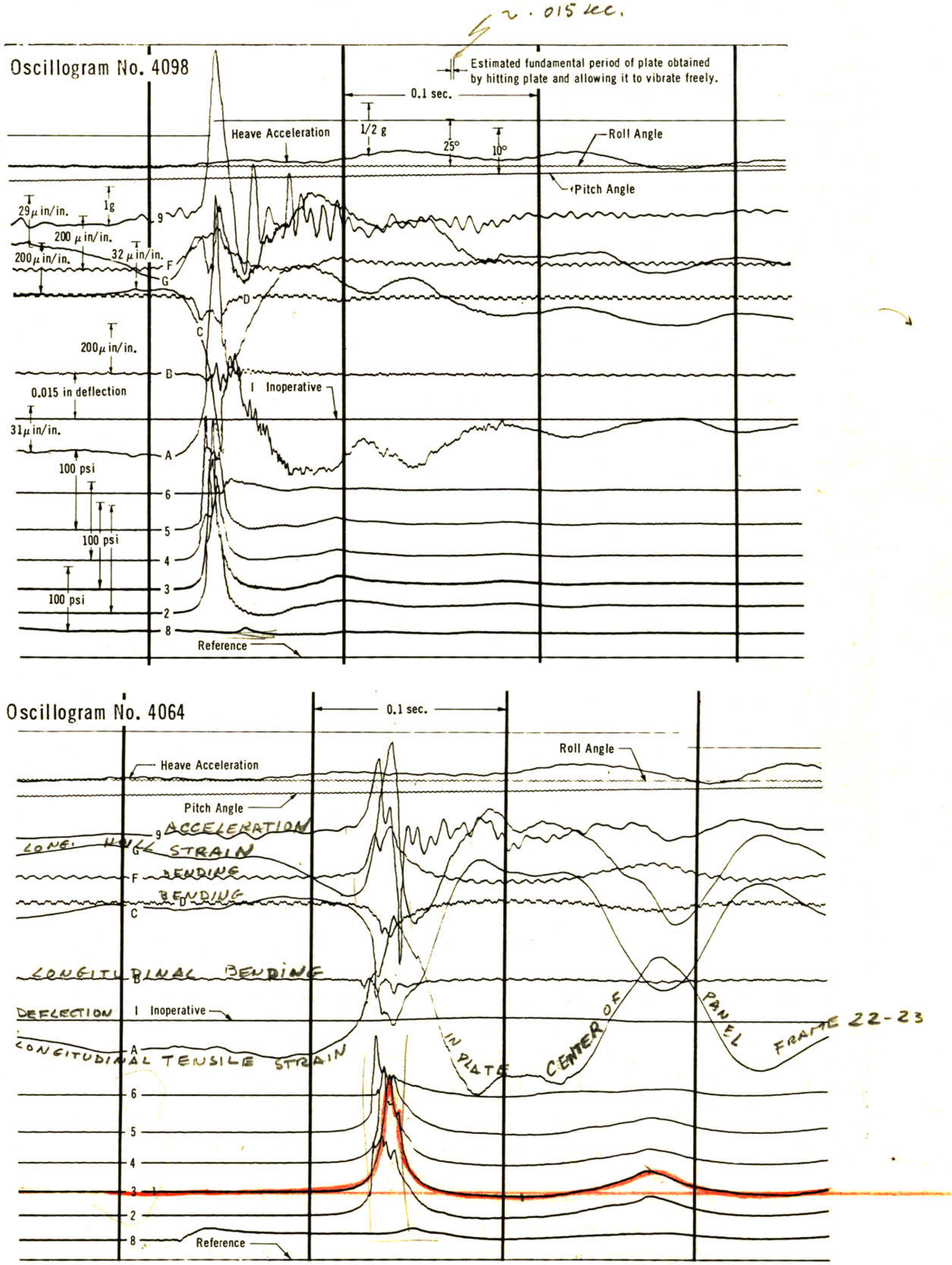

Figure 5a - Variation of Pressures in the Bottom Plating with Time

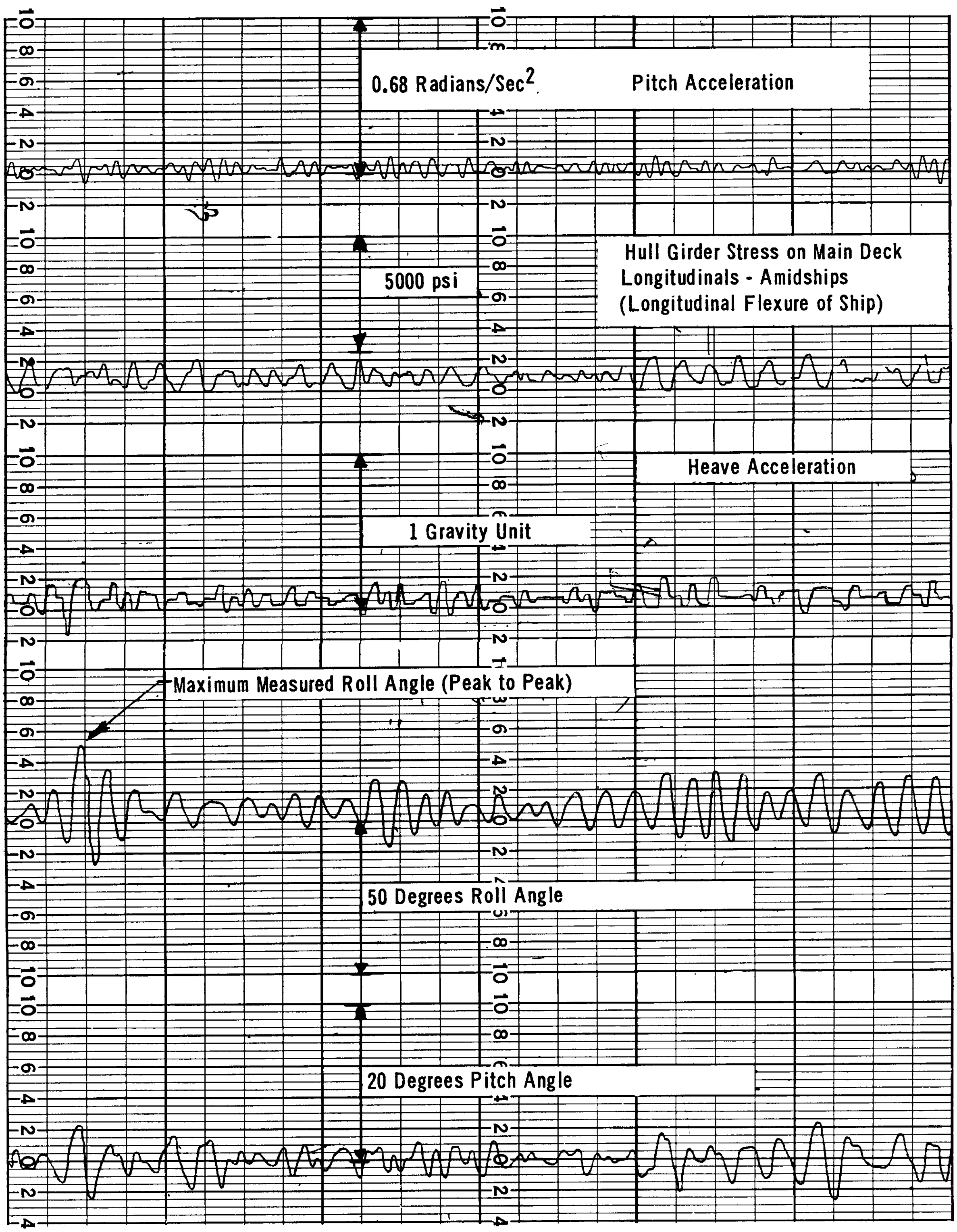

Figure 5b - Oscillogram at Time of Maximum Measured Roll Angle 16 Jan 55

Maximum Roll Angle	40 deg	Ships Speed	7.5 knots
Significant Wave Ht	21 ft	Relative Heading of Seas	135 deg
Wind Velocity	32 knots	Heading of Waves	090 deg
Wind Direction	090 deg	Heading of Ship	315 deg

$\theta = 0^\circ$

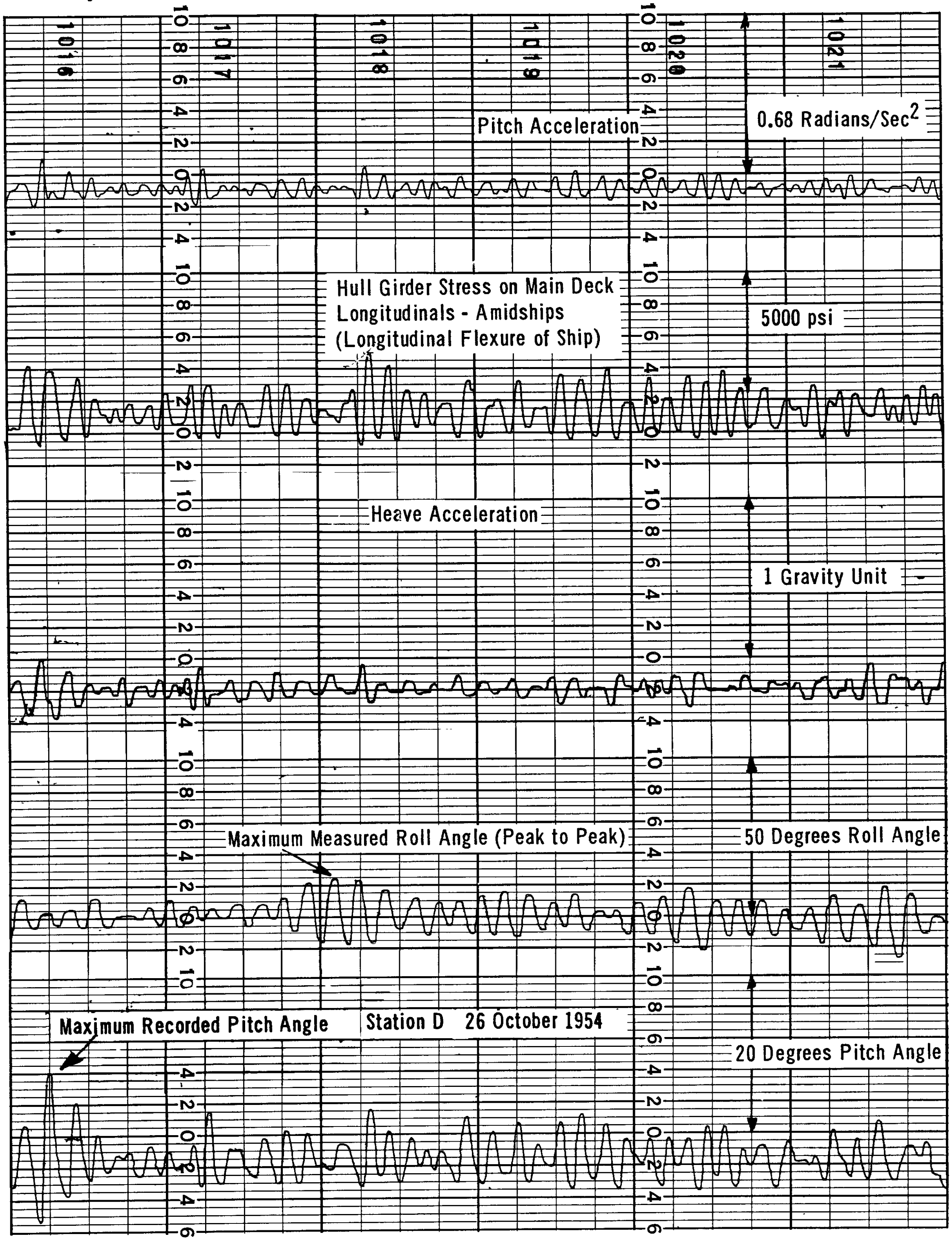

Figure 5c - Oscillogram at Time of Maximum Measured Pitch Angle 26 Oct 1954

Maximum Pitch Angle	18½ deg	Ships Speed	0.0 knots (Patent Log)
Significant Wave Height	25-29 ft	Relative Heading of Seas	000 deg
Wind Velocity	50 knots	Direction from Which Waves Come	260
Wind Direction	270 deg	Heading of Ship	260

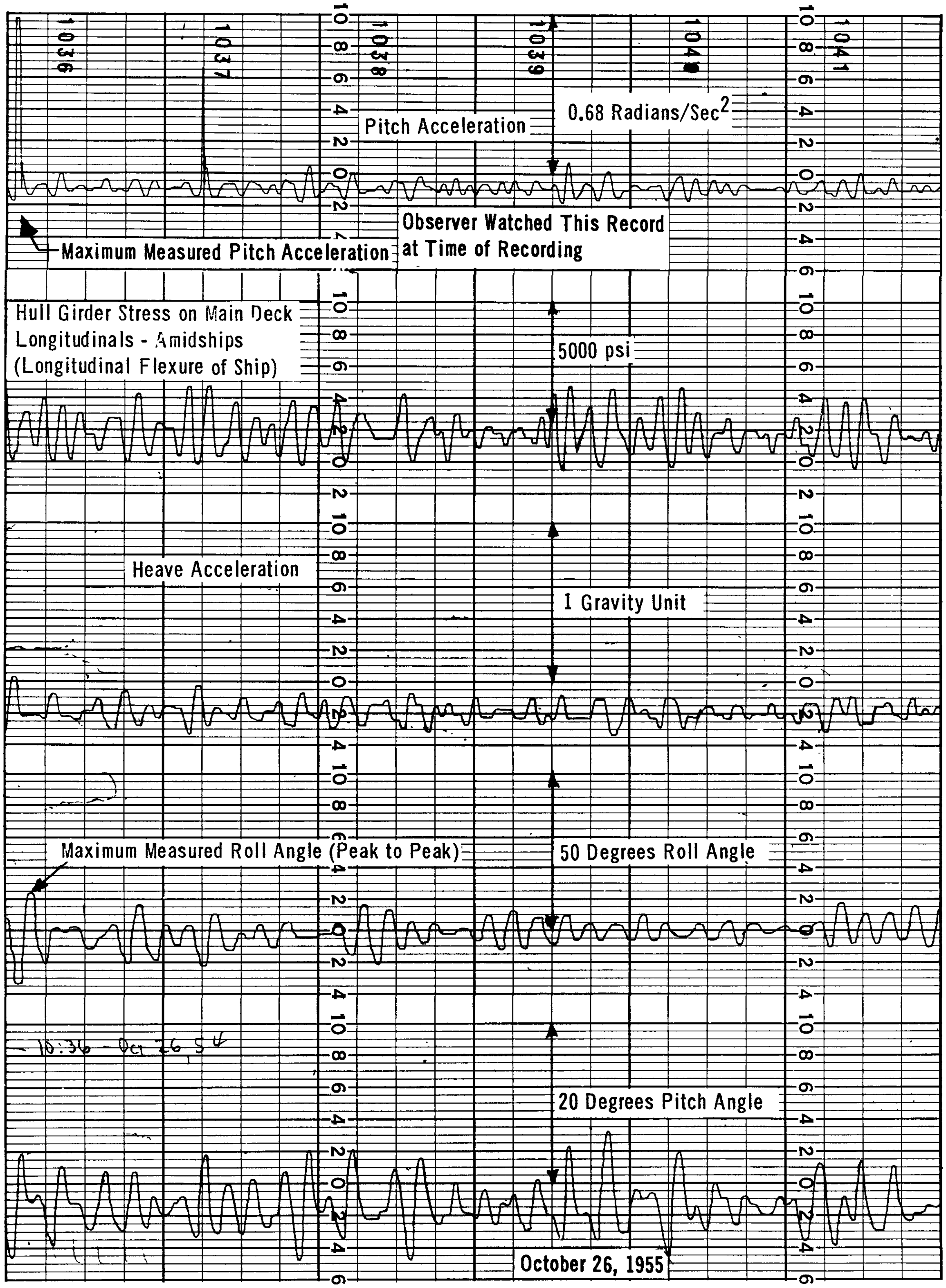

Figure 5d - Oscillogram at Time of Maximum Measured Pitch Acceleration 26 Oct 1954

Maximum Pitch Acceleration	0.77 rad/sec^2	Ships Speed	0.0 knots (Patent Log)
Significant Wave Height	29 ft	Relative Heading of Seas	010 deg
Wind Velocity	50 knots	Direction from Which Waves Come	270 deg
Wind Direction	270 deg	Heading of Ship	260 deg

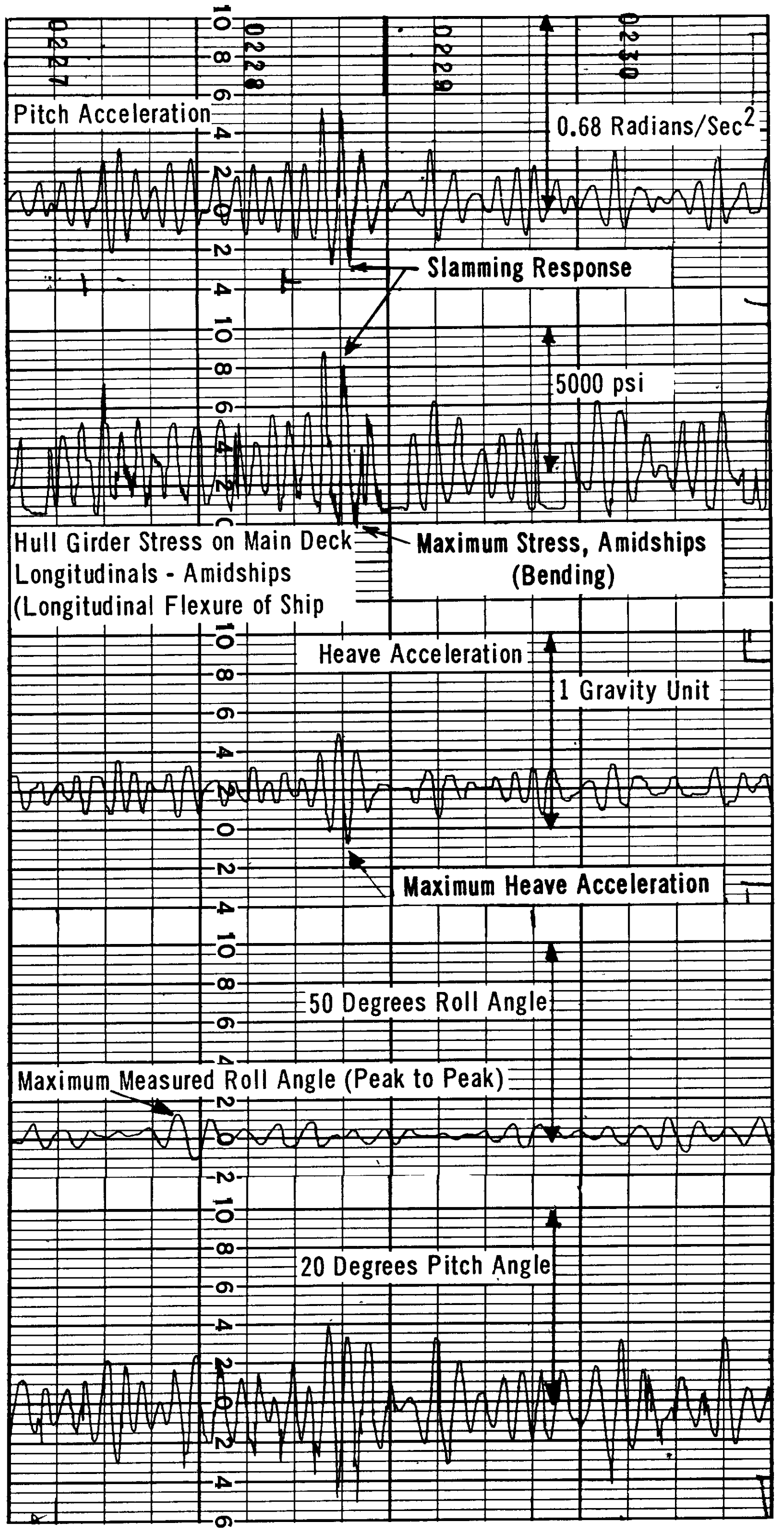

Figure 5e - Oscillogram at Time of Maximum Measured Stress and Heave Acceleration 1 Feb 1955

Maximum Stress	5900 psi	Ships Speed	14.2 knots
Maximum Heave Acceleration	0.55 g	Relative Heading of Seas	015 deg
Significant Wave Height	20 ft	Direction from Which Waves Come	090 deg
Wind Velocity	32 knots	Heading of Ship	075 deg
Wind Direction	079 deg		

The maximum pressure measured during the slam* shown on Oscillogram 4064 was 200 psi (Gage 3). The time of rise and the duration of this pressure peak were of the order of the natural period of the plate, and theoretical considerations[3] indicate that the maximum deflections and strains due to the "slamming" pressure may be approximated by assuming that this pressure load acts statically on the plate.

The largest pressures were measured near the keel. It is probable, however, that conditions could arise where the larger pressures would occur at locations outboard of the keel. The deflections and strains in the bottom plating of the UNIMAK, incident to large slamming pressures, were quite small because the bottom structure forward had been reinforced since the construction of the ship in order to reduce bottom damage experienced in service.

The maximum peak-to-peak variations in the stress** measured in the keel 15 in. aft of Frame 23 were 3500 psi associated with presently undefined higher modes of the hull structure which were excited subsequent to slamming at the bow. It appears reasonable to assume that this 3500-psi stress in the keel, which lasted only a few milliseconds, is primarily associated with the deformation of the local bottom structure since similar tests on the USCGC CASCO indicated no such high-frequency strain variation in the hull girder near Frame 61 (keel) and Frame 41 (on keel and main deck longitudinals) during intervals when slamming took place. These areas on the CASCO were not subjected to local impact loading during the strain measurements, whereas on the UNIMAK local impact forces were acting on the area of bottom adjacent to the keel near Frame 23 where the strain was measured.

It seems fairly safe to say that at points free of stress concentration, the nominal hull girder stresses induced by slamming are no greater–and probably less–than the hull girder stresses induced by the passage of the waves. Furthermore the frequency of occurrence of hull girder stresses due to slamming is certainly much less than that of the ordinary wave-induced stress variations. However there is a strong possibility that peak wave-induced stresses and "slamming" stresses may occur simultaneously at a time when cargo dead-load stresses are appreciable and under conditions of temperature which favor brittle fractures. In this situation, slamming may well lead to a major fracture.

The linear vertical acceleration of the hull (measured by an accelerometer located on the keel at Frame 24) in the area subjected to the slamming pressures attained values of the order of one to two times the acceleration of gravity *at the time of the slamming action,* although this magnitude was maintained only for a few milliseconds.

In order to estimate how often slamming occurred during a given interval of time, a digital counter was connected to the pressure switch† during operation at Station D. Thus the counter indicated (Table 4) the number of times that the pressure at the keel, Frame 19, was

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*The maximum pressure measured at any time was of the order of 300 psi (Gage 5).

**Stress was computed on the basis of the measured strain.

†During periods of the order of several hours, while the counter indicated frequent emergence of the bow from the sea, it was noted that not more than one count was made during any one cycle of pitching or heaving motion.

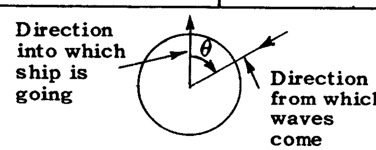
TABLE 4

Frequency of Slamming and the Conditions Under Which Slamming Occurred

Date Oct 1954	Ship's Time Hr:Min	Interval Hr:Min	Significant Wave Height Ft	Wind Force Beaufort Scale	Ship's Speed (Pat. Log) Knots	Relative Bearing* of Direction from Which Waves Come Deg	No of Slams** Indicated by Counter	
24	00:50 11:20	10:30	7 to 13	3 to 6	0 to 5.0	Predominantly 90	37	3.7
24	11:20 22:10	10:50	13 to 20	7 to 8	0.2 to 7.6	150 (3 hr) 340 (8 hr)	293	25
24 25	22:10 01:05	2.55	20 to 17	8	0 to 6.9	340	289	97
25	01:05 09:00	7:55	17	7 to 9	0.3 to 1.1	340	343	43
25	09:00 10:35	1:35	17	8	0.4 to 0.6	0 & Various Others	83	60
25	10:35 21:45	11:10	17 to 23	8 to 9	0.1 to 10.0	140 (3 hr) 20 (7 hr)	466	42
25 26	21:45 09:15	11:30	23 to 29	8 to 9	0 to 0.8	20	615	54
26	09:15 19:00	8:45	29 to 28	8 to 9	0 to 3.3	340	744	55
26 27	19:00 09:05	14:05	28 to 27	7 to 9	0.2 to 10.2	20 (8 hr) 200 (3 hr) 340 (3 hr)	521	--

* The relative bearing is the angle θ shown in the sketch.

**As indicated by the pressure sensitive "trigger" located at the keel, Frame 19. Whenever this gage indicated that the pressure had fallen to a value less than ½ ft of water, a digital counter was actuated.



less than ½ ft of water, which probably may be taken to signify that the bow emerged from the sea. Table 4 indicates that slamming may occur quite frequently under some conditions of operation.

A few preliminary model tests were made at the Taylor Model Basin during which bottom pressures incident to slamming of a model of a LIBERTY ship in waves were measured. These tests did, at least in a rough qualitative way, indicate pressures of the order of 100 psi or more, and the pressure-time variations on the model were, in general, similar to those measured on the UNIMAK.

It would seem advisable to give serious consideration to the use of model tests for the purpose of establishing the order of magnitude of the impact pressures and to help define the general area over which they are likely to occur in actual operation.

OBSERVATIONS AND MEASUREMENTS OF WAVE HEIGHTS AND WAVE LENGTHS

Estimates of wave heights have been made by trained weather observers assigned to U.S. weatherships over a period of several years. In accordance with the method specified by the U.S. Weather Bureau, observers report the severity of the sea in terms of the significant wave height, which is defined as the mean height of the one-third highest waves.* These estimates are reported to and collected by the Weather Bureau. Similar observations are made by meteorological groups assigned to certain naval vessels.

Accordingly, weather personnel were available aboard the UNIMAK to observe and record at 3-hr intervals the condition of the sea, the direction of the waves and of the ship, and the speed of the ship. The available observations of wave heights (U.S. Weather Bureau) at Stations B and D, where most of the present data have been collected, are presented in Figures 6 and 7. Note that there is little difference between the data for the two stations.

In view of this rather extensive body of wave observations, it is surprising that there appears to be no evaluation available as to the accuracy of such observations. In order to obtain some slight measure of the accuracy of these wave observations, arrangements were made between the U.S. Weather Bureau and the Model Basin to utilize the sea tests of the UNIMAK to take stereophotographs of the waves at the same time that one or more trained observers were estimating the wave heights. In addition, a number of observations of wave lengths were made by weather personnel and compared with measurements of the same waves obtained by means of a marked line, carrying a buoy, which was reeled off the stern.

During these measurements, the ship was headed into the waves. The observer selected a group of waves as they approached the ship. Out of this group, he chose one wave of outstanding dimensions and estimated its height. A stereophotograph was taken approximately at the time when the crest or trough of the wave passed amidships and the vessel was as nearly level as practicable (the stereo cameras were oriented with their optical axis horizontal in the athwartship direction).

In addition to the stereophotographs taken at the time when a particular wave height was estimated, many additional photographs were taken for particular test runs in order to specify the sea conditions under which the stress, pressure, and ship motion data were obtained. Inasmuch as sea conditions do not change much within a 3-hr period, these latter stereophotographs could be used to check the estimated significant wave height reported at intervals of 3 hr. Approximately 160 stereophotographs were taken throughout the test period; these are now being analyzed and results will be reported later.

HULL GIRDER STRESSES AND MOTIONS (EXCLUDING EFFECTS OF SLAMMING)

Hull girder strains and motions were recorded for a wide variety of combinations of sea condition and ship speed and heading relative to the waves. Conditions for which continuous

*If the wave heights are arranged in descending order of magnitude, then the average value of the first third of these is the significant wave height.

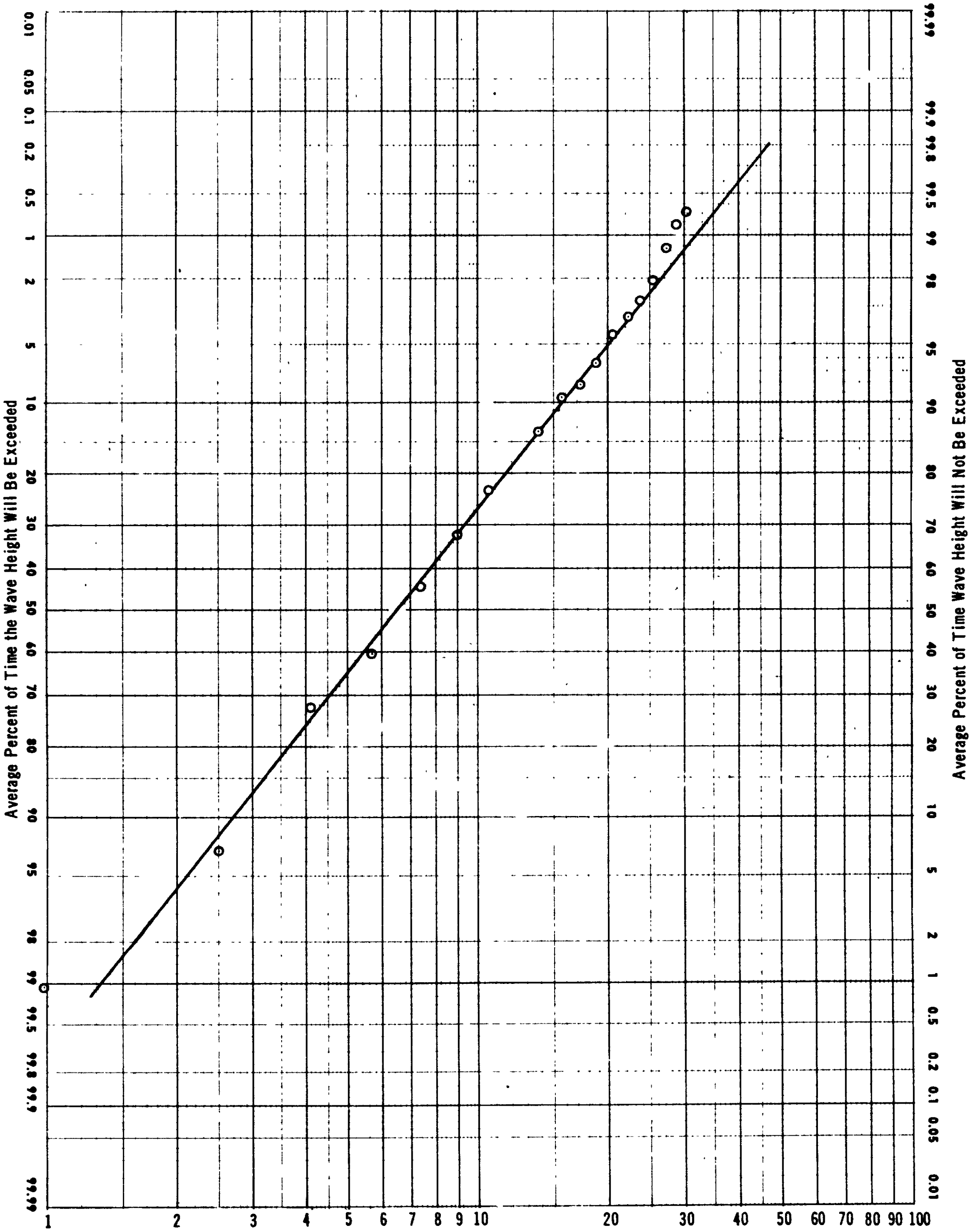


Figure 6 - Distribution of Significant Wave Heights at Station B (56°30′N, 51°00″W) North Atlantic

These observations of "significant wave heights" were made by U.S.Weather Bureau personnel at intervals of 3 hr over the period Jan 1949 to Dec 1954, comprising a total of 15,547 observations. The circles represent the observed data and the straight line represents a computed logarithmically normal distribution fitted to the observed wave data.

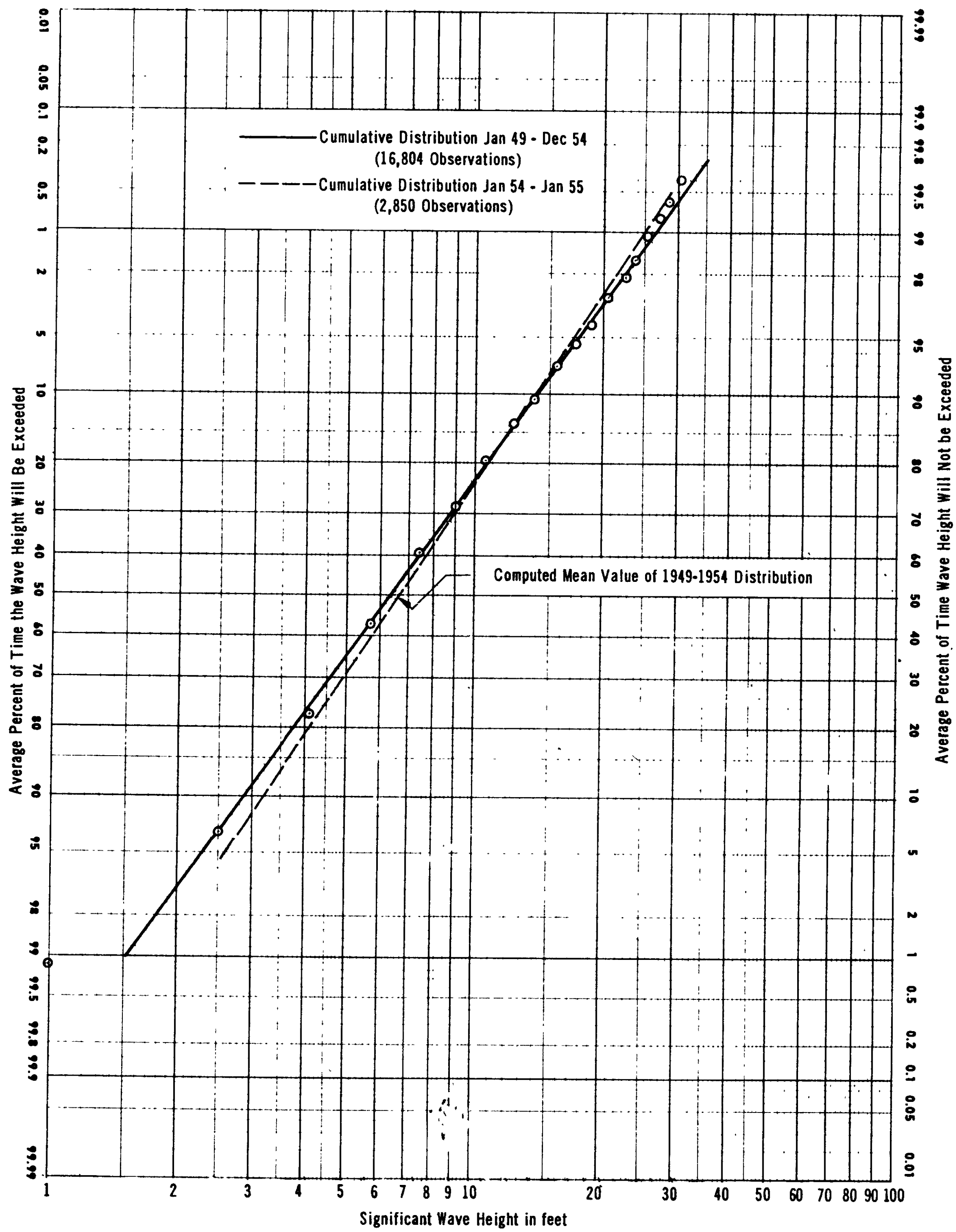


Figure 7 - Distribution of Significant Wave Heights at Station D
(44°00′N, 41°00′W) North Atlantic

These observations of "significant wave heights" were made by U.S. Weather Bureau personnel at intervals of 3hr over the period Jan 1949 to Dec 1954, comprising a total of 16,804 observations. A straight line on this chart represents a logarithmically normal distribution of significant wave heights.

records of approximately ½ hr or more were obtained have been listed in Table 3, see page 10. It is intended to analyze many of these records in order to establish the frequency distributions (histograms) of stresses or bending moments and the rigid-body motions to be expected for this type of vessel corresponding to the various conditions. By proper addition of the various distribution patterns, one may estimate the magnitudes and frequency of incidence of stresses and motions to be expected over the operating life of the ship.

A preliminary analysis of the distributions corresponding to the conditions listed in Table 4 indicates that most of these experimentally determined distributions can be approximated by a one-parameter distribution; one typical distribution is shown in Figure 8. Expected maximum values and other statistical parameters can be readily obtained for each one of these distributions. For the series of measurements shown in Figure 8, the predicted maximum variation in pitch angle is 16 deg and the actual maximum value 18 deg; thus the agreement is good.

The maximum measured values of rigid-body motion and of hull girder stresses experienced during the two patrols in the North Atlantic are listed in Table 5, and the corresponding oscillograms, obtained by means of the automatic statistical recorder, are shown in Figures 5b through 5e. Inspection of this table and Figure 7 indicates that during both voyages (Stations B and D), the ship experienced approximately the same order of severity of weather,

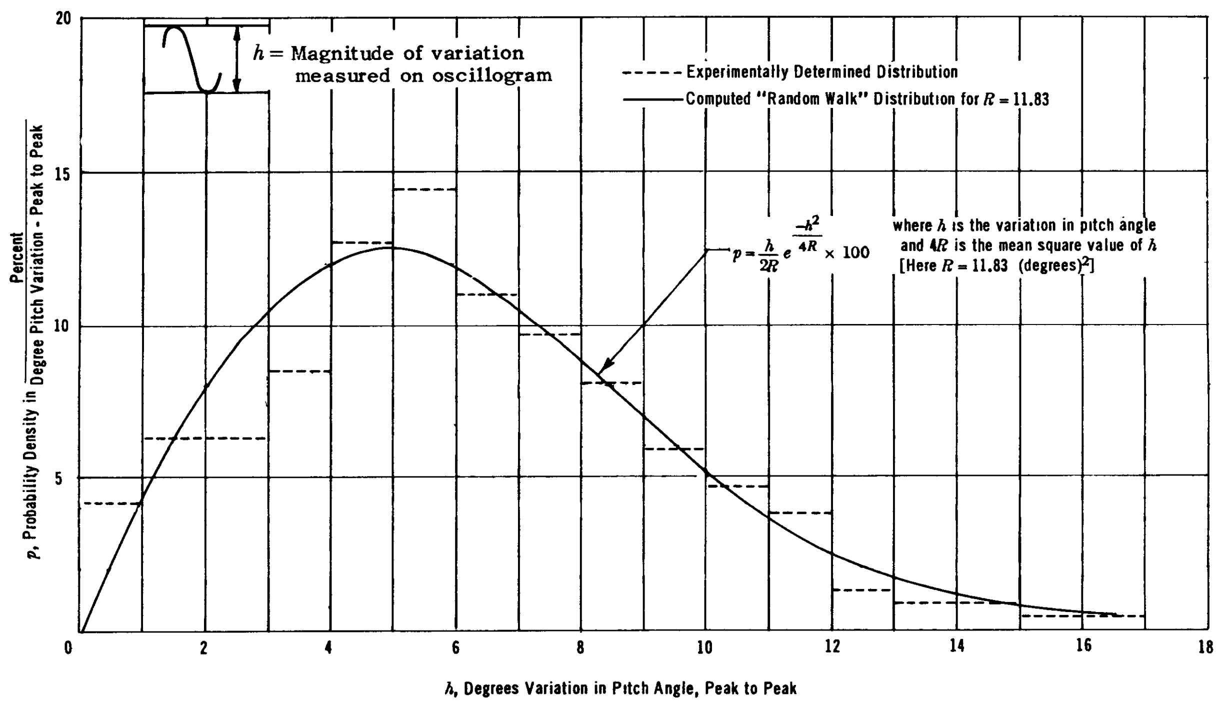


Figure 8 - Distribution of Variation in Pitch Angle

The test conditions were: Sea State 5, Significant Wave Height 21 ft, Head Seas, Ship's Speed 7½ knots. The data were obtained from 13:55 to 14:20 on 15 Jan 1955; the corresponding stereophotographs are numbers 507 to 509. There were a total of 236 variations in a period of 27 min 22 sec. The maximum measured variation in pitch angle during the period of measurement was 18 deg. The statistically predicted largest probable variation based on the theoretical distribution, is 16 deg in 236 measurements.

TABLE 5

Largest Values of Hull Motions and Stress Measured in the North Atlantic Ocean During Winter 1954-1955

The coordinates of Station D are 44°N, 41°W - The coordinates of Station B are 56°30′N, 51°W

	Relevant Data	Conditions at Time of Maximum Measured									
		Roll Angle		Pitch Angle		Pitch Acceleration		Heave Acceleration		Hull Girder Stress, Main Deck Frame 76½, Centerline Amidships	
	Station (Voyage)	D	B	D	B	D	B	D	B	D	B
Approximate Data from Ship and Aerology Log	Date	Oct 25, 54	Jan 16, 55	Oct 26, 54	Feb 1, 55	Oct 26, 54	Feb 4, 55	Oct 27, 54	Feb 1, 55	Oct 25, 54	Feb 1, 55
	Ship Speed, Knots*	0.6	7.5	0.0	14.2	0.0	7.5	10.3	14.2	1.0	14.2
	Ship's Heading, Deg	250	315	260	075	260	195	020	075	265	075
	Swells from, Deg	260	090	260	090	270	360	290	090	250	090
	Relative Bearing of Waves**	010	135	000	015	010	165	270	015	345	015
	Wind Velocity, Knots	46	32	50	30	50	30	40	30	40	32
	Wind Direction, Deg	270	090	270	090	270	000	270	079	270	079
	Significant Wave Height, Ft	21	21	25-29	18-20	29	15-22	27	20	19	20
	Approximate Zone Time	22:00	23:00	09:00	14:30	11:00	16:00	21:00	15:00	00:00	15:00
	Roll Angle, Deg	29†	40†	4	7.5	29†	23	14	6.3	15	2.5
	Pitch Angle, Deg	5.7	9.6	18.5†	18†	13	14.5	8.2	16.7	14.8	17.0
	Pitch Acceleration, Rad/Sec^2	0.04	0.07	0.20	0.31	0.77†	0.74†	0.18	0.42	0.20	0.42
	Heave Acceleration, g's	0.15	0.20	0.35	0.48	0.40	0.33	0.54†	0.55†	0.28	0.55†
	Hull Stress, psi	800	700	3400	5000	3000	2700	2200	5200	5000†	5900†
	Maximum Variation Indicated by Cycle Counter	>25° <50°	>50°	>20°	>20°	>0.50 rad/sec^2	>0.50 rad/sec^2	>1G	>1G	>6700 psi	>6700 psi
	No of These Variations	187	4	6	11	16	19	2	1	2	3

*Speeds for Station B are taken from a calibration curve of shaft rpm vs knots. Speeds for Station D are taken from Patent Log readings.

**The relative bearing of the waves is the bearing of the direction from which waves come relative to the ship's course.

†These values represent the largest oscillographic recorded value during the given voyage. The values of the other oscillographically recorded quantities were measured during the passage of the same wave which resulted in the indicated maximum.

hull girder stresses, and motions. It is believed that both voyages were subject to typical winter conditions in the North Atlantic.

Although the seas and the vessel's operation in the sea were such as to induce very severe ship motions and slamming, the hull girder stresses, free of stress concentrations, were quite small. The maximum recorded stress variation at the main deck amidships was 5900 psi, and the counter gages, which operated continuously, indicated that the stress at this location exceeded 6700 psi only twice during the voyage in the fall of 1954 and twice during the voyage of January and February 1955. These values may be compared with the following data from the original design calculations for this vessel taken from Reference 11.

Maximum Value of Bending Moment at Location of Strain Gage, Frame 76, 23.75 ft Above Baseline:

22,964 ft-tons (hogging)

17,500 ft-tons (sagging)

Stress at Gage Location Corresponding to this Bending Moment:

11,900 psi (hogging)

9200 psi (sagging)

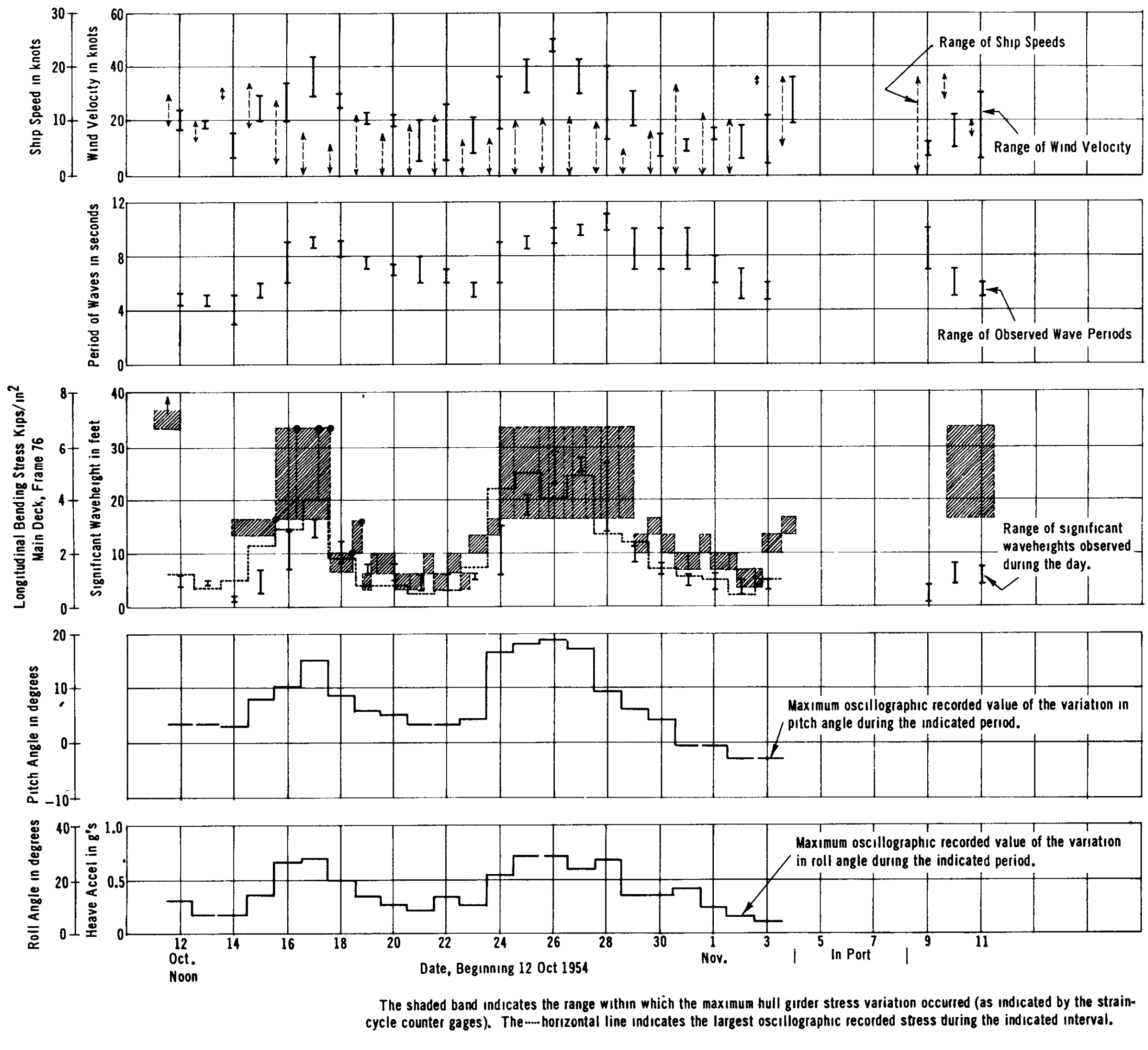
(By use of the designer's computed section modulus which neglects the contribution of the deckhouse to the hull girder strength, the calculation assumes the ship encounters a wave 300 ft long and 15 ft high)

The CASCO[2] sea trials indicated that the superstructure of these vessels is fully effective in resisting hull bending, thus resulting in a section moment of inertia of 761 ft^4 and a position of the flexural neutral axis above the baseline of 13.8 ft. With the latter values, the measured 5900-psi stress variation (hog to sag) would correspond to a variation in bending moment of 28,900 ft-tons (hog to sag), which is likely to be reasonably close to the actual bending moment experienced. This value is also close to the maximum bending moment that was estimated for the most severe hull girder stress variation measured on the USCGC CASCO; this estimate was 26,800 ft-tons (hog to sag) at Frame 71 1/2 corresponding to Conditions 8 and 6 of Table 3 in Reference 2.

In general, it can be said that the UNIMAK was operated under very severe conditions which are believed to have subjected the vessel to nearly as large loads as it would be expected to encounter throughout the winter season. The vessel was intentionally operated to cause severe and repeated slamming. Nevertheless the maximum measured wave-induced variation (hog to sag) in hull girder stress amidships was only 5900 psi (see Figure 5), and the maximum dynamic stress induced by slamming measured in the keel near the area of intense local impact loading was only about 3500 psi, although the local plating stresses at the bow would have been excessive[9] for plates of the original dimensions.

It is concluded on the basis of data available on these ships that the hull girder strength is more than adequate and that the design value of the wave-induced stress variation will probably never be experienced by these ships. One reason for the relatively low wave-induced stresses is the fact that the superstructure makes a considerable contribution to the hull girder strength—a contribution which was neglected in the hull strength design.

The local strength of the bottom structure in the area subjected to slamming loads, as originally designed, is somewhat inadequate as indicated by a history of bottom damage; see also Reference 9. The largest measured values of ship motions and hull stresses for each day at sea together with the corresponding environmental condition are given in Figure 9. The data on ship motion and hull girder stress are more complete for Figure 9a than for Figure 9b. It is apparent that in the overall picture, high wind velocities accompany large significant wave heights which, in turn, produce relatively large pitching and rolling motion; this is, of course, to be expected. The frequent occurrence of rather large pitching motion is, perhaps, unexpected. If Rankine's formula for waves in deep water is used to convert the observed

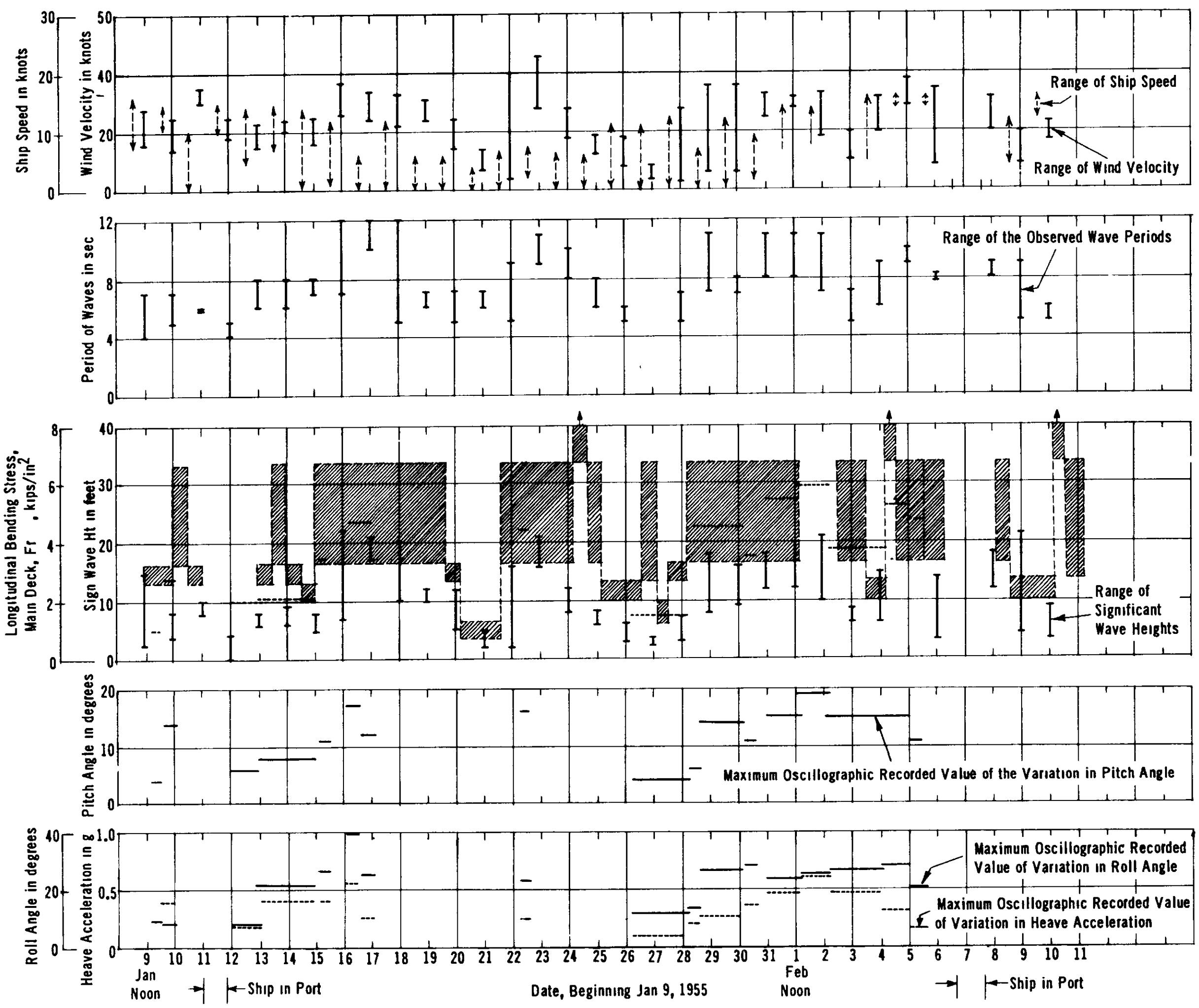


The shaded band indicates the range within which the maximum hull girder stress variation occurred (as indicated by the strain-cycle counter gages). The —— horizontal line indicates the largest oscillographic recorded stress during the indicated interval.

Figure 9a - Data for the Voyage Starting 12 Oct 1954

wave periods (Figure 9) to wave lengths, it becomes apparent that the vessel will have encountered waves nearly equal to her own length throughout much of the time at sea.

Table 6 gives the data tabulated by the automatic statistical gages and counters, which analyze the variations of the hull motions and stresses in terms of the number of times that the magnitude of the variation was greater than a predetermined value. These gages and counters were active continuously while at sea except as indicated.



The shaded band indicates the range within which the maximum variation in hull girder stress occurred (as indicated by the strain cycle counter gage). The horizontal line indicates the largest oscillographically recorded stress during the indicated interval.

Figure 9b - Data for the Voyage Starting 9 Jan 1955

Figure 9 - Ship Motions, Stresses, and Environmental Conditions Plotted Against Time

Measurements of ship's motion and hull girder stress were made for typical conditions at various times during each day for the period covered by Figure 9a, and at less frequent intervals for the period covered by Figure 9b. All values given correspond to the total magnitude (peak-to-peak) of the variation.

TABLE 6

Tabulation of Data Given by the Statistical Counter-Type Gages

N denotes the total number of cyclic variations that were measured and tabulated by the automatic statistical counters throughout each voyage, except that (a) counters were inactivated during one day at Station B and (b) the counters were active only during the period 13 Oct - 11 Nov 54 for the trip to and from Station D; this period covers the voyage from Argentia, Newfoundland to Station D, the patrol at Station D and the return trip to Boston. Thus a total of 32 days and 29 days are covered by the data for Stations B and D, respectively.

The magnitudes given here denote the double amplitude of the variations.

North Atlantic Station	Pitch Angle		Roll Angle		Stress Frame	Stress Centerline Amidships	Heave Acceleration		Pitch Acceleration	
	N	Magnitude Exceeded Deg	N	Magnitude Exceeded Deg	N	Magnitude Exceeded Psi	N	Magnitude Exceeded Gravity Units	N	Magnitude Exceeded Rad/Sec^2
	171,840	2	136,539	5	169,064	670	74,361	0.1	113,314	0.07
B	84,497	4	59,039	10	76,268	1340	21,607	0.2	32,064	0.14
Latitude	38,598	6	17,555	15	21,896	2010	1075	0.3	5128	0.20
Longitude	14,219	8	2245	20	11,001	2680	213	0.4	1400	0.27
10 Jan - 11 Feb 55	4530	10	430	25	3303	3350	35	0.5	328	0.34
	11	20	4	50	3	6700	1	1.0	19	0.68
	69,437	2	70,116	5	67,841	670	32,798	0.1	38,319	0.07
D	31,222	4	24,987	10	29,278	1340	10,208	0.2	3080	0.14
Latitude	15,322	6	6553	15	13,262	2010	931	0.3	277	0.20
Longitude	6882	8	765	20	4955	2680	167	0.4	45	0.27
13 Oct - 11 Nov 54	3017	10	187	25	1744	3350	20	0.5	34	0.34
	6	20	0	50	1	6700	2½	1.0	16	0.68

CONCLUSIONS AND RECOMMENDATIONS

1. The measurements of the bottom pressures induced by slamming show that pressures of the order of 100 psi may occur frequently on this class of vessel. Pressures of the order of several hundred pounds per square inch may be expected in service. It is probable that pressures of this order of magnitude are to be expected also near the bow on other ships when slamming occurs. The time variation of these pressures is such that the consequent stresses and deflections in the plating may be approximated by assuming that the pressures act statically.

2. The measured slamming pressures were largest near the keel. The pressure measured near the turn of the bilge was invariably less than that measured nearest the keel in the same transverse plane. It is probable, however, that occasions do arise where the largest pressure during a particular slam is experienced at locations outboard of the keel.

3. The deflections and strains in the bottom plating of the UNIMAK incident to large slamming pressures were quite small because the bottom structure forward had been reinforced since the building of the ship in order to reduce the bottom damage experienced in service.

Considerably larger deformation could be expected in the relatively more lightly built bottom structures of some other ship types. Design procedures for bottom structure should consider the high slamming pressures (several hundred pounds per square inch) which may be expected in service.

4. Model tests may be useful to determine the area within which pressures induced by slamming may be severe as well as the order of magnitude of these pressures. It is suggested that model tests of the AVP-Class vessels, representing the UNIMAK full-scale tests, be run in order to check the suitability of model tests in making predictions of full-scale results.

5. Inasmuch as slamming can occur many thousands of times within a few days, under certain operating conditions, it may be necessary to consider the effect of repeated loading in the design of the local bottom structure.

6. The largest hull girder stresses associated with the flexure of the ship moving through the waves are very probably much larger than the hull girder stresses associated with the whipping of the ship subsequent to a slam, as evidenced by the measurements secured on the CASCO and the UNIMAK. However, there is a strong possibility that the peak of a wave-induced stress may occur simultaneously with a "slamming" stress at a time when cargo dead-load stresses are appreciable and under conditions of temperature favoring brittle fractures, and in such a situation slamming may well lead to a major failure.

7. The strains and motions measured on the UNIMAK and the CASCO taken together with the corresponding sea conditions lead to the conclusion that the overall hull girder strength of these vessels is adequate, at least. The original structural design was deficient in local strength of the bottom structure forward. The additional strengthening of this bottom structure of the UNIMAK does provide satisfactory strength to withstand slamming loads in this area.

ACKNOWLEDGMENTS

These tests would not have been possible without the splendid cooperation of the U.S. Coast Guard, in particular Mr. Slover and LCDR Renshaw at Coast Guard Headquarters, D.C., and the personnel of the Coast Guard Yard at Baltimore. The Captain of the UNIMAK, CDR F. Young, gave his wholehearted cooperation in providing the ship speeds and headings desired for the tests, intentionally and repeatedly forcing the ship to slam in rough seas; we are deeply grateful to him. The Weather Bureau's Atlantic Patrol Headquarters in Boston, their representatives in Washington, D.C., and the weather observers on the UNIMAK were fully cooperative in making arrangements for special observations to be made during the trials. This project was sponsored by the Bureau of Ships, Code 442. Mr. John Vasta of Code 442 has been particularly helpful in furthering this type of research.

The test installation and the conduct of the tests was made under the supervision of Mr. J.T. Birmingham. Dr. Szebehely of the Taylor Model Basin, who has done much work on the theoretical aspects of slamming assisted in selecting the location of the pressure gages.

Mr. Smith of the Taylor Model Basin Instrumentation Division did an excellent job in keeping the equipment operative aboard ship and securing the mass of valuable data obtained at Station Baker practically single-handed. Mr. J.E. Greenspon of the Taylor Model Basin analyzed the oscillograms showing the pressure and strain variations incident to slamming. The overall program is under the direction of Mr. Jasper. This report was written by Mr. Jasper with the assistance of Mr. Birmingham. It was reviewed by Mr. R.T. McGoldrick and Dr. E.H. Kennard of the Taylor Model Basin staff.

APPENDIX

INSTRUMENTATION

TMB AUTOMATIC STATISTICAL RECORDER

The TMB automatic statistical recorder (Figure 10) is essentially an assembly of several instruments: a null-balancing 5-channel recorder, five statistical cycle contact devices for use with cycle counters, and five power amplifiers. The recorder has provision for automatic sampling of the five inputs to the recorder from five selected transducers. It can be set to take records for a period of 30 min or less at intervals of 1, 2, 4, or 8 hr. In addition, provision is made to take a record whenever a preset magnitude of any of the inputs has been exceeded. The time and date are automatically stamped on each record. This recorder is designed with a frequency response which will severely attenuate the signals associated with the higher frequency vibratory response of the ship since only those variations associated with the pitching, heaving, and rolling motions of the vessel are desired. The frequency response of the recorder is linear from 0 to ½ cps.

The five statistical cycle contact devices, Figure 10c, which are built into the recorder, operate continuously even though no actual oscillogram is being taken. The cycle gages are, in turn, connected to statistical counters. The counters classify the output of each transducer in terms of the number of cycles of strain or motion, etc., which have exceeded six predetermined magnitudes. Thus a statistical histogram is obtained directly without the necessity for laborious record analysis. The types of counters used are shown in Figure 4a.

The equipment operates on 110-volt, 400-cycle alternating current although 110-volt, 60-cycle alternating current can be used as each recorder is furnished with a motor-generator set which operates from a 110-volt 60-cycle source.

DIAPHRAGM PRESSURE GAGE

This gage, shown in Figure 11, is installed with its face flush with the outside of the ship's plating so as to measure the pressure at that point. The gage consists of a gage cup and a differential transformer with a zero adjustment; see Figure 11c. The diaphragm is 1¼ in. in diameter and is made in various thicknesses in order to obtain the desired pressure range. A small soft-iron core attached to the center of the diaphragm moves relative to the primaries and secondaries of a differential transformer an amount proportional to the pressure, thus changing the voltage induced in the secondary winding of the transformer.

The gage body is made of K Monel and has shown no evidence of deterioration after about six months' exposure to sea water. Figure 11a indicates the diaphragm thicknesses and the corresponding linear ranges. The differential transformer used with this gage is Schaevitz Engineering Company Model* 033X-LS.

*The Model 033X-LS transformer has a linear range of $\pm$ 0.033 in. core displacement at an excitation frequency of 400 cps

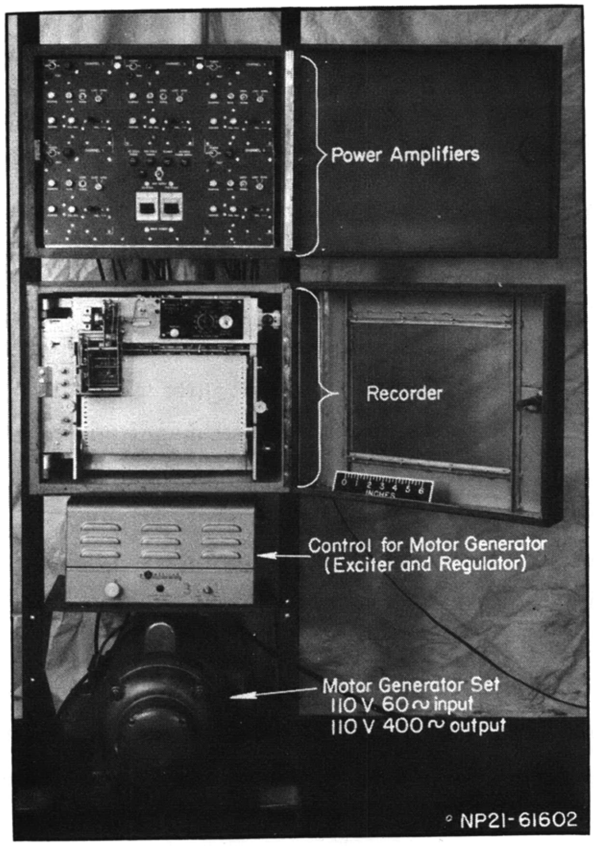


Figure 10a - Front View of Recorder

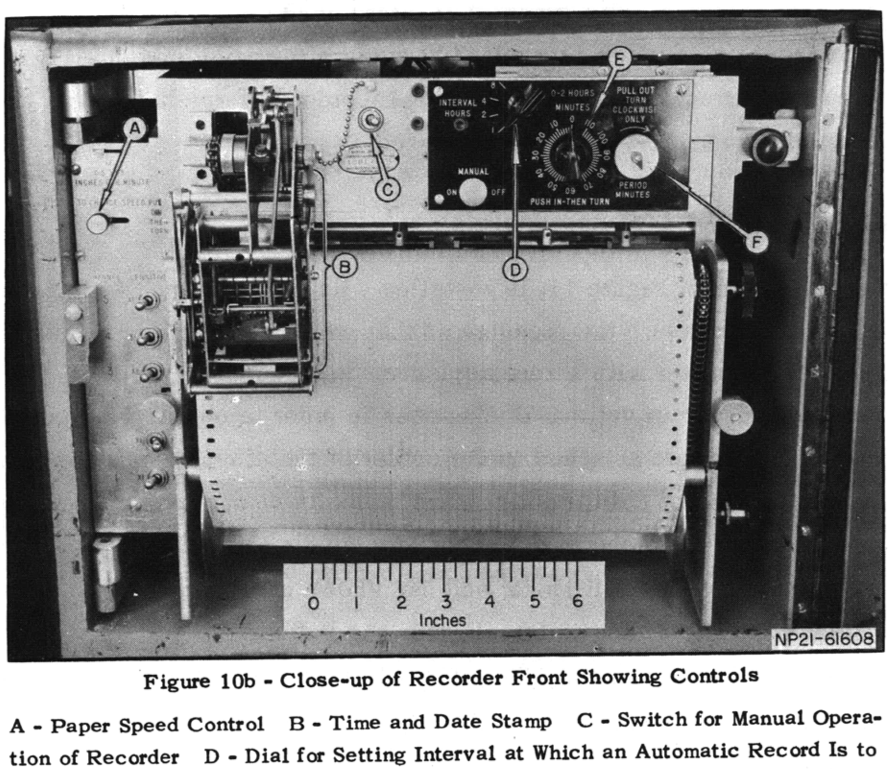


Figure 10b - Close-up of Recorder Front Showing Controls

A - Paper Speed Control B - Time and Date Stamp C - Switch for Manual Operation of Recorder D - Dial for Setting Interval at Which an Automatic Record Is to Be Taken E - Dial for Setting Duration of Manually Controlled Single Record F - Dial for Setting Duration of Automatic Recording Cycle

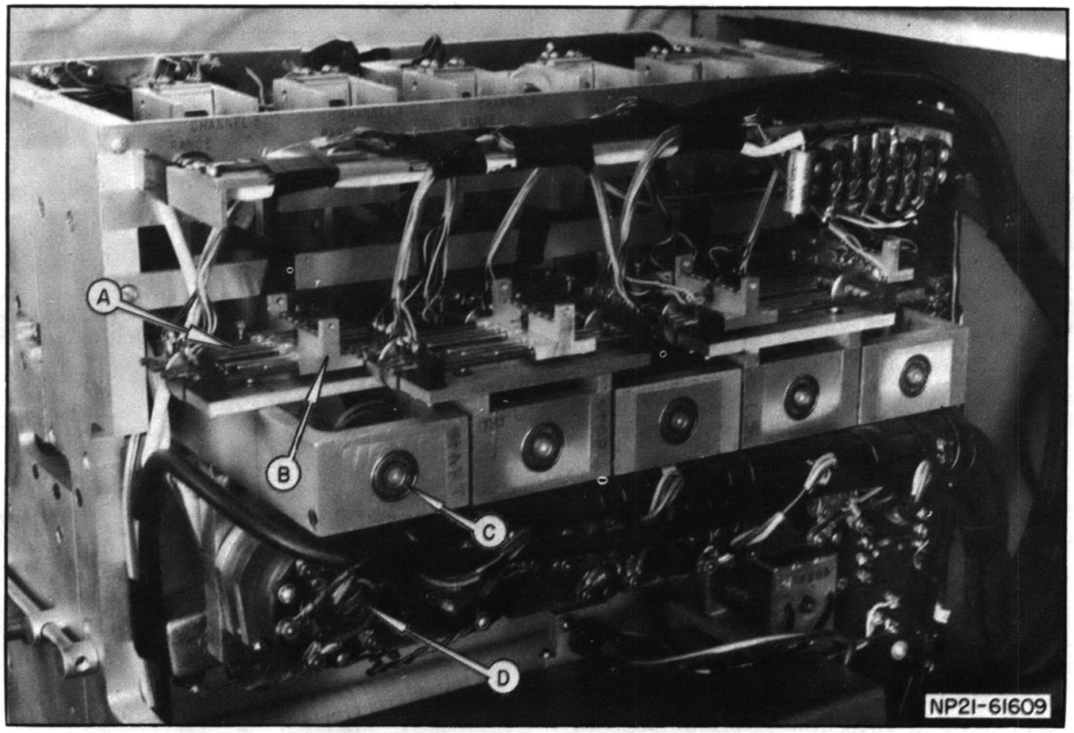


Figure 10c - Rear View of Recorder Chassis, Showing Statistical Cycle Gages

A - Silver Bar the Length of Which Corresponds to the Magnitude of the Quantity that Will Be Registered on a Digital Counter Whenever It Is Exceeded. B - One of the 5 Statistical Cycle Gages C - Drive Shaft of Balance Motor in Servo Loop D - Drive Motor Actuating the Drive Shaft

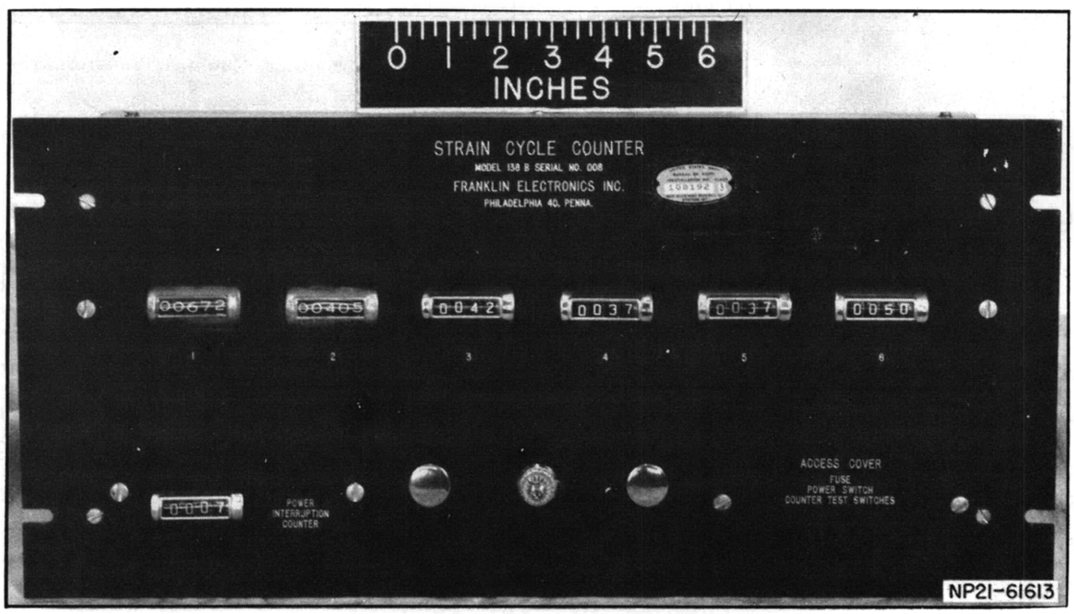


Figure 10d - Digital Cycle Counter
Used for Totalizing Number of Times Given Magnitudes Have Been Exceeded

Figure 10 - TMB Automatic Statistical Recorder

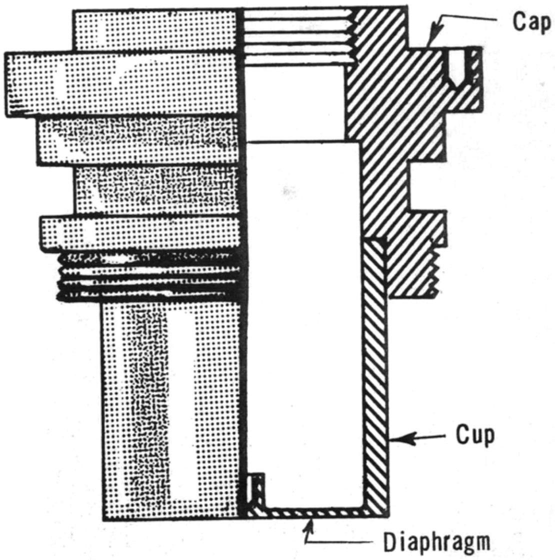


Figure 11a - Details of Pressure Gages

The gages used on UNIMAK had the following characteristics:

Diaphragm Thickness	Range	Sensitivity, mils deflection of center of diaphragm/psi
0.032	500 psi	0.029
0.037	900 psi	0.020

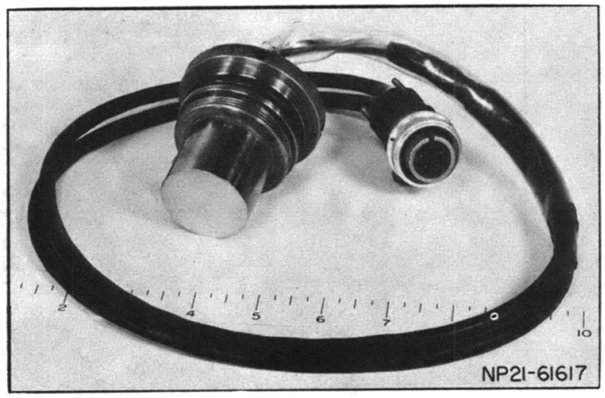


Figure 11b - Pressure Gage Assembly

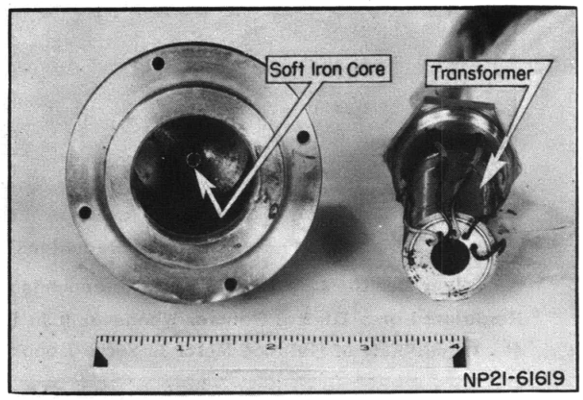


Figure 11c - Gage Cup and Transformer

Figure 11 - Diaphragm Pressure Gage

ANGULAR ACCELEROMETER

This instrument has been especially developed for measuring the low-frequency, low-intensity angular acceleration associated with the pitching and rolling motions of ships. These accelerometers (Figure 12) essentially consist of two matched, oil-damped, linear accelerometers, physically mounted a distance of several inches apart in one housing and with their outputs electrically connected in series opposition. Thus the combined signal is proportional to angular acceleration. The sensing elements are Schaevitz differential transformers which give an amplitude-modulated, 400-cps carrier output. The manufacturer's designations of these accelerometers are Types F and WS.

The accelerometers have a natural frequency of 3 to 4 cps, a range of ½ rad/sec^2, an output of the order of 70 mv per volt 400-cycle input per radian per second^2, and are relatively insensitive to linear accelerations and to angular accelerations about axes perpendicular to their sensitive axes. These angular accelerometers have given satisfactory service to date.

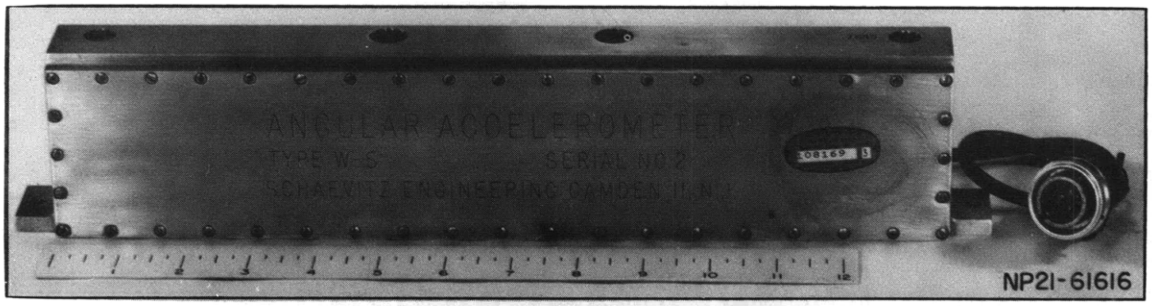


Figure 12 - Angular Accelerometer for Measuring Ship Motions

LINEAR (HEAVE) ACCELEROMETER

This accelerometer is made by the Schaevitz Engineering Company and is designated by the manufacturer as Type VC-S.

The accelerometer is sensitive to acceleration along one axis and relatively insensitive to other accelerations. It has a natural frequency of 20 cps, a range of ± 1 g, and a sensitivity of 150 mv per volt imput for an acceleration equal to the acceleration of gravity. The pickup is shown in Figure 13. The sensing element again is a differential transformer which gives an amplitude-modulated carrier signal. The carrier frequency used in this installation was 400 cps.

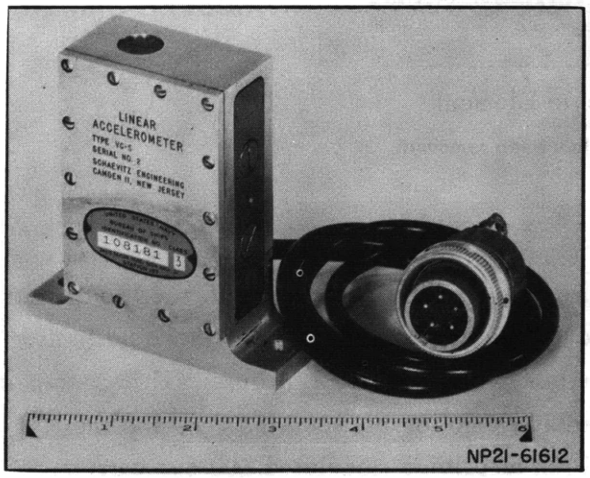


Figure 13 - Linear Accelerometer for Measuring Ship Motion

STABLE ELEMENT (FOR MEASURING ROLL AND PITCH ANGLE)

A Minneapolis Honeywell vertical gyro, Type JG 7003 A11, was used to give a signal proportional to angle of roll and pitch; see Figure 14. The gyro consists of a high-speed rotor supported in a cardan suspension by two gimbals, erecting torque motors which are actuated through the action of mercury switches mounted on the gimbals, and wire-wound potentiometers from which electrical signals of angular position can be obtained by means of wipers attached to the gimbals.

The dimensions of the unit are 9 1/8 by 6 1/4 by 5 1/2 in. overall; its weight is 5 lb, and its linear range is ± 52 deg in pitch and roll. The gyro requires an electrical supply of 115 volts 400 cycles and has an accuracy of ± 1/8 deg.

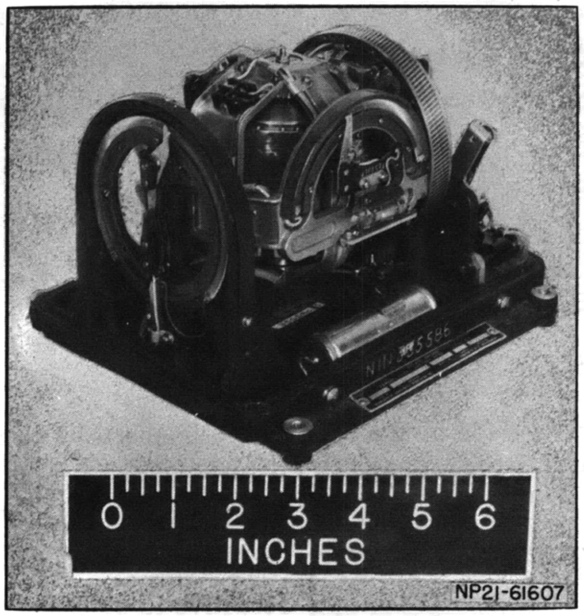


Figure 14 - Stable Element

The protective cover has been removed.

DEFLECTION GAGE

The deflection gage is illustrated in Figure 15. One of its parts is attached to a rigid support, which is secured to the longitudinals bounding the particular panel whose deflection is to be measured. The gage itself consists of a Schaevitz Type 10 L differential transformer and a soft-iron core attached to the plate. The relative motion between the core and the transformer proper results in an electrical signal (an amplitude modulated 400 cps carrier) proportional to this deflection.

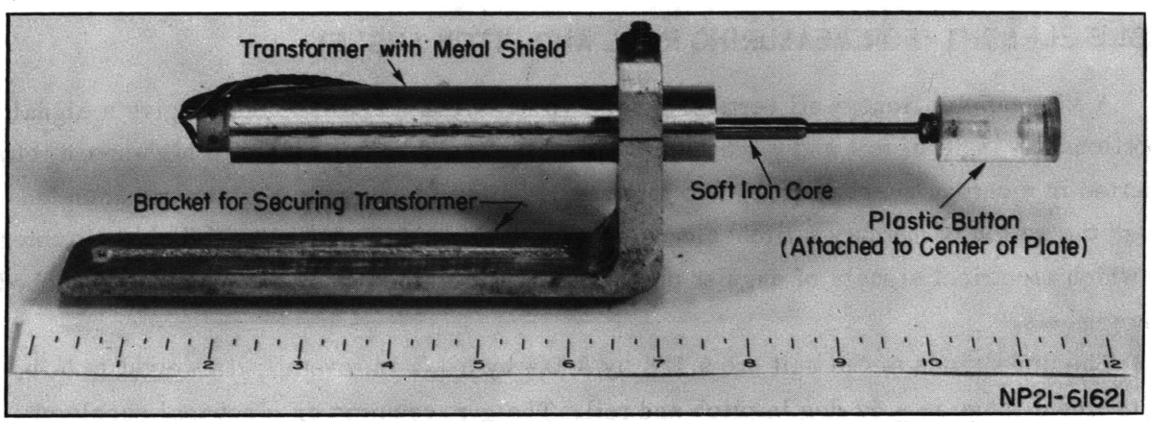


Figure 15 - Deflection Gage

STEREO CAMERAS

Two Type K24 aerial cameras were used to provide stereophotographs of the sea to supplement the observations made by the official weather observers. The cameras have a 1/150-sec focal-plane type shutter. The focal lengths of the lenses used with these cameras were approximately 7 in. The calibrated focal length was obtained from the Bureau of Standards. The settings of the aperture were made according to the prevailing environmental conditions. Super XX film was used. These cameras were modified by the addition of a glass platen that was used to keep the film flat.

The cameras were located 52 ft apart approximately 56 ft above the baseline.

LOW-SPEED TAPE RECORDER

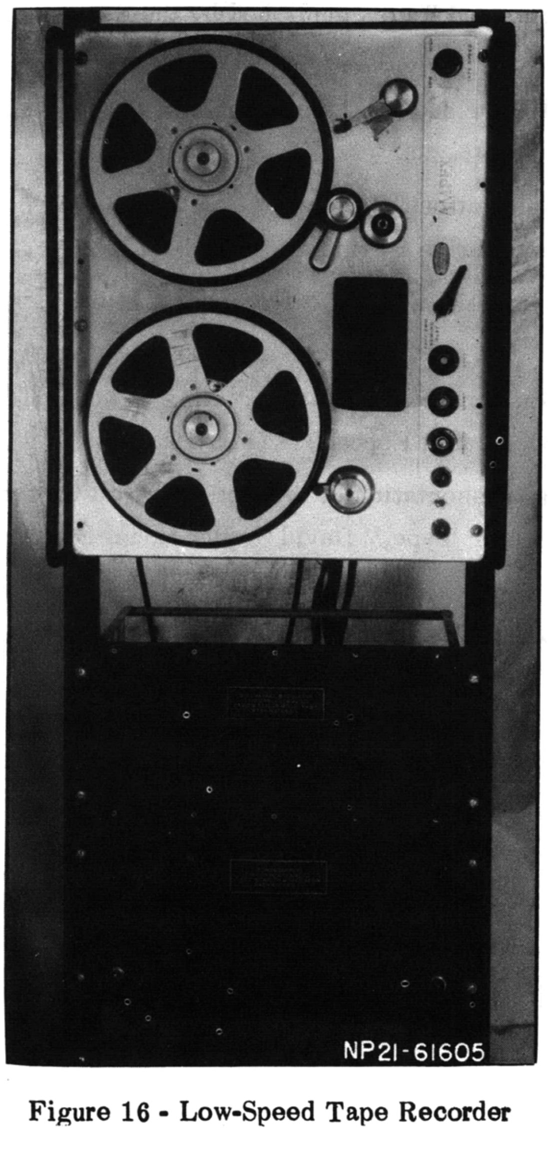


Figure 16 - Low-Speed Tape Recorder

The tape-recorder system, shown in Figure 16, consisted of a modified Ampex Model 307 tape transport, a frequency modulator, and a power supply. The output frequency of the modulator was varied linearly by the signal from the roll and pitch stable element. The recording tape speed was 3.4 in./min. Type 109 "Scotch" magnetic tape (2400 ft long) was used. The demodulating system used previously with this type of data recorder was not entirely satisfactory, and an improved type of demodulator is under development at the Taylor Model Basin.

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