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DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

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EXPERIMENTAL DETERMINATION OF PRESSURE AND STRAIN ON THE BOW SONAR DOME OF USS BARRY (DD 933)

by

Louis A. Becker

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

July 1960

Report 1395

PRNC-TMB-648 (Rev. 3-58)

DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

IN REPLY REFER TO
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3 August 1960

From: Commanding Officer and Director, David Taylor Model Basin
To: Chief, Bureau of Ships (335) (in duplicate)

Subj: Bow sonar dome of USS BARRY (DD 933); pressure and strain measurements on

Encl: (1) DATMOBAS Report 1395 entitled "Experimental Determination of Pressure and Strain on the Bow Sonar Dome of USS BARRY (DD 933)" 3 copies

1. As part of Project 50169 OP EVAL the David Taylor Model Basin made measurements on the bow sonar dome of USS BARRY (DD 933) during full-scale trials to determine the pressure loadings on and the structural response of the dome. These measurements are reported in enclosure (1).

2. The measurements showed the dome to be adequate to withstand the stresses resulting from all maneuvers conducted during the trials.

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Louis A. Becker

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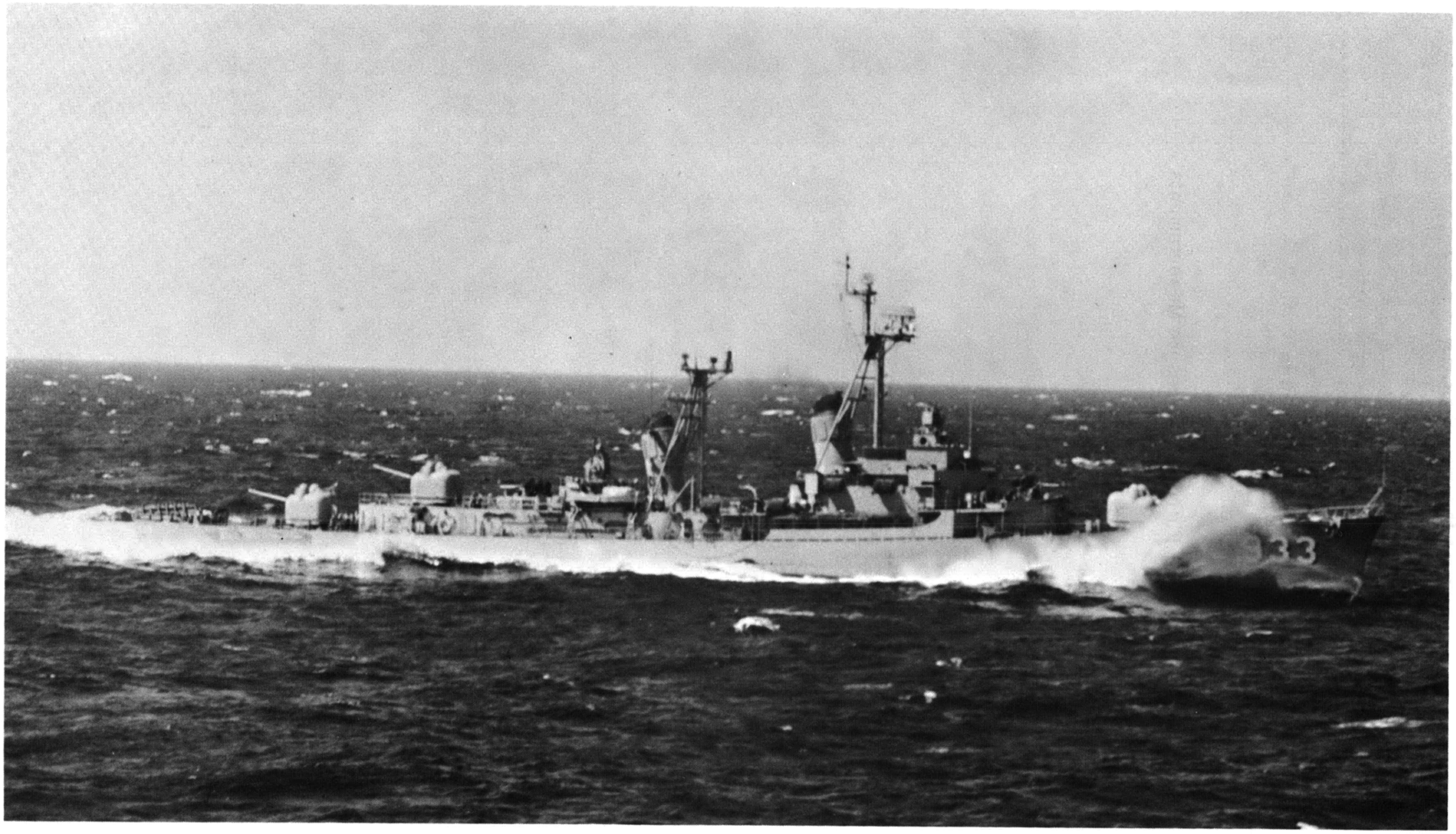

USS BARRY (DD 933)

ABSTRACT

Measurements were made on the bow sonar dome of USS BARRY (DD 933) during full-scale trials to determine the pressure loadings on and structural response of the dome. These measurements are correlated with ship motions and sea states. The maximum stress measured in the dome structure was 13,500 psi, compression. The maximum pressure observed during the trials was 42 psi. Both the maximum pressure and the maximum stress occurred during a slam in a State 6 sea. In this sea condition acceleration at the bow reached ± 1.1 g, and the pitch was as high as ± 5 deg.

From the measured strains in the hull, a maximum midships bending stress of 18,750 psi tension and a maximum quarterpoint shear stress of 3400 psi were determined. The measurements show the dome to be adequate to withstand the stresses resulting from all maneuvers conducted during the trials.

INTRODUCTION

With the advent of nuclear power and guided missiles, the submarine has become more important as a weapon, and thus the problem of submarine detection has become even more critical. As part of the submarine detection program a new sonar has been developed. This new sonar was first installed on USS BARRY (DD 933) early in 1959. The installation was unique in that the sonar was housed in a free-flooding steel dome located at the bow. The dome was made an integral part of the bulbous bow.

The sonar dome of BARRY is very difficult to analyze structurally because of its complex shape and a lack of knowledge of the loads. Since other domes of this type are planned, the Bureau of Ships[1]* requested the David Taylor Model Basin to measure the strains and pressure on the BARRY dome, in order to obtain the loading and structural response of the dome.**

This report presents the results of the full-scale structural tests conducted in April 1959 off the east coast of the United States. Strains and pressures were recorded during various maneuvers in seas up to State 6, where some slamming occurred. The hull stresses were also determined. All the data are correlated with ship motions.

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*References are listed on page 18.

**Reference 1 also requested the Underwater Sound Laboratory to make simultaneous self-noise measurements in the dome. The results of those measurements will be reported by that Laboratory.

DESCRIPTION OF DOME

The sonar dome of BARRY is a steel structure mounted at the bow; see Figure 1. The dome, the front of which is removable for access to the transducer, is constructed of a ¼-in. stainless steel skin (with a nominal yield strength of 30,000 psi) stiffened by two sets of intercostal trusses. The trusses, which run longitudinally and either transversely (fixed section) or radially (removable section), are flame-cut from 30.6-lb plating with a nominal yield strength of 47,000 psi. In the bottom of the dome the stiffeners are of rectangular cross section. The removable part of the dome is shown in Figure 2. A closeup of the trusswork and steel skin is shown in Figure 3. The removable part, resembling a quarter sphere, is bolted to the fixed section, which is an integral part of the hull, and to the hull, as shown in Figures 1 and 2.

The dome is located at the bow of the ship. When the ship is at sea, the dome is about 15 ft below the waterline. The dome is always flooded when the ship is afloat, through flooding holes at the rear of the fixed section.

INSTRUMENTATION AND PROCEDURE

The sonar dome was originally instrumented with strain and pressure gages, as shown in Figure 4. The pressure gages were waterproofed by the method described on page 33 of Reference 2, whereas the strain gages were waterproofed by the methods described on pages 10 and 13. All instrumentation was installed before the removable section was attached.

During installation of the removable section some of the instrumentation was damaged. Then additional damage was caused when the dome was flooded because of the very limited amount of area for waterproofing at each strain-gage location on the narrow (¾-in.) trusswork. The damage was not discovered until after the ship was undocked; thus the repairs had to be made while the ship was in the water. A complete repair of strain gages was impossible because of excessive condensation and leaks in the dome. No repair of pressure gages was possible since they were exposed to the sea and removal would have flooded the dome. Hence it was possible to repair only about half of the instrumentation. The gages that were repaired were waterproofed with Epibond.*

In addition to the instrumentation in the dome, the following instrumentation was installed on the ship:

Instrument	Location (Frame No.)	Quantity Measured
Accelerometer (linear)	7 and 102	Vertical accelerations
Accelerometer (angular)	17	Pitch accelerations
Gyro	17	Pitch and roll
Wave-height recorder	111	Sea state
Strain gages	111	Hull bending
Strain gages	50	Hull shear

*Epibond is an epoxy resin manufactured by Furane Plastics, Inc.

(Text continued on page 6.)

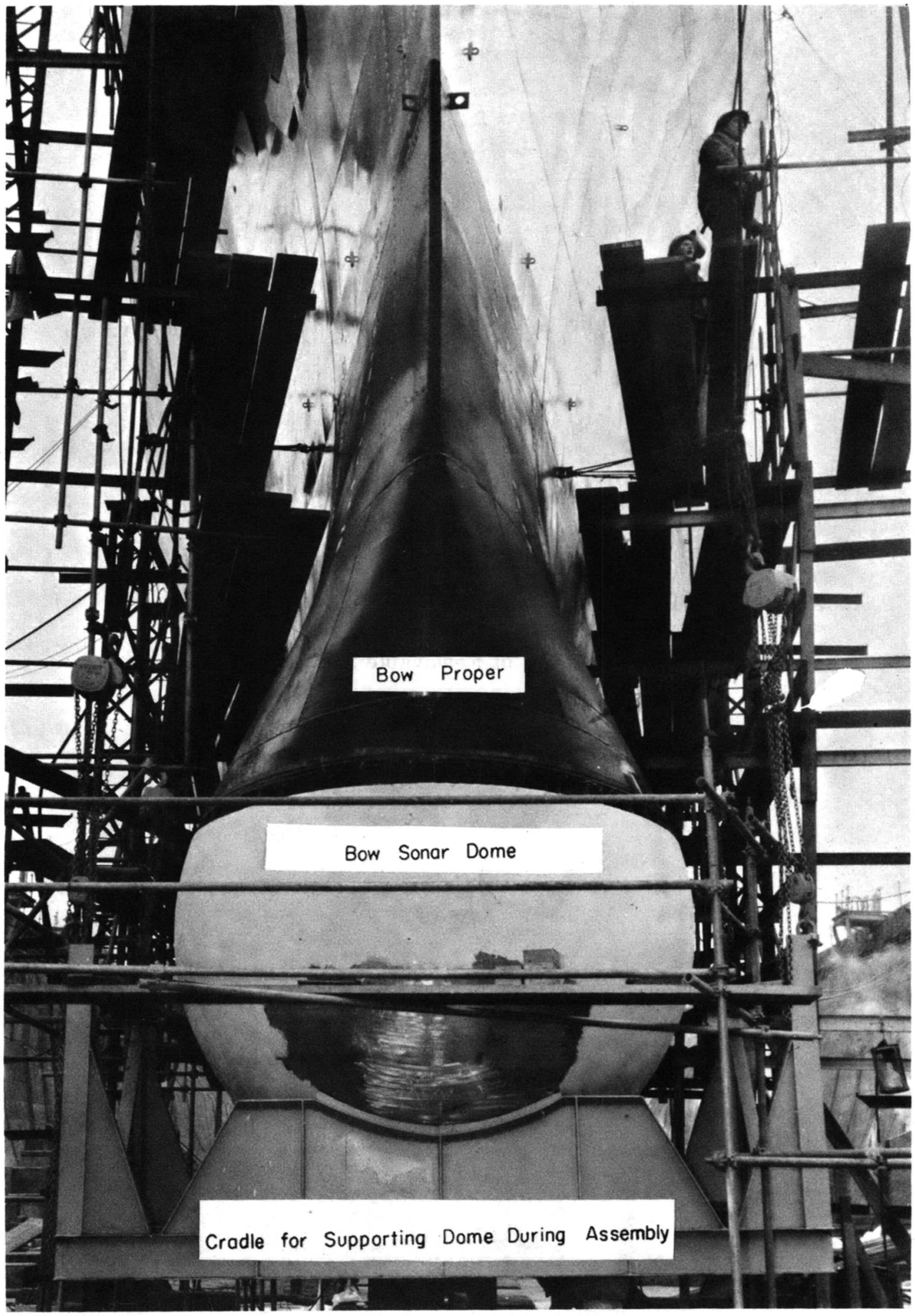

Figure 1 – Bow Dome Being Fitted on BARRY in Drydock

Figure 2 – Interior View of Removable Section of Bow Dome

Figure 3 – Closeup of Trusswork in Dome

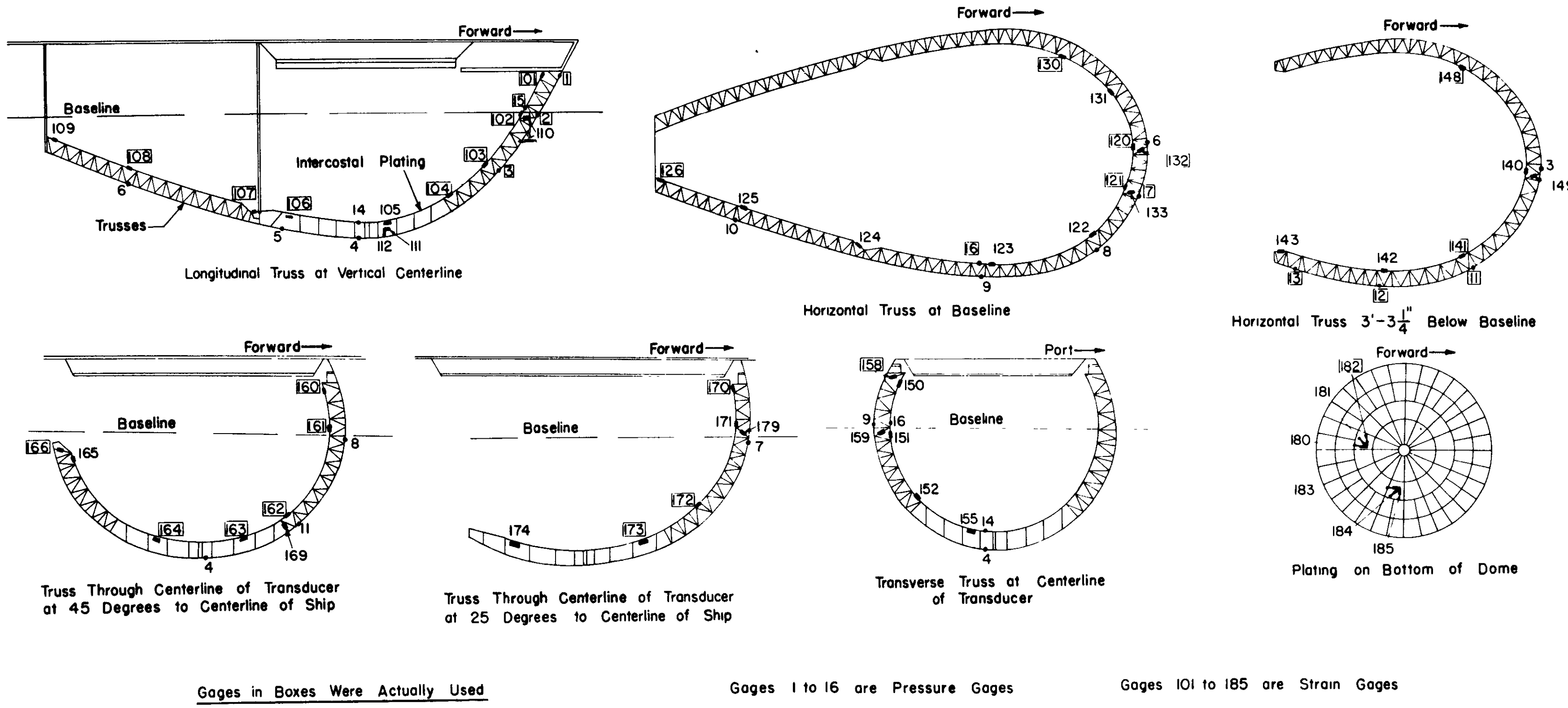

Figure 4 – Locations of Strain and Pressure Gages

The signals from all the strain and pressure gages were amplified and recorded on two electromagnetic oscillographs. The remainder of the instrumentation was recorded on a direct-writing recorder. The records from all three recorders were synchronized by introducing a common time signal.

All amplifiers were balanced, and zero readings were taken before the ship got under way. As the various sea conditions were encountered, the runs listed in Table 1 were made.

TABLE 1

Test Schedule

Run*	Sea State**	Speed (knots)	Initial Sea Direction	Maneuver
501	4	10	Head	Steady Run
502	4	15	Head	Steady Run
503	4	20	Head	Steady Run
504	4	25	Head	Steady Run
505	3	30	Quarter Head Port	Steady Run
506	3	32	Quarter Head Port	Steady Run
508	4	FP	Quarter Head Port	Steady Run
510	3	FP	Beam Port	Steady Run
512	3	FP	Quarter Following Port	Steady Run
513	6	FP	Quarter Following Stbd	Steady Run
514	4	FP	Following	Steady Run
515	3	FP	Head	Full Ahead to Full Astern
519	4	15	Head	Steady Approach Followed By A 0-15R-15L-0 Turn
520	5	15	Head	Steady Approach Followed By A 0-25R-25L-0 Turn
521	5	15	Head	Steady Approach Followed By A 0-35R-35L-0 Turn
521 A	6	15	Head	Steady Approach Followed By A 0-35R-35L-0 Turn
522	6	25	Head	Steady Approach Followed By A 0-15R-15L-0 Turn
523	6	25	Head	Steady Approach Followed By A 0-25R-25L-0 Turn
524	6	25	Head	Steady Approach Followed By A 0-35R-35L-0 Turn
525	3	FP	Following	Steady Approach Followed By A 0-15R-15L-0 Turn
526	3	FP	Quarter Head Port	Steady Approach Followed By A 0-25R-25L-25R-0 Turn
528	3	FP	Quarter Head Stbd	Steady Approach Followed By A 0-35R-35L-35R-0 Turn
530	6	25	Head	Steady Run

*Runs begin with 501 because they were part of the special performance trials. Runs are not in order of occurrence.

**State 3, 3–5 ft waves; State 4, 5–8 ft waves; State 5, 8–12 ft waves; State 6, 12–20 ft waves.

During the runs at constant heading, strains and pressures were recorded for 3 min and ship motions were recorded for 10 min. For the maneuvering runs, the strains, pressures, and ship motions were recorded during the entire run. As soon as the ship returned to port, zero readings and calibration records were again taken.

TEST RESULTS

The strains and pressures measured during the full-scale trials are listed in Table 2. The maximum strain in the dome was 450 μin/in., compression (Gage 103), which occurred during Run 523, a 25-knot run into a State 6 sea. The maximum hull bending strain, measured on the port side 2½ ft above the bilge keel, was 625 μin/in. tension (corresponding to a sagging stress of 18,750 psi), and the corresponding hogging strain was +285 μin/in. (8550 psi). The maximum hull shearing strain was 295 μin/in. (corresponding to a stress of 3400 psi). The maximum pressure, 42 psi, was recorded during a run into a quarterhead State 6 sea. Examination of Figure 5, a reproduction of the oscillograph record taken during this run, indicates that slamming did occur. The long period when the pressure is zero indicates that the gage was free of the water; the following high-pressure spike indicates that the dome slammed back into the water. The fact that slamming had occurred was further verified by determining the instantaneous pitching axis, computing the pitch angle necessary for slamming, and comparing it with the measured pitch angles. The approximate angle that will cause slamming is 4½ deg, and, as noted in Table 3, there are several runs during which pitch angles of 4½ deg (9 deg double amplitude) or more were measured. It is interesting to note some negative pressures* on the dome.

The ship motions measured during the trials are summarized in the probability curves of Figures 6 through 9. These curves show the percentage of all cycles with a magnitude exceeding any given value of the abscissa, and are found by a cycle-by-cycle analysis of the motion records. The maximum values of motion recorded during each run are listed in Table 3, but it must be noted that the maximum values for a given run did not necessarily occur at the same time.

Some whipping motions were detected during slamming. The motion had a frequency of 73 cpm, which is very close to 78 cpm, the first vertical mode frequency of the class (obtained from USS DECATUR (DD 936), which had no bow sonar dome[3]). The amplitude of this motion was small, and the resulting vibratory strains were on the order of 120 μin/in.

DISCUSSION OF RESULTS

During the first day at sea the maximum sea conditions specified in the original test agenda,[4] i.e., State 6, were encountered, and runs up to 25 knots were made into this sea. The 30-knot and higher speed runs were abandoned because of heavy topside damage at speeds in excess of 27 knots. Full-power runs were obtained on the second day, but these were never run into a head sea. During the runs in heavy seas, slamming was noted and slamming pressures were recorded.

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*Zero pressure is the pressure indicated by the gage in the atmosphere, and negative pressure is pressure that is less than atmospheric pressure.

(Text continued on page 15.)

Table 2 – Summary of Recorded Strains and Pressures

ns in Sonar Dome Strains are rounded off to ± 5 μin/in. Negative values are compression.

Run	501	502	503	504	505	506	508	510	512	513*	514	515	519	520†	520	521	521	521A	521A	522*	522*	523*	523*	524*	524*	525	5
	145	170	205	240	– 35	70	100	75	90	100	65	35	180	205	195	185	220	195	195	230	235	250	245	255	250	– 50	
	20	40	10	5	–	25	20	– 5	20	25	15	5	60	50	60	60	60	55	55	55	55	50	70	55	55	5	–
	– 80	– 80	– 70	– 60	–130	–125	–115	–120	–110	–155	–125	–115	– 90	– 70	60	– 75	– 75	– 85	– 70	– 70	– 65	–110	–450	–275	–175	–115	–1
	140	145	140	155	145	95	100	110	120	90	110	120	170	170	180	155	185	170	160	165	190	185	255	195	175	100	
	110	120	120	70	– 35	– 25	–	– 45	–	– 65	– 75	10	100	100	125	70	80	110	135	380	180	150	205	125	115	40	-
	20	30	35	35	5	– 45	10	10	15	25	– 5	20	50	55	60	60	60	65	95	220	60	50	120	90	95	20	-
	50	40	55	–	85	125	–	40	90	145	120	15	65	65	80	120	135	240	250	330	355	300	315	285	290	10	-
	55	65	90	175	85	100	–	–	140	155	140	– 15	85	95	95	170	105	180	230	195	235	250	285	215	190	85	-
	–	45	35	125	– 30	– 40	– 65	– 60	– 50	–120	– 50	5	60	55	70	115	135	125	135	–	–	140	205	100	80	–	-
	80	65	70	70	– 20	– 25	5	5	10	– 55	– 5	20	55	60	70	95	110	–	120	275	265	130	195	115	120	25	-
	100	125	160	105	235	–290	90	170	135	–215	–270	–	–135	–180	185	–125	–130	–	–	–	–	–350	–340	–335	–315	10	
	25	30	25	40	– 20	25	–	–	25	60	45	20	25	35	20	110	110	–	200	– 35	130	120	115	115	120	45	-
	– 30	– 25	– 10	10	– 35	– 25	– 5	– 30	– 25	–145	– 20	10	10	15	35	150	–	135	315	365	195	165	245	175	165	– 75	-
	80	70	–	110	– 10	– 20	– 20	– 30	– 15	50	15	–	5	15	20	120	115	105	105	260	85	125	105	125	90	10	-
	180	180	200	225	135	105	115	140	165	220	95	140	195	175	175	315	345	390	320	345	380	360	435	380	310	210	-
	5	5	10	15	– 45	– 25	65	55	45	– 75	– 35	50	20	25	30	95	105	20	25	30	40	35	45	30	35	70	
	35	25	30	45	– 50	– 45	– 35	– 45	– 35	– 60	– 40	– 25	65	40	45	35	55	40	40	35	45	45	30	50	40	– 25	–
	65	–	– 20	– 35	65	35	0	5	25	80	40	15	160	105	110	130	125	350	120	325	125	155	160	135	115	20	-
	10	95	125	–	35	65	70	–	60	85	60	30	160	145	140	135	140	115	125	– 45	150	160	140	175	185	70	-
	85	45	–	65	– 40	– 65	70	– 30	– 15	– 35	– 20	–	80	50	45	40	40	50	45	230	55	35	65	50	40	15	-
	30	50	–	–	10	– 5	– 10	– 10	–	–	–	– 5	–	–	–	–	–	–	–	–	–	–	– 30	– 15	– 15	– 5	-
	75	85	105	115	50	30	25	30	60	115	60	95	80	100	100	–	40	95	70	125	85	70	110	85	70	70	-
	65	90	95	125	45	– 30	–	10	25	95	15	15	80	100	90	–	135	130	110	–	–	130	150	130	150	15	-
	40	85	80	65	25	10	–	10	10	20	30	10	70	85	75	95	95	– 5	– 5	– 5	– 5	– 5	– 20	– 5	– 5	15	-
	70	70	80	110	– 10	45	70	55	65	85	45	75	90	95	85	95	100	90	75	110	110	115	115	120	120	40	

ins in Hull Strains are rounded off to ± 5 μin/in. Negative values are compression.

	501	502	503	504	505	506	508	510	512	513*	514	515	519	520†	520	521	521	521A	521A	522*	522*	523*	523*	524*	524*	525	5
I ir	80	130	140	90	120	115	80	135	130	165	105	85	–	100	90	85	175	160	130	105	170	135	295	85	115	130	-
I ng	175	130	–	210	– 80	125	145	225	125	150	65	210	220	340	320	475	490	250	475	510	520	490	625	520	535	285	-

ssures on Sonar Dome Pressures are rounded off to ± 1 psi. Where two values are given, they are the maximum and the minimum pressures recorded during the given run. Negative values indicate pressures below

	501	502	503	504	505	506	508	510	512	513*	514	515	519	520†	520	521	521	521A	521A	522*	522*	523*	523*	524*	524*	525
	12	15	18	23	21	21	22	25	27	27	26	23	19	16	15	13	17	19	13	25	25	25	28	27	24	25
	12	14	18	23	20	20	23	27	29	25	29	28	19	15	15	14	17	18	14	24	25	24	28	26	23	25
	13	13	16	16	12	11	13	12	14	42 / – 6	16	12	18	15	16	16	17	20	14	22	24	24	28 / – 1	26 / – ½	23	14
	9 / –	7 / –	6 / –	4 / – 5	– / – 6	– / – 6	– / – 8	– / – 10	– / – 13	3 / – 18	– / – 11	7 / – 6	11 / –	9 / –	12 / –	11 / – 5	14 / – 3	16 / –	11 / –	9 / – 7	10 / – 10	10 / – 3	13 / – 7	13 / – 6	14 / – 2	– / – 11
	11	9	12	16	17	12	18	28	17	22 / –2	18	22	13	10	11	9	12	18	13	21	22	21	26	22	22	17
	13	12	10	10	12	11	12	11	– 6	12	11	11	14	13	13	14	14	14	11	9	11	10 / – 7	11 / – 1	10 / – 8	1 / – 9	11
	6 / – 1	3	2 / –	– 4	– 6	– 6	– / – 3	1 / – 4	17	6 / – 11	– 7	12	2 / – 7	– 5	– 6	– 8	– 10	3 / – 8	– 6	– 7	– 10	– 13	2 / – 14	– 15	– 15	8
	7	4	6	10	– 6	– 2	4	7	3	8	3	–	7	8	8	– 2	– 2	5	5	13	13	9	9	10	10	7
	12	10	12	14	13	11	11	10	11	15	13	16	13	11	11	12	13	14	11	15	15	17	17	18	16	11

*Runs indicate slamming. †Where there are two columns with the same number, the first column is the steady approach and the second is the turn.

†Large values of negative pressure are questionable since gages were not designed to read pressure much below atmospheric.

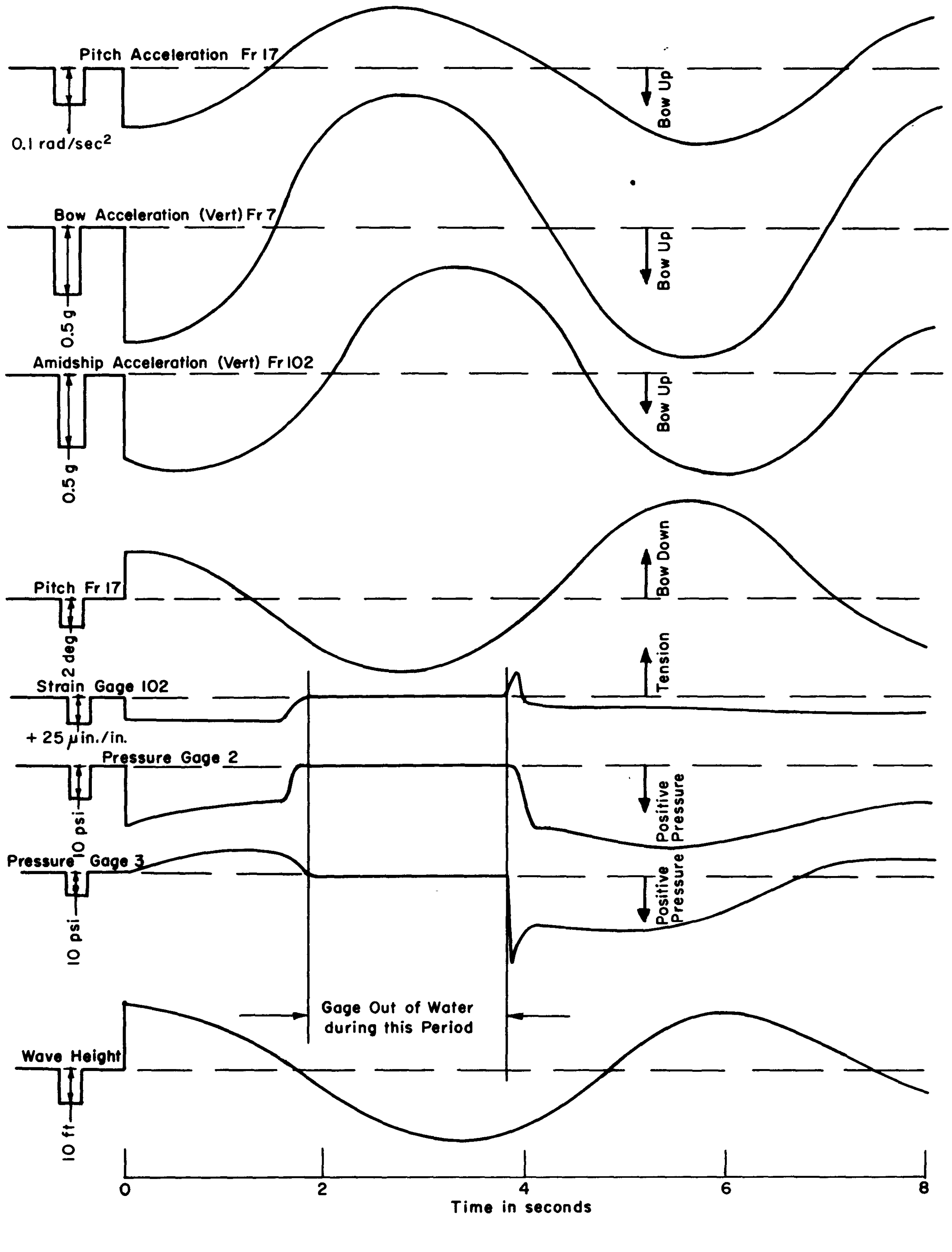

Figure 5 – Typical Motion and Strain Records

TABLE 3

Maximum Peak-to-Peak Motions Measured

These data were not taken at same time instant.

Run	Pitch Acceleration rad/sec^2	Bow Acceleration g	Amidship Acceleration g	Pitch Angle deg	Roll Angle deg
501	0.08	0.6	0.20	3	8
502	0.06	0.6	0.20	3	13
503	0.08	0.7	0.25	3	7
504	0.12	1.0	0.40	3	6
505	0.05	0.5	0.25	2	12
506	0.08	0.4	0.15	2	13
508	0.10	0.6	0.30	5	16
510	0.04	1.2	0.60	3	14
512	0.04	0.8	0.20	5	16
513	0.18	2.0	0.70	8	13
514	0.08	1.6	0.30	3	20
515	0.07	0.4	0.16	4	9
519	0.14	1.1	0.30	5	12
520	0.12	1.1	0.25	5	16
521	0.16	1.6	0.30	7	28
521 A	0.16	1.2	0.30	10	22
522	0.22	1.6	0.50	8	20
523	0.24	2.2	0.70	8	17
524	0.26	2.0	0.60	9	18
525	0.03	0.3	0.20	3	11
526	0.04	0.3	0.17	2	12
528	0.02	0.4	0.17	2	9
Average period (sec)	5	5	5	6¼	8½

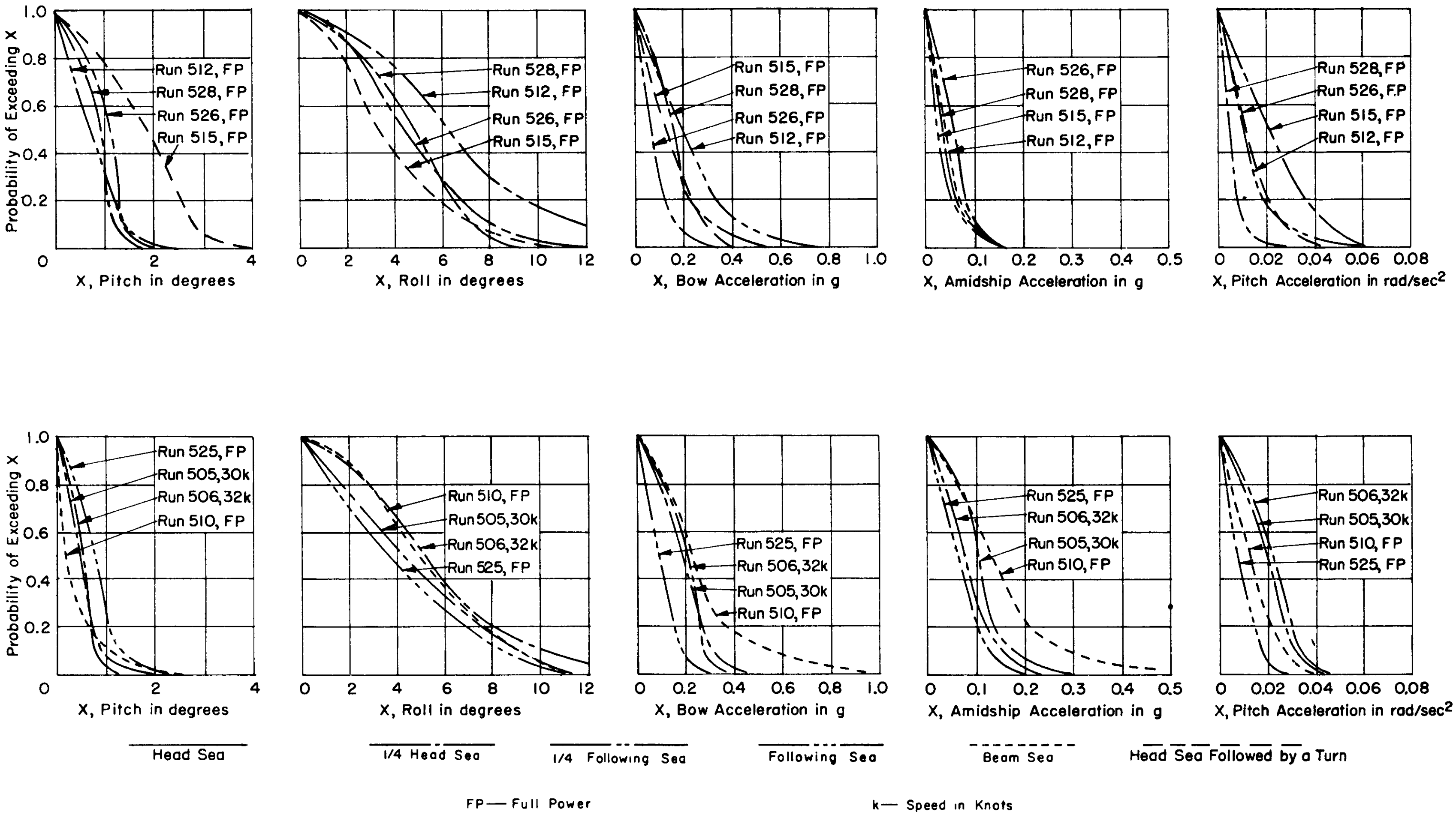

Figure 6 – Ship Motion Data in State 3 Sea

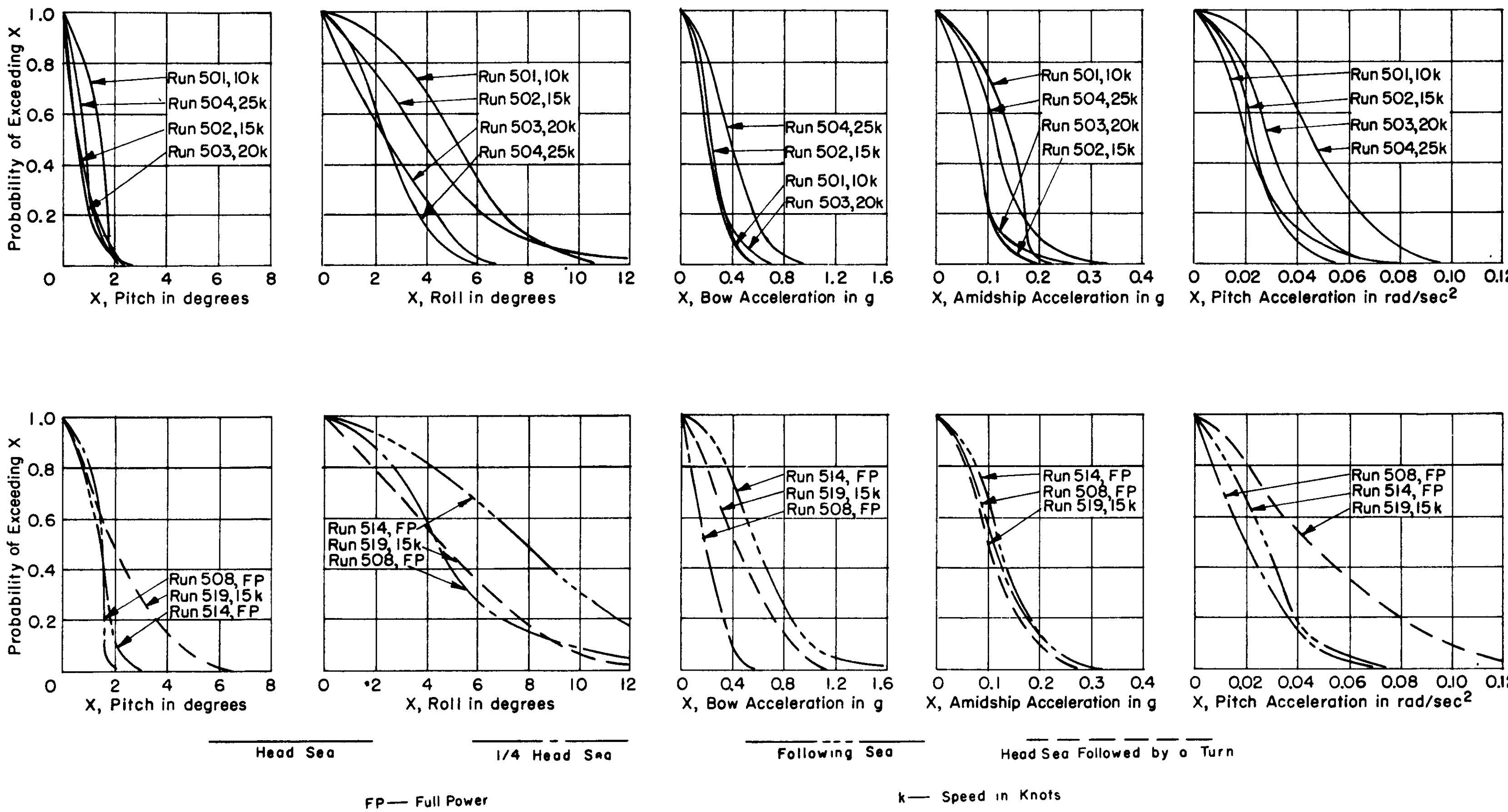

Figure 7 – Ship Motion Data in State 4 Sea

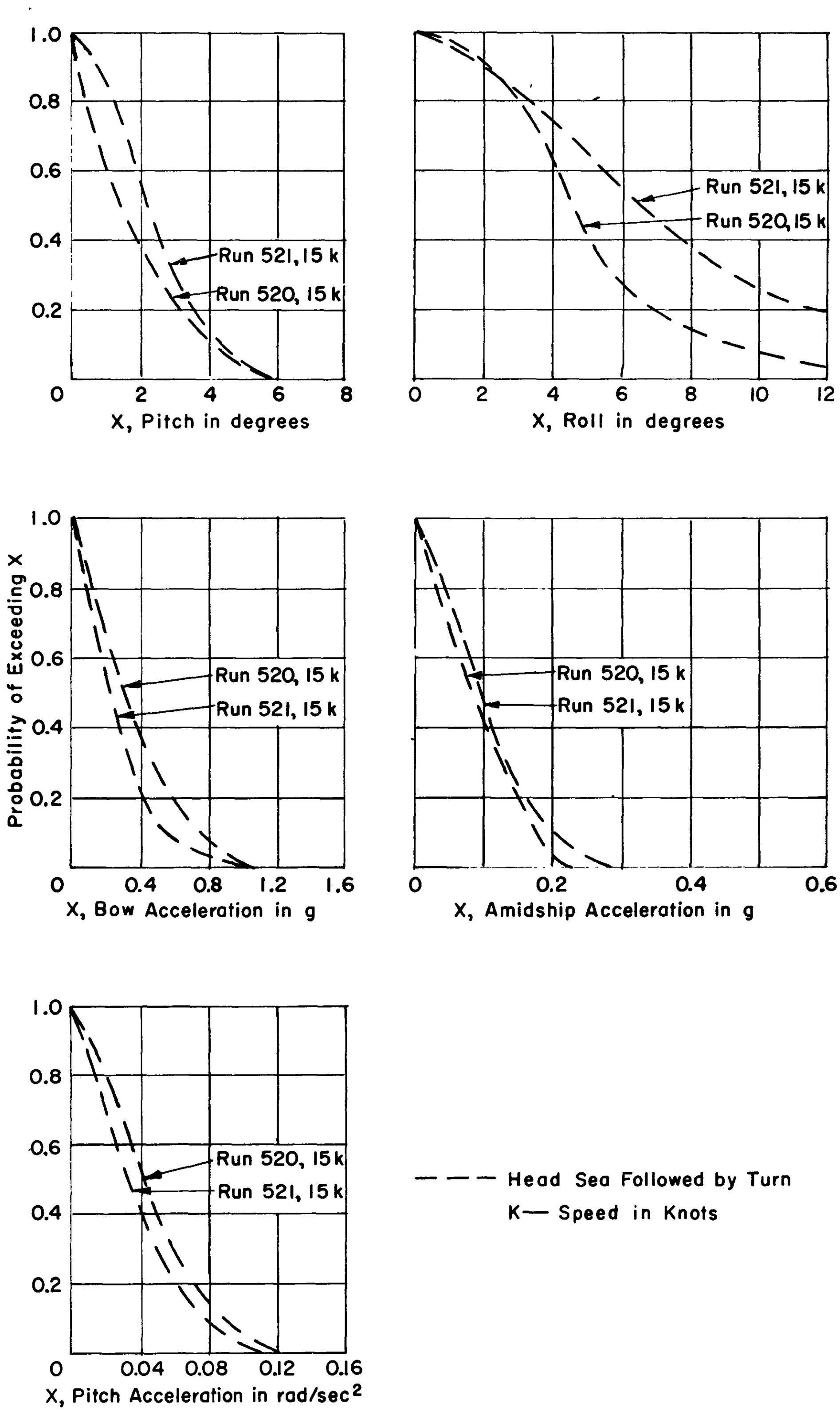

Figure 8 – Ship Motion Data in State 5 Sea

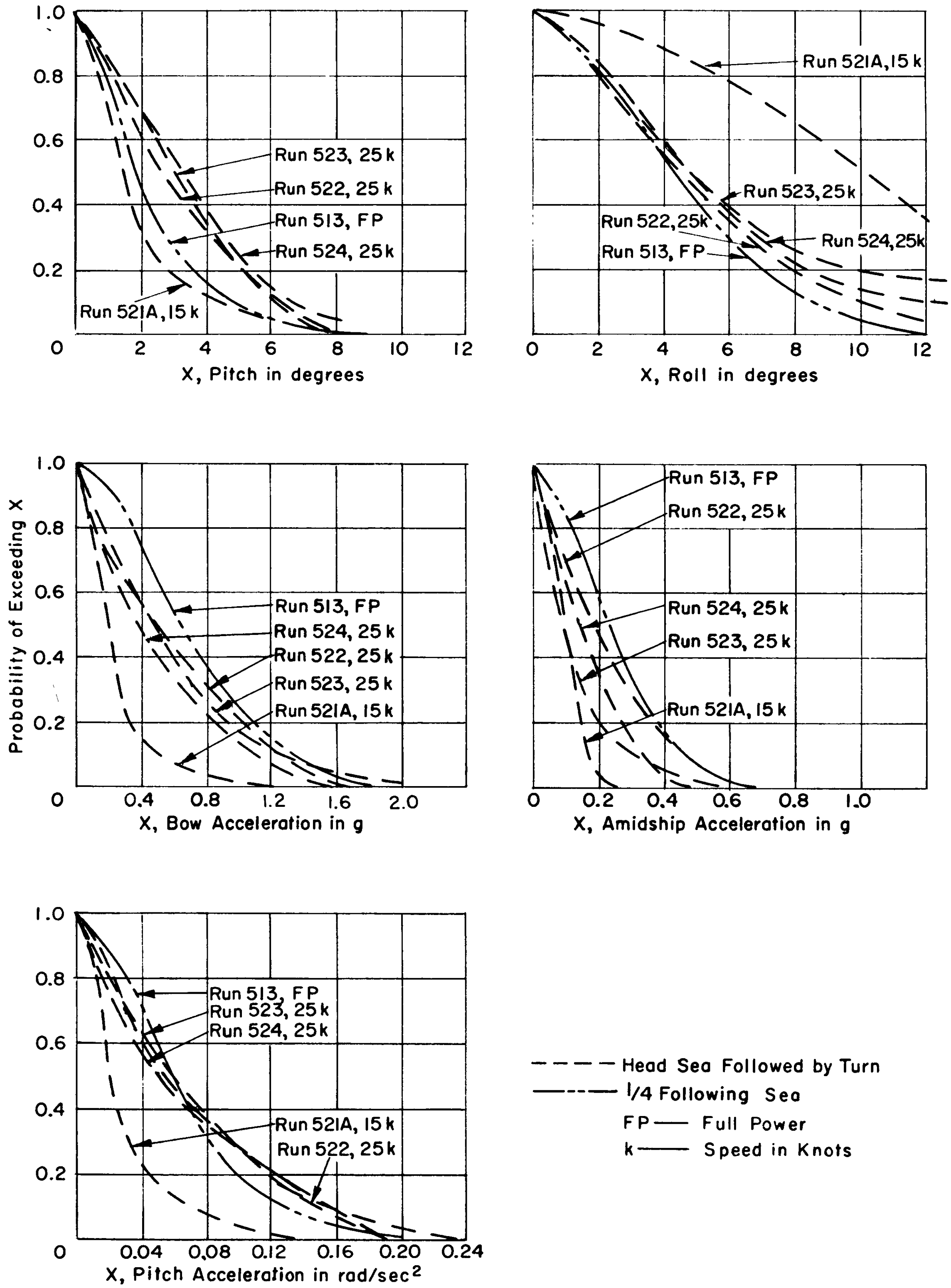

Figure 9 – Ship Motion Data in State 6 Sea

The maximum pressure recorded during these trials was 42 psi, which compares well with the value of 38 psi computed from Formula [77],[5] using the velocity obtained from the bow accelerometer data and the dead-rise angle measured from the plans of the structure. The maximum pressure was recorded by Gage 3, which is not at the bottom of the dome. The gage at the bottom, where the highest pressure would be expected, was not operating, but model studies[6] indicate that this bottom pressure would be of the same order of magnitude as that measured by Gage 3. The results of model studies,[7] listed in Table 4, indicate good agreement between model and full-scale pressures along the keel line and horizontal centerline but poor agreement on the 45-deg plane. The poor agreement on the 45-deg diagonal is attributed to the steep pressure gradient in that location.

TABLE 4

Comparison of Model and Full-Scale Pressure Measurements

Pressure, psi			
Gage	Location	Model	Full Scale
1	Vertical centerline truss	20	17
2	Vertical centerline truss	19	21
3	Vertical centerline truss	13	5
7	Horizontal centerline truss	– 9	–12
11	3-ft 3¼-in. waterline truss	0	22
12	3-ft 3¼-in. waterline truss	–12	4
13	3-ft 3¼-in. waterline truss	– 4	5

Examination of the strain data indicates very low strains in the dome, even during slams. To verify these results, an attempt was made to calculate the strains in the dome by assuming that one width of plating with a stiffening truss at its center was acting along the keel, and that this section was reinforced by a similar vertical section (Figure 10). It was further assumed that this entire structure was loaded with a uniform external pressure of 22 psi, the difference between the average external and internal pressures. To facilitate the calculations, the fixed section was considered part of the ship, and the removable section was considered hinged at the two bolt circles. The geometry of the keel line and stiffener was considered to be circular arcs with cross sections, as shown in Figure 10.

The strains in the structure were then calculated by writing the general moment equation, evaluating all constants from boundary conditions, computing the deflection at the stiffener intersection, making the deflections compatible, and computing the maximum moment. From this procedure a stress of 14,700 psi, tension which corresponds to a strain of 490 μin/in., was calculated. It is seen that this calculated strain is opposite in sign to the measured

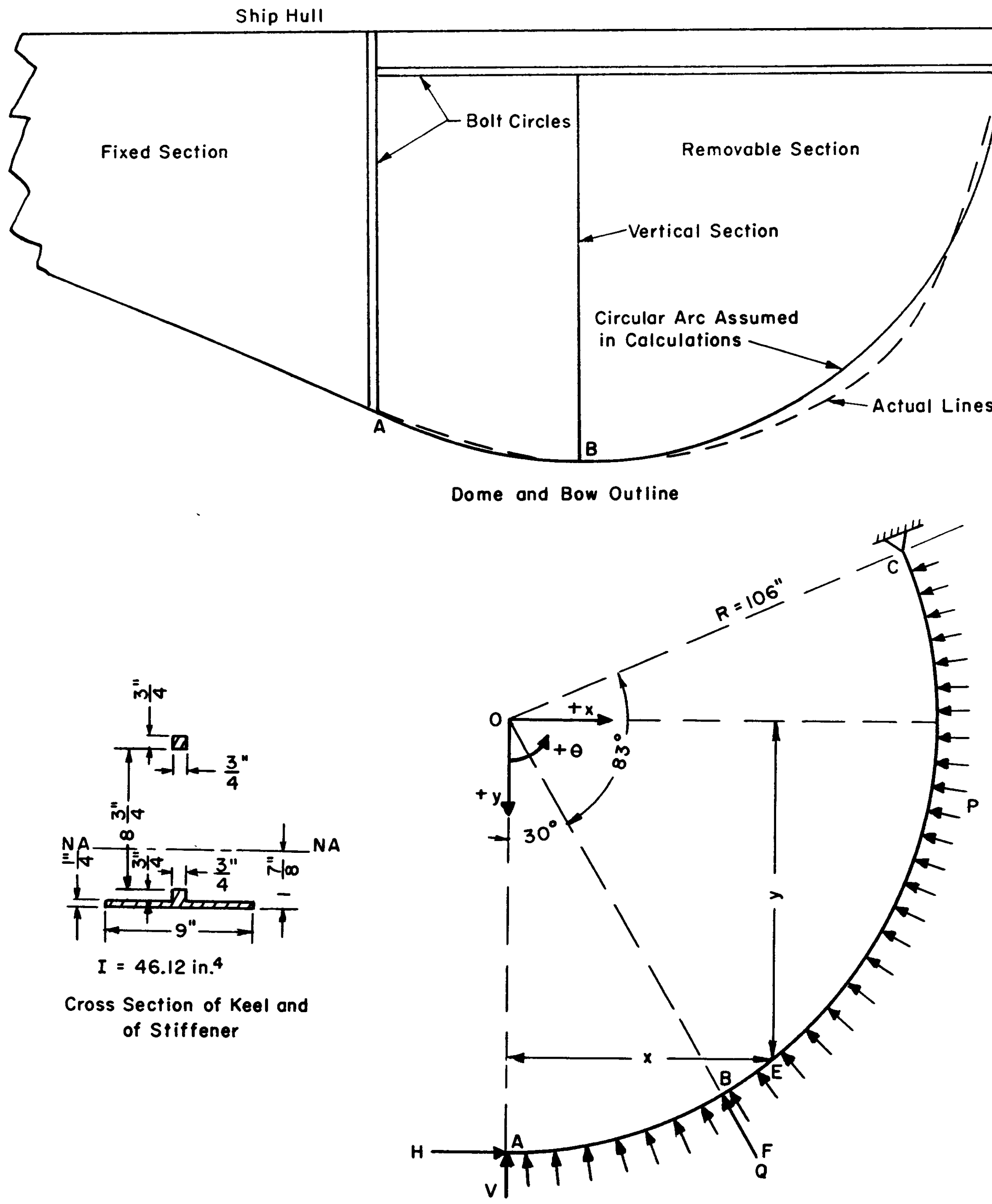

Figure 10 – Coordinate and Loading Systems Used for Calculations

strain in Table 2. Therefore, the good agreement in magnitude of the two strains must be regarded as fortuitous, and the strength of the dome can best be evaluated by experimental methods.

SUMMARY AND CONCLUSIONS

1. The maximum slamming pressure recorded during these tests was 42 psi at the 3-ft 3¼-in. waterline on the centerline. Unfortunately, the gage at the very bottom was not operating during the trials. However, model studies indicate that pressure at the 3-ft 3¼-in. waterline is approximately the same as that at the bottom of the domes.

2. The maximum strain was observed during a State 6 sea and was 450 μin/in.

3. The full-scale pressure data agree well with the model data obtained around the bottom and on the horizontal centerline. There are some discrepancies around the 3-ft 3¼-in. waterline.

4. The maximum hull bending strain measured during these tests occurred during a State 6 sea and was 625 μin/in.

5. The maximum hull shearing strain occurred during the same sea and was 295 μin/in.

6. During slams the hull vibrates vertically in its first natural mode. The amplitude of this motion is small, and the resulting hull bending strain is of the order of 120 μin/in.

It is concluded that the sonar dome is adequate to withstand all the State 6 sea maneuvers undertaken during these tests. Since topside damage was inflicted during the tests, it is concluded that the dome is adequate to withstand most normal operational maneuvers.

RECOMMENDATIONS

In view of the low strains measured, it is recommended that consideration be given to lightening the structure for future ships if no greater performance requirements are anticipated. However, local buckling must be considered in such a redesign.

It is recommended that future strain-gage installations for such sonar dome studies be made in drydock after the removable section has been installed.

ACKNOWLEDGMENTS

The author wishes to express his thanks to all the members of the Model Basin staff who assisted with the trials, and in particular, Messrs, D.J. Duffy, K. Hom, V.A. Morrison, C.A. Quackenbush, A.J. Wiggs, and J.E. Wolfe who participated in the repairs while the ship was in wetdock.

The cooperation of the Boston Naval Shipyard, during both the instrumentation and the repair, is gratefully acknowledged. Much of the success of the trials was due to the interest and initiative of Mr. W.E. Tims of Shop 51.

Special thanks go to all the officers and men of BARRY for their cooperation and interest in the trials and, in particular, to CDR I.A. Johnson, USN, for his complete cooperation in providing all desired maneuvers.

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