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STRUCTURAL TEST OF DMS23 POLE MAST AND RIGGING DURING DEPTH-CHARGE FIRING

by

Norman H. Jasper

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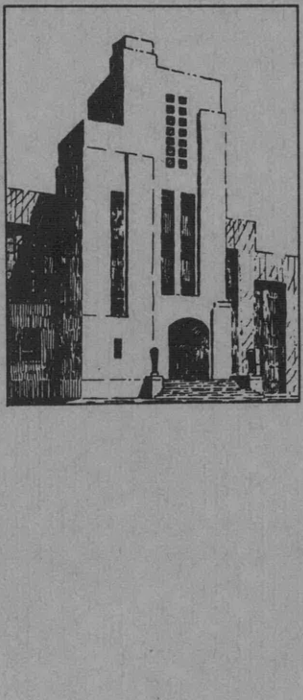

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ABSTRACT

This report discusses the tests which were made during structural firing trials of the USS MACOMB (DMS23) in order to evaluate the suitability of the pole mast rigging as well as to determine the severity of hull stresses during depth charge firing.

It is concluded that the revised rigging is satisfactory and that the dynamic stresses in the mast and rigging are not appreciably affected by variations in the initial tension in stays and shrouds.

A uniform procedure for the loading of stays and shrouds is proposed.

INTRODUCTION

The USS MACOMB (DMS23), formerly the DD458, underwent depth charge structural firing tests on 3 May 1950, at which time a severe whipping motion of the mast was observed.[1] The mast whipped so as to cause alternate slackening and tightening of stays so that fracture of the mast and of the radar antenna mounted atop the mast appeared imminent (see the ship's report, Reference 1).

Subsequent to these tests the Bureau of Ships authorized[2] an alteration to the mast rigging which, it was hoped, would reduce the whipping of the mast resulting from depth-charge firing; see Figure 1. According to the old rigging arrangement, the upper backstay was attached to the mast some 8 feet below the upper forestays so that any considerable tension in the stays would subject the mast to high bending stresses. In accordance with the BuShips request, the upper backstay was moved from its original position to a point directly opposite the point of attachment of the upper forestays. This revised arrangement made it possible to put considerable initial tension into the stays without developing large bending stresses in the mast.

The Bureau of Ships requested[3] that the Taylor Model Basin conduct certain tests during repeat structural firing trials of the DMS23 in order to evaluate the suitability of the revised rigging. Discussions with the ship's officers, held about two days before the scheduled trials, indicated that the test program should be expanded to include some data on the severity of hull stresses during depth-charge firing, inasmuch as a main deck longitudinal in the after steering engine room had been fractured and numerous less severe failures had occurred during the structural firing trials of 3 May 1950. The tests which form the basis of the present report were made on 15 December 1950 in waters off the Charleston Naval Base.

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[1] References are listed on page 16.

This report will be concerned only with the strains and motions of the hull and mast which were measured by the Taylor Model Basin. In addition, during these tests, the Naval Research Laboratory measured the shock motions at various locations such as on machinery foundations.

PLAN OF TEST

It was intended to study the behavior of the mast under two conditions, namely:

A. Loaded Condition

All stays were to be preloaded with a force equivalent to about 20 percent of the "minimum breaking strength"* of the wire rope, but with the restriction that the components of these loads, inducing bending of the mast, be kept to a minimum. The shrouds, also, should be given an initial tension.

B. Slack Condition

All stays and shrouds were to be given a minimum of initial tension. This condition would ideally be that of an unstayed mast, but the Bureau of Ships did not wish to assume the risk involved and requested that this so-called "slack condition" of the stays be taken to represent initial loads of the order of 10 percent of those used for the "loaded condition."

The calculated loads for these two conditions are tabulated in Table 1, together with other pertinent data. To measure the loads in the stays, tension dynamometers were designed and built to replace one rigging screw in the turnbuckle which adjusted the tension in each stay. These dynamometers (Figure 2) employ wire-resistance strain gages as the sensitive elements. A typical calibration for one of these load-measuring devices is shown in Figure 3.

It is obvious that the motions and strains of the mast are a function of the hull motion which, in turn, is determined by the severity of the depth-charge detonation as well as the position of the charge relative to the ship at the time of the explosion. To permit comparison of the response for the loaded and slack conditions of the mast, it was necessary to obtain a measure of the relative severity of the hull response for the several conditions. This was done by measuring the acceleration of the hull at the fantail and at the base of the mast. It was decided to measure the response of the mast to the depth-charge firing in terms of (a) the load in the upper backstay, (b) the fore-and-aft bending strain in what would appear to be a relatively highly-

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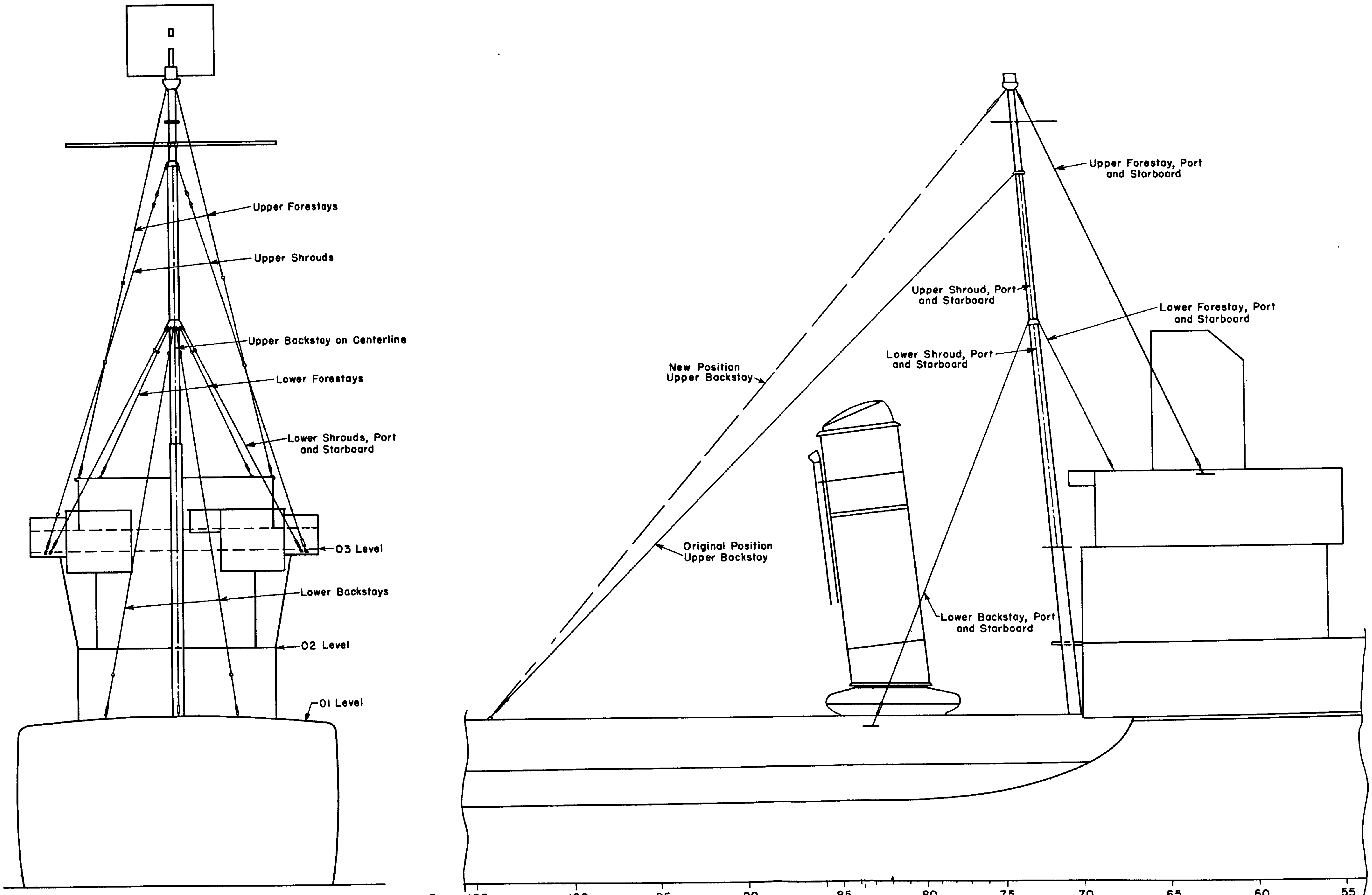
*Minimum breaking strength as required by specifications.



Frame 70 Looking Forward

Figure 1 - General Arrangement of Pole Mast, Rigging and Antennae

TABLE 1

Data on the Static Loading of the Mast Rigging

	Lower Backstay		Upper Backstay	Forestay		Shrouds	
	Port	Starboard		Upper	Lower	Upper	Lower
Diameter of stay, in.*	3/8	3/8	1/2	5/8	3/8	3/4	5/8
Cross-sectional area of steel, sq. in.	0.050	0.050	0.0889	0.139	0.050	0.1999	0.139
Length of wire stay, feet-in.	38-9	38-5	78-0	35-2	13-1	34-8	18-6
20 percent of ultimate strength, lb*	2224	2224	3800	5824	2224	8320	5824
Calculated Values							
Loaded Condition** - Desired load, lb	1430	1740	3800	4000	2220	-	-
Elongation of stay, in.	1.00	1.22	3.07	0.93	0.54	-	-
Assumed E* x 10^{-6}, psi	13		13	13			
Slack Condition† - Load, lb	143	174	380	400	222	-	-
Actual Test Values							
Loaded Condition - Load, lb	1080	1570	3570	4250(P) 4100(S)	2240(P) 2220(S)	Approx. 2300	Approx. 1800
Elongation,†† in.	0.94	1.01	3.55	0.49(P) 0.62(S)	0.45(P) 0.41(S)	0.44	0.31
Effective E x 10^{-6}, psi	10.7	12.7	9.1	23.4(P) 18.1(S)	14.0(P) 14.6(S)	11.0	9.3
Slack Condition - Load, lb	85	420	303	1000(P) 1150(S)	150(P) 260(S)	-	-

*Information furnished by BuShips, Code 442.

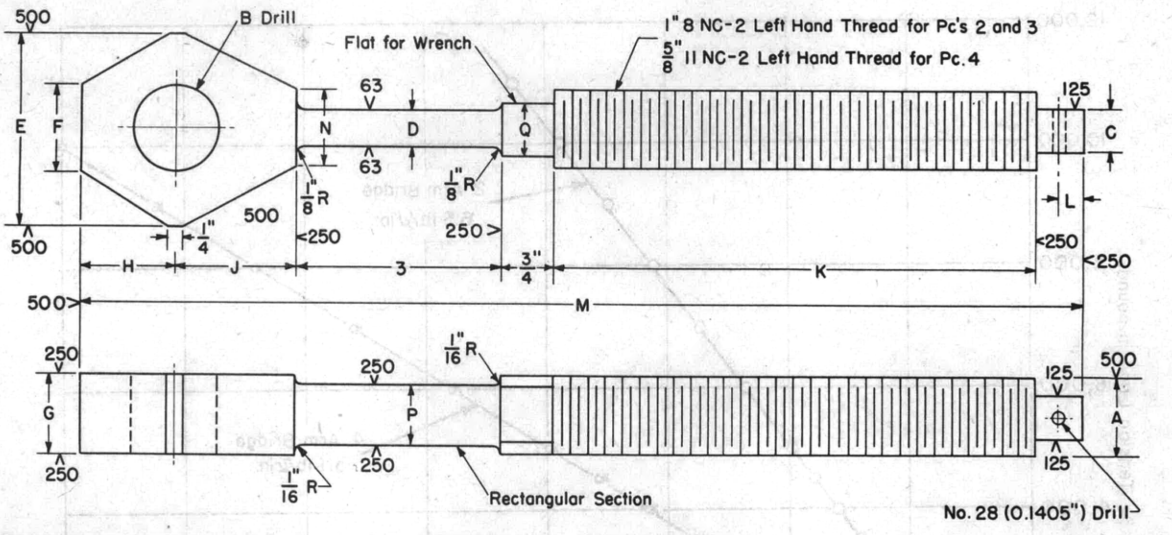
**For the loaded condition, loads were applied so as to produce a minimum of load components normal to the mast. Cable loads are to approach 20 percent of ultimate strength.

†For the slack condition, loads are 10 percent of those required for the loaded condition.

††This elongation is that measured due to about 90 percent of the total force applied during loading.

strained portion of the mast, (c) the axial strain in the mast, and (d) the fore-and-aft motions of the mast. The positions of the gages and the quantities measured are given in Table 2.

It has been mentioned in the preceding section that the hull was structurally damaged to some extent as an apparent consequence of the firing trials of 3 May 1950. At that time a main deck longitudinal, 4 feet off the centerline, had been fractured at Bulkhead 183. A strain gage was installed



	Piece Number	A	B	C	D ±.01	E	F	G	H	J	K	L	M	N	P	Q
U. Forestay	2	1	1 1/16	1/2	0.31	2 1/4	1 1/8	1	1 1/8	2 1/4	5 1/2	1/4	13 3/16	1	7/8	3/4
U. Backstay	3	1	15/16	1/2	0.31	2 1/4	1 1/8	13/16	1 1/8	2 1/4	5 1/2	1/4	13 3/16	1	7/8	3/4
L. Forestay and Backstay	4	5/8	11/16	5/16	0.25	1 1/4	5/8	11/16	5/8	1 3/4	5	3/16	11 5/8	5/8	11/16	1/2

Figure 2a

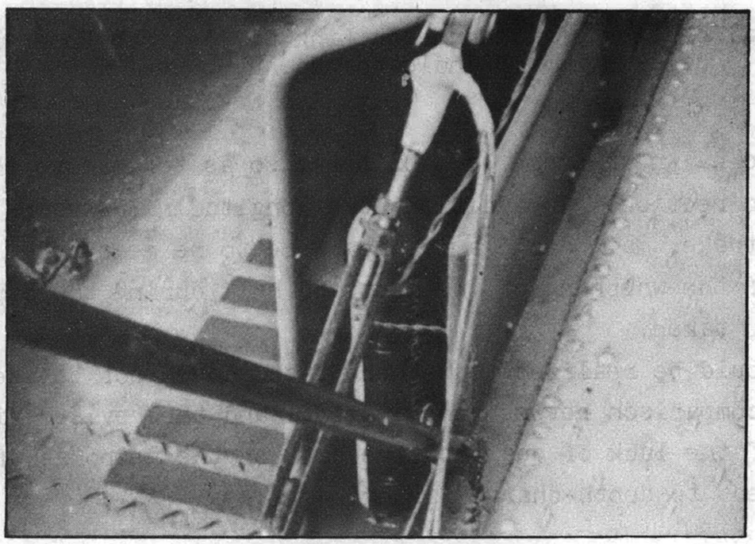


Figure 2b

Figure 2 - Tension Dynamometer

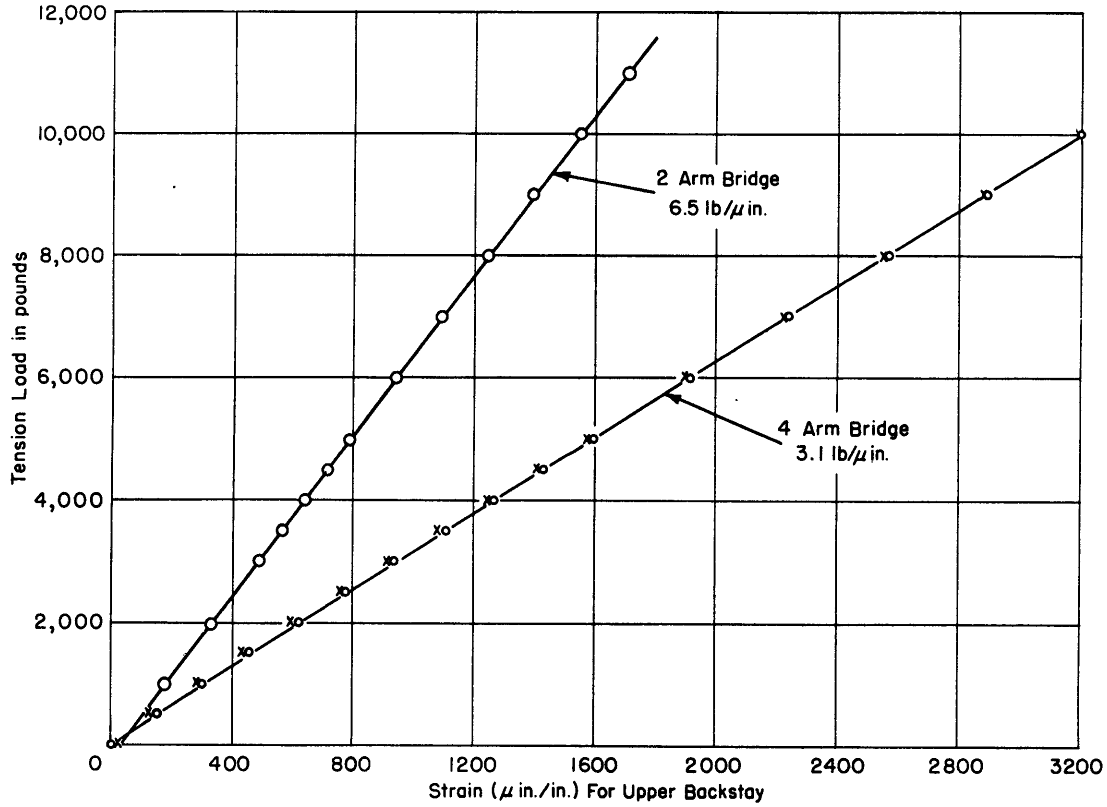


Figure 3 - Calibration of Dynamometer Link No. 3-1 for Upper Backstay
Baldwin Strain Indicator No. D-58194

on this longitudinal near Frame 185, oriented so as to measure the strain in a fore-and-aft direction. In addition, the longitudinal strains in the starboard gunwale strake, main deck, amidships were to be measured. Moving-picture films of the whipping of the mast and hull during the depth-charge firing were also taken.

It should be realized that these tests could not be used to provide a quantitative comparison between the original and the revised rigging arrangements because of the lack of quantitative data on the response of the mast, as originally rigged, to depth-charge firing.

TEST INSTALLATION AND PROCEDURE

Tension dynamometers were rigged for all stays, but none were provided for the shrouds, see Figure 2. Vacuum-tube accelerometers and wire-resistance strain gages were installed as indicated in Table 2. A strain gage installation is shown in Figure 4. The mast rigging was preloaded on the day before the actual firing trials. A transit was used to determine the position of the upper and lower staypoints while the rigging was slack. Then the stays

TABLE 2

Location of Accelerometers and Strain Gages

Galvanometer	Type of Measurement	Gage Location
1	Acceleration, fore-and-aft	Radar Foundation, top of pole mast
2	Acceleration, fore-and-aft	Man overboard light
3	Acceleration, fore-and-aft	03 Level at pole mast
4	Acceleration, vertical	03 Level at pole mast
5	Acceleration, vertical	Fantail, 4 1/2 ft forward of Frame 195
8	Axial strain in mast	Pole mast, 12 ft 3 in. above 03 level
9	Load	Upper backstay
11	Longitudinal strain	Main deck longitudinal in steering engine room, 4 1/2 ft port of centerline and 12 in. aft of Frame 185
13	Fore-and-aft bending strain	Pole mast, 35 ft 4 in. above navigating bridge
14	Longitudinal strain	Gunwale strake, amidships

attached to the lower staypoint were loaded in ten approximately equal steps by means of the turnbuckles until the desired tension for the loaded condition was obtained; see Table 1. A similar procedure was used in loading the stays that are attached to the upper staypoint. The load applied to each wire and the elongation of the wire for given increments of load were recorded. The transit indicated that the applied loads had not introduced appreciable bending deflections of the mast. Next, the shrouds were preloaded with approximately equal tension in all shrouds. The fundamental natural frequencies of fore-and-aft, as well as athwartships, vibration of the mast were determined for both the loaded and the slack condition of the rigging.

It was rather difficult to adjust the loads in the stays properly because an adjustment in one stay would change the load distribution in all the others. It is suggested that the preloading of rigging be accomplished by taking up the turnbuckles a given distance and making sure that symmetrical

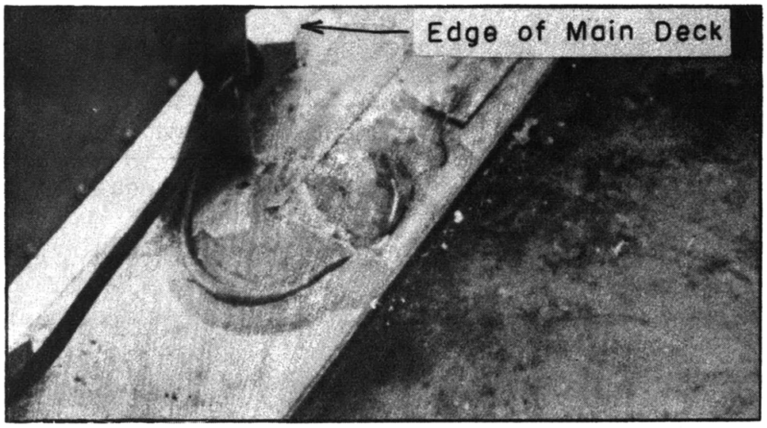


Figure 4 - Strain Gage Installation Amidships

stays and shrouds have about the same initial tension. The amount to be taken up should be given on the rigging plan; see the Appendix for a suggested rigging procedure.

The signals from the accelerometers, the strain gages, and the dynamometers were recorded simultaneously on a 14-channel Consolidated oscillograph. It was intended to proceed with the test in the following sequence:

a. Drop a single charge in order to provide an idea of the approximate level of the signals to be expected.

b. Drop a standard pattern of charges, omitting those projected by the Y guns,* and obtain the desired measurements.

c. Slack off the wire stays and shrouds until the slack condition is obtained.

d. Drop a standard pattern of charges, as in b, and obtain the data for the slack condition.

Some difficulties were experienced in dropping the desired patterns of charges. Furthermore, damage to the steering engine as the result of the first three detonations was such that it was considered advisable to curtail the number of charges to be exploded. The actual charges were dropped in the following sequence:

1. A single charge; rigging in loaded condition.
2. A pattern of two consecutive charges; rigging in loaded condition.

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*It is evident that the charges projected by the Y guns have very little effect on the ship; the settings of the charges, etc., were in accordance with the instructions of USF8.

3. A pattern of two consecutive charges; rigging in loaded condition.

4. A single charge; rigging in slack condition. The depth charges were designated Mark 9, Mod 2 or Mod 4, and all were dropped off the stern racks.

TEST RESULTS AND ANALYSIS OF RESULTS

Typical oscillograms are shown in Figure 5 for the loaded and the slack conditions of the mast rigging. Inspection of these oscillograms shows that the motion of the mast and the hull does have initial high-frequency small-displacement (relatively large acceleration) components which are soon attenuated. The principal motions of interest here are the low-frequency whipping motions of the hull and mast which are associated with the major dynamic load variations in the stays and in the hull girder. The frequencies predominating throughout these tests are about 1.4 and 2.9 cps, which are believed to correspond to the lowest two modes of vertical flexural vibration of the hull.

The natural frequencies of flexural vibration of the pole mast were determined to be as follows:

Fore-and-aft direction; 3.25 cps slack condition,
3.75 cps loaded condition.

Athwartships direction; 2.9 cps slack condition.

An interesting conclusion may be drawn from Oscillograms B_1 and B_2. It is quite apparent that the second charge of the "two-charge pattern" resulted in definitely larger motions and stresses than the first and that the shock motion due to this second explosion was such as to reinforce the whipping motion due to the first explosion. Oscillograms C_1 and C_2 evidenced the same phenomenon. It is apparent, therefore, that if the explosions of successive charges are suitably timed, it is possible that the consequent motions and stresses may reinforce one another and lead to failure. The probability of such reinforcement is not small. Oscillograms C_1 and C_2, recorded during another two-charge pattern, show very nearly the same type of response as B_1 and B_2. This behavior probably explains the statement in Reference 1 relative to the observed successively greater whipping motions of the hull and mast.

An analysis of the test data in terms of significant quantities is presented in Table 3. The relative severity of the response of the hull girder to the depth-charge explosion is indicated by the whipping motions of the hull, see Columns 3 and 5 cf Table 3. It is seen that the data of Records B_1 and C_1, for the loaded condition, are comparable to those of Record D for the slack condition. This comparison is made in Table 4. On the basis of the data in this table, it is evident that the dynamic response of the mast and

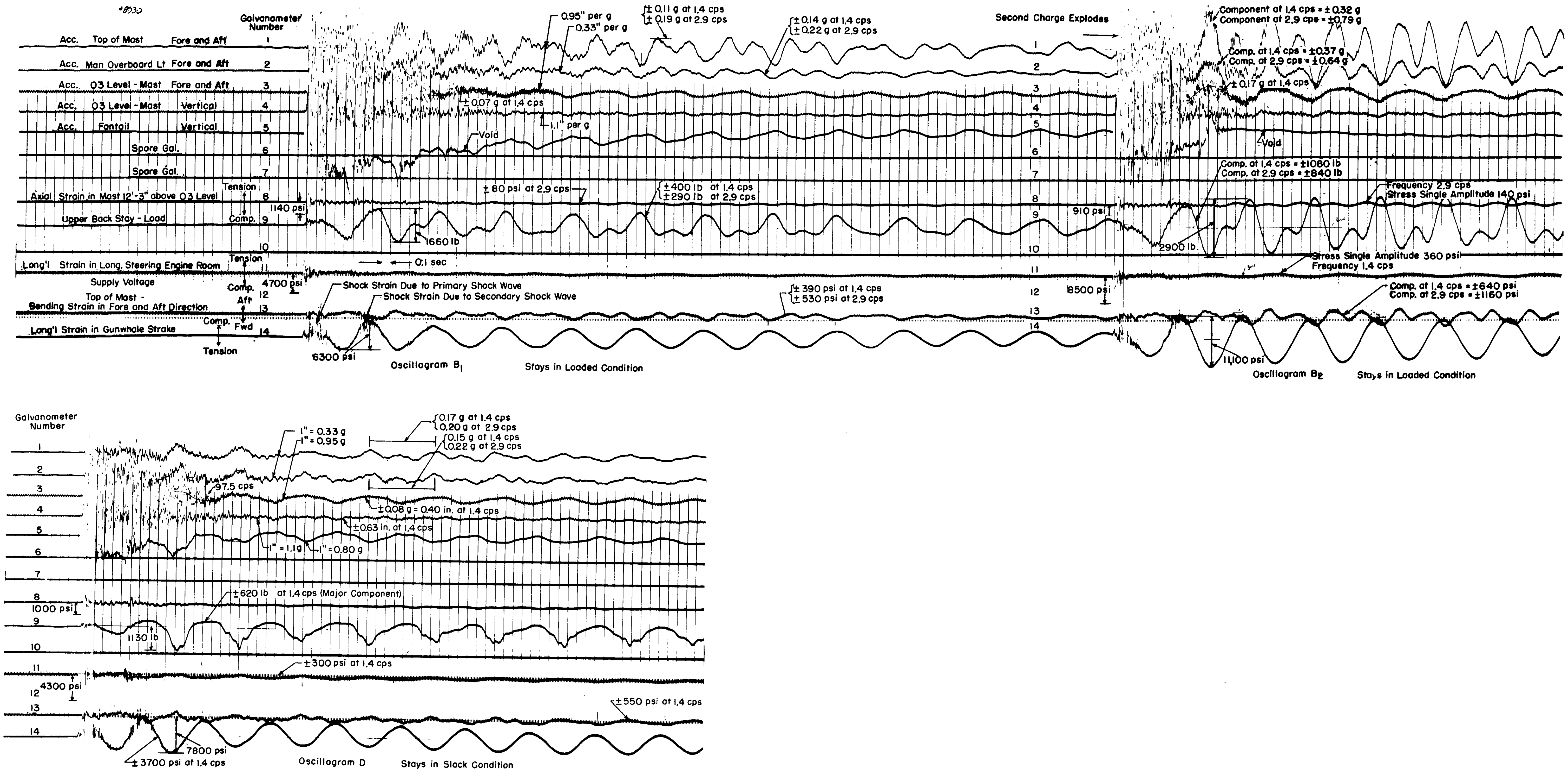


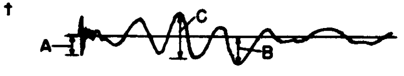
Figure 5 - Oscillograms of Strains and Motions Measured During Firing Trials

TABLE 3

Motions and Stresses Determined During Depth-Charge Firing

Galvanometers		1		2		3		4		5		8
		Accelerometers										
Condition of Test	Type of Variation†	Mast Top Fore and Aft		35 feet 4 inches Above Navigation Bridge Fore and Aft		Navigation Bridge Fore and Aft		Navigation Bridge Vertical		Fantail Vertical		Axial Stress in Mast 12 ft 3 in. above Navigation Bridg psi
		Accel-era-tion g	Displace-ment S.A. in.	Accel-era-tion g	Displace-ment S.A. in.	Accel-era-tion g	Displace-ment S.A. in.	Accel-era-tion g	Displace-ment S.A. in.	Accel-era-tion g	Displace-ment S.A. in.	
240 Shaft RPM	Steady State	0.038	0.002	0.066	0.004	0.023	0.001	0.014	0.001	-		Neg.
Single Depth Charge Stays Loaded	A	0.88††	0.005			0.33††		0.28††				950
	B	0.33		0.42		0.12*		-		0.56††*		240**
	C	0.90		0.76		0.21		-		0.75††*		710
	D_1	0.32*	1.6	0.29*	1.45	0.12*	0.58	Neg.		0.31††*	1.55	Neg.
	D_2	0.49**	0.59	0.43**	0.52	Neg.		Neg.		Neg.		120**
First of a 2-Charge Pattern Stays Loaded	A	††		††		††		††				1140
	B	0.46		0.27		0.10		-		No		-
	C	0.74		0.75		0.13		-				-
	D_1	0.18*	0.90	0.23	1.15	0.07*	0.35	Neg.		Record		-
	D_2	0.32**	0.39	0.36	0.43	Neg.		Neg.				80**
Second of a 2-Charge Pattern Stays Loaded	A	0.88††		2.6††		††		††				910
	B	0.84		0.76		0.20		-		No		-
	C	1.35		1.30		0.34		-				-
	D_1	0.32*	1.60	0.37*	1.85	0.17	0.85	Neg.		Record		-
	D_2	0.79**	0.95	0.64**	0.77			Neg.				140**
First of a 2-Charge Pattern Stays Loaded	A	††		††		††		††		††		1250
	B	0.38		0.24		0.08		-		0.33*		-
	C	0.58		0.49		0.11		-		0.38*		-
	D_1	0.14*	0.70	0.12*	0.60	0.09*	0.45	Neg.		0.21*	1.05	-
	D_2	0.23**	0.28	0.26**	0.31	-		Neg.		-		60**
Second of a 2-Charge Pattern Stays Loaded	A	††		††		††		††				1000
	B	0.79		0.76		0.20		-		No		-
	C	1.52		1.58		0.32		-				-
	D_1	0.28*	1.40	0.23*	1.15	0.17	0.85	-		Record		-
	D_2	0.65**	0.78	0.61*	0.73	-		-				180**
Single Depth Charge Stays Slack	A	††		††		††		††		††		1000
	B	0.55		0.61		0.11		-		0.44*		-
	C	0.91		0.91		0.19		-		0.50*		-
	D_1	0.27*	1.35	0.24*	1.20	0.08*	0.40	-		0.19*	0.95	-
	D_2	0.33**	0.40	0.36**	0.43	-		-		-		200**

†



Typical Oscillogram

A Signal due to initial shock (at relatively high frequency)
B Maximum deviation from condition existing prior to explosion (at relatively low fr
C Maximum change of stress or acceleration
D_1 Lowest frequency component of whipping motion (single amplitude)
D_2 Higher frequency component of motion (single amplitude)

††Accurate reading of record was impossible.
*Predominantly 1.4 cps frequency.
**Predominantly 2.9 cps frequency.
-Not significant.
g. Negligible.

TABLE 4

Comparison of Test Results for Loaded and Slack Conditions of the Mast

Galvanometer Number	Type of Data	Rigging Loaded Record B_1	Rigging Slack Record D
3	Fore-and-aft motion at navigating bridge, single amplitude in inches	0.35 at 1.4 cps	0.40 at 1.4 cps
1	Maximum low-frequency acceleration* at mast top (whipping frequency)	0.46 g	0.55 g
5	Vertical motion at fantail, single amplitude in inches	1.05** at 1.4 cps	0.95 at 1.4 cps
8	Axial stress in mast, lb per sq. in.	80 at 2.9 cps	200 at 2.9 cps
9	Load in upper backstay,* lb	800	1130
10	Longitudinal stress in steering engine room due to shock (high frequency), lb per sq. in.	4700	4300
14	Longitudinal stress in gunwale strake amidships (stbd.), lb per sq. in.	4300 at 1.4 cps	4000 at 1.4 cps
13	Bending stress* (fore-and-aft) in mast, 35 ft 4 in. above navigating bridge, lb per sq. in.	1100	1300

*Values are maximum changes from the condition existing just prior to the explosion of the depth charge. Their time variations correspond to the whipping motions of the ship and mast.

**This value is taken from Record C_1 which, for the intended purpose, is comparable to Record D.

rigging to underwater explosion is not greatly affected by the amount of initial tension in the rigging, provided the initial tension is applied so as not to put appreciable bending loads on the mast. The stresses in the mast were not excessive for the revised rigging used during these tests. The stresses in the upper backstay are appreciable, but acceptable. Due to the lack of quantitative data on the behavior of the old mast rigging, there is no basis for a direct comparison of the old and revised rigging arrangements. However, the ship's report[1] indicated large visible whipping motions of the mast during the structural firing tests of 3 May 1950, whereas such motions were not particularly apparent during the tests with the revised rigging. It is quite obvious that the revised rigging arrangement is a definite improvement, since it does appreciably reduce the tendency to put bending loads on the mast when initial tension is applied to the shrouds and stays; see Figure 1.

Inspection of the oscillograms indicating the dynamic strains in the hull amidships and in the longitudinal at Frame 185 (Galvanometers 14 and 11) shows that, in each case, there occur high-frequency shock strains immediately following the explosion, which are superimposed on the strains corresponding to the whipping motion of the ship. The shock strains are of appreciable magnitude. About 0.6 second after the initial explosion, another shock wave gives rise to shock strains of relatively smaller magnitude; see the response indicated by Galvanometer 14. It is evident, on the basis of previous experience with underwater explosions, that the second shock wave is due to the collapse of the gas globe formed as a result of the explosion of the depth charge. It is interesting to note that the time interval between the first and second shock waves is approximately the same as the period of the lowest mode of vertical whipping motion of the hull, and thus the second shock wave reinforces the whipping of the hull initiated by the first shock wave.

It is conceivable that the whipping motion of the ship may build up to a dangerously large degree due to (a) the reinforcing action of the secondary shock wave associated with the collapse of the gas globe and (b) the possible reinforcing action of successive depth-charge detonations.

The predominant strains amidships are those associated with the fundamental whipping motion of the hull. The shock strains, on the other hand, are by far the more important ones in the steering engine room (Galvanometer 11). The main-deck longitudinal illustrated by the sketch, Figure 6, had been fractured at Frame 183 during the previous firing trials of 3 May 1950. This failure was probably due to the high shock strains combined with the effects of the sharp discontinuity at the bulkhead, Frame 183. Such sharp discontinuities should not be permitted.

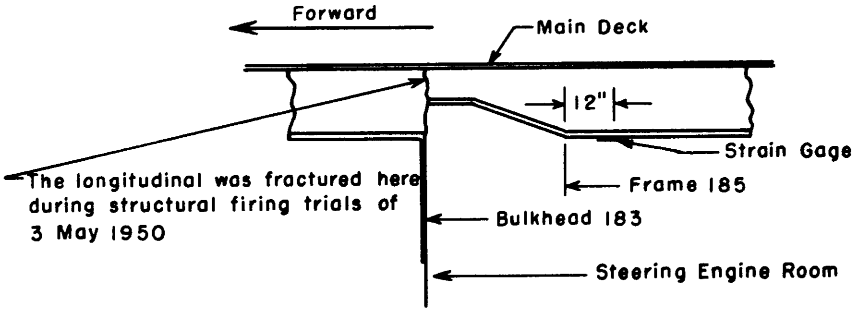


Figure 6 - Elevation of Longitudinal, 4 1/2 Feet Port of Centerline

CONCLUSIONS AND RECOMMENDATIONS

1. The revised rigging arrangement is a definite improvement over the original arrangement, and the revision should be carried out for other vessels of this class.

2. The dynamic strains and motions of the mast and rigging are not appreciably affected by the amount of initial tension in the stays and shrouds, provided this tension is applied so as not to put initial bending moments on the mast.

3. The stresses in the mast and upper backstay were not excessive for the revised rigging and under the conditions of the present test.

4. The rigging of pole masts should be designed so that the possibility of introducing large bending loads, when the rigging is subjected to initial tension, is minimized.

5. The initial loading of stays and shrouds should be accomplished as recommended in the Appendix.

6. The danger of excessive stresses and motions due to (a) reinforcing action of successive depth-charge explosions, and (b) reinforcing action of the secondary shock wave associated with the collapse of the gas globe, is a real one.

7. The local reduction of cross section of the longitudinal and the sharp re-entrant corner in it, as illustrated in Figure 6, were features that caused serious weakness at this point.

8. In future tests of this type, it would be advisable to provide all accelerometers with low-pass filters in order to remove the high-frequency shock accelerations, which are not of great interest in this particular case.

APPENDIX

SUGGESTED PROCEDURES FOR THE DESIGN AND INSTALLATION OF STANDING RIGGING FOR POLE MASTS

Care should be taken in the design and layout of the stays and shrouds to maintain a proper symmetry in their arrangement, so that it will be possible to preload them to about 20 percent of their ultimate strength without introducing appreciable bending moments in the mast.

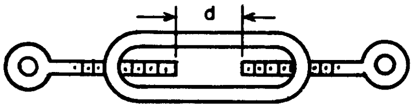
If at all practicable, a sufficient number of stays and shrouds should join at each point of attachment on the mast (staypoint) to permit cancellation of all load components normal to the mast.

The rigging plan should indicate the desired initial tension in each stay and shroud, and, in addition, should indicate its elongation under the given initial load on the basis of some average effective modulus of elasticity of wire rope.

A simple practical procedure for preloading the shrouds and stays would be as follows:

a. After installation take up the slack in each stay by turning the turnbuckle with one bare hand until it is hand-tight.

b. Measure the distance d between the ends of the turnbuckle bolts.



c. By means of the turnbuckle, increase the tension in the stay until the change in the distance d is equal to the elongation specified on the rigging plan for the specified initial tension.

d. Complete this procedure for all stays and shrouds at each staypoint, one at a time, starting with the staypoint closest to the point of attachment of the mast to the hull.

It is believed that the above procedure is readily accomplished by any shipyard or by the ship's force. It requires no special equipment and will, at the same time, provide an effective uniform procedure which is lacking at the present time.

REFERENCES

1. Commanding Officer, USS MACOMB ltr DMS23/JSB over A5-7, Serial 010-50 of 16 May 1950, copy on BuShips file.

2. BuShips Speedletter DMS(513), Serial 513-2064 of 28 November 1950 to Charleston Naval Shipyard.

3. BuShips CONFIDENTIAL ltr C-DMS23(442) over Serial 442-023 of 28 November 1950 to TMB.

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