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MEASUREMENTS OF STRAINS IN THE CYLINDRICAL GUN FOUNDATIONS OF THE USS SARSFIELD (DD837)

by

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PERSONNEL

The test was conducted by E. Wenk, Jr., assisted by A. Menzak, W.A. Lovell, E.W. Larson, Jr., and J. Rhodes. Results of the test were analyzed by Ann B. Pailthorp and Marion R. Pauley, and checked by Margaret E. Duke. The report is the work of Mr. Wenk.

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ABSTRACT

A new type of cylindrical gun foundation for destroyers of the DD692 Class has been developed by the Bureau of Ships for supporting dual-purpose twin 5-inch guns which are equipped with novel ammunition-handling devices. To investigate the load-carrying capacity and stress distribution of the foundation in service, tests were conducted during structural firing trials of the USS SARSFIELD (DD837). From strains measured with metalectric gages, the apparent stresses at each gage station were computed.

The maximum stress was 12,600 pounds per square inch; it occurred at the base of Foundation 2 during broadside firing at zero elevation. From the alternations of strain indicated by the records, the transverse natural frequencies of Foundations 1 and 2 were found to be 25 and 16 cycles per second respectively. The longitudinal frequencies were 22 and 12 cycles per second respectively.

The test results indicated that the cylindrical foundations have a high structural factor of safety, but they did not determine whether any reduction in scantlings would be permissible if adequate strength and elastic stability were to be maintained. The boundary conditions of the cylindrical foundation were found to be of primary influence on the elastic behavior of the structure, and should be further investigated for the development of design criteria.

INTRODUCTION

Mounts for dual-purpose 5-inch guns on vessels of all catergories have usually been supported by quadrangular frames or by grids formed by intersecting bulkheads. However, the recent ammunition-handling equipment devised by the Bureau of Ships to improve the operation of the 5-inch guns has required changes in the supports. When a combination of a storage ring and a hoist for ammunition was attached to the under side of the gun mount, a foundation was required that would serve jointly as a support and as a protective envelope for both ammunition and gun crew. The unstiffened cylindrical form was adopted, following designs previously used on cruisers and battleships of the United States Navy. This type was first used on destroyers with twin mounts in vessels of the DD692 Class.

In addition to meeting structural requirements, the cylindrical foundation provides a continuous splinter shield for the cage, it is light in weight, and is easily fabricated. This foundation, shown in Figure 1, was designed to surround the ammunition cage completely, and thus its diameter had to exceed that of the bolting circle of the mount. Consequently an annular projecting lip with stiffening brackets was worked around the top of this cylindrical foundation to provide a suitable support for the twin mounts. This is shown in detail in Figure 2. The history and development of this structural feature is given in Reference (1),* which describes the cylindrical foundation for single mounts.

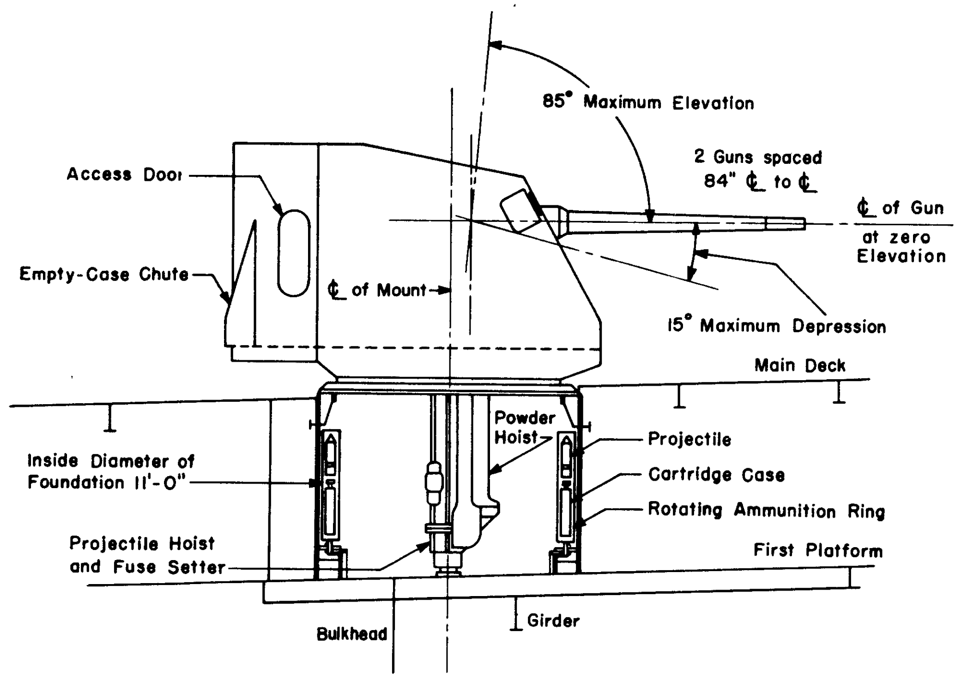

Figure 1 - Schematic Diagram of Cylindrical Foundation and Ammunition-Handling Equipment for Gun Foundation 1 of the USS SARSFIELD (DD837)

The cylindrical foundation was designed as a free-standing cantilever supported only at its base; on most installations, however, decks that were approximately level with the top of the cylinder provided additional transverse restraint. Stresses and deflections of the structure restrained in this manner were believed to be so small that no doubt existed regarding its structural safety. Nevertheless, measurement of strains during gunfire was believed desirable to establish criteria for use in future designs of similar structures where greater economy of material might be involved.

The Bureau of Ships therefore requested the David Taylor Model Basin (2) to conduct tests on vessels of two classes, then in service, which

* Numbers in parentheses indicate references on page 14 of this report.

carried these cylindrical foundations, one of the DD692 Class and one of the modified DD356 Class. The plating used in the foundations on these two classes of vessels differed in thickness sufficiently to warrant a comparison of elastic behavior. The plating for foundations on vessels of the DD692 Class is 3/8 inch thick; that on vessels of the DD356 Class is 1/4 inch thick.

The first vessel available for these strain investigations was the USS SARSFIELD (DD837), and tests were conducted during her structural firing trials on 18 August 1945. The results of these tests and their analyses are given in this report.

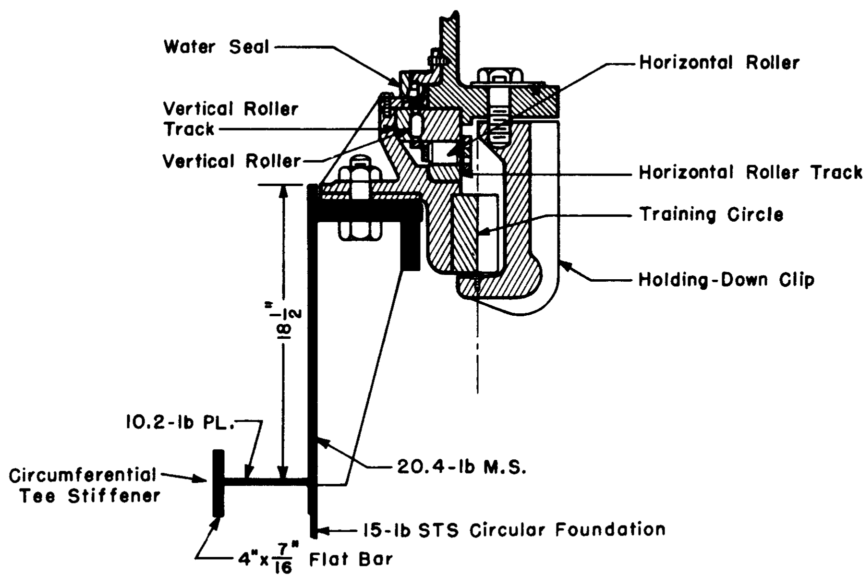

Figure 2 - Detail Showing Construction of Annular Lip Connecting Gun Mount and Foundation

TEST SETUP AND PROCEDURE

Vessels of the DD692 Class carry three twin mounts, two forward and one aft of the superstructure. All cylindrical foundations are 11 feet in inside diameter and are fabricated of 3/8-inch STS plate. Although the structural and ordnance arrangements are almost identical in construction and operation for the three mounts, minor differences exist in both the vertical and the horizontal members which support the foundations. These differences produce various degrees of flexibility of the elastic restraints provided by the supports.

The greatest difference in structural arrangements was believed to exist between Foundations 1 and 2, inasmuch as Foundation 1 was supported laterally at its top by the main deck, which frames into the sides of the vessel, whereas Foundation 2 was supported at its top only by a relatively light superstructure frame. Consequently, to permit a comparison of observed stresses on the basis of the difference in fixity of the two supports, strain gages were mounted on both foundations at locations having similar physical or elastic characteristics. One group of stations was chosen near the bases of the cylinders at points directly above structural hard spots, such as stanchions or bulkheads, which are productive of stress concentrations.* Gages in Group a were mounted vertically and numbered 2, 4, 6, 12, 14, and 16, as shown in Figure 3. Gages 1, 3, 5, 11, 13, and 15, in Group b, were located vertically on the cylinders at points directly above the stations in Group a, along planes just below the upper supporting decks. This latter gage orientation was chosen to permit an investigation of the elastic behavior of the cylinders and their supports by comparing strains at the two widely separated planes near the base and near the top of the cylinder.

In addition to the gages mentioned, others were mounted vertically on two stanchions which support the cylinders. These are indicated in Figure 3 as Stations 8 and 18. Gage 7, was mounted horizontally on the center of the flange of the circumferential Tee stiffener where the brackets supporting the gun mount frame into the head of the cylinder. This gage was positioned primarily to measure strains which would reveal the amount and direction of radial rotation of the brackets when they are subjected to loads during gunfire.

At all stations two Type A-1 metalectric strain gages were employed for the measurements. One of the gages served as the active strain-sensitive element at the station; the second was mounted on an unstressed steel block, as shown in Figure 4, and served as the fixed arm of a Wheatstone bridge as well as a temperature-compensating element. To make strain indications independent of the effects of local bending of unstiffened members, pairs of gages were installed in identical positions on opposite sides of the members and were connected electrically so that only the average strain was recorded, and all but direct strain was balanced out.

The outputs of all gages were connected by electric cables to units which functioned as combined carrier-fed Wheatstone bridges, vacuum-tube amplifiers, and strain-calibrating units. This measuring system operated as follows: A strain at a gage station produced in the gage a proportional

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* Stress concentrations at structural hard spots were observed in tests of the 1/8-scale model of the CL144 turret stool. Measurements were made of axial strain at 39 stations around the periphery during vertical and horizontal loading of the stool. Deviations from the normal strain distribution were evident at all points directly above supporting stanchions or bulkheads, and could be defined on a basis of apparent stress concentration factors which were as great as 3.

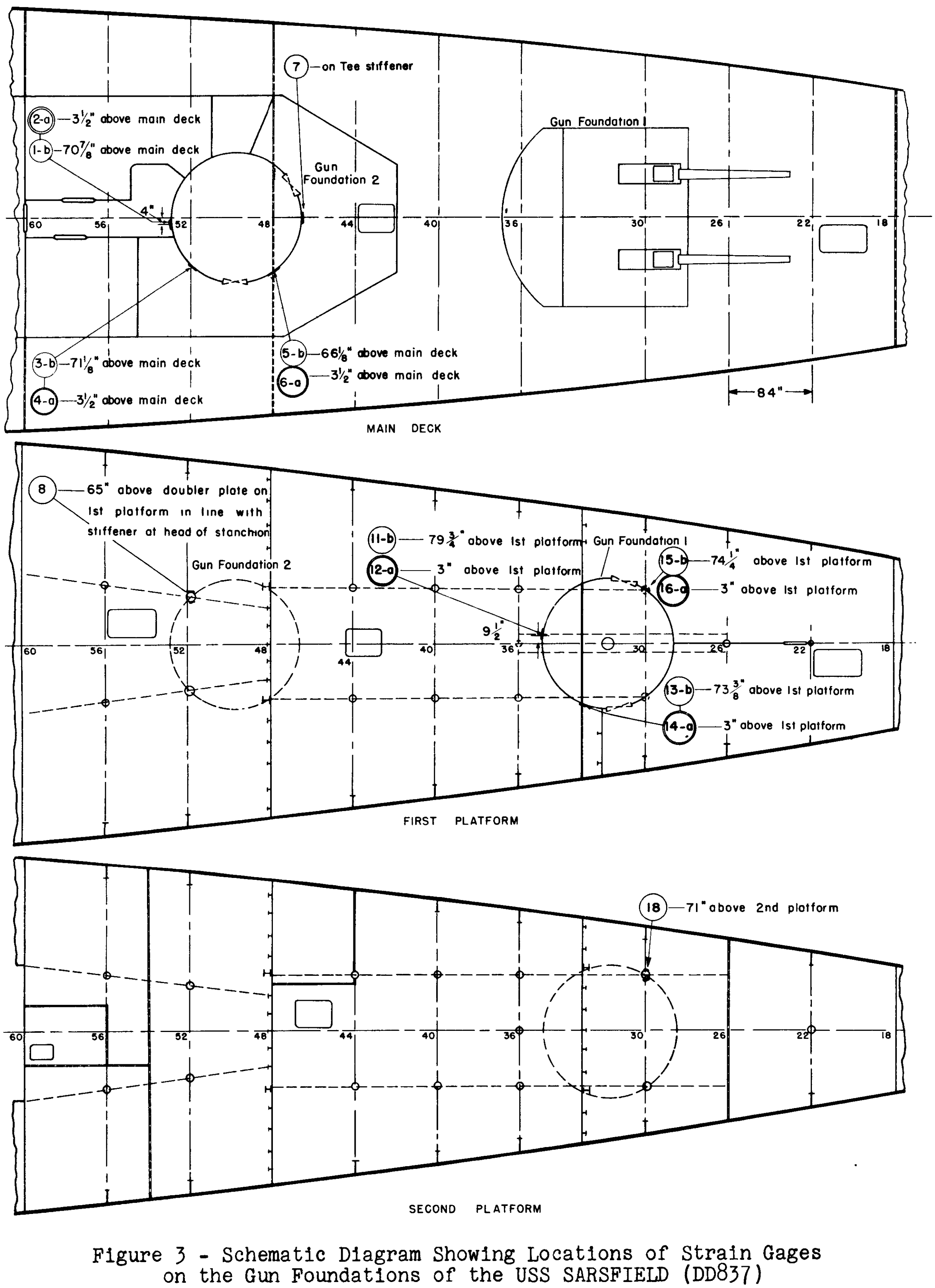

Figure 3 - Schematic Diagram Showing Locations of Strain Gages on the Gun Foundations of the USS SARSFIELD (DD837)

Gages in Group a, indicated in double circles, were mounted near the base of the cylinder above structural hard spots productive of stress concentrations. Gages in Group b, indicated in single circles, were aligned vertically above the gages in Group a and were at planes near the top of the foundation.

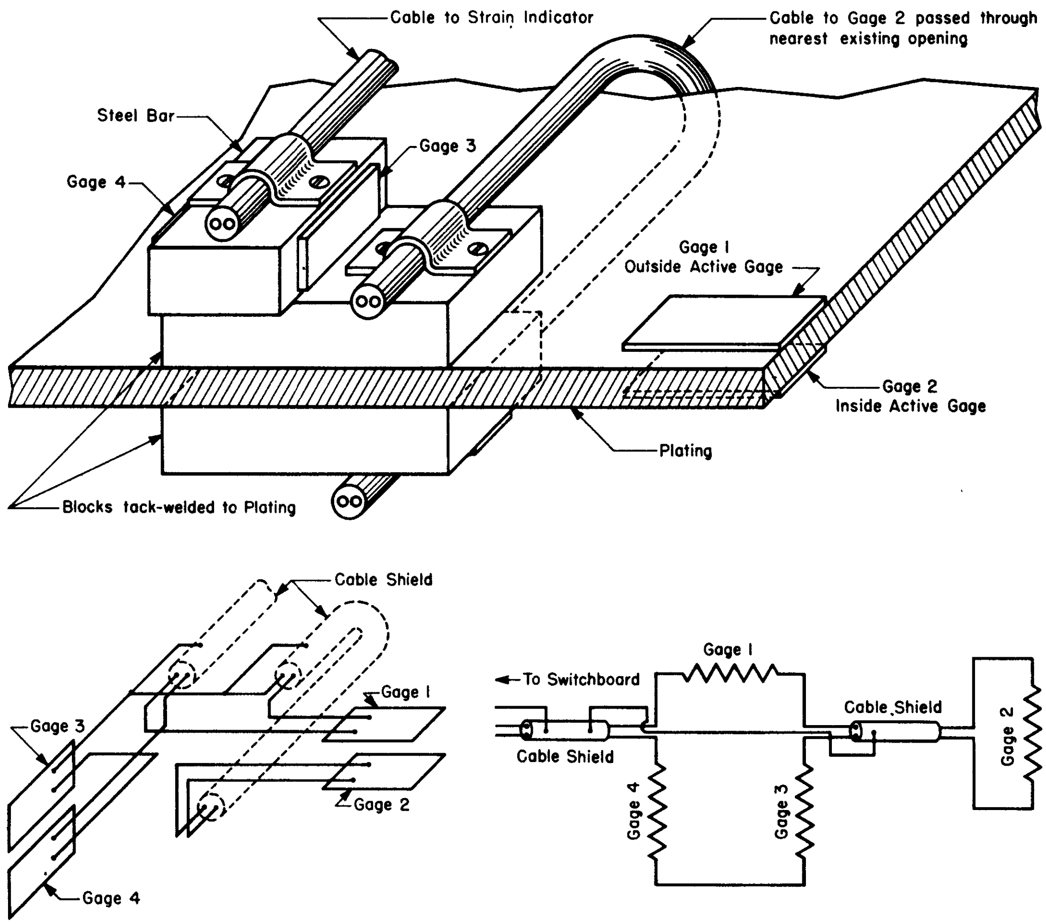

Figure 4 - Sketch Showing Arrangement and Connections of Gages

Strain Gages 1 and 2 were mounted on opposite sides of the gun-foundation plating to measure the average strain. Gages 3 and 4 were mounted on unstressed steel blocks and served as temperature-compensating gages.

change in resistance which upset the balance in the Wheatstone bridge to which it was connected. This unbalance, in the form of a change in voltage, was fed to electronic amplifiers, whose output consisted of a small current directly proportional to the change in resistance of the gage, and thus also to the strain. This output current activated string galvanometers, and their light-beam deflections were photographically recorded on moving sensitized paper. The graphical record thus represented a plot of strain against time, where the scales of both variables were established by suitable calibration procedure and marking.

Strain records were made during gunfire according to the schedules indicated by Figure 5. Extreme gun trains and elevations were chosen so as

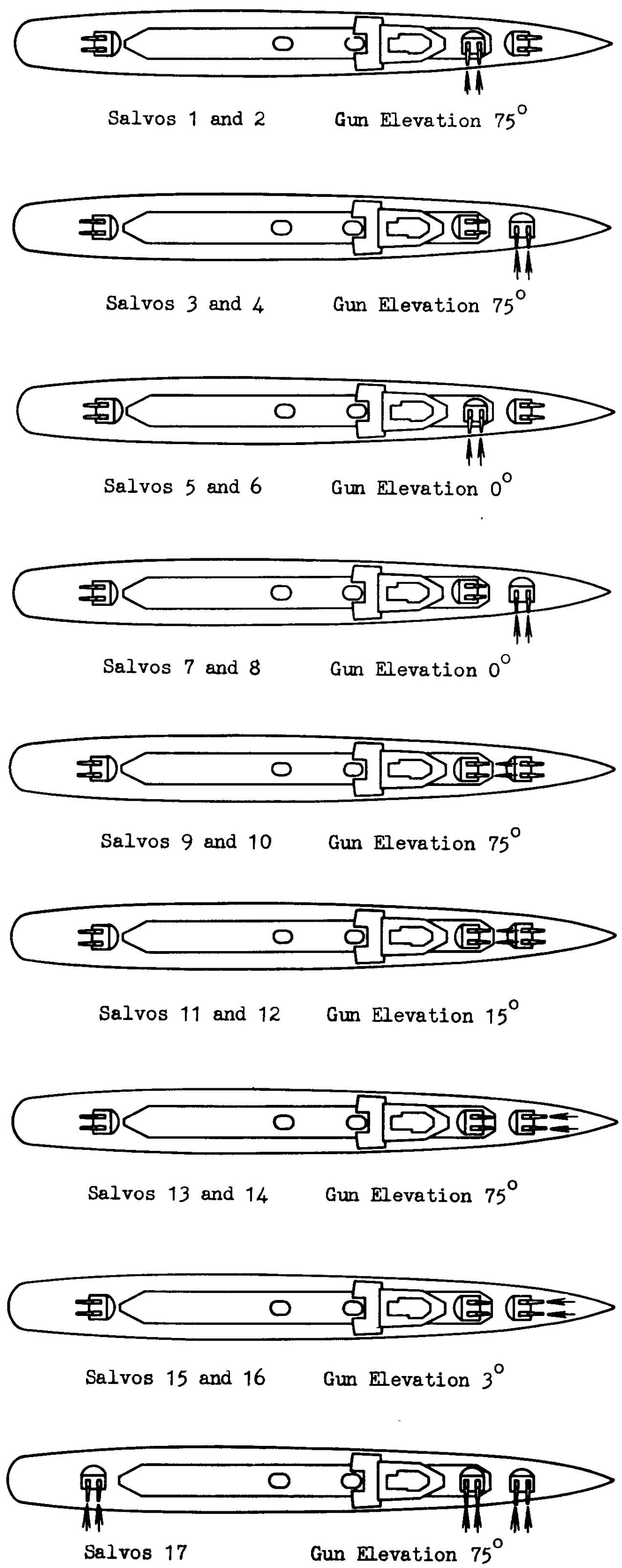

Figure 5 - Diagrams Showing Train and Elevation of Guns during Structural Firing Trials

to produce strains approaching the maximum.* Inasmuch as more than four gages were installed on each foundation and only four amplifier channels were available, salvos were repeated for each position of train and elevation. For each pair of salvos the elastic behavior was assumed identical. Both guns of each mount were discharged simultaneously, and no misfires or hangfires occurred.

TEST RESULTS

A typical strain record is shown in Figure 7 on page 9. All strain records have been scaled, and the results are summarized in Table 1. The three predominant peak strains are given, as well as the elapsed time between the estimated instant of firing and the occurrence of each peak. Compressive strains are indicated by minus signs. On the basis of previous field and laboratory tests, the experimental error is believed to be less than 5 per cent for all magnitudes of strain greater than 40 microinches per inch; the least count is 5 microinches per inch.

The reliability of the strain measurements is somewhat substantiated by the excellent agreement of strains recorded during Salvo 17 and Salvos 3 and 4, which for purposes of analysis could be considered identical.

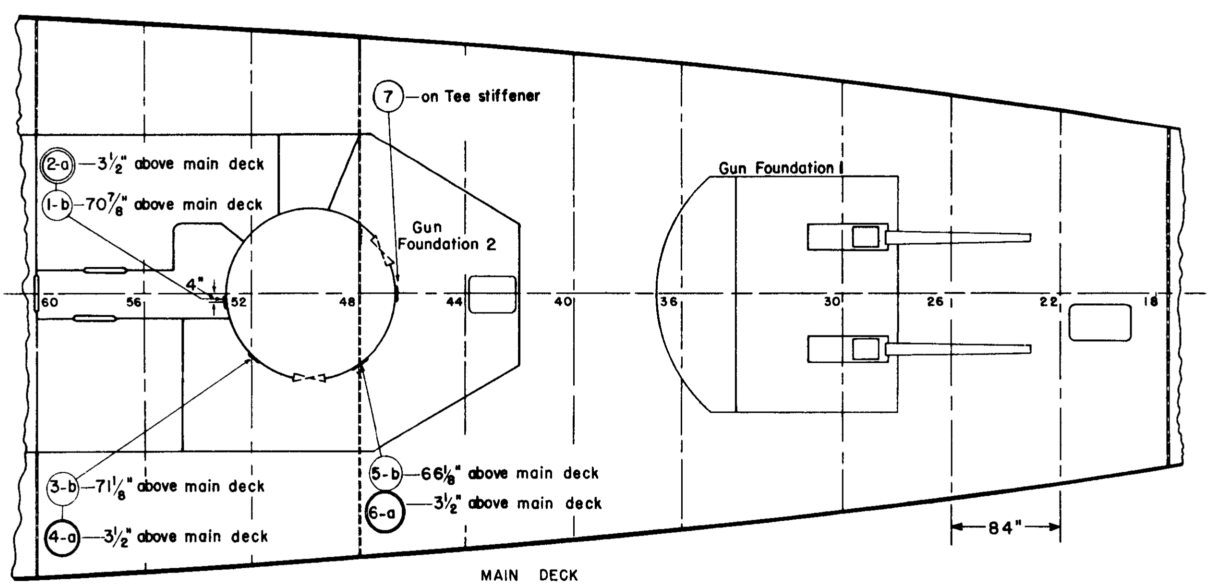

Figure 6 - Schematic Diagram of Main Deck of USS SARSFIELD Showing Locations of Strain Gages

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* Tests on the 1/8-scale model of the CL144 turret stool indicated that the maximum strains in the stool were produced at the hard spots by horizontal loading in the direction of the supporting bulkheads, namely at 0 degree and at 90 degrees of train. Insufficient time for the firing trial precluded tests with intermediate gun positions.

The strains at Stations 11, 12, 16, and 18 differ by less than 10 per cent, and the strain-time relations are almost identical.

The product of E* times strain gives the stress that would have existed at that gage if the stress had been uniaxial and in the direction of the axis of the gage. The maximum stress calculated in this manner was 12,600 pounds per square inch; it occurred at Station 6 during Salvo 6, in the location shown in Figure 6.

Various frequencies of cyclic variation of strain were identifiable on the records, and they are given for each salvo in Table 1. The predominant frequencies were 12, 16, 22, and 25 cycles per second.

ANALYSIS OF RESULTS

The test results, Table 1, indicate a wide range of strain amplitudes and somewhat unsystematic strain-time relations. However, the shapes of the strain curves and the type and amplitude of the strains recurred often enough to warrant analysis and further investigation of the phenomena associated with these repetitions.

With few exceptions, the initial peaks of strain were the maximum peaks, and the time which elapsed from the instant at which strains were evident to the first peak was 0.028 second. The rate at which the strain increased up to the first peak appeared to be independent of the frequency of subsequent cyclic variations of strain, probably because the duration of the gunfire load was long compared with that of the vibration period (3). The

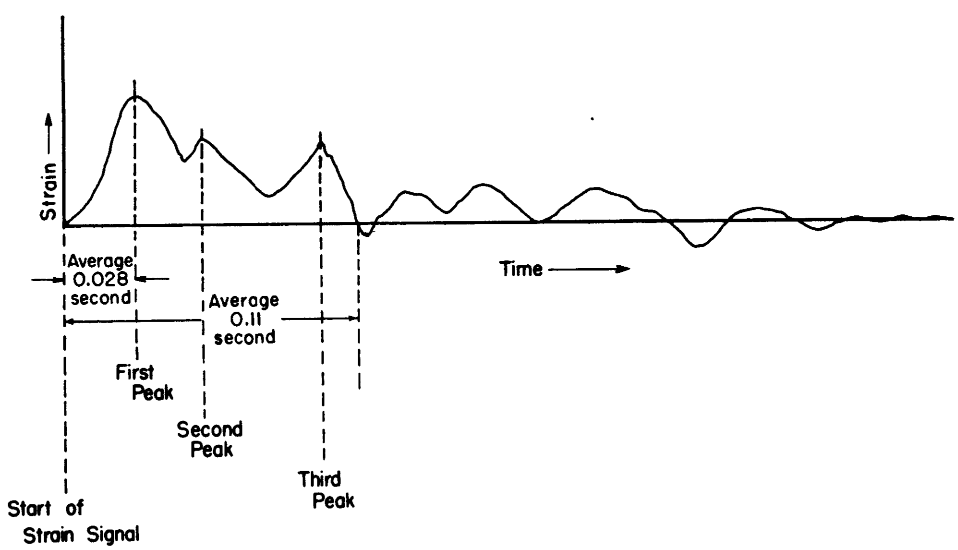

Figure 7 - Typical Strain Record Obtained during Firing Trial of the USS SARSFIELD (DD837)

* The modulus of elasticity E was assumed to be 30 x 10^6 pounds per square inch.

TABLE 1

Observed Strains during Structural Firing Trials of the USS SARSFIELD (DD837)

The asterisk indicates that no record was obtained; the dash (—) indicates absence of a peak; the minus sign indicates compressive strain.

Salvo	Gage Station	Foundation	Guns	Train degrees	Elevation degrees	First Peak: Observed Strain micro-inches per inch	First Peak: Time to Peak milli-seconds	Second Peak: Observed Strain micro-inches per inch	Second Peak: Time to Peak milli-seconds	Third Peak: Observed Strain micro-inches per inch	Third Peak: Time to Peak milli-seconds	Frequency of Observed Cyclic Variations cycles per second
1	1	2	3,4	90	75	50	28	35	67	15	103	25
	2					*						
	3					-40	30	20	55	—	—	12
	4					-75	29	-35	77	-35	150	20
2	5	2	3,4	90	75	-65	21	-45	103	20	128	20
	6					-200	28	-115	95	40	129	16
	7					85	27	-100	38	185	44	50
	8					-60	29	-30	73	-35	102	22
3	11	1	1,2	90	75	-45	30	-25	108	-20	180	13
	12					-140	25	-105	54	-90	73	40
	13					-20	25	30	50	10	90	29
	14					-130	28	-70	75	-65	105	25
4	11	1	1,2	90	75	*						
	15					-25	25	-65	40	-30	54	66
	16					-135	35	-60	100	-30	144	23
	18					-110	37	-55	106	-30	144	25
5	1	2	3,4	90	0	10	16	-40	50	10	116	16
	2					*						
	3					120	50	40	146	25	213	13
	4					130	47	45	153	35	218	17
6	5	2	3,4	90	0	175	55	50	145	35	224	12
	6					420	51	135	137	80	226	16
	7					-90	31	-60	38	90	45	59
	8					100	50	40	149	20	215	16
7	11	1	1,2	90	0	-20	22	20	58	-20	85	24
	12					-25	17	15	35	20	60	33
	13					100	48	30	185	—	—	9
	14					175	55	75	105	-50	165	20
8	11	1	1,2	90	0	*						
	15					-100	38	—	—	—	—	—
	16					-100	28	-135	52	-70	86	30
	18					-65	22	-70	50	-55	86	29
9	5	2	3,4	0	75	-85	30	-35	75	-65	105	20
	6					-30	19	-60	43	-95	76	25
	7					-175	35	125	46	-115	55	50
	8					-85	36	-30	110	-25	145	31
10	1	2	3,4	0	75	40	48	15	130	10	230	12
	2					*						
	3					-65	43	-20	118	-15	173	20
	4					-95	33	-50	73	-30	165	30
11	1	2	3,4	0	15	80	45	25	127	10	190	13
	2					*						
	3					-110	50	-40	130	-30	176	19
	4					-100	48	-40	130	-25	196	12
12	5	2	3,4	0	15	140	52	45	154	35	218	21
	6					*						
	7					-300	26	95	35	-205	45	100
	8					-95	48	-35	130	-25	196	19
13	11	1	1,2	0	75	*						
	15					-70	31	—	—	—	—	—
	16					-95	30	-40	85	20	126	14
	18					-95	27	45	126	-50	146	12
14	11	1	1,2	0	75	-35	39	-10	97	—	—	17
	12					-240	28	—	—	—	—	—
	13					-120	33	-55	103	-40	171	23
	14					-165	29	-105	105	-40	172	13
15	11	1	1,2	0	3	-90	38	-30	134	-20	209	13
	12					*						
	13					-65	40	-35	120	-25	210	11
	14					-100	43	-35	117	-40	168	20
16	11	1	1,2	0	3	*						
	15					*						
	16					120	41	40	126	30	209	12
	18					160	38	45	135	-50	203	12
17	11	1,2,3	1 to 6	90	15	-50	30	-40	60	-40	93	25
	12					-130	30	-115	62	—	—	32
	16					-125	40	-95	60	-60	75	50
	18					-105	40	-70	55	-45	110	50

records indicate further that the strain fluctuated as much as 1/5 of its peak amplitude for approximately 0.3 second. As shown in Figure 7, however, the strains returned to zero after an average elapsed time of 0.11 second from the beginning of the record, and this interval corresponded to the duration of the brake-recoil load for 5-inch guns. The fluctuations of strains for the 0.11-second period generally included several minor peaks that were of the same sign as the initial peak, that is, these fluctuations of strains were seldom complete alternations. Nevertheless, there was sufficient periodicity to indicate the frequencies of the mechanical vibrations of the structures. The observed fluctuations were often obviously the result of superposition of several frequencies, although the maximum peaks were caused by the fundamental or unimodal vibration of the cylindrical foundation, either transverse of longitudinal, depending on the direction of gunfire.

The most pronounced cyclic variations of strain on each record are listed in Table 1. The frequencies occur over a considerable range; however, averages of 25 and 16 cycles per second were believed to be the transverse natural frequencies of Foundations 1 and 2 respectively, and the frequencies of 22 and 12 were believed to be the longitudinal natural frequencies of the same structures.*

Motion of the circumferential Tee stiffener, whose elastic behavior was indicated by the gage at Station 7, indicated torsional frequencies of 50 and 100 cycles per second. These two frequencies are those of the two modes of vibration that are excited by either vertical or horizontal gunfire.

The irregularities of the strains other than the periodic fluctuations were probably due to interference by vibrations of the ship's hull or of associated secondary structures, and to the bouncing of the mount on its tracks as a result of gunfire and ship roll. In addition, some peaking probably occurred when the random variable of clip and roller-track clearance was taken up by the mount during gunfire from low angles of elevation.

Table 1 shows that for horizontal as well as for elevated gunfire the strains at pairs of stations in vertical alignment, such as 1 and 2, or 3 and 4, have the same sign at each corresponding peak. This condition reveals that the elastic behavior of the foundation during the initial application of load, as well as during subsequent vibrations, was such that no point of contraflexure appeared in the cylindrical foundation between the two supporting decks. Such a uniflexural deformation and the related stress distributions could occur only with a lateral displacement of the top of the cylinder

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* It should be noted that the frequency response of the recording system was linear up to 200 cycles per second, which is much greater than the observed frequencies of mechanical vibration; thus all strain records can be considered free of attenuation.

with respect to its base, that is, an elastic deformation which accompanies the racking of both decks.

In general, the structural design of foundations which are supported by two or more decks has been based on elastic behavior that depends on an estimated fixity of the base; the flexibility of the decks has always been ignored. These hypothetical modes of elastic deformation are shown in Figure 8 and are compared with the observed deformations discussed in the preceding

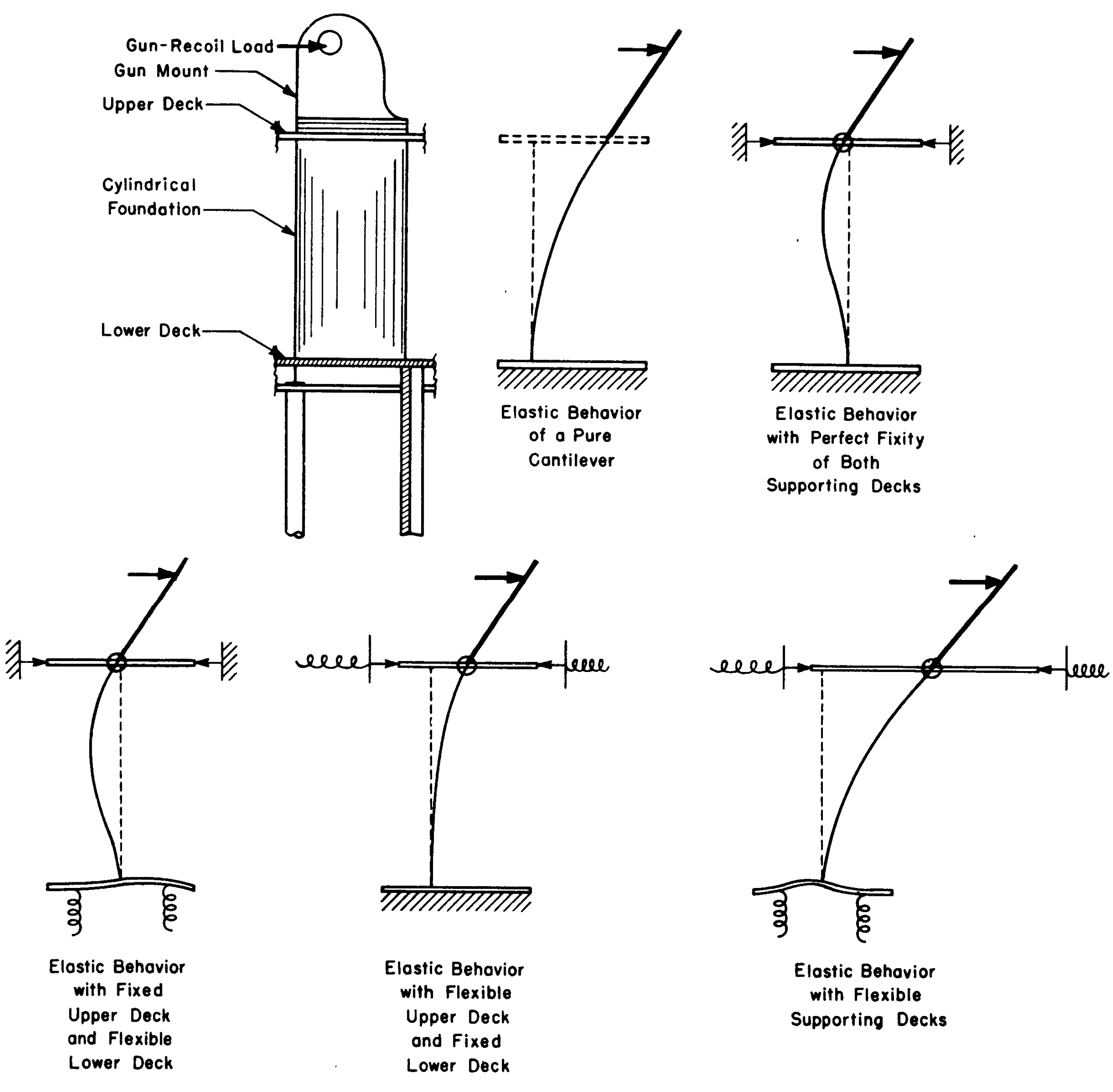

Figure 8 - Schematic Diagram Showing Variety of Elastic Deformations of Gun Foundations

The condition shown in the lower righthand diagram was that observed; the other conditions were assumed.

paragraph. It now appears that design criteria should be established for the degree of restraint of decks as well as for that of the base or "fixed" end. Information concerning the effect of variations in these several boundary conditions on the behavior of the structure is incomplete, and the subject should be investigated further.

Apart from the significance of the absolute magnitudes of strains as they are related to the streng' ı of the material, individual magnitudes are of importance when compared with other magnitudes at stations having similar physical or elastic characteristics. For instance, a comparison of strains at Stations 3 and 4 with those at Stations 5 and 6 shows that in Foundation 2 strains at points above the bulkhead were higher than those above the stanchion. The comparison of strains for Foundation 1 demonstrates similar concentrations, although the difference is not so marked. Strains in stanchions under both cylindrical foundations were essentially the same as those at points in the foundations immediately above.

A comparison of strains at Station 3 with those at Station 15, of those at 4 with those at 16, 5 with 13, and 6 with 14 reveals that at these elastically similar points strains in Foundation 2 were greater than strains in Foundation 1. This relation is probably a result of the greater flexibility of the horizontal support provided at the top of Foundation 2 by the superstructure deck.

An interpretation of the ratios between stresses at the base of the foundation and those near the top could not be given, inasmuch as the ratio depended on two independent variables, namely, the degree of stress concentration above the hard spots and the elastic behavior of the foundation as a beam.

In general, the strains accompanying horizontal gunfire was approximately twice those accompanying elevated fire. There was, however, no information regarding gunfire at intermediate elevations, so the relation of the magnitudes of strain to the elevation of gunfire load could not be determined.

It should be emphasized that the computed maximum apparent stress cannot be employed to calculate the factor of safety nor can it be used as a basis for determining permissible reduction in scantlings. Experience has shown that failure in cylindrical foundations is produced by buckling, and no information has been obtained regarding the elastic stability of the foundation. Accordingly, the factor of safety can be determined only by tests on models or full-scale structures in which loads are applied until some type of failure occurs.*

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* In Reference (4), failure of gun foundations and turrets was defined as a permanent deformation productive of a distortion of the roller track that would impair operation or function of the rotating portion, and the allowable distortion was arbitrarily set at 8 minutes of tilt of the track.

CONCLUSIONS

1. The strains measured in the cylindrical gun foundation indicate a maximum apparent stress of 12,600 pounds per square inch, which is well below the yield strength of the special-treatment steel used in the foundations. It is not known whether higher apparent stresses existed at points in the foundation structure at which stresses were not measured, or would have been produced at the selected stations as a result of gunfire from intermediate trains and elevations. On the basis of other tests, however, the strains that were measured should be considered representative.

2. From these test results, it would at first appear that adequate structural strength could be maintained with steel plating somewhat thinner than that employed on vessels of the DD692 Class. However, even if the practical limitations on thickness as set by splinter-protection requirements are disregarded, the thickness required for adequate strength can be determined only from tests to failure, where buckling, which is not susceptible of exact theoretical analysis, could be induced.

3. The tests indicate that the elastic deformations and stress distribution in the foundation depend as much upon the flexibility of the horizontal reactions provided by the decks as upon the fixity of the base, although at present the relations of variations in these boundary conditions to elastic behavior are unknown.

4. The number of salvos was insufficient to determine the complete relation between the strains in the foundation and the direction of gunfire.

RECOMMENDATIONS

Inasmuch as this test emphasizes the importance of the flexibility of the horizontal and vertical structural supports in governing the elastic behavior of gun foundations, more complete tests with both models and prototype should be conducted to evolve design criteria.

REFERENCES

(1) "Model Tests of a Circular Foundation for a 5-Inch 38-Caliber Gun," by E. Wenk, Jr., TMB Report R-255, in preparation.

(2) BuShips CONFIDENTIAL letter C-DD692 Class/S74(332) of 9 November 1943 to TMB.

(3) "Effects of Impact on Simple Elastic Structures," by J.M. Frankland, Ph. D., TMB Report 481, April 1942.

(4) "Measurements of Strains and Deflections of a 1/8-Scale Model of the Turret Stool for Cruisers of the CL144 Class," by E. Wenk, Jr., TMB Report 562, in preparation.