NAVY DEPARTMENT

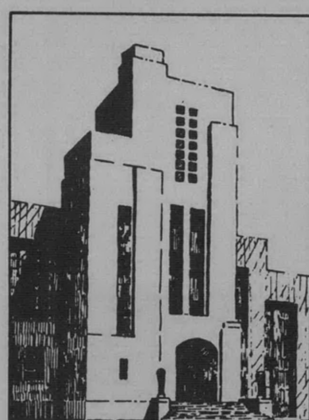
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

THE ELASTIC BEHAVIOR OF THE ROTATING STRUCTURE OF THE CA139-CLASS PILOT TURRET UNDER STATIC LOADING

by

Edward Wenk, Jr. and Charles A. Wagley



March 1950

Report C-166

NS 731-002

INITIAL DISTRIBUTION

Copies

15 Chief, Bureau of Ships, Project Records (Code 362) for distribution:
- 5 Project Records
- 1 Technical Assistant to Chief of the Bureau (Code 106)
- 1 Research (Code 330)
- 1 Preliminary Design and Ship Protection (Code 420)
- 2 Hull Design (Code 440)
- 1 Scientific (Code 442)
- 1 Armament and Mechanical (Code 447)
- 1 Battleships and Cruisers (Code 511)
- 2 Structural, Battery, and Guided Missiles (Code 633)

2 Chief, Bureau of Ordnance, Re5b

2 Chief, Bureau of Ordnance, Library

2 Commander, U.S. Naval Proving Ground, Dahlgren, Virginia

1 Commander, U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland

1 Superintendent, U.S. Naval Gun Factory, Washington 25, D.C.

2 Commander, Philadelphia Naval Shipyard, Naval Base, Phila. 12, Pa.

2 Supervisor of Shipbuilding and NIO, Newport News Shipbuilding and Drydock Company, Newport News, Virginia

2 Chief, Office of Naval Research, Scientific Literature Branch (N482), Washington 25, D.C.

1 Superintendent, U.S. Naval Postgraduate School, Annapolis, Md.

1 Commanding Officer, Naval Training Schools, Massachusetts Institute Of Technology, Cambridge 39, Mass.

1 Chief of Naval Operations, Operations Evaluation Group (OP-34H8), Washington 25, D.C.

1 Supervisor of Shipbuilding and NIO, Bethlehem Steel Co., Shipbuilding Division, Quincy 69, Mass.

1 Director, Technical Information Division, Aberdeen Proving Ground, Aberdeen, Md.

1 Chief of Ordnance, U.S. Army, SPOTX-AR, Technical Reports, Washington 25, D.C.

~~1 Director, Armour Research Foundation, 35 West 33rd St., Chicago 16, Ill.~~

Copies

1 Director, National Bureau of Standards, Ordnance Division, Washington 25, D. C.

1 Prof. N.M. Newmark, Structural Research Division, 111 Talbot Laboratory, University of Illinois, Urbana, Ill.

1 Director, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Md.

1 Prof. J. Ormondroyd, Department of Engineering Mechanics, University of Michigan, Ann Arbor, Mich.

1 Prof. L.S. Jacobson, Stanford University, Stanford, Calif.

THE ELASTIC BEHAVIOR OF THE ROTATING STRUCTURE OF THE CA139-CLASS PILOT TURRET UNDER STATIC LOADING

by

Edward Wenk, Jr.,

and

Charles A. Wagley

March 1950 Report C-166

FOREWORD

The new main-battery turret for the CA139-Class cruisers incorporated many novel structural and mechanical features which rendered it capable of firing its three 8-inch 55-caliber guns more rapidly than any of its predecessors. To check its operation, perhaps the most extensive structural investigation ever conducted on turrets was performed. A 1/10-scale structural model was fabricated and tested at the David Taylor Model Basin, and a full-scale pilot turret was tested at the Naval Proving Ground. The results have subsequently been checked by structural firing trials conducted on the USS DES MOINES (CA134), the first naval vessel to carry these new turrets. As its part of the over-all program, the David Taylor Model Basin was given the responsibility of measuring (a) the performance of the turret structure and roller track, (b) the behavior of the recoil-counterrecoil system, (c) the operation of the training buffer, and (d) the motion of the guns and turret during elevating and training exercises.

Apart from the primary objective of confirming the safety and the satisfactory performance of the new turret in advance of construction of the ships themselves, secondary objectives were established to derive experimentally information which could be employed to confirm or refute design criteria for guns and turrets, and for structural assemblies which are similarly loaded.

The results of the test of the pilot turret under static load are given in this report. The other results are given in additional reports and memoranda, as follows:

1. "Description of Test of Hydraulic Training Buffer of CA139-Class Pilot Turret," TMB RESTRICTED Report C-38, February 1948.

2. "An Elastic-Tube Gage for Measuring Static and Dynamic Pressures," TMB Report 627, May 1948.

3. "Description of Instruments Employed in the Operational Tests of the Gun-Elevating Systems of the CA139-Class Pilot Turret," TMB RESTRICTED Report C-29, October 1947.

4. "The Measurement of Performance of the Gun-Elevating System of the 8-Inch 55-Caliber Turret," TMB RESTRICTED Report C-163 (in preparation).

5. "The Measurement of Performance of the Training System of the 8-Inch 55-Caliber Turret," TMB RESTRICTED Report C-164 (in preparation).

6. "The Dynamical Response of the Rotating Structure of Turrets with Particular Reference to the 8-Inch 55-Caliber Turret," TMB RESTRICTED Report C-81 (in preparation).

7. "Structural Design Studies of a 1/10-Scale Model of the 8-Inch Gun Girder on the CA139-Class Cruisers," Thesis, Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, 1949.

8. "Schedule of Measurements to be Made by the David Taylor Model Basin during Tests of the CA139 Pilot Turret," TMB Memo 2, CA139 Class/S72-1 of 13 November 1945 (revised 25 April 1947).

9. "Experimental Analysis of Stress and Deformation of a 1/10-Scale Model 8-Inch Gun Turret for the CA139-Class Cruisers," TMB RESTRICTED Report 571, February 1948.

10. "The TMB Tension Dynamometer," TMB Report 605 (in preparation).

11. "An Investigation of Buffer Action and Motion Characteristics of the 8-Inch 55-Caliber Recoil Counterrecoil System," TMB RESTRICTED Report C-165 (in preparation).

12. "The Elastic Behavior of the Rotating Structure of the CA139-Class Pilot Turret with Gunfire Loading," TMB RESTRICTED Report C-231 (in preparation).

13. "Natural Frequencies Measured on the CA139-Class Pilot Turret," TMB RESTRICTED Report C-82, December 1948.

Whereas the experimental and theoretical analyses were conducted for this turret investigation to obtain specific data regarding performance, a vast amount of general information was obtained pertaining to the behavior of hydraulic energy-absorbing systems and to the elastic behavior of complex structures subjected to dynamic loading. It is now planned to present these more general results in two separate reports:

1. Considerations for the Design of Complex Structures Subjected to Dynamic Loads, as Derived from Experimental Analysis.
2. New Considerations for the Design of Hydraulic Buffers as Derived from Experimental Analysis.

TABLE OF CONTENTS

ABSTRACT

A new turret for the 8-inch 55-caliber gun, which permits greatly increased rate of gunfire, was designed for the CA139 Class of cruisers. To check the safety of the structure, tests were performed on a 1/10-scale steel model, and to confirm these results tests were also conducted on a full-scale pilot turret with both static and dynamic loading. Thus, through various steps of experimental study—tests of the model, static and dynamic tests of the pilot turret, and later, full-scale firing trials of the turret installed in the ship itself—a chain of information was anticipated by which the elastic behavior of the turret structure would be fully determined and by which the accuracy of prediction of full-scale dynamic performance from static tests of small-scale models could be confirmed. The static tests of the pilot turret, described in this report, justified this anticipation.

The stresses and deflections measured in the structure were of such small magnitude as to confirm the safety of the design. The measured elastic behavior was in excellent agreement with predictions from tests of the scale model, and thus validated the structural-model technique. Where measured results differed from the design computations the disagreement has been attributed to the conservative nature of design assumptions. More direct information concerning the boundary conditions for inboard gun girders was obtained from the test, and an analysis of these conditions is given in this report. The observed deformations of the rotating structure were analyzed to determine deflection errors which would result from gunfire loads, and the errors were found to be much less than those due to the slippage at the turret roller track and deformations of the structural foundation.

The care with which this test was conducted and the accumulation of large quantities of data from electrical strain gages permitted statistical studies of the results to determine experimental errors and inconsistencies which might be expected from similar full-scale structural investigations. These inconsistencies were found to be reduced, by the application of good techniques, to stress values of approximately 300 psi.

INTRODUCTION

During the early part of World War II an entirely new group of 6-inch and 8-inch gun turrets was designed to fire much more rapidly than earlier turrets. The most important improvement in the 8-inch turret for use on the CA139-Class of cruisers was the incorporation of automatic ammunition-handling arrangements which permitted the charging of guns at any angle of elevation, either with the guns stationary or moving to follow targets. This feature involved mechanical equipment which required more space than existed on earlier turrets, but the increase in weight—which would accompany the resulting increase in size—was severely limited by the design hull displacement. Such limitations necessitated the use of unique structural arrangements which, it appeared, might be accompanied by a reduction in strength and stiffness. It was therefore decided that the acceptability of the new design should be determined by full-scale tests. It was thus deemed necessary to construct and test a pilot model to determine the performance well in advance of actual construction of the naval vessels; and at the same time it was considered essential that information be collected which would be of value in the design of other similar turrets which might be required during the war.[1,2,3]

A full-scale pilot model of the 8-inch 55-caliber turret was subsequently built and tested with both static and gunfire loads at the Naval Proving Ground by personnel of that activity and of the Taylor Model Basin. Results of the static tests of the rotating structure are given in this report. There is first discussed the information which was required to satisfy the objectives of the program, followed by a description of the instrumentation which was provided for measurement of the desired quantities and of the test facilities specifically designed to apply static loads to the pilot turret. The test procedure is described and the results summarized. The principal results show that the structure as designed is safe but uneconomical, that predictions of full-scale behavior based on model tests were confirmed, but that the design calculations were in considerable error (on the safe side) owing to the conservative nature of assumptions regarding boundary conditions.

Inasmuch as this static test was the most complete one of its type yet conducted by the Navy Department with contemporary scientific instrumentation, there is also discussed in some detail the techniques of measurement and the experimental errors which are involved in the use of wire-resistance strain gages under field conditions.

During the static loading, additional observations were made of the behavior of the roller track and stool. These data are not reported herein, but have been placed on file at the Taylor Model Basin.

BACKGROUND OF STATIC TESTS

The Bureau of Ordnance decided in 1944 that, because of the tactical importance then anticipated for cruisers which would mount the new 8-inch rapid-fire guns, it would be desirable to proof-test a pilot turret with all the important structural and mechanical components prior to actual ship construction. With this primary objective in mind, a complete pilot turret was

---

[1]References are listed on page 47 of this report.

ordered to be built by the Philadelphia Naval Shipyard and the Naval Gun Factory, and installed at the Naval Proving Ground at Dahlgren, Va., for test. To speed the construction and testing, the center gun of the three was never installed.

As this program of testing was originally conceived, proof of satisfactory operation of structure and mechanisms was not to be obtained merely by visual observation; instead, elaborate instrumentation was planned to measure all the design quantities so that actual operation could be permanently recorded and performance determined by instruments which would be sufficiently sensitive to detect malfunctioning that might otherwise be overlooked. With such complete instrumentation, should there be evidence of unsatisfactory operation, the records would be immediately available for analysis, so that remedial measures could be scientifically planned and quickly applied.

It is apparent that the provision of instrumentation to measure the important quantities by which performance of the turret could be appraised also concomitantly permitted checks on the original design criteria. Thus, it was agreed early in the planning of the pilot-turret test that instrumentation required to satisfy the primary objective of determining performance could easily be employed to satisfy secondary objectives of confirming the criteria employed in the design of this particular turret.

There was yet one additional consideration in planning of the pilot-turret tests. At that time, one of the most important functions of naval vessels was to serve as floating platforms for guns. Since it was impossible to forecast with complete confidence either the duration of the conflict or the trend of naval tactics, it was believed wise to continue with considerable emphasis the development of additional rapid-firing naval guns and turrets. Until the development of this 8-inch turret the criteria employed by both ordnance and structural designers had been proved safe over a period of years—on the basis of few failures in service—but these criteria had never been proved fully satisfactory from the point of view of providing the lightest structure or mechanism that would satisfactorily perform its intended function. Perhaps the most important reason for the absence of refined criteria was the lack of scientific instrumentation required to measure the design quantities as they exist in turret structures used in actual service.

During the planning of the pilot-turret test it was recognized that great advances were concurrently being made in the field of scientific instrumentation. It followed that there could be either obtained commercially or developed for the test all the instrumentation which would be necessary to study the behavior of the structures and mechanisms from a broader point of view than that of simply proving the performance of a specific and unique design. Consequently, a third and more general objective was established for tests of the pilot turret: the collection of scientific data by which generalized criteria, applicable to the design of all turrets and guns, could be derived.

It was in consideration of this third objective that proposals were made to study the pilot turret under static loading as well as with forces of gunfire. By such tests, certain elements of design information could be obtained experimentally that would otherwise remain as pure conjecture in the mind of the designer. First, by comparing strains and deformations of the structure during gunfire and during static loading, the value of the dynamic factor which is employed in the design could be unequivocally determined; and second, the accuracy of the structural-model test, which had been performed to predict prototype behavior, could be checked.[4] There would thus be made available for appraisal of the structural-model technique, the chain of experimental results obtained from static tests of a small-scale model, static tests of a full-scale pilot turret, gunfire tests of the full-scale pilot turret, and finally, gunfire tests conducted aboard the completed naval vessel.

The application of static load to the pilot turret would make possible one additional study. It was recognized that the accurate measurement of the forces of recoil would be required during tests with gunfire so that the relationships between external stimuli and the structural response could be determined. Up to that time, the measurement of recoil forces had been an approximate procedure because of the limitations of instrumentation and because it was recognized that all the constituent elements of the recoil force had to be measured simultaneously. The integrated effect of these various force components had been measured on small-caliber guns, and it was believed possible to make similar measurements with the 8-inch gun through the use of strain gages mounted on the structure which is immediately adjacent to the trunnion supports. If this structure had sufficient rigidity, the time-history of strain developed in it during gunfire would reveal the time-history of force applied to the trunnion. Then the magnitude of the force could be determined simply by comparing strains measured during gunfire with those measured during the application of a static load of known magnitude. That is, the strain gages mounted on this structure would serve as recoil-force dynamometers which would be calibrated by means of static load applied to the pilot turret.

To summarize briefly, the static tests of the pilot turret were conducted to provide the following information which could not otherwise be obtained:

1. Determination of the dynamic-load factor accompanying recoil force.

2. Check on the accuracy of using small-scale structural models for predicting full-scale performance.

3. Calibration of strain gages to be employed as recoil-load dynamometers.

There should be added to this list those general objectives for the entire turret test, achievement of which would be better realized by the performance of these static tests:

4. Determination of the stress distribution and mode of deformation of the turret structure so that the accuracy of analysis can be determined.

5. Determination of accuracy of assumptions employed in the theoretical analysis of the turret structure, particularly with respect to boundary conditions.

6. Determination of the load-carrying capacity of the entire structure and possible redundancy of components in consideration of the important objective of minimizing topside weight in naval vessels.

7. Study of the elastic behavior of the roller-track system.

8. Appraisal of the deformations on the basis of possible damage to interlocking mechanisms.

9. Avoidance of errors in gunfire due to excessive deformations of the turret structure.

DESCRIPTION OF ROTATING STRUCTURE OF CA139-CLASS TURRET

The general arrangement of the 8-inch 55-caliber turret is shown in Figure 1, taken from the BuOrd publication describing the equipment.[5] As with earlier designs, the turret consists first of a structural system which supports the guns and which rotates on a roller track about a vertical axis, and second, of a cylindrical foundation which supports the roller track. This investigation pertains primarily to that portion of the turret above the roller-track level, usually referred to as the rotating structure or turret weldment.

The rotating structure comprises a cylindrical bulkhead bounded at the top by a shelf plate and at the bottom by a pan plate. The bulkhead contains four girders disposed to support the three gun trunnions. The center of the trunnions lies several feet above the shelf plate so that the trunnions themselves are supported by extensions of the four girders acting as cantilevers.

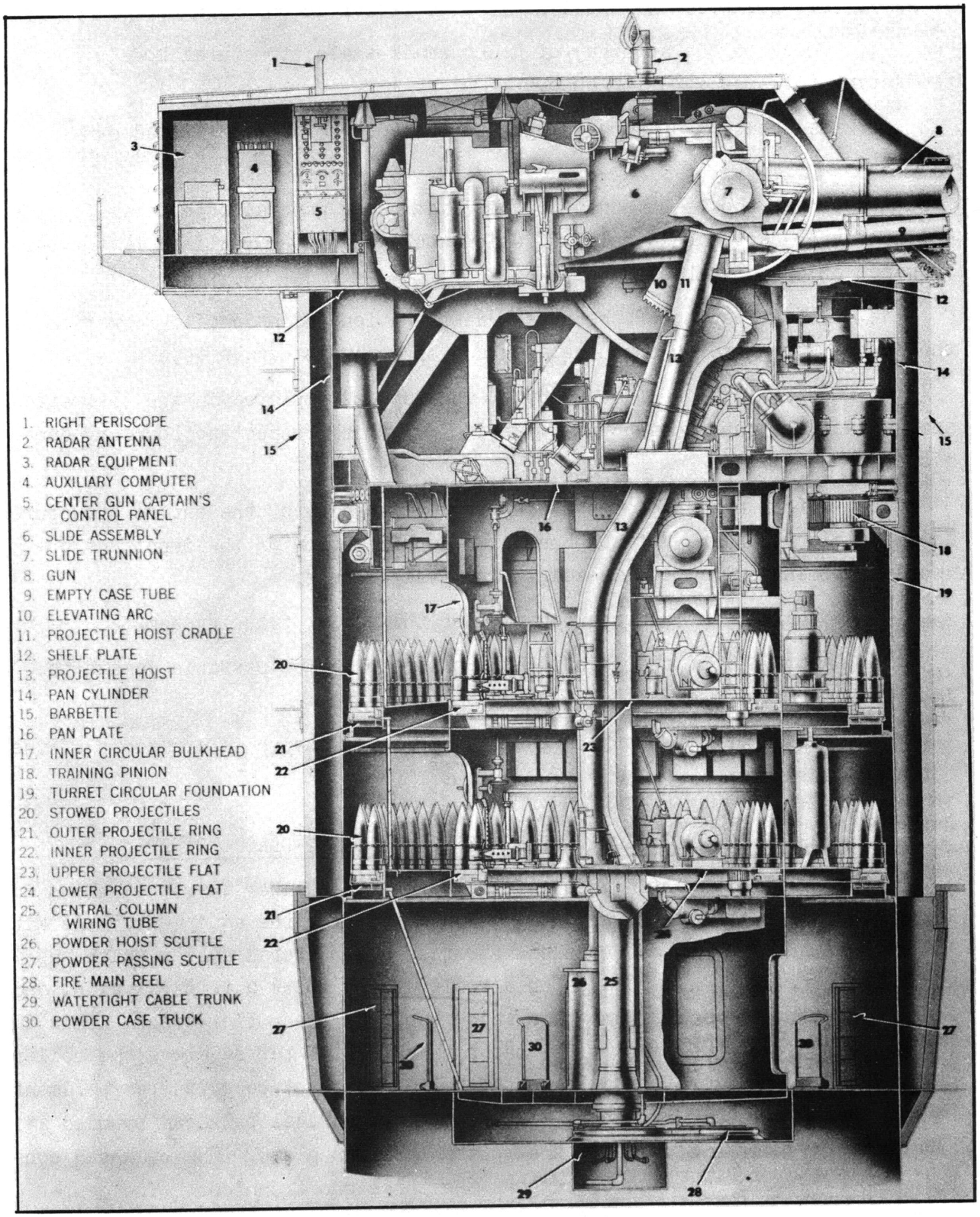


Figure 1 - Cross Section of 8-Inch 55-Caliber Rapid-Fire Turret for CA139-Class of Cruisers

In the case of this 8-inch turret, the inboard girders are formed as open trusses made up of rolled H-sections. The outboard girders are formed as stiffened plate girders. The details of these components and their assembly is shown by photographs of a 1/10-scale cardboard model, Figures 2 to 5. The dimensions of the full-scale truss and its adjoining structure are given in Figure 6.

The most radical departure of structural arrangements from earlier turrets was the use of open trusses in lieu of heavy double-plate girders, and it was around the performance of these trusses that the structural investigation was planned.

ANALYSIS OF ROTATING STRUCTURE

For design purposes,[6] the inboard girders or trusses were isolated from the remaining turret structure and studied as two-dimensional systems with a concentrated load applied at the trunnion and with horizontal and vertical reactions at the roller tracks only; see Figure 7. The trunnion load on the truss is made up of two identical halves of the recoil force from the firing of the center gun and the wing gun so that the magnitude of load at the trunnion supported by a truss is exactly equal to the recoil force from one gun. This force was estimated for design purposes to be 215,000 pounds, applied in a horizontal direction. It was derived from the theoretical value of maximum recoil force at a 60-degree gun elevation with the addition of a factor of safety of 1 1/4 to take into account unknowns of recoiling action. In connection with other phases of the turret tests, the maximum value of recoil has been found experimentally to be 200,000 pounds. Considerations of the difference between the design value and the value actually observed will be discussed in a later report.[7]

The assumption in design calculations, that the truss has only horizontal reactions at the roller-track level, is of great importance to the accuracy of the calculations. This assumption is unquestionably safe, but the omission of elastic supports—which actually exist at the shelf-plate level and at the connections between the trusses and the circular bulkhead—is a simplification which defeats the objective of economy of structure. A more likely distribution of the reactions is shown in Figure 8.

In any case, the assumptions with regard to the loading and the reactions made possible a design analysis with conventional engineering methods. The resulting axial forces, moments, and shears are shown schematically in

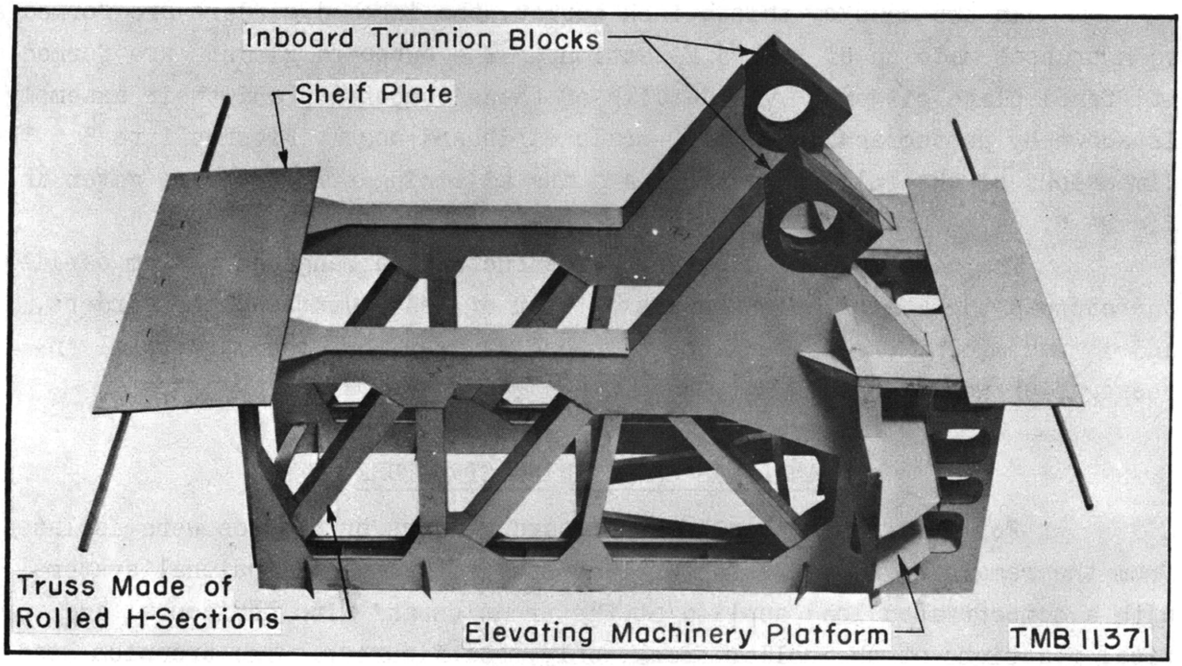


Figure 2 - Cardboard Model of Trusses of 8-Inch Gun Turret

The inboard trunnion blocks that form common housings for adjacent trunnion bearings are cantilevered up from open trusses. The support for the elevating arc guide and the framing of the turret officer's booth are not included here.

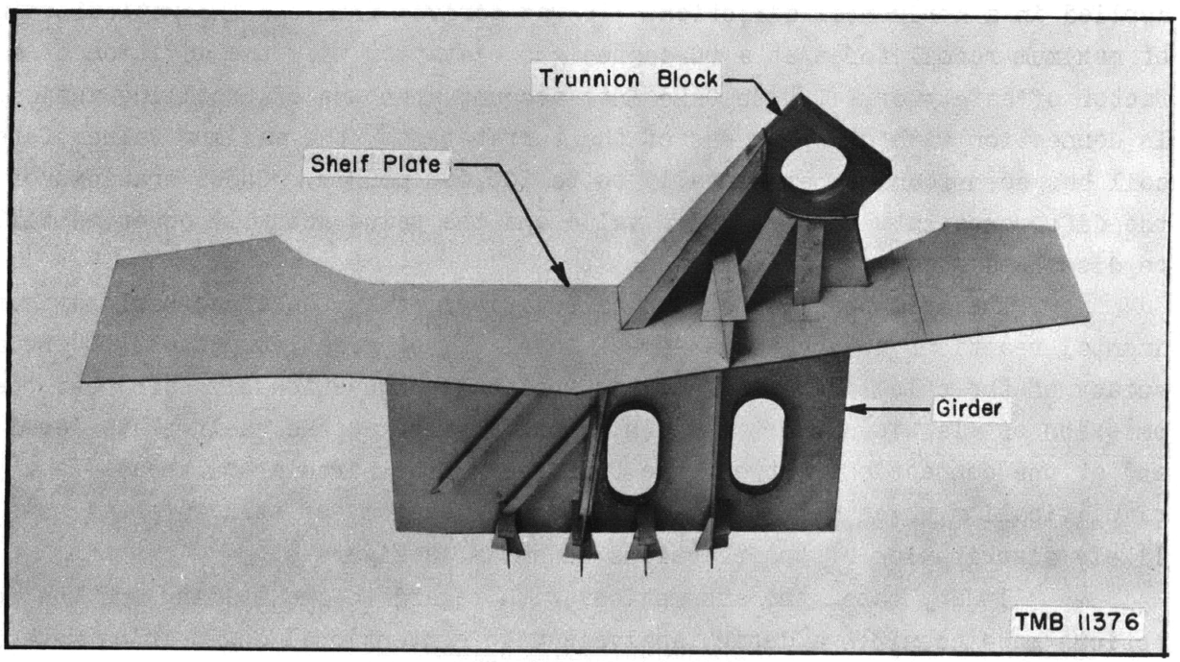


Figure 3 - Cardboard Model of Starboard Outboard Gun Girder of 8-Inch Turret

The outboard trunnion blocks are supported by conventional stiffened-plate girders.

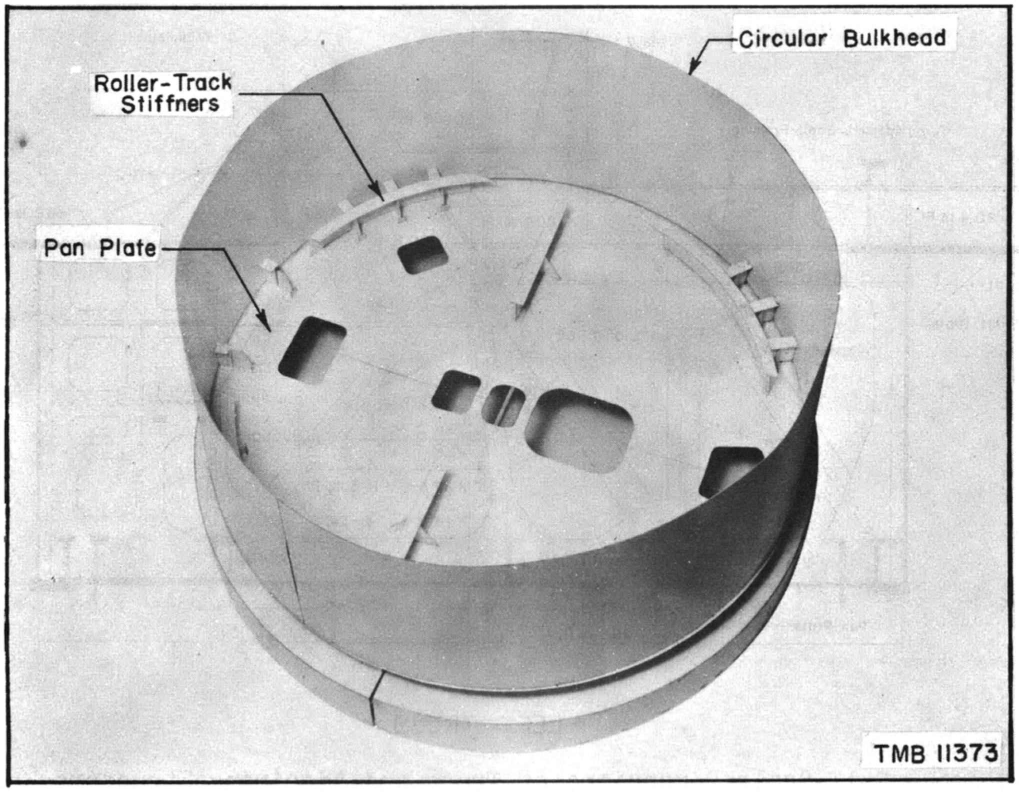


Figure 4 - Cardboard Model of Pan Plate and Circular Bulkhead of 8-Inch Turret

The pan plate and circular bulkhead used on the CA139 turret are lighter than those used on previous turrets of comparable size.

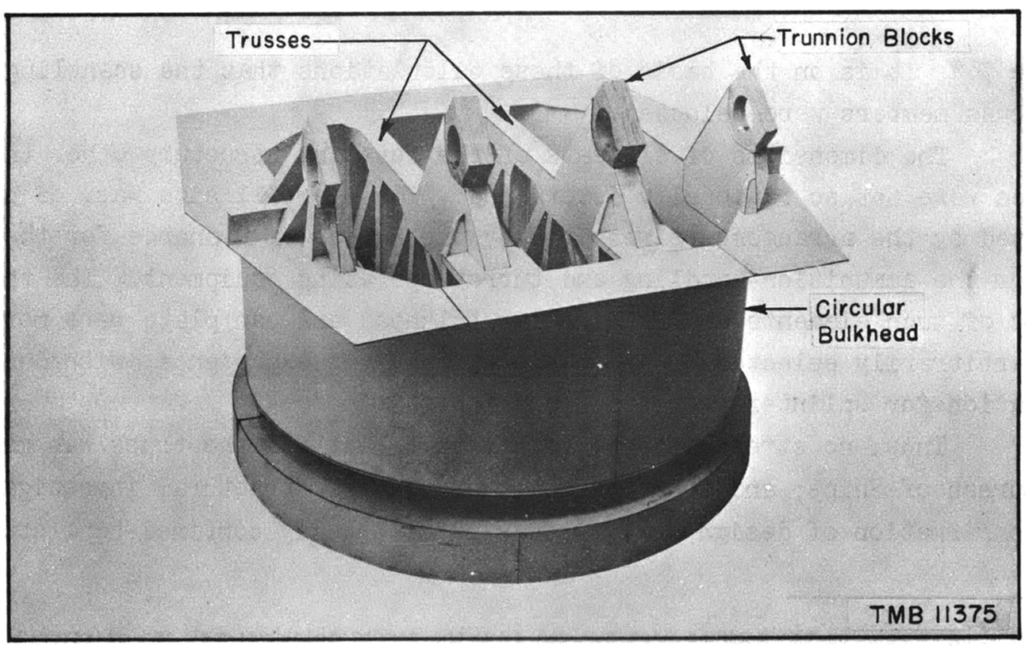
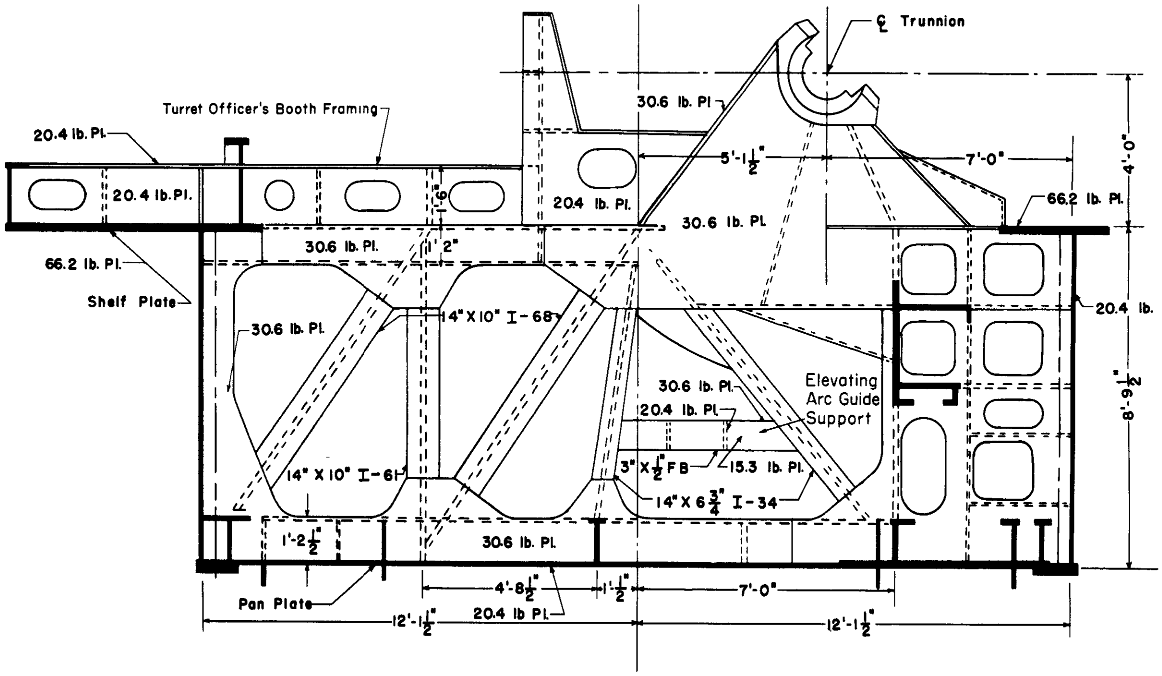


Figure 5 - Cardboard Model of Rotating Structure of 8-Inch Turret

This view shows the relationship of the trusses, girders, trunnion blocks, circular bulkhead, and pan plate.



LEFT TRUSS

Figure 6 - Full-Scale Dimensions of Truss and Adjoining Structure Which Supports Guns for 8-Inch Turret

The elevating arc guide support and turret officer's booth framing were not considered in the design calculations or in tests of a scale model, but they are of such size as to influence stress dis-distribution in the truss and should be considered as primary members.

Figure 7.* It is on the basis of these calculations that the scantlings of the truss members were selected.

The dimensions of elements of the rotating structure other than the trusses were not so rationally determined. The over-all size was, of course, dictated by the arrangements required by the Bureau of Ordnance for the guns and for the ammunition-handling and turret-operating equipment. The thicknesses of such elements as the circular bulkhead and pan plate were more or less arbitrarily selected on the basis of previous experience, with due consideration for splinter protection and for stiffness.

Thus, no stress analysis other than that for the truss was made by the Bureau of Ships; and from the point of view of structural investigation the confirmation of design analysis was automatically confined to a study of

*The shear forces on the members were derived from the moment calculations, and additional external forces, not given in design calculations, were assumed to act at the shelf plate to bring the system into equilibrium.

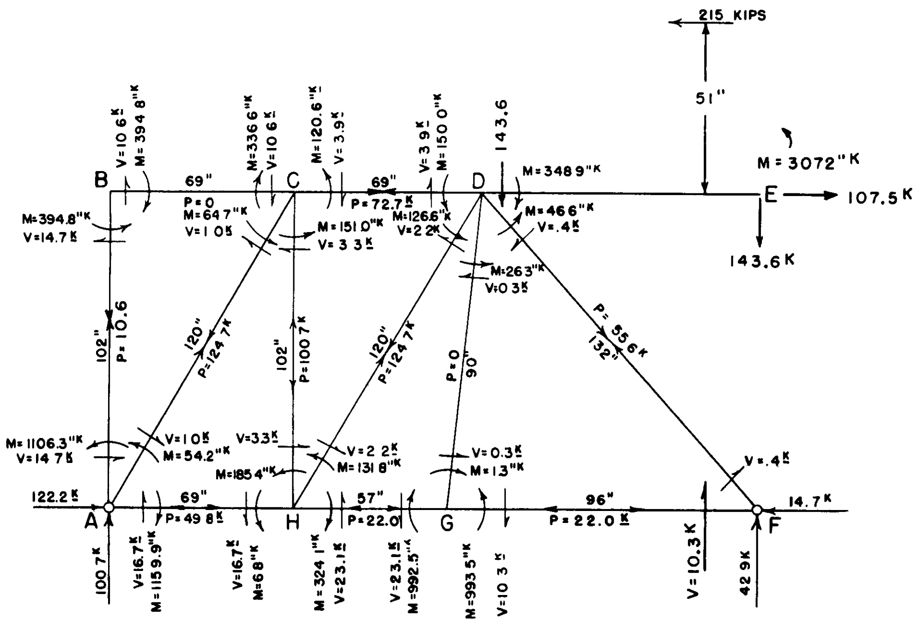
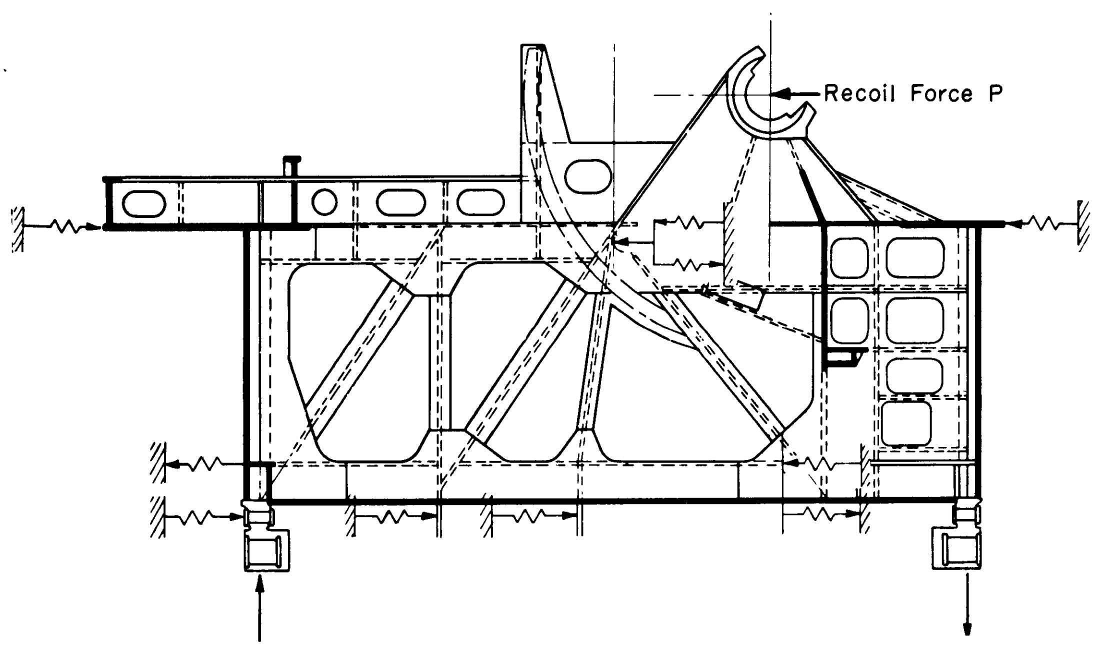


Figure 7 - Schematic Diagram of Truss Showing Loads, Reactions, and Elastic Behavior As Determined from Design Calculations

M is moment in inch-kips, V is shear in kips, and P is load in kips.



Boundary Conditions as Measured on $\frac{1}{10}$ Scale Steel Model

Figure 8 - Schematic Diagram of Truss Showing Boundary Conditions As They Probably Exist in the Truss

the truss members alone. As will be developed later, the program of static tests and the instrumentation was, therefore, planned primarily around a study of these trusses.

PROGRAM OF STATIC TESTS

In order to achieve all the earlier stated objectives, the static tests were planned so that the application of loads to all three gun positions would be along the line of gunfire at zero elevation. The static forces were accurately measured with suitable dynamometers, and simultaneously the response of the structure was measured by means of wire-resistance strain gages and dial deflection gages. The strain gages were intended to measure structural performance during both static and gunfire tests of the pilot turret. The dial deflection gages, however, would be suitable only for static measurements, so that other types of instruments were required for comparable measurements of the rapidly applied loads.[8]

DESIGN OF TEST FACILITIES

The first problem confronted in planning the static tests was the provision of a suitable test facility for the application of static loads of intensities comparable to the gunfire forces. After consideration of many different schemes, it was decided to provide an anchor tower behind the pilot turret from which forces could be applied. This tower was conveniently situated to house the measuring and recording equipment required for gunfire tests. Consequently, instead of an open framework, the anchor tower was designed as an enclosed structure that would serve two functions.

The primary design of the tower was executed by the David Taylor Model Basin.[9] It consisted of a hollow steel cube on the top of which were mounted hydraulic rams and yokes to apply loads through heavy steel cables to the gun trunnions at the pilot turret. This tower was to be prefabricated as a unit and bolted to a composite steel and concrete emplacement—the latter required to resist the overturning moment imposed by the static forces at the top of the tower. The interior of the tower was designed as an instrument room and had suitable illumination, ventilation, and soundproofing. Splinter protection was offered to the interior space by the 1-inch steel panels which constituted the envelope of the tower. A preliminary loading diagram for the tower design is shown in Figure 9.

Before describing details of this loading arrangement, several additional comments are introduced regarding the general design, because this loading tower is believed somewhat unique in both function and arrangement.

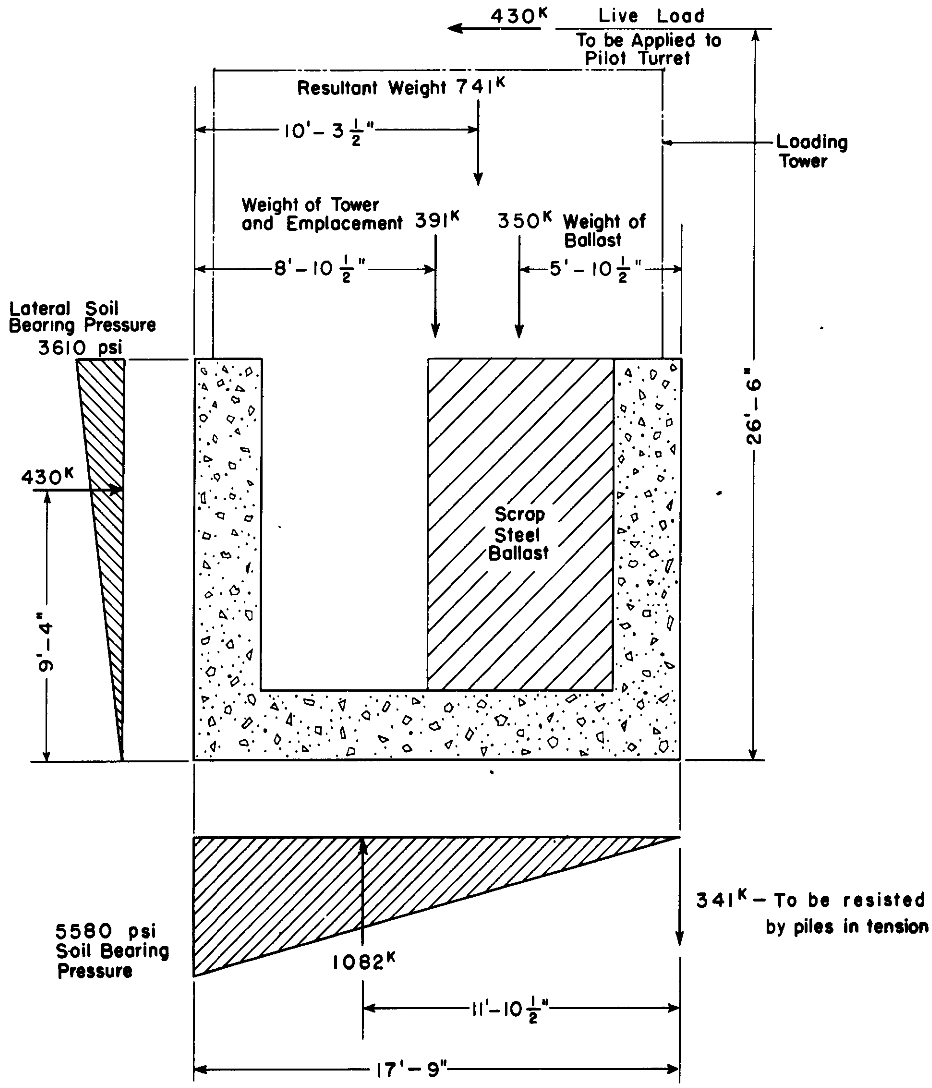


Figure 9 - Design Loading Diagram for Tower Employed to Apply Static Loads to the Pilot Turret

The first design consideration was the space available at the Proving Ground for the installation of this test tower. Inasmuch as the loading cables would be installed for long periods of time, it was essential that they in no way interfere with crane operations which took place intermittently along some tracks which ran behind the pilot turret emplacement. Between these tracks and the pilot turret, however, there was available an area approximately 20 feet by 20 feet. This space restriction thus determined the over-all size of the tower and required that the overturning of the tower be resisted by a system of vertical tensile and compressive forces that would be separated by only 20 feet. This short base resulted in larger forces than are ordinarily experienced in building foundations. It was believed that piling driven into the soil underneath the tower could sustain both types of forces through skin friction developed on the surface of the pile; in fact it soon became apparent that this system was the only one by which such large forces could be resisted. To reduce the load on the piles, however, it was decided to furnish dead-weight ballast by means of a foundation room under the loading tower which would be filled with 175 tons of scrap steel; this scrap was available at the Naval Proving Ground in large quantities. The final arrangement of the static loading system is shown schematically in Figures 10 and 11.

The foundation for the loading tower consists of a reinforced-concrete foundation which is contained by sheet piling. It forms in plan a hollow square approximately 18 feet on the outside and 12 feet on the inside. Steel H-section bearing piles were driven to a depth of 75 feet along both the front and the back to sustain the vertical loads which resist overturning. The loading tower was locked in place with holding-down bolts which were cast into the concrete foundation to match holes in the tower base. The emplacement was built under the cognizance of the Bureau of Yards and Docks, and the combination loading tower and instrument room was designed and fabricated by the Philadelphia Naval Shipyard. The tower was assembled on the site in February 1947 and put into operation as an instrument house immediately thereafter.

The static forces were applied by three Watson-Stillman hydraulic jacks of 150-ton capacity, operating at 7500 psi; these were mounted in a horizontal position on the roof of the instrument house so that the centerline of each of the three jacks coincided with the centerline of each of the three gun positions. Hand pumps to operate these jacks, as shown in Figure 12, were located inside the instrument house and were suitably connected to the jacks with steel piping. Inasmuch as forces were to be applied to the pilot turret through cables, loading yokes were placed over the jacks so that the force of the jack could be applied in the intended direction.

These static forces were measured with TMB bar-type dynamometers[10] which had a capacity of 200,000 pounds and an overload capacity of 100,000 pounds. These dynamometers were essentially bars made of alloy steel on which were mounted wire-resistance strain gages arranged to give maximum electrical output when the bar was axially loaded. The bars were calibrated in a laboratory testing machine and the output of the electrical strain gages measured with a Baldwin-Southwark Type-K Strain Indicator. The dynamometers were found to be linear and accurate to within 1 percent, and the temperature compensation by means of dummy gages on the bar was fully effective.

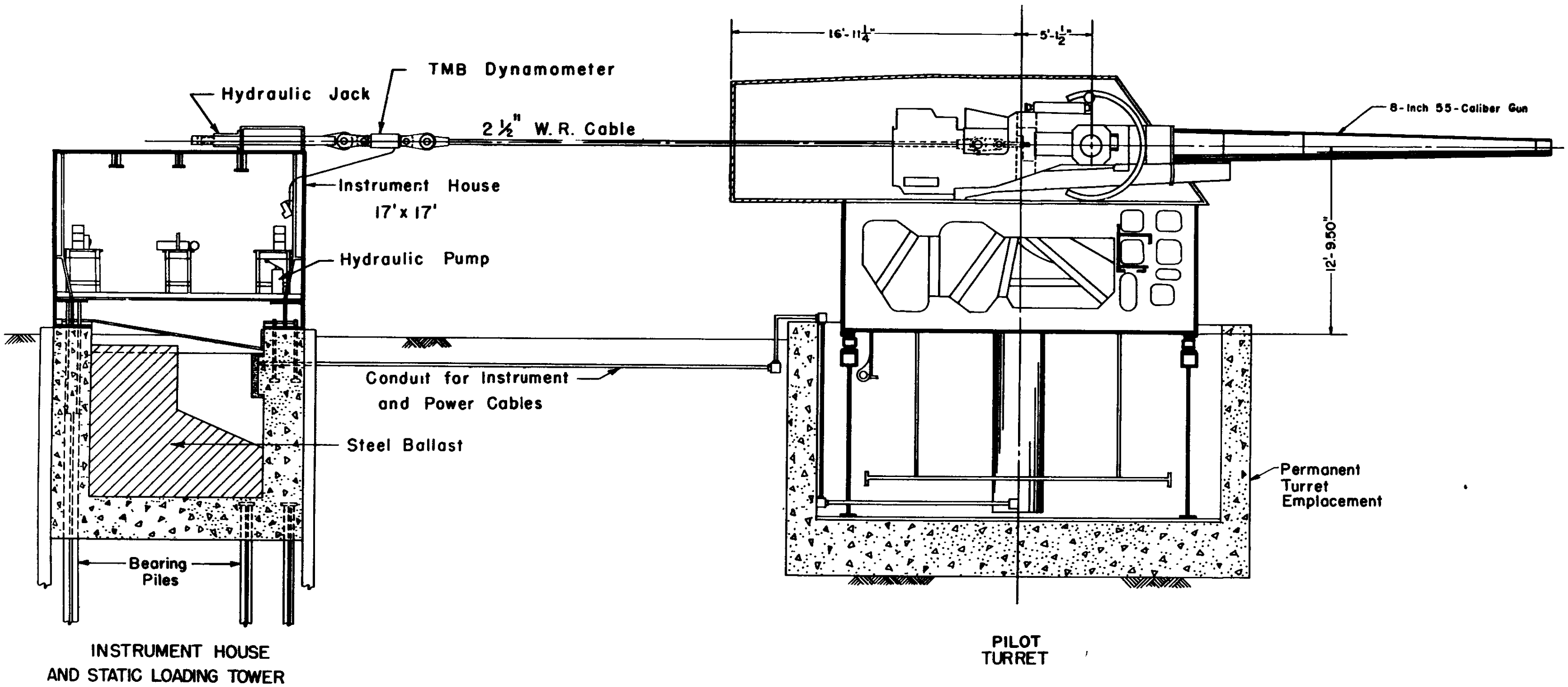


Figure 10 - General Arrangement for Static Tests of 8-Inch 55-Caliber Pilot Turret

RESTRICTED

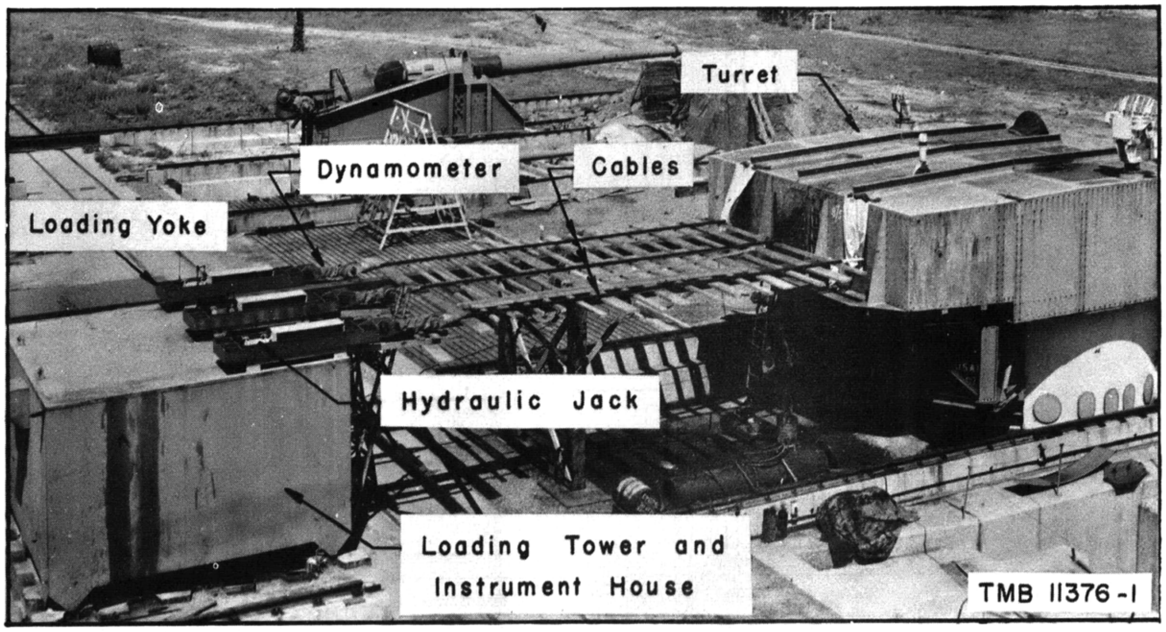


Figure 11 - Photograph of the Pilot Turret and Loading Tower Showing the Jacks and Rigging Required to Load the Turret

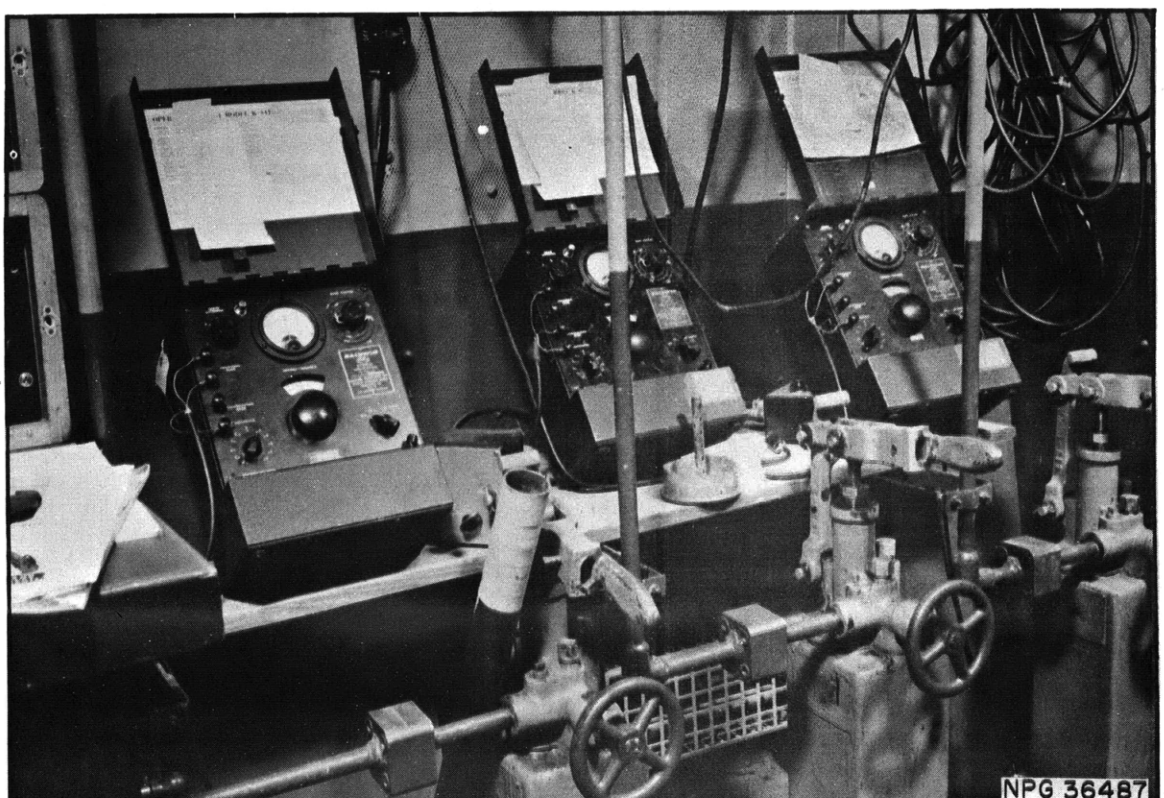


Figure 12 - Hand Pumps for Powering the Hydraulic Jacks

Each hydraulic jack was controlled from a separate pump, and the load on each dynamometer was read with a separate strain indicator

The cable connecting the pilot turret to the loading tower was made of 6- by 19-inch high-grade plow steel, 2 1/2 inches in diameter. The cable was made of preformed strands; and after the suitable end-fittings were installed it was preloaded to the design service load of 215,000 pounds. Because these heavy cables were expected to sag appreciably between supports, a wooden scaffold was provided on the site to hold up the cables throughout their length.

The two guns in the pilot turret were left installed during static tests but were provided with special breechblocks that had been drilled and tapped for eyebolts which matched the cable fittings. A special trunnion was mounted in the center gun position and was provided with an eye for attachment of the center cable. During the static tests, the ramming mechanisms for the two guns were removed so as not to interfere with the loading cables.

Because of the restrictions on distance between the bearing piles, the forces imposed as a result of overturning moment were greater than would be desired, particularly because information was lacking on the ability of piles to resist constant tension. Thus, originally, in order to hold the load on these piles at a minimum consistent with the forces required to be applied to the pilot turret to produce sensible strains, the load limitation was established as 215,000 pounds per gun, but with a total of 430,000 pounds. However, after preliminary static tests showed that this magnitude of force was insufficient to produce strain quantities in the turret of desirable magnitudes, it was decided at the site to increase this force to 645,000 pounds, which represents the full service load of 215,000 pounds per gun. The load was increased with the knowledge that the foundation and the loading tower were designed with a considerable factor of safety. Nevertheless, observations were made of the deflection of the loading tower during the increase of load from 430,000 to 645,000 pounds and a continuous plot of the observations was maintained to check on the occurrence of nonlinear or excessive deflections. No evidence of incipient failure of the loading tower was apparent and thereafter, during the test, loads of 645,000 pounds were frequently applied.

INSTRUMENTATION

The original tests of the pilot turret were planned in the summer of 1945, and at that time the structural arrangement was studied to determine the location of instruments required to develop the maximum amount of information with the minimum quantity of instruments. This principal of economy was maintained throughout the test.

On the rotating structure, wire-resistance strain gages were selected to measure strains at stations (a) that were believed to have high strains and thus constitute the region closest to failure, (b) that were believed to have low strains and thus constitute elements in which material could be removed if this belief were confirmed, (c) in those structural components for which the design analyses were available and could thus be checked with experimental results, and (d) in those regions where measurements of strain would produce information concerning the structural boundary conditions. The locations of the wire-resistance strain gages on the rotating structure are shown schematically in Figure 13. Gages 1 through 10 were mounted at the midpoints of truss members to measure strains accompanying axial loads. Gages 20 through 51 were mounted at the ends of left truss members to determine strains indicative of bending moments and shear forces. Gages 11 through 17 and Gage 19 were arrayed to measure strains at other points on the truss. Gage 18 was located to determine the stress in the stiffener which joins the two trusses. Gage 53 was located on the diagonal stiffener of the left girder and Gages 54 through 56 constituted a rosette to measure principal stresses in the girder. All gages mounted on the right truss and right girder at stations which correspond to gages on the left truss and left girder were given corresponding numbers with the numeral "1" prefixed to the gage number. Single gages were always oriented in the direction believed to constitute the axis of principal stress. All gages were SR-4 Type A-1, 120 ohms in resistance with a base length of approximately 1 inch. Gages mounted on unstiffened plating were installed in pairs on both sides to balance out local effects.

In addition to gages on the rotating structure, strain gages were mounted on the trunnion bearers to serve as recoil-load dynamometers and on the stool to indicate its elastic behavior. The results from the gages intended as dynamometers were so low that they could not be used. The results from the gages mounted on the stool will be the subject of a future report.

It was anticipated that during both static and dynamic tests, all electrical strain gages would be used with auxiliary amplifying or indicating equipment that was designed for two-arm bridge operation. Thus, there was provided at each active gage station a second gage which would constitute a second arm of the bridge, but would, as an auxiliary function, serve as a temperature-compensating element. To reduce installation time in the field, these temperature-compensating gages were mounted on steel blocks and provided with electrical terminal strips in the laboratory so that there was required in the field only the bolting of these blocks to suitable mounts and the soldering of electrical leads into appropriate electrical circuits. To keep the dimensions of these temperature blocks to a minimum, Type A-7 strain

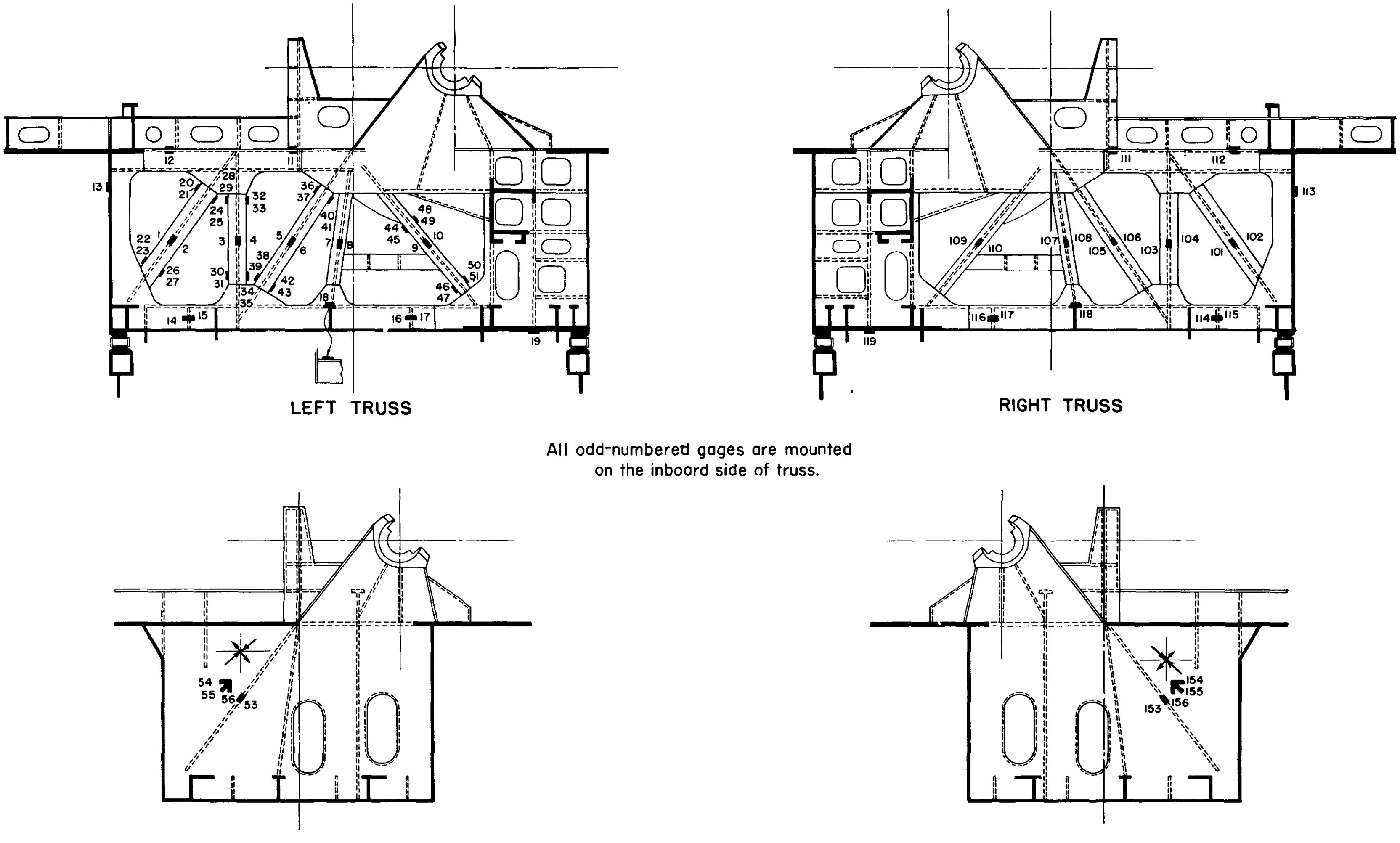


Figure 13 - Location of Strain Gages on Rotating Structure During the Static Load Test

RESTRICTED

gages were used as dummies even though it was known that they had a slightly different gage factor than the active gages. The efficacy with which automatic temperature compensation is achieved when using an A-7 with an A-1 gage was checked in the laboratory; and the results of tests of several specimens showed that no noticeable difference appeared within ranges of 30 degrees Fahrenheit between the use of two A-1's or an A-1 and an A-7.

After installation, all strain gages were baked at 140 degrees Fahrenheit with infrared lamps for periods not less than 2 hours, and immediately after were waterproofed with Ozite B, a commercial bitumastic compound. Each pair of active and compensating gages was then electrically connected to panel boards, located at the pan-plate level in the center gun alley, by means of two wire-shielded microphone cables. The shield was used as the electrical lead common to both the active and the compensating gage. A photograph of the electrical panel board is shown in Figure 14. A schematic diagram showing a typical electrical array is shown in Figure 15.

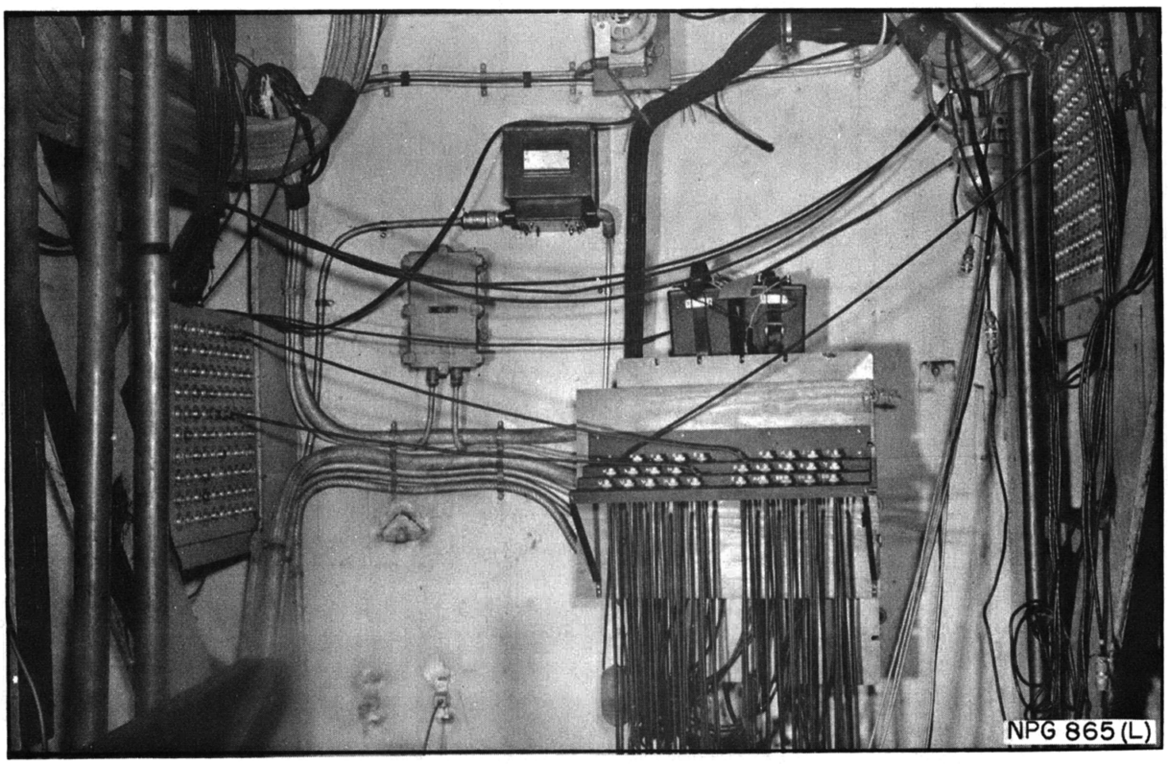


Figure 14 - The Panel Boards for Electrical Strain Gages Employed During Both Static and Gunfire Tests of the Pilot Turret

The panel boards on right and left contained plugs which were electrically connected to strain gages distributed throughout the turret. The plugs at the center were connected to cables which led to the instrument house for remote recording during gunfire tests.

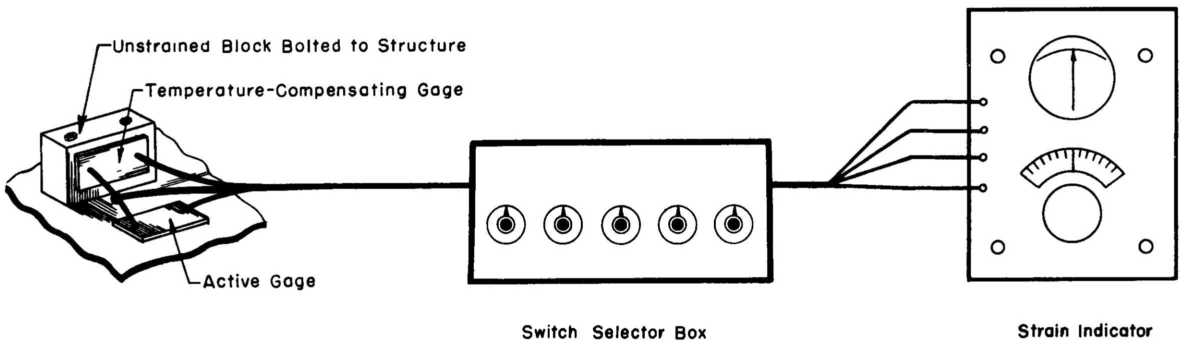


Figure 15 - Schematic Diagram Showing the Connections of the Strain Gages to the Strain Indicator

During static tests, two strain-indicating stations were installed in the turret at the pan-plate level in the spaces beneath the wing guns. At each station, a switch box was connected by means of separate cables for each gage station to the panel boards located in the center space of the turret. The output from the switch box was fed to the Baldwin-Southwark Type-K strain indicator. The selector switches were of a commercial type that had silver contacts to minimize switch resistance. A separate switch was provided for each of the three conductors leading from the gages.

As a check on the stability of the strain indicator used during the test, a dummy gage was provided at the panel board for which readings were taken each time strains in the turret structure were observed. Also on every occasion that tests were conducted a simulated strain was manually introduced into the dummy-gage circuit by changing the resistance of the dummy gage a known amount to determine if the change in indicated strain was repeated.

As the details of instrumentation were planned, it was realized that the results once obtained would have to be conclusive because of the difficulty and cost of repeating such a test. To ensure an adequate quantity of reliable data, considering that all of them would be obtained manually and thus subject to human error, all possible precautions to preclude error were taken. Among these was the repetition of tests during which strain data were recorded photographically for possible use should manually obtained data be considered doubtful. This was accomplished by the use of TMB Type-1A strain indicators and a string oscillograph. Each strain gage was connected to a strain indicator which serves as a combination alternating-current bridge and amplifier, and the output was fed to the oscillograph for recording. Loads on the turret were applied in increments, at each of which the oscillograph was operated at slow film speed for a short interval of time. The result was, for each strain channel, a series of steps corresponding to the increments of load. A scale was ascertained for the record by application of a calibration step of known strain.

Because the manually recorded results were found to be of high quality, the automatically recorded results were never reduced or analyzed but have been placed on file.

To supplement the measurements of strain and to achieve the objectives of this static test, measurements were also made of deformations, particularly horizontal deflections of the trunnion bearers relative to the pan plate. The arrangement employed during the test is shown in Figure 16. Wooden scaffolds supported at the pan-plate level were built up to hold dial gages

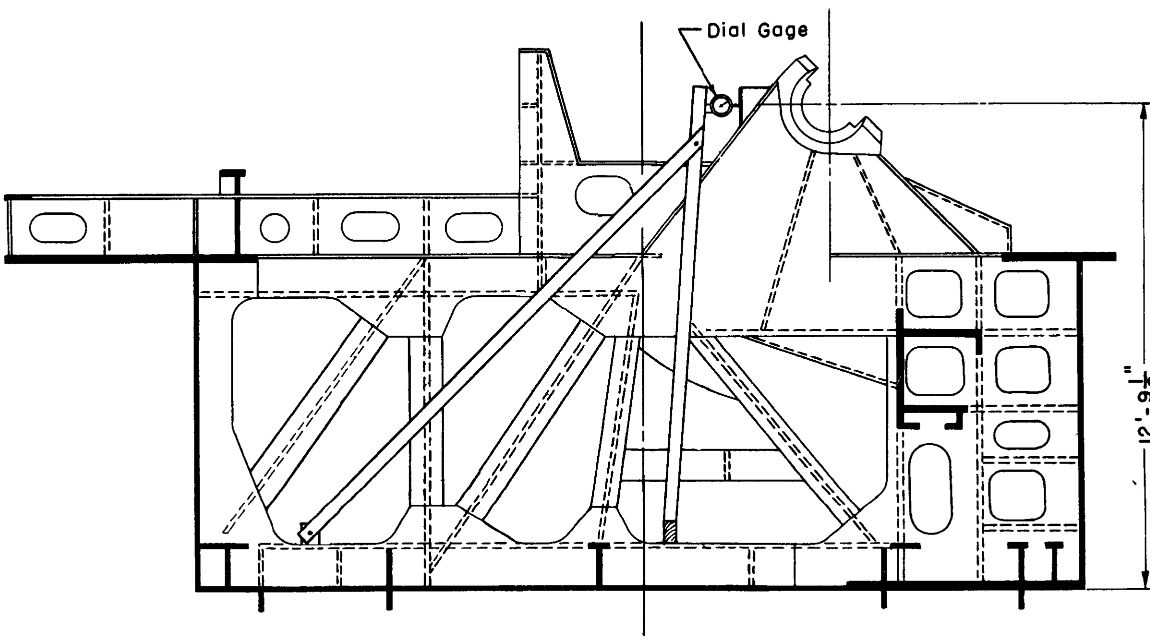


Figure 16 - Arrangement of Dial Gages to Measure the Trunnion Deflection Relative to the Pan Plate

The dial gages were mounted on wood scaffolds that rested on stiffened sections of the pan plate so local deformations would not affect the dial gage readings.

whose plungers rested on the trunnion bearers. The dial gages were graduated in 0.0001-inch units, and the direct readings were utilized to obtain the deflections.

As a check on these deflection readings, additional measurements were made by means of dial gages supported from the roof of the turret and arranged to measure horizontal deflection in a fore-and-aft direction at the trunnion level. These latter gages, however, were not found to perform properly because of excessive deformations of the roof of the turret which resulted from wind, gun blast from adjacent gun tests, and heating effects of the sun.

Four additional dial gages were mounted on the concrete emplacement which supports the pilot turret and were oriented to measure the rotation of the turret at the pan plate relative to the emplacement. This arrangement is shown in Figure 17. The method of mounting the dial gages is shown in the photograph, Figure 18. Dial gages were also installed during the static tests to measure the general behavior of the roller track at locations as shown in the Appendix.

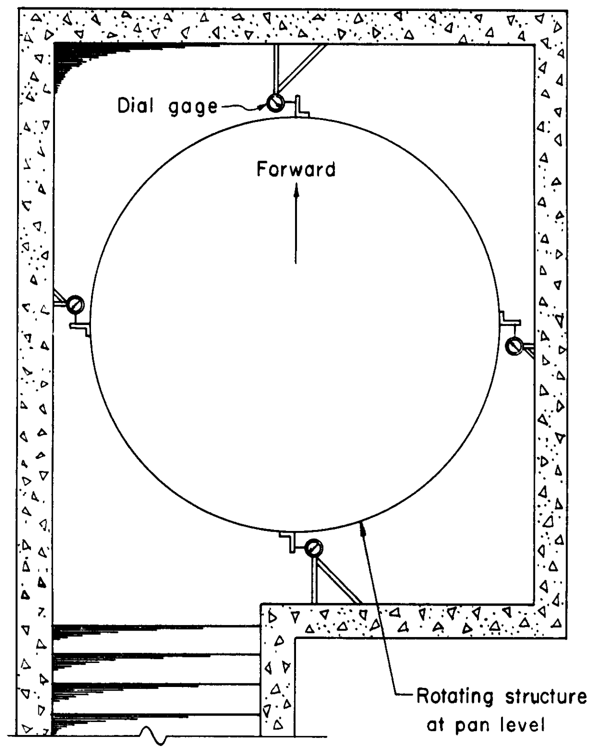


Figure 17 - Schematic Locations of Dial Gages Used to Measure the Rotation of the Turret Relative to the Ground

TEST PROCEDURE

Static tests were performed in two series, the first with shims inserted at the holding-down clips so that the motion of the rotating structure relative to the stool would be minimized. The second series of tests constitute a repetition of the first but with the shims removed.

During all tests, the training-gear B-end shaft was locked with a Prony brake to prevent rotation of the turret, particularly with the application of unsymmetrical loading. Forces were then applied at each gun position separately and in different combinations so that they would involve seven different loadings: (1) left gun, (2) center gun, (3) right gun, (4) left and center guns, (5) center and right guns, (6) left and right guns, (7) all three guns.

The forces were applied by manually operating the hydraulic pumps, during which time the load was observed on the strain indicators electrically connected to the load dynamometers. A tare load of 5000 pounds was employed throughout the test. The center trunnions were first loaded in increments of 15,000 pounds until sufficient data were obtained to determine if the turret and the loading system were performing as expected. This performance was found to be satisfactory, but since strains produced by this increment of load

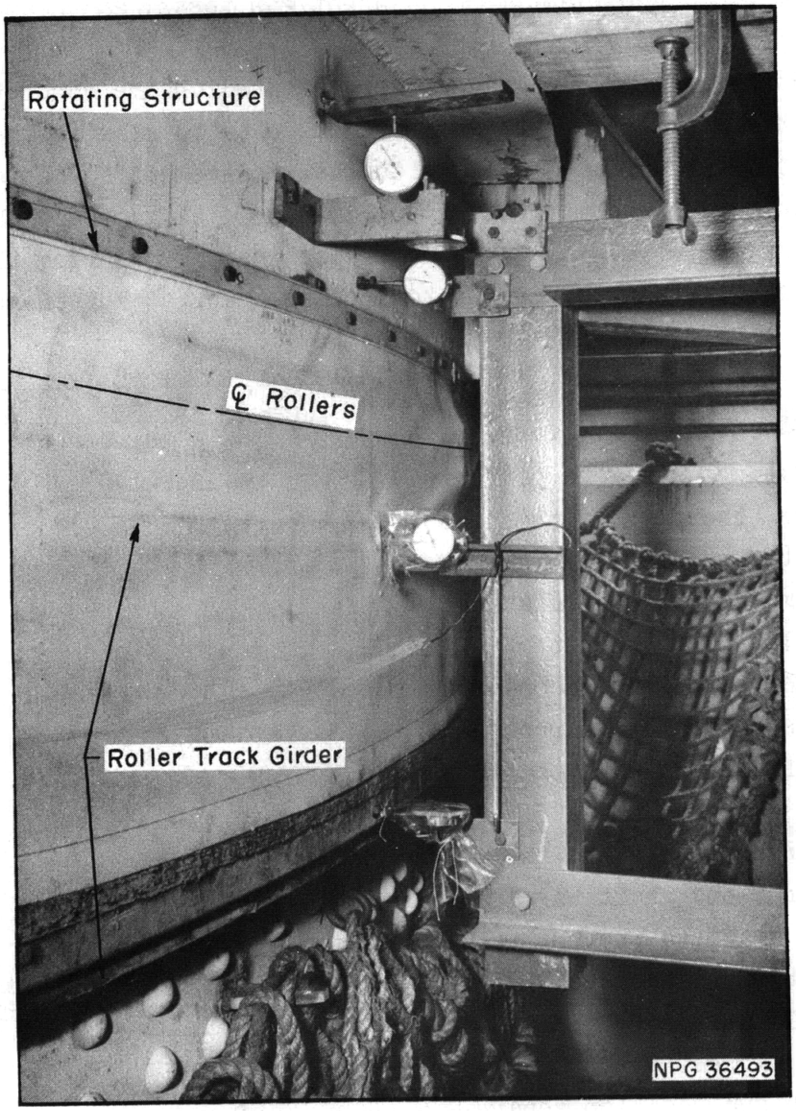


Figure 18 - Photograph of Dial Gages Used to Measure the Rotation of the Turret Relative to the Ground

The two lower dial gages were used to study the general behavior of the roller-track girder.

were so small, the load increments were increased to 30,000 pounds and that size increment was employed throughout the remainder of the test. A maximum of 215,000 pounds was applied to each gun. To guarantee the accuracy of test results, all load conditions were repeated.

Because there were insufficient personnel available to observe strains and deflections simultaneously, additional loadings were required to obtain deflection measurements. These tests were conducted as rapidly as possible so as to complete measurements at all increments of load without interference by blast effects of gunfire from adjacent guns at the Proving Ground.

The hand-pumping operation was very time-consuming, requiring approximately half an hour to go from tare to maximum load. During measurements of strain, at which time observations were made of all gages at each increment of load, a time interval of approximately half an hour was required per increment and a period of approximately 3 hours was required to make observations at all the necessary increments from tare to full load. Observations were made upon the removal of load so as to permit comparison between the tare-load conditions before and after each test.

TEST RESULTS

All strain and deflection data recorded during static tests with and without shims were checked for arithmetical accuracy and the results then plotted. It was found without exception that the load-strain relationships were linear with but a small amount of scatter; and further, that the slopes of the lines drawn through the plotted points for two different identical-condition tests were in excellent agreement. The extent to which these slopes agreed is shown graphically in Figure 19; it can be seen that for 90 percent of the strain gages, the deviation of slopes was less than 0.07 microinch per inch per kip of load, which represents approximately 15 microinches per inch at maximum load.

As a result of this agreement between the results of two tests, all the lines plotted for the two sets of data were averaged; the averaged value was then used to determine the apparent stress at each gage station, by multiplying the value for each gage by an assumed modulus of elasticity of 30,000,000 psi, and by the value of service load. The service load selected for the comparison of all results of static tests on the pilot turret is 215,000 pounds, as assumed in design. The stresses computed in this manner are summarized in Table 1. It is to be noted that these are values of apparent stresses, which are actual stress values only in cases where the stress field is uniaxial and the gage is oriented in the direction of the stress.

The strains measured on the truss members have been employed to determine the actual forces, moments, and shears in three of the members, as shown in Figure 20.

The strain results obtained during the two series of tests with and without shims show good agreement.

The technique of applying several different combinations of loads permitted a check of the results on a basis of applicability of the superposition principle. The strains measured during application of loads to the three guns separately should agree with the results obtained when all three guns are simultaneously loaded. The extent of agreement is shown in Tables

(Text continued on page 30)

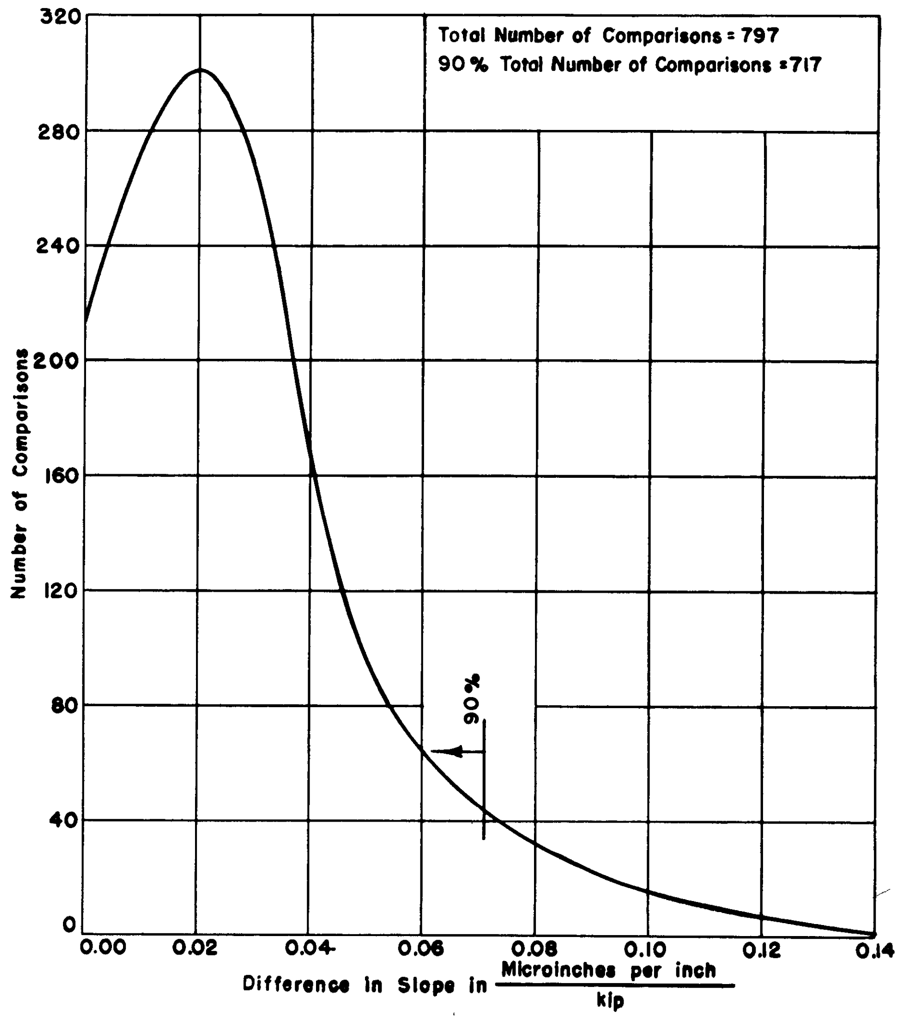


Figure 19 - Frequency Distribution Curve for Agreement of Strain Data for Two Identical Loading Conditions

The comparison was based on the difference between slopes of lines drawn through two sets of plotted points.

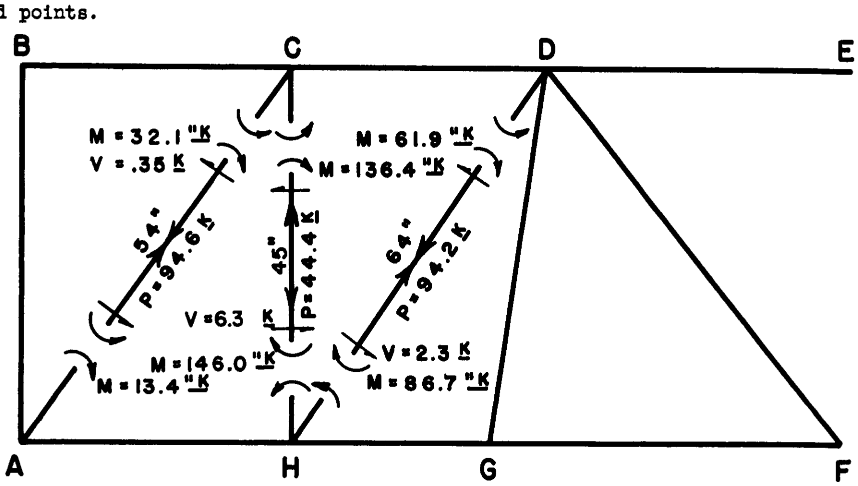


Figure 20 - Moments, Shears, and Axial Forces Developed in Three of the Truss Beams with Horizontal Load

TABLE 1

Summary of the Apparent Stresses Observed During the Static Load Test

Test with Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded						
	Left	Center	Right	Left and Center	Center and Right	Left and Right	Three Guns
1	-2200	-1900	-700	-4500	-2600	-3200	-5200
2	-1700	-2200	-800	-3700	-3000	-2300	-4600
3	500	700	500	1700	1200	900	2100
4	600	600	+0	1600	900	700	1700
5	-2300	-1700	-400	-4100	-1900	-2500**	-4300
6	-1700	-1800	-800	-3600	-2800	-2300	-4500
7	-700	-400	+0	-700	0	-0	-600
8	-0	-0	+0	-500	-500	-300	-700
9	600	600	1100	1500	1600	1700	2600
10	+0	+0	800	1600	1400	1900	2700
11	-1000	-1000	0	-2200	-1000	-1100	-1900
12	-600	-700	0	-1200	-600	-600	-1100
13	+0	0	0	0	0	-0	-0
14	+0	+0	0	600	0	+0	+0
15	0	0	0	600	0	+0	500
16	500	+0	0	1000	0	+0	-0
17	500	+0	0	1000	0	+0	+0
18	-1000	-600	+0	-1600	0	-600	-1100
19	+0	+0	0	+0	400	300	0
20	-1000	-1300	-1200	-3000	-2900**	-2300**	-3800
21	-1400	-1000	-600	-2100	-1600	-2200	-2800
22	-1700	-2100	-500	-3800	-2200	-1700	-3500
23	-2400	-1900	-0	-4600	-2500	-2500	-4900
24	-2600	-3000	-800	-5400	-3200	-2800	-5500
25	-3400	-2900	-600	-6100	-3600	-3600	-6400
26	-1600	-2200	-1000	-3100**	--	-3500**	-5200

Test with No Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded				
	Left	Center	Right	Left and Right	Three Guns
1	-2500	-2100	-700	-3900	-5500**
2	-1600	-2100	-700	-2100	-4300
3	600	600	600	800	1700
4	600	600	+0	800	1700
5	-2200	-1600	-500	-2300	-4200
6	-1400	-1700	-800	-2100	-4300
7	-700	-0	500	-0	-600
8	-0	-500	0	-500	-800
9	+0	300	1000	1400	1700
10	600	0	800	1500	1900
11	-1000	-900	-1200	-1300	-2200
12	-600	-600	0	-500	-1500
13	0	-0	0	-500	-500**
14	+0	+0	-0	0	0
15	+0	0	-0	-0	300
16	+0	0	-0	-0	-400
17	500	0	0	0	-300**
18	-1200	-600	-500	-800	-1400
19	+0	0	+0	0	-500
20	-1300	-1600	-800	-2600	-5000
21	-1700	-1000	-600	-2200	-3900
22	-1800	-1900	0	-1300	-2600
23	-2300	-2100	500	-2800	-4600
24	-2400	-2800	-700	-2700	-5200
25	-3700**	-2500	0	-3100	-5800*
26	-2000	-1900	-1000	-3200	-6000*

*Zero shift greater than 15 microinches per inch.

**Difference in slope greater than 0.07 microinch per inch per kip.

+ or - with zero value indicates a stress of less than 300 psi of the type represented by the sign.

RESTRICTED

RESTRICTED

TABLE 1 (continued)

Summary of the Apparent Stresses Observed During the Static Load Test

Test with Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded: Left	Center	Right	Left and Center	Center and Right	Left and Right	Three Guns
27	-2100	-2000	-900	-3800	-2700	-3100**	-5400
28	2700	3000	1000	6100	4400	4000	7200
29	3700	3400	1200	7400	5000	4900	8800
30	-1600	-1600	-800	-3200	-2800	-2500**	-4200
31	-1700	-1100	0	-3100	-1600	-1900	-3400
32	-1300	-1300	-500	-2800	-2100	-2200**	-3400
33	-1700	-1300	0	-3000	-1400	-1600**	-3100
34	3100	3400	1300	6700	5200	4300	8200
35	3600	3200	1200	7200	4800	4700	8300
36	-1100	-1100	-0	-2100	-1600	-1100	-2300*
37	-1600	-1000	0	-2500	-800	-1300	-2300*
38	-3100	-3400	-1500	-6700	-5400	-4800	-8300
39	-3800	-3000	-900	-7200	-4100	-4500	-8300
40	-2500	-2500	-1400	-5300	-4100	-4000	-7000
41	-3100	-2700	-1200	-6400	-4300	-4600	-7800*
42	-0	-600	-0	-1000	-800	-1000**	-1200
43	-1000	-0	0	-900	0	-1200*	-1100
44	--	--	--	5700	5000	4800	8100*
45	3200*	1900	2900	5500	5400	6000	7900
46	1400	-300	1000	1500	1400	2100**	2300
47	700	500	1100	1400	2000**	1300**	2100
48	-1100	-1400	-0	-2200	-2100	-1900*	-3200**
49	-1200	-1000	-0	-2100	-1200	-1700	-2500
50	1200	500	1200	1600	2100	2600	3000
51	1200	800	1000	2100	1700	2000	2900
53	-1200	-0	0	-1600	-0	-1300	-1700

Test with No Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded: Left	Center	Right	Left and Right	Three Guns
27	-2100*	-1800	-1700**	-3000	-5900*
28	2700*	3100	800**	3400	6600
29	3500	2800**	1200	3500	6900**
30	-1600	-1700	-1100**	-2300	-3900
31	-1900	-1300	0	-2300	-3500
32	-1300	-1600	-500	-1900	-3000
33	-1700	-1200	0	-1800	-2900
34	3100	3000	1400	3900	7700
35	3400	3200	1000	4300	7700
36	-1000	-1400**	0	-1300	-2100
37	-1600	-1000	0	-1500	-2000
38	-3000	-3300	-1700**	-4400	-8200
39	-3900	-2900	-1200	-5000	-8200
40	-2600	-2500	-1700**	-4000	-6700**
41	-3000	-2800	-1500**	-4500	-7600**
42	0	-700	0	-600	-900*
43	-800**	-400	0	-600	-1000
44	3000	1800**	2200	4300	6800
45	2300	2000	2200**	4400	6600
46	700	700	800	2200	1800
47	+0	400	1000	1200	1900
48	-1000	-1200	-500	-1300	-2800
49	-1100	-1000	0	-1300	-2600
50	700	+0	1300	2200	2400**
51	1000	600	600	1500	2300
53	-1200	-0	0	-1400	-1800

*Zero shift greater than 15 microinches per inch.

**Difference in slope greater than 0.07 microinch per inch per kip.

+ or - with zero value indicates a stress of less than 300 psi of the type represented by the sign.

RESTRICTED

TABLE 1 (continued)

Summary of the Apparent Stresses Observed During the Static Test

Test with Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded						
	Left	Center	Right	Left and Center	Center and Right	Left and Right	Three Guns
54	0	0	+0	0	0	+0	-0
55	-1200	-0	0	-1400	0	-1100	-1400
56	-500	0	0	-500	-0	-0	-400
101	-600	-1900	-2400	-2200	-4300	-3000	-4800
102	-800	-2200	-1600	-3200	-3900	-2500	-4600
103	1000	1300	1000	1700**	2000	2100**	2300
104	+0	600	800	800	1500	900	1700
105	-500	-1700	-2300	-2200	-4000	-2500	-4300
106	-700	-1900	-1700	-3000	-3800	-2500	-4400
107	+0	-400	-800	0	-1000	-600	-700
108	-0	-600	-500	-900	-1200	-800*	-1200
109	1000	500	500	1600	1200	1600	2200
110	800	+0	+0	900	1000	1400	1700
111	+0	-900	-1000	-1000	-2100	-1100	-1900
112	0	-500	-500	-500	-1100	-700	-800
113	0	0	0	-0	-0	-400	-0
114	0	+0	+0	0	800	+0	-0
115	0	0	+0	+0	+0	+0	+0
116	0	+0	+0	+0	800	+0	400
117	+0	+0	500	+0	800	500	400
118	700	-0	-1400	0	-1800	-500	-1100
119	500	400	500	500	500	800	500
153	0	-0	-1200	-0	-1400	-1200	-1800
154	0	0	-0	0	0	-0	-200
155	0	0	-1100	-0	-1300	-1000	-1400
156	0	0	-0	0	-0	-0	-500

Test with No Shims Inserted Between Holding Down Clips

Strain Gage Number	Guns Loaded				
	Left	Center	Right	Left and Right	Three Guns
54	-0	0	0	0	0
55	-1300	0	0	-1000	-1400
56	-400	-0	0	-600	-300
101	-600	-1800	-2100	-2700	-5400
102	-700	-2100	-1600	-2200	-4300**
103	600	900	1000	1000	2100
104	0	600	800	1000	1700
105	-0	-3100	-2100	-2600	-4600
106	-700	-2000	-1600	-2300	-4400
107	+0	-600	-800	-400	-700
108	0	-800	-0	-500	-1500
109	1000	+0	500	1100	1900
110	700	0	+0	1100	1500
111	0	-900	-800	-800	-2100
112	0	-500	-0	0	-1300**
113	-0	0	0	-0	-600
114	0	+0	0	-0	-0
115	-0	0	0	-0	-500
116	-0	0	0	-0	-0
117	-0	0	+0	0	0
118	0	0	-1400	-600	-1800
119	+0	0	500	0	0
153	-0	0	-1300	--	-1700
154	0	0	-0	--	0
155	0	-0	-1000	--	-1400
156	0	0	-400	--	-600

*Zero shift greater than 15 microinches per inch.

**Difference in slope greater than 0.07 microinch per inch per kip.

+ or - with zero value indicates a stress of less than 300 psi of the type represented by the sign.

RESTRICTED

2, 3, and 4, which give the differences in strain for combinations of loads that should produce the same strains. It is to be noted that strains were only observed to the closest 5 microinches per inch, so that the least count of strain obtainable corresponds to 150 psi. The least count of agreement between any two values is thus 300 psi. The quality of the results can thus better be appraised with this figure in mind; on that basis, the consistency of results is believed to be excellent.

TABLE 2

Difference in Apparent Stress, in psi, between Results of Tests with Loads on Guns: Three Separately *and* Three Simultaneously

Gage Number	Difference	Gage Number	Difference	Gage Number	Difference	Gage Number	Difference
1	-400	23	-600	45	100	107	500
2	100	24	900	46	400	108	-100
3	-400	25	500	47	200	109	-200
4	-500	26	-400	48	-700	110	-900
5	100	27	-400	49	-300	111	0
6	-200	28	-500	50	-100	112	200
7	500	29	-500	51	100	113	0
8	-700	30	-200	52	100	114	0
9	-300	31	-600	53	-500	115	0
10	-1900	32	-300	54	0	116	-400
11	100	33	-100	55	-200	117	100
12	200	34	-400	56	100	118	-400
13	0	35	-300	57	-200	119	900
14	0	36	-100	58	-500	152	-300
15	-500	37	300	59	600	153	-600
16	500	38	-300	60	200	154	-200
17	500	39	-600	101	100	155	-300
18	500	40	-600	102	0	156	-500
19	0	41	-800	103	1000	157	-800
20	-300	42	-600	104	-300	158	0
21	200	43	-100	105	200	159	200
22	800	44	--	106	-100	160	300

Still another basis exists for the consistency of results. Strains measured at two stations which are symmetrically disposed with respect to the load should give identical results. A study of Table 1 will show that stresses obtained from gages on the left truss with the left-gun load compared favorably with those of the right truss with the right-gun load, and so on.

TABLE 3

Difference in Apparent Stress, in psi, between Results of Tests with Loads on Guns: (Left and Center + Right and Center - Center) *and* (Three Simultaneously)

Gage Number	Difference	Gage Number	Difference	Gage Number	Difference	Gage Number	Difference
1	0	23	300	45	1100	107	-100
2	-100	24	100	46	300	108	300
3	100	25	400	47	800	109	100
4	200	26	--	48	-300	110	200
5	0	27	-900	49	-200	111	300
6	100	28	300	50	200	112	300
7	-300	29	200	51	100	113	0
8	300	30	200	52	900	114	800
9	-100	31	200	53	-100	115	0
10	300	32	200	54	0	116	400
11	-300	33	0	55	0	117	400
12	0	34	200	56	100	118	700
13	0	35	500	57	-100	119	100
14	600	36	300	58	700	152	-300
15	100	37	0	59	400	153	-400
16	1000	38	400	60	200	154	-200
17	1000	39	0	101	-200	155	-100
18	-100	40	-100	102	300	156	-500
19	400	41	200	103	100	157	-400
20	-800	42	0	104	0	158	-600
21	-100	43	-200	105	200	159	400
22	400	44	--	106	500	160	700

The deflections observed with dial gages during application of static loads have been reduced and presented in Tables 5 and 6. Because of the irregular take-up of clip clearance during application of load, it was found that equal increments of deflection did not occur with equal increments of load, particularly at those locations near the roller track. Consequently, deflection data could not be plotted and an average line drawn through the points to represent the behavior. Lack of agreement on succeeding tests precluded averaging results at each increment of load. Consequently, all deflection data were analyzed separately at each increment of load, and the results presented in the report are typical results obtained from one specific test; the readings given correspond to results at maximum load.

TABLE 4

Difference in Apparent Stress, in psi, between Results of Tests with Loads on Guns: (Left and Center + Right and Center - Left and Right) *and* (2 x Center)

Gage Number	Difference	Gage Number	Difference	Gage Number	Difference	Gage Number	Difference
1	100	23	800	45	1100	107	-400
2	0	24	-200	46	200	108	100
3	600	25	300	47	1100	109	200
4	600	26	--	48	-400	110	500
5	100	27	-600	49	-400	111	200
6	500	28	500	50	100	112	-100
7	-100	29	300	51	200	113	-400
8	700	30	300	52	200	114	800
9	200	31	600	53	300	115	0
10	1100	32	100	54	0	116	800
11	100	33	200	55	300	117	300
12	-200	34	800	56	500	118	1300
13	0	35	900	57	-400	119	-600
14	600	36	400	58	700	152	-300
15	600	37	0	59	100	153	200
16	1000	38	500	60	300	154	0
17	1000	39	800	101	-300	155	300
18	-200	40	400	102	200	156	0
19	100	41	700	103	-1000	157	0
20	1000	42	-400	104	200	158	-600
21	-500	43	-300	105	300	159	0
22	100	44	--	106	500	160	600

TABLE 5

Horizontal Deflections of Trunnions Relative to the Center of Pan Plate Obtained at a Maximum Load of 215,000 Pounds on Each Gun

The deflections shown are in 0.0001-inch units. A minus sign indicates that the motion was forward or opposite to the direction of load.

Gun Position Loaded	With Shims Inserted Between Holding-down Clips				Without Shims Between the Holding-down Clips			
	Left Girder Trunnion	Left Truss Trunnion	Right Truss Trunnion	Right Girder Trunnion	Left Girder Trunnion	Left Truss Trunnion	Right Truss Trunnion	Right Girder Trunnion
Left	205	180	20	0	205	180	25	5
Center	45	170	165	50	25	165	155	45
Right	-5	25	170	210	-20	10	175	185
Left and center	235	370	210	75				
Center and right	115	200	375	255				
Left and right	205	195	210	210	220	210	215	220
All three positions	290	385	400	260	310	355	375	250

TABLE 6

Displacements of the Turret Relative to the Ground Obtained at a Maximum Load of 215,000 Pounds on Each Gun

The values shown are in 0.0001-inch units. A minus sign indicates that the motion was forward or to the left. No sign indicates that the motion was to the rear or to the right. These values are not in all cases the maximum values obtained but are the values obtained at a load of 215,000 pounds on each gun.

Gun Position Loaded	With Shims Inserted Between Holding-Down Clips Dial-Gage Location				Without Shims Between the Holding-Down Clips Dial-Gage Location			
	Aft	Left	Forward	Right	Aft	Left	Forward	Right
Left	1125	1305	-750	-625	1085	1275	-740	-605
Center	35	320	-25	265	65	385	-70	225
Right	-1010	-565	790	1185	-970	-555	645	1275
Left and center	1195	1575	-795	-210				
Center and right	-1570	-480	445	2175				
Left and right	-335	445	385	1210	-410	460	425	1285
All three positions	-5	1195	130	1345	-995	690	1015	2630

EXPERIMENTAL ERRORS

Thus far, the comparison of strain measurements demonstrates excellent consistency, but that type of agreement of results may not be used alone as a measure of experimental error. Inasmuch as this test constituted the most elaborate full-scale investigation with static loading that has been conducted by the Navy with contemporary instrumentation, a further discussion is given here of the experimental errors in results.

Experimental errors may be considered in two categories: absolute errors and relative uncertainties. The absolute errors are those which are not subject to control of the operator, whereas relative uncertainties may be minimized by the use of high-quality techniques. For wire-resistance strain gages, absolute errors arise out of errors in gage factor; according to the manufacturer these exist to the extent of 2 percent. Relative uncertainties may arise from (a) human errors in observing strains, (b) human errors in tabulating strains, (c) human errors in performing arithmetical computations of results, (d) improper mounting of strain gages, (e) ineffective temperature compensation, and (f) malfunctioning of the strain indicator or switch box. The control of these relative uncertainties as exercised during this test was believed to be the maximum possible for such an extensive field installation.

The proper operation of the strain indicator was checked, as outlined earlier, by the use of the system by which simulated strains were frequently injected into the system.

The best techniques for applying strain gages were employed, although there is never any guarantee that any single gage is functioning as intended. However, the quantity of zero shift (the difference in strain readings at the two tare loads immediately before and immediately after each test) has been considered a significant criteria for proper operation of gages, as well as an indication of the effectiveness of temperature compensation. An examination of the results showed that 90 percent of the gages had, throughout the test, zero shift of 15 microinches per inch or less. The frequency distribution of zero reading is shown in Figure 21. These results are for 1308 sets of data during which temperatures ranged from 40 to 95 degrees Fahrenheit. The time interval between zero readings was generally 3 hours.

A further check on the proper operation of the gage, as well as on the human errors which may be introduced, is provided by the agreement between data obtained on successive identical runs. As demonstrated earlier, in Figure 19, the difference in strain readings for 90 percent of the gages amounted to approximately 15 microinches per inch or less at maximum load.

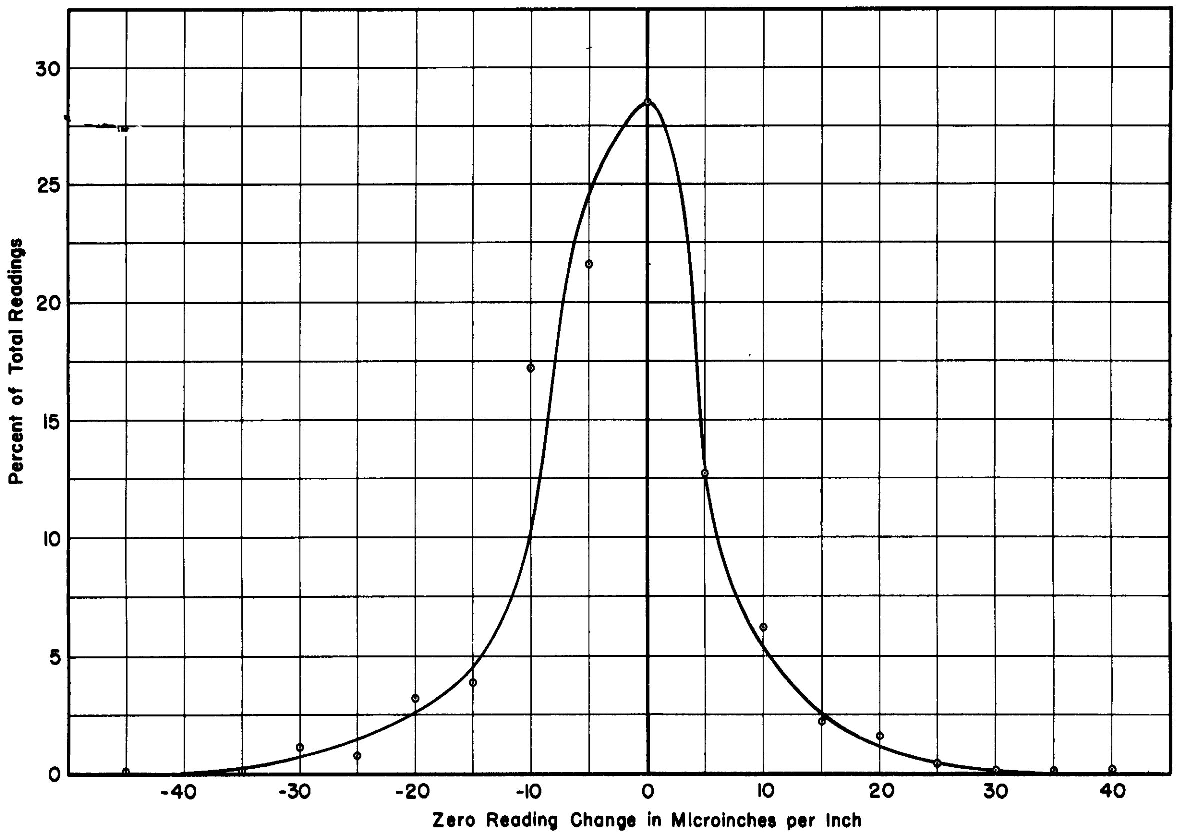


Figure 21 - Frequency Distribution Curve for the Zero Shift

The data for this curve were obtained from 1308 different comparisons of zero readings. The zero reading change means the difference in microinches per inch from the initial reading at tare load before a run to the reading at tare load after a run.

The correspondence between these two determinations of inconsistency, obtained by two independent methods, suggests that for this test the relative uncertainties amount to 15 microinches per inch for all strain data regardless of magnitude of strains measured. The results whose uncertainties fall outside of that range, have been appropriately annotated in Table 1.

Thus far in this discussion, the relative inconsistencies of strain data have been attributed entirely to inaccuracies of the strain-measuring technique. This has been inferred from the assumption that the specimen under test comprises a linear, that is, elastic system. Nonlinear behavior of the structural system can certainly be expected from the effects of clip and roller clearances in the roller-track system. The rotating structure after load seldom returned to its original position on the track, and such random positioning with accompanying random restraints could possibly affect stress distribution in the vicinity of the track system, although little nonlinearity of strains in the girder could be attributed to this cause. Additional sources of inelastic behavior may also lie first, with yielding at local points of stress concentration and second, with elastic buckling of the oilcan type where more than one position of stability exists for a compressive member. These last two effects may result in the observation of hysteresis and zero shift even in a system made up of fully elastic components. It is unlikely that the inelastic behavior would be observed after the exercising of the structure specimen by the first few applications of load.

In consideration of all the different sources of inconsistencies in the strain data, approximately 90 percent of the results show deviations of less than 15 microinches per inch. This strain represents approximately 450-psi stress, and in a material having yield stress in excess of 33,000 psi, such a magnitude of error would be called insignificant; in fact, the accuracy of results would, in general, be termed excellent. The collection of this quantity of data under controlled field conditions thus permits some statement of the accuracy of strain measurement which can be expected with gages of the type employed and permits the establishment of a criterion for acceptability of results.

Because the stresses under service load were expected to be small, it was believed that the experimental error might obscure the desired exactness in correlation between full-scale and model results with static loading, and correlation between pilot-turret results with static and with dynamic loading. In anticipation of this difficulty, reduction in the possible inconsistencies was realized by repetition of tests with both static and gunfire loading, because the average value selected from two or three sets of data is considerably more reliable than data from any single set of measurements. In fact, from two sets of measurements the average value can be expected to be in error by 30 percent less than that for a single set of data. It is, therefore, believed that even though the relative inconsistencies for any set of measurements were on the order of 450 psi, the process of repetition reduced the errors by about 30 percent, so that average results for strain measurements would be in error only about 300 psi.

All the comments regarding errors in strain measurements apply in general also to errors in measurement of deflection of the trunnions. The results for symmetrically disposed structural members, as shown in Tables 5 and 6 indicate excellent agreement and consistency. Insufficient deflection data were recorded to make possible as elaborate a statistical analysis of error as for the strain measurements. The relative inconsistency was thus simply estimated to be 1/1000 inch at maximum load.

APPLICABILITY OF RESULTS

The strain measurements cited in Table 1 may be appraised at a glance to appreciate the safety of the structure as designed. The maximum observed stress was 8800 psi. This is considerably less than the 20,000 psi which would be permitted in the design of a structure of this type which is made up of short alloy-steel members. Further, with regard to load-carrying capacity the observed results are in complete harmony with observations of strain made on the 1/10-scale model. Therefore it can be said that, in general, the safety of the rotating structure as predicted from model tests is affirmed.

These strain measurements have also been compared with observed results from two tests of the 1/10-scale model to determine the accuracy with which full-scale behavior was predicted. Measurements—from early tests of the model[4] conducted in March 1944 and later tests[11] conducted in August 1948—are given for the truss members in Table 7, and it can be immediately discerned that agreement is excellent between results of the two model tests conducted several years apart. Results of model tests were fully substantiated by the full-scale tests.

It is to be noted that the model differed from the full-scale pilot turret in that it was constructed with only the primary members, so that the support for the elevating arc guide and the framing of the turret officer's booth were omitted. Strain Gages 9, 10, 11, and 12 are located, in both the model and the pilot turret, on structures adjacent to these members omitted in the model; therefore agreement in results between model and pilot turret should not be expected at these stations. The correlation between model and pilot-turret behavior should provide comfort to the designers who used the results of the model test when accepting the original design.

There has been included in Table 7 some results of the design calculations so that a ready comparison may be made with the behavior of the pilot turret with static loading. In most cases the calculated stresses are higher than the observed stresses, and in all but one case—Gage 7 of the first model test—the results of the model tests are in better agreement with full-scale behavior than are the calculations. Such an overestimate of the stresses is not surprising in view of the conservative nature of the assumptions made in design concerning the boundary conditions of the truss. Support by adjacent structure as shown in Figure 8 has considerable restraining effect on the truss, but information concerning the characteristics of this support is generally not available to the designer. Information such as was obtained by this full-scale static test can thus be employed to determine those boundary conditions that exist for a specific structure, and such information when properly collated may be employed in future design of similar structures. The observed boundary conditions for the truss as deduced from the model tests are shown in Figure 22.*

TABLE 7

Apparent Stresses Measured in the Pilot Turret with a Static Load of 215,000 Pounds per Gun As Compared with Bureau of Ships Computations and Stresses Measured during Two Tests of the 1/10-Scale Model

(Stresses are in psi)

Gage Number			Left-Gun Load		Right-Gun Load		Three-Gun Load			
Pilot Turret Test	First Model Test†	Second Model Test††	Pilot Turret Test	First Model Test	Pilot Turret Test	First Model Test	Pilot Turret Test	First Model Test	Second Model Test	Bureau of Ships Computations+
1,2	2	1	-2200	-2050	-700	-X	-4600	-3750	-4000	-6200
3	4	3	500	1350	500	X	2100	2700	2800	7200
4	3	4	600	--	Z	--	1700	2300	2400	7200
5	6	5	-2300	-2300	-400	X	-4300	-4100	-3900	-6200
6	5	6	-1700	-1600	-800	-800	-4500	-4750	-4100	-6200
7	8	7	-700	-700	-Z	600	-600	-800	-1000	0
8	7	8	-Z	-X	Z	-X	-700	-2100	-1200	0
9	10	9	600*	-X	1100*	-X	2600*	-X	-X	-5600
10	9	10	-Z*	-700	800*	-550	2700*▲	-1300	-X	-5600
11	11	11	-1000*	-1650	Z*	-X	-1900*	-3700	-3300	
12	12	12	-600*	-X	Z*	X	-1100*	-1350	-3200▲	
18	18		-1000	-X	Z	-X	-1100	-1450		
53	14		-1200	X	Z	-2400	-1700	-2150		
113	22		Z	-X	Z	-X	-Z	-X		
114,5	15		Z	X	Z	650	Z▲	1200		
116,7	16		Z	-X	Z	X	400	600		500
119	19		500	X	500	X	500	1050		

†Tests were conducted in March 1944 and reported in TMB Report 571, Reference 4.

††Tests were conducted in August 1948 and reported in MIT thesis, Reference 11.

+Bureau of Ships computations are taken from Reference 6.

▲Observed data are somewhat doubtful.

ZApparent stress is 300 psi or less.

XApparent stress is 500 psi or less.

*Strains measured at these stations are not directly comparable with model-test results because the model- and pilot-turret structures differed at these points.

*Complete analysis of the truss as it actually behaved is given in Figure 23 of Reference 11.

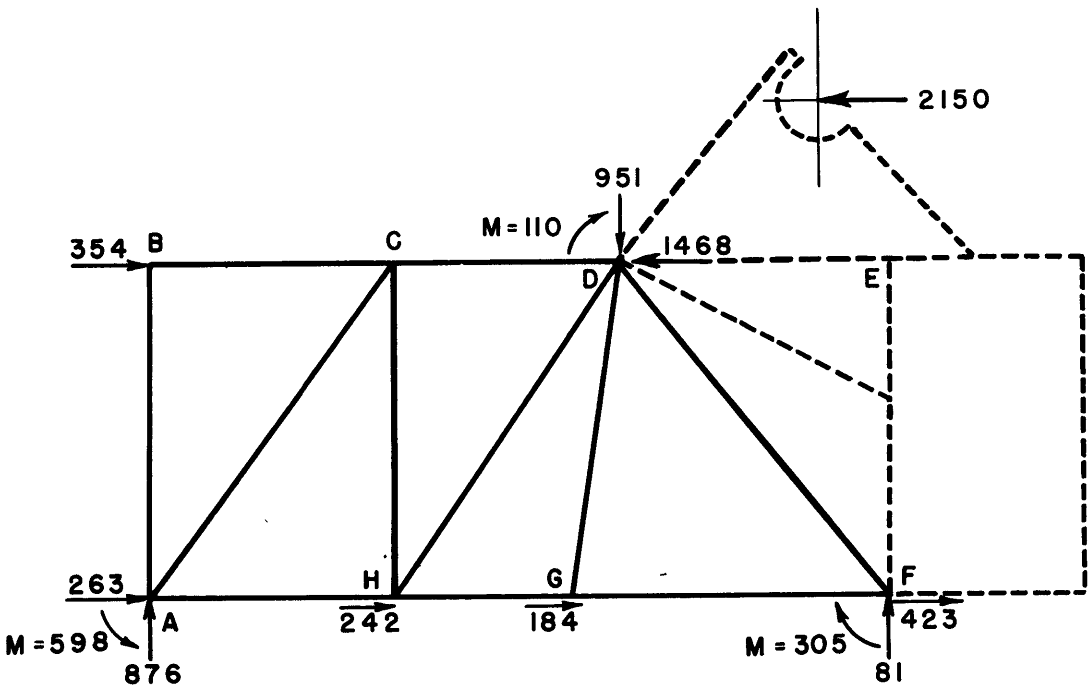


Figure 22 - Force and Moment Reactions Computed from Strains Measured on 1/10-Scale Model

The loads and reactions shown are in pounds. The moments are in inch-pounds.

These results can be compared with the reactions assumed in design calculations, Figure 7.

From these results, it can be observed that with a horizontal load H applied to the trunnion, only 0.68 H is applied to the gun girder, the remainder being absorbed by the shelf plate at the front. Of the 0.68 H or the gun girder, approximately 25 percent is absorbed by the shelf plate at the rear, which leaves 0.53 H to be absorbed by reactions at the pan-plate level in the proportions 0.20 H, 0.20 H, and 0.13 H at the front, center, and rear of the plate. Moment reactions exist at the juncture of the trunnion bearer and truss, and front and rear of the pan plate as shown. It is to be noted that these boundary conditions and reactions are for a single truss alone, and are not to be interpreted as total reactions at the roller-track level.

The deflection data from static tests of the pilot turret have been compared with model-test results in Table 8 to permit additional studies of the accuracy of prediction of full-scale behavior. As can be seen from the table, the model-test results are in good agreement with the pilot-turret deflections for three-gun loading. The deflections observed with the model as scaled up are slightly greater than the corresponding full-scale deflections, probably because the intermittently welded construction of the model was relatively more flexible than the continuously welded pilot turret. The agreement here is nevertheless excellent, and serves further to validate the structural model technique.

TABLE 8

Comparisons of Deflections of Trunnion Blocks Relative to the Back of the Pan Plate on the Pilot Turret and the Model

All figures given are in 0.0001 inch. The model used was to a 1/10-scale so the model test results were multiplied by 10 for comparison with the pilot turret results.

Guns Loaded	Left Girder		Left Truss		Right Truss		Right Girder	
	Pilot Turret	Model	Pilot Turret	Model	Pilot Turret	Model	Pilot Turret	Model
Left	221	510	196	350	36	-20	16	-150
Right	-48	-150	-18	-20	127	350	167	500
3 Guns	400	370	495	580	510	580	370	380

Under eccentric loads, such as the left-gun load or the right-gun load, the agreement between model and pilot turret is not good. The reason for this discrepancy probably lies in the difference in methods used in the two tests to measure the trunnion-block deflections. In the model test, the deflections of the trunnion blocks and the rear edge of the pan plate were measured relative to a common datum, and the deflections of the trunnion blocks relative to the pan plate taken as the differences in deflections of the trunnion blocks and the rear edge of the pan plate. In the pilot-turret test, the trunnion-block deflections were measured directly from scaffolds that covered a large area at the base and were mounted on stiffened sections of the pan plate. The data from dial gages located outside the pilot turret showed distortion of the pan plate when loads were applied. Under a symmetrical load, the distortion was probably uniform, but under eccentric loading, the distortion of the pan plate of the pilot turret was probably not uniform and would thus cause the discrepancy during wing-gun loading. It should be pointed out that the deflection results for the model and for the prototype are consistent within themselves, and of the two sets of data, the model results are believed more reliable.

The observations of deflections of trunnion blocks relative to the pan plate can also be employed to compute errors in train. It is to be noted that errors in train due to structural deformations are made up of: first, elastic deformation of the rotating structure—that is, the deflection of the trunnion relative to the pan plate as shown in Figure 23; second, the slippage and rotation which occur in the roller system as shown in Figure 24;

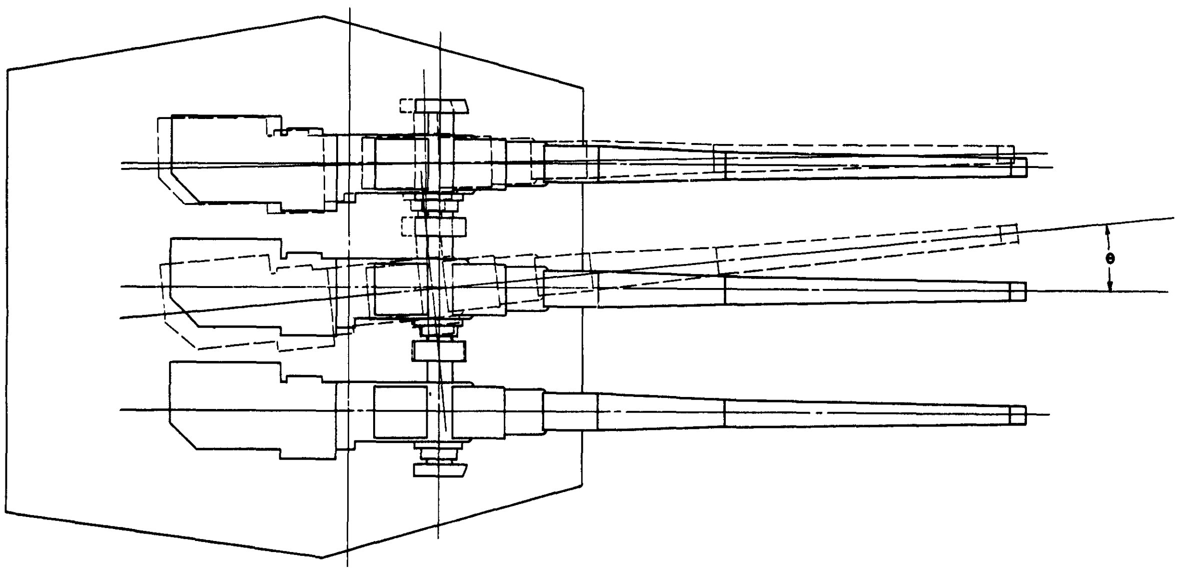


Figure 23 - Rotation of Guns Productive of Errors in Gunfire, Due to Unequal Deflections of Trunnions

As one gun fires, the trunnions of the adjacent gun are deflected a small amount; this causes a small rotation of the adjacent gun, angle θ, and an error in gunfire of that gun if it is discharged in the deflected condition.

third, the elasticity of the B-end training shaft and system which serve as a lock between the rotating structure and the turret foundation; fourth, the elasticity of the cylindrical turret foundation; and lastly, the flexibility of the structure system of the hull which serves as the support for the turret foundation. None of these effects will be observed if guns are discharged symmetrically, but if a wing gun is discharged, the various deformations will be superposed so that the turret will no longer be pointed at the target; and if in this position the other guns are then discharged, deflection errors will most certainly result. These errors cannot be compensated by present fire-control systems. Of course, it is desirable to minimize all these errors but in so doing it must be realized that stiffness can be achieved only at the sacrifice of lightness of structure. The inverse relationship holds as well, so that if material is more highly stressed, it will be accompanied by a reduction in stiffness.

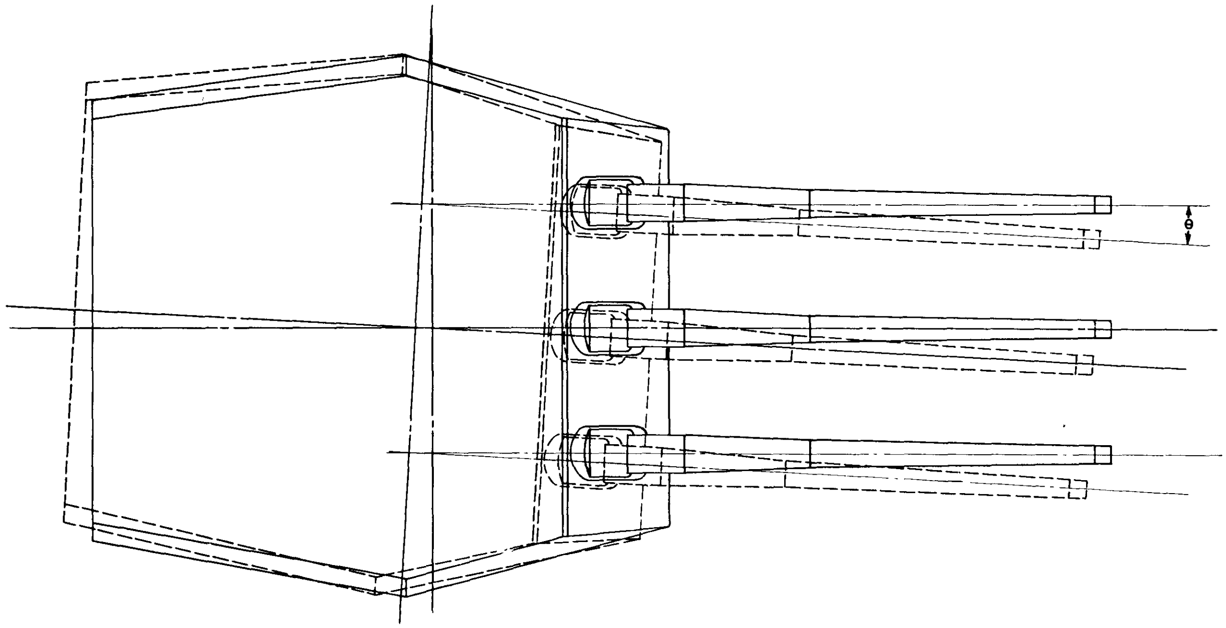


Figure 24 - Rotation of Turret Productive of Errors in Gunfire Due to Backlash at the Roller Track

When a wing gun is fired separately, or simultaneously with the center gun, the turret is rotated a small amount as shown by the angle θ; this causes errors in gunfire if other guns are discharged with the turret in twisted condition.

Up to this time no criteria for such stiffness have ever been set forth, and absolute standards for stiffness are certainly required. In the absence of such criteria it may be well to use relative deformations as the basis for determining stiffness requirements. It is estimated that under action of a wing gunfire the twist of the turret stool would be approximately 0.000007 radian.* The backlash in the training system on the pilot turret was observed, from results given in Table 6, to be approximately 0.00063 radian even though the turret had been preloaded to move it to its final position before the test run was made. The rotation of the trunnions relative to the pan plate due to twist of gun girders was found from model test results in Table 5 to be 0.00043 radian.

These results show that deflection errors due to twist of the gun girders were small; it may be concluded, therefore, that the reduction of material in the turret weldment to raise the stress to normal working levels would be accompanied by increased flexibility but without serious impairment to accuracy of gunfire. Impairment to operation of mechanical equipment from elastic deformations of this magnitude is also unlikely.

*A rotation of 0.0001 radian corresponds to a deflection error of 1 yard at a range of 10,000 yards.

The strain measurements obtained during this static test may be compared with those obtained during gunfire to derive the dynamic factor associated with the response of structures to rapidly applied loads. This comparison is to be treated fully in the report of measurements during gunfire tests.[8]

CONCLUSIONS

It is believed that all the objectives of the static test of the pilot turret have been successfully achieved, and that the accuracy and consistency of results permitted determination of:

1. Load-carrying capacity and stress distribution of the structure.

2. Validity of the structural-model technique for predicting full-scale performance.

3. The dynamic-load factor to be employed in design of structures similarly loaded in service from comparison with measurements under firing loads.

4. The elastic deformations of structure and effect on accuracy of gunfire.

5. The boundary conditions for analysis of the truss-type gun girders.

This test provided opportunities for development of techniques of full-scale measurements which were proved satisfactory on a basis of accuracy and consistency of results. These techniques may be employed with confidence in any full-scale static tests.

Inasmuch as the maximum observed stress was 8800 psi, it is concluded that the load-carrying capacity of the turret structure is sufficient and that the design is safe but not economical in weight.

The agreement of strains and deflections between model and the full-scale pilot turret was so good that, with similar loading conditions, validity of the structural-model tests for predicting full-scale performance is believed fully confirmed.

The elastic deformations of the rotating structure are so small that no impairment of mechanical equipment would be likely to occur, and the maximum deflection errors resulting from these deformations should be on the order of 4 yards at a range of 10,000 yards. On a basis of this observation, the use of turret structures which develop stresses higher than observed in this turret would be accompanied by slightly reduced stiffness, but this reduction would be insufficient to impair the accuracy of gunfire.

Knowledge of the boundary conditions is a prerequisite for economical structural design, and information concerning boundaries can best be obtained experimentally. In advance of full-scale construction, such information can be developed from structural-model tests.

Models must be fabricated to include not only the structural elements under direct study but also adjoining structure which furnishes it support. If a preliminary design is executed in which assumptions are made regarding the boundaries, the model can be tested to affirm or refute the assumptions, and the design refined on a basis of experimental results.

ACKNOWLEDGMENTS

These tests were planned and conducted with the assistance of Messrs. L.M. DeLand, E.T. Habib, J.F. Rhodes, V.J. Mildenberg, Miss M.E. Duke, Mrs. G.E. Finley, and personnel from the machine shop of the David Taylor Model Basin. The results of this test have been checked by Mr. DeLand.

The tests were conducted at the Naval Proving Ground and were made possible by the enthusiastic cooperation of personnel from that activity.

Assistance and advice was also cordially given by personnel in the Bureau of Ordnance, the Bureau of Ships, the Bureau of Yards and Docks, the Naval Gun Factory, and the Philadelphia Naval Shipyard.

APPENDIX

SCHEMATIC DIAGRAMS SHOWING LOCATIONS OF STRAIN AND DEFLECTION GAGES MOUNTED ON TRUNNION BEARERS, STOOL, AND ROLLER TRACK

Test results are on file at the David Taylor Model Basin.

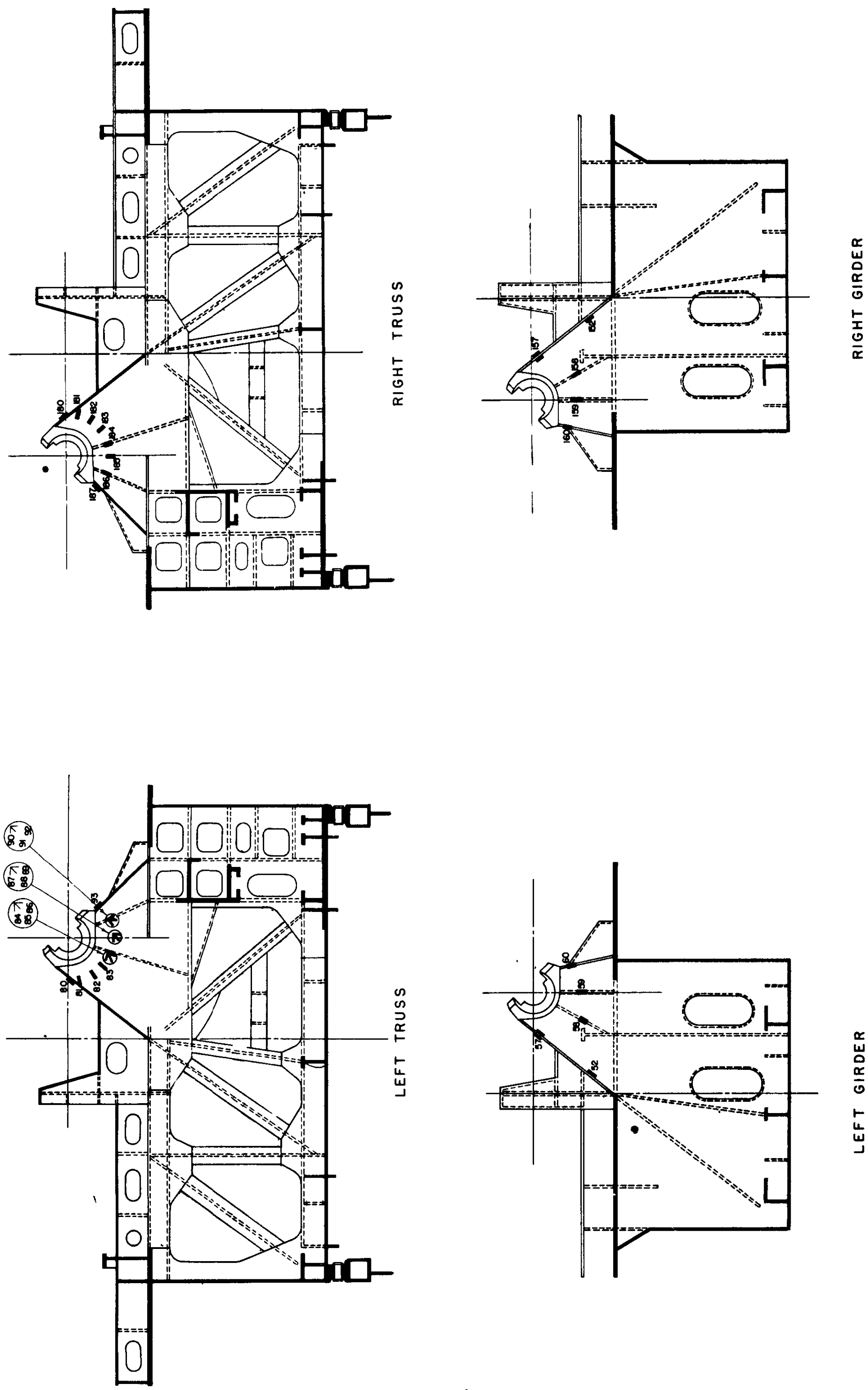


Figure 25a - Strain Gages on Trunnion Bearers

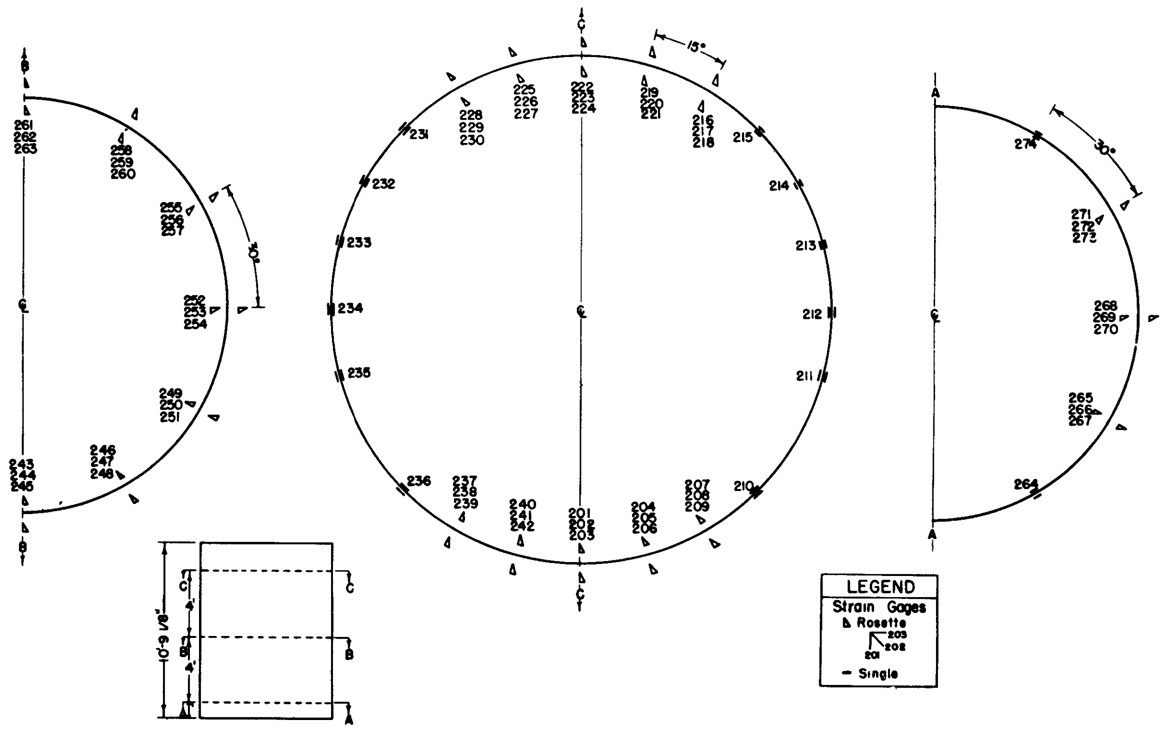


Figure 25b - Strain Gages on Turret Stool

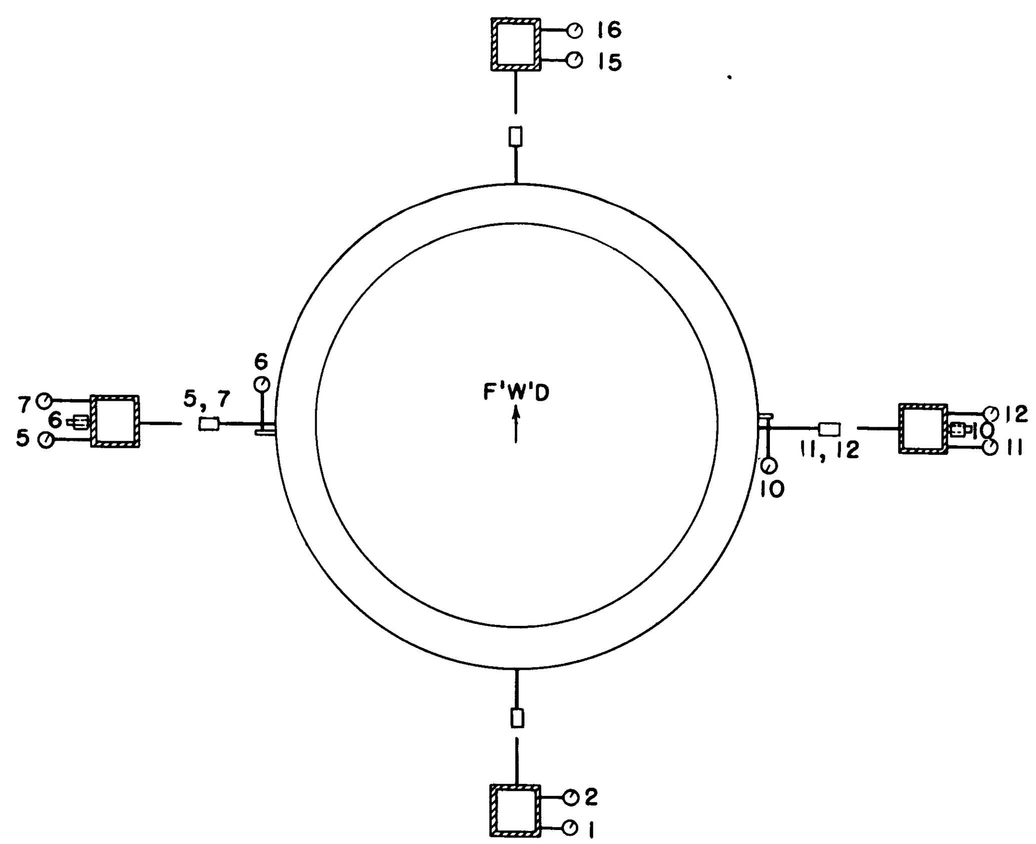


Figure 25c - Deflection Gages on Roller Track

REFERENCES

1. Conference at BuShips on 22 June 1945 with representatives of BuShips, BuOrd, and DTMB summarized in TMB Memorandum C-S72-1 (EW:CBK) of 23 June 1945.

2. "General Specifications to Cover the Tests to be Conducted on the 8-Inch 55-Caliber Pilot Turret CA139 Class," NAVORD OS3873, dated 10 October 1945 (revised 25 September 1946).

3. "Schedule of Measurements to be Made by the David Taylor Model Basin during Tests of the CA139 Pilot Turret," TMB Memo 2, CA139 Class/S72-1 of 13 November 1945 (revised 25 April 1947).

4. Wenk, Edward, Jr., "Experimental Analysis of Stress and Deformation of a 1/10-Scale Model 8-Inch Gun Turret for the CA139-Class Cruiser," TMB RESTRICTED Report 571, February 1948.

5. "8-Inch 3-Gun Turrets—Main Armament for USS SALEM Class—Turret Description and Operation," BuOrd Publication OP1180, Vol. 1, 31 July 1947.

√ 6. BuShips Booklet No. 022032—"Turret Structure Calculations" (for CA139-Class Turret).

7. Habib, E.T., "Experimental Analysis of the Recoil System of the 8-Inch 55-Caliber Gun, Mk 1," TMB RESTRICTED Report C-165, March 1950.

8. DeLand, L.Mason, "The Elastic Behavior of the Rotating Structure of the CA139-Class Pilot Turret with Gunfire Loading," TMB RESTRICTED Report C-231 (in preparation).

9. "Proposed Static Loading Tower for CA139 Pilot Turret," C200, TMB Plan No. A-10933, A-10934, and A-10935.

10. Stainback, R.F., CDR, USNR, "The TMB Tension Dynamometer," TMB Report 605 (in preparation).

11. Griswold, J.A., Dixon, W.J., Jr., and Horn, D.A., Lieutenants, USN, "Structural Design Studies of a 1/10-Scale Model of the 8-Inch Gun Girder on the CA139-Class Cruisers," Thesis, Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, 1949.

NAVY DPPO PRNC WASH D C