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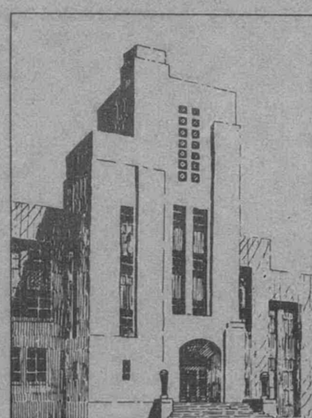
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

EXPERIMENTAL ANALYSIS OF STRESS AND DEFORMATION OF A 1/10-SCALE MODEL 8-INCH GUN TURRET FOR THE CA139 CLASS CRUISERS

BY EDWARD WENK, JR.



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EXPERIMENTAL ANALYSIS OF STRESS AND DEFORMATION OF A 1/10-SCALE MODEL 8-INCH GUN TURRET FOR THE CA139 CLASS CRUISERS

ABSTRACT

Strains and deflections were measured on a 1/10-scale steel model of the 8-inch gun turret of the CA139 Class of heavy cruisers to determine, in advance of construction of the vessels, the stress distribution and load-carrying capacity of the entire structure and the mode of deformation of various elements under a combination of service loads. To establish a basis for the evaluation of these measurements, similar tests were also made on a steel model of the turret of a CA68 Class cruiser which had proved satisfactory in service.

In the model tests of both turret designs, equivalent static loads were applied to simulate both the brake-recoil forces and the lateral components of the weights of the guns and slides during rolling of the ship; the forces acting between the elevating arc and its pinion were also simulated in the tests of the CA139 Class model.

At the specified value of 3-gun recoil load, 6450 pounds, the maximum observed stress in the CA139 turret model was 4750 pounds per square inch. The load-carrying capacity of the turret was found to be in excess of three times the specified value of recoil load. The deflections in the direction of recoil load of the outboard and inboard trunnion blocks with respect to the pan plate were 3.7×10^{-3} and 5.8×10^{-3} inches, respectively. At a wing-gun recoil load of 2150 pounds the maximum observed angular deflection of adjacent trunnion blocks was 2.1 minutes, at a lateral load of 630 pounds it was 5.5 minutes.

On a basis of the test results and their comparison with results from similar tests on the model of a CA68 turret known to be satisfactory in service, the stresses and deflections of the CA139 turret are considered to be within safe limits.

In order to add to the available information concerning the accuracy of structural model tests, it is recommended that predicted prototype behavior be checked by measurements made during full-scale firing trials.

INTRODUCTION

Heavy cruisers of the CA139 Class which mount 8-inch guns will be similar to ships of the CA68 Class now in service except that they will have a higher rate of fire through the use of guns that can be loaded at any angle of elevation. This novel operating feature required greater space for ammunition handling than is ordinarily provided in an 8-inch gun turret, and consequently necessitated internal structural arrangements that differed from those in the earlier CA68 turrets.

As most of the innovations introduced in the CA139 Class turret appeared to be accompanied by a decrease in strength and stiffness, an investigation of the acceptability and safety of the full-scale structure was required. Because of the inexactness of structural calculations, the behavior of the prototype could best be determined in advance by tests on structural models built of steel.

The David Taylor Model Basin was accordingly requested (1)* (2) to make strain and deflection measurements on a 1/10-scale steel model of the CA139 Class turret to determine, in advance of construction of the vessels, the stress distribution and load-carrying capacity of the entire structure and the mode of deformation of various elements under a combination of service loads.

Because of the highly indeterminate character of the complex structure in a gun turret there is still, after 60 years or more, a dearth of information concerning the numerical relationships between the applied loads and the accompanying deformations and stresses. Consequently, few standards based on actual tests have been established for these elastic characteristics, and most design criteria now in use appear in the form of empirical relationships that involve large factors of safety. Thus an appraisal of the absolute magnitude of strains and deflections measured in a test of the CA139 turret model would not necessarily suffice to prove the acceptability and safety of the full-scale structure. As a result, similar tests were requested on a model of the CA68 Class turret (1) so that, on a basis of model-test results, the elastic behavior of the proposed structure could be compared with that of a turret which had performed satisfactorily in service.

In this report the results of tests conducted on the CA139 turret model, and the results of similar tests on the CA68 turret model, are presented and analyzed. Complete details of the latter test will, however, be given in a separate report (3).

APPLICATION OF THE LAW OF SIMILITUDE TO TURRET MODEL TESTS

If a test model is fabricated of a steel which has approximately the same modulus of elasticity as the steel employed in the prototype, with identical loading, the strains and deflections of the prototype can be calculated on a basis of the model behavior according to the laws of similitude. That is, the stresses and angular deflections of the prototype should be

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* Numbers in parentheses indicate references on page 58 of this report.

equal to those measured in the model when the model is subjected to a load equal to the prototype load divided by the square of the scale ratio. Deflections of the prototype should then be greater than those found on the model by a multiple equal to the scale ratio of the model.

As the furniture steel generally employed for the structural models has approximately the same modulus of elasticity as the high-strength steel to be used for the CA139 Class turret, the laws of similitude with regard to stresses and deflections should apply, provided no elastic instability or plastic action occurs. Because of the difference in yield strengths of the two steels in the model and prototype no direct relationship of the modes of failure can be defined.

With the scale of 1 to 10 selected for this model, a load on the model of 1/100 the specified full-scale load could be expected to produce stresses and angular deflections equal to those in the prototype, and deflections 1/10 those of the prototype.

It is known that static loads applied to the model may produce elastic behavior that differs from that accompanying dynamic loads of equal magnitude. The exact relationship is unknown, but present design procedure based on results of tests (4) indicates that the dynamic effect of gunfire would produce stresses and deflections in the turret foundation approximately 30 per cent greater than those accompanying equal static loads. For the prediction of prototype behavior, results from a test in which static forces simulating recoil loads are employed should thus be increased by approximately that amount. The dynamic factor to be applied to the rotating structure is believed lower than 1.3, but there has not yet been conducted any comprehensive tests to determine the exact value for this quantity.

DESCRIPTION OF CA139 CLASS TURRET STRUCTURE AND HISTORY OF MODEL TESTS

With the increase in naval engagements during World War II that were joined without benefit of direct observation of the target, and with the increase in the number of surprise attacks in which great damage was done by one ship to another before the latter could open fire on the first, the need arose for increasing the rate of fire of naval guns so as to effectively make use of both the tactical and time elements of surprise. Accordingly, the Bureau of Ordnance designed for the CA139 Class of cruisers a turret mounting three 8-inch 55-caliber guns which could be loaded automatically at any angle of elevation. This feature, completely eliminating the need for returning the guns to fixed positions for loading, permitted a much more rapid rate of fire than was formerly possible.

The ammunition-handling equipment employed to load projectiles and powder into these rapid-fire guns required a rotating structure both deeper and greater in diameter than any which had been used in earlier 8-inch turrets. The additional weight that would normally be necessary for the larger structure was severely limited in this case by the design displacement of the hull carrying the turrets. Consequently, great care was necessary in the design of the rotating structure which was to support the guns to ensure an efficient and economical proportioning of material.

The final design by the Bureau of Ships of the structure for the CA139 Class included several features entirely new in turret construction.

First, the inboard gun girders were built as open trusses, by welding together rolled H-sections of high-tensile steel.

Second, the pan plate and circular bulkhead enclosing the rotating structure were made of special-treatment steel that was thinner than any previously employed on turrets of equal size.

Third, the structure directly supporting the trunnion blocks was left free of stiffeners and the blocks were independently cantilevered above the gun girders without transverse tie rods. Adjacent blocks on the inboard gun girders were formed as a common housing for the two adjacent trunnion bearings.

Fourth, the elevating mechanism consisted of an arc-and-pinion drive instead of a hydraulic cylinder or a screw-and-nut gear. Details of these new features are shown in photographs of the preliminary cardboard and wood model, Figures 1 through 4. The trunnion blocks are shown schematically in Figure 5, and the elevating-gear mechanism in Figure 6. The roller-track structure and other details of the new turret follow the conventional forms of 8-inch turrets now in service.

Engineering calculations were made (5) for all new structural elements of the CA139 Class turrets, but the complexity of the structure and the empirical basis of assumptions for boundary conditions and other factors left the accuracy of the calculations in doubt. The safety of the design was then investigated by means of structural-model tests; further detailed exploration of stress distribution and modes of deformation were also studied by these tests.

Actual testing of a 1/10-scale steel model was begun on 10 March 1944 and completed 10 August 1945; preliminary test results were reported for appraisal by the interested activities on 23 March 1944. Statically equivalent forces were applied to simulate gunfire loads, lateral components of the weights and inertia of the guns during a 30-degree roll, and forces transmitted by the elevating-gear system. Strains were measured to determine the

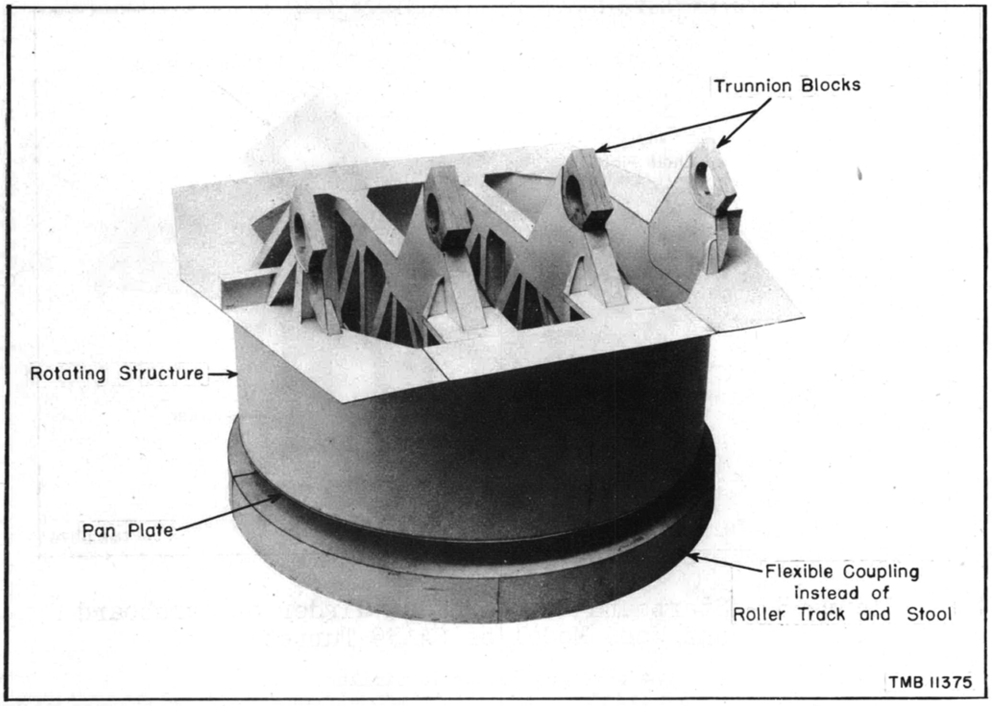


Figure 1 - Assembly of Cardboard and Wood Model of CA139 Turret

The cardboard and wood model was built to 1/10 scale and was employed as a guide for the fabrication of the steel model. A flexible coupling was employed in the models for mounting them on the test frame. It was designed to transmit loads to supports with approximately the same distribution as found in the prototype roller-path assembly. The new feature of cantilevering trunnion blocks above the shelf plate without transverse tie rods can be noted here.

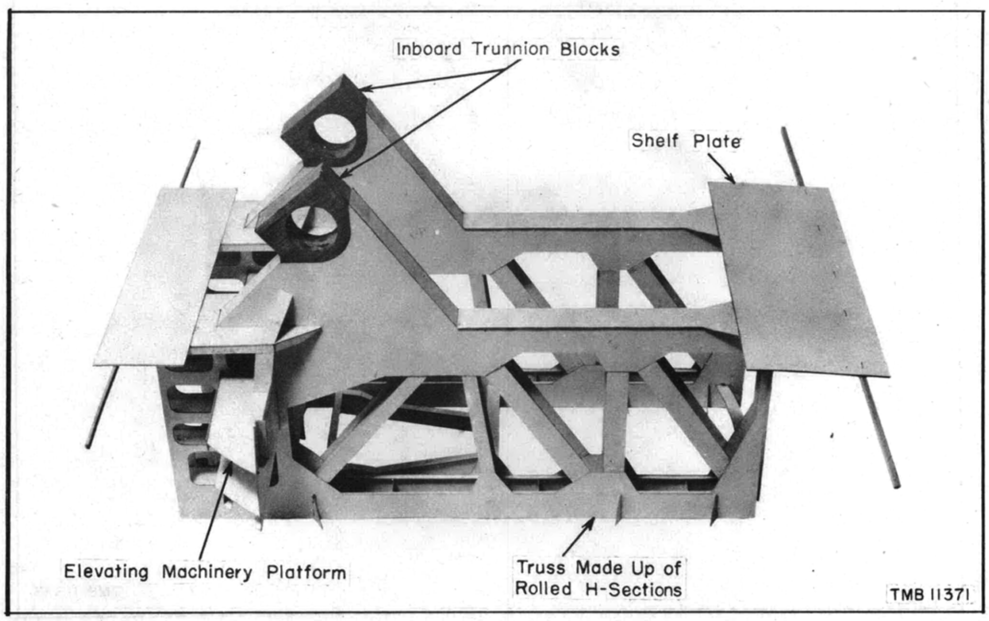


Figure 2 - Inboard Gun Girders of Cardboard and Wood Model of CA139 Turret

This truss-type construction of the gun girders is in contrast to the solid-plate girders employed in earlier turrets which carry guns of the same size.

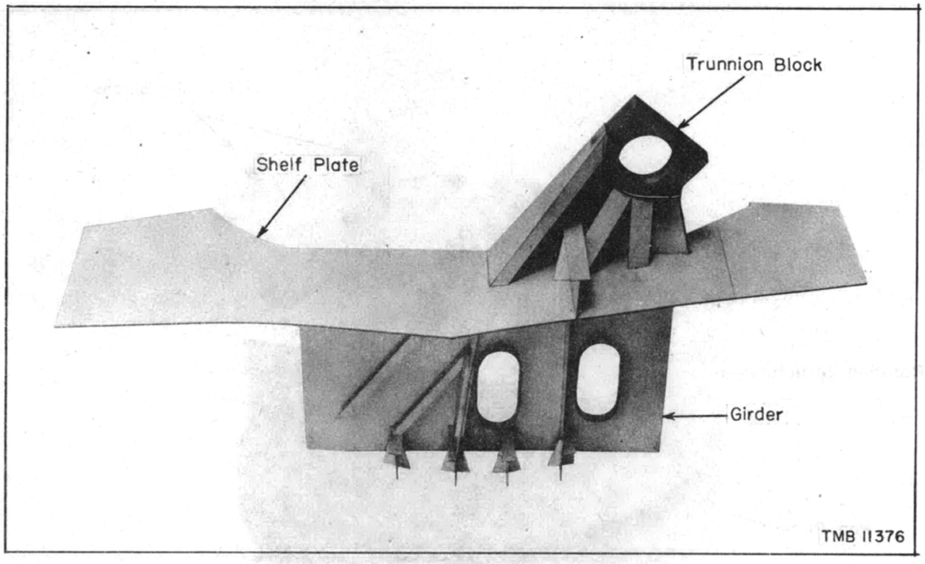


Figure 3 - Starboard Outboard Gun Girder of Cardboard and Wood Model of CA139 Turret

The port gun girder is similar.

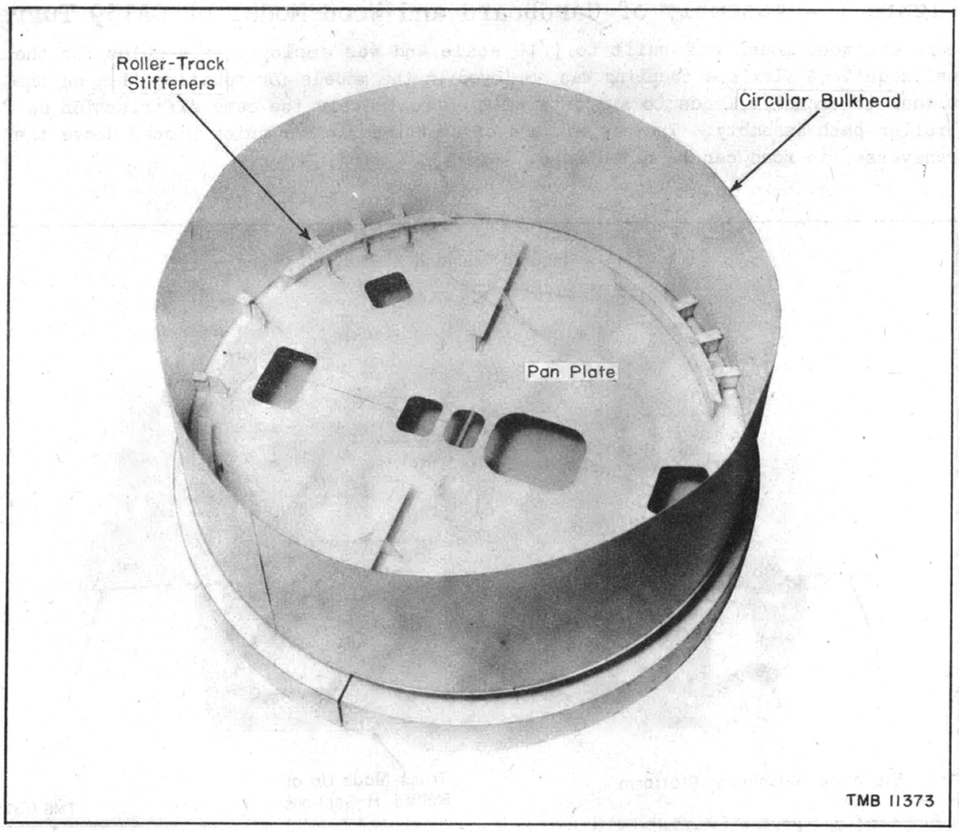


Figure 4 - Pan Plate and Circular Bulkhead of Cardboard Model of CA139 Turret

Though not visible here, the thicknesses of the pan plate and the circular bulkhead are less than those for any previous turrets of comparable size.

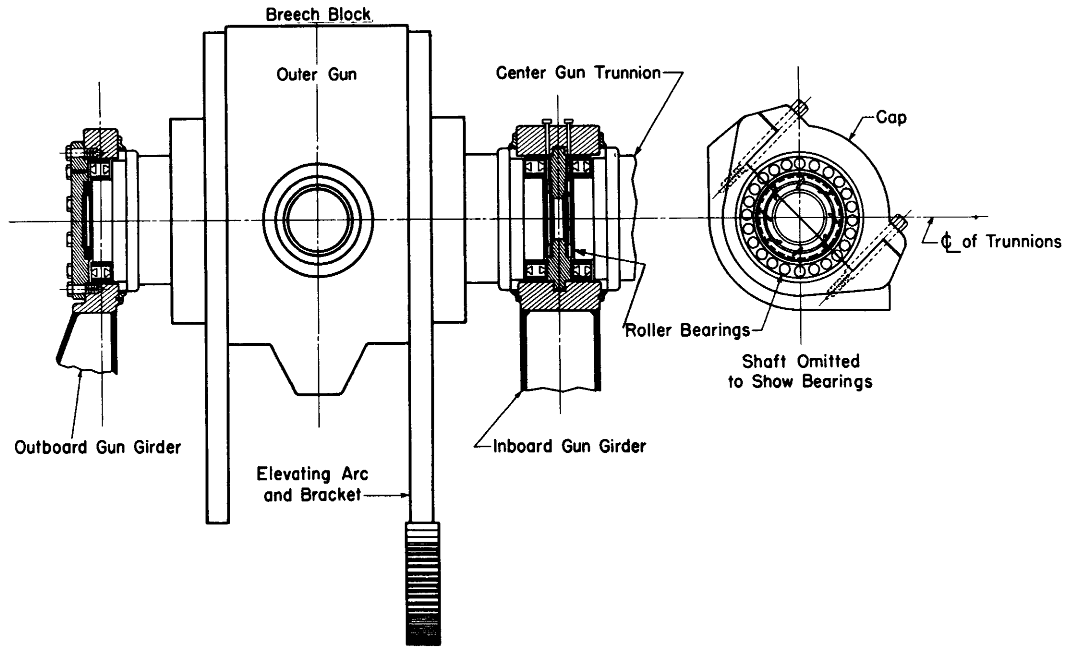


Figure 5 - Diagram Showing Details of Trunnion Bearing Blocks and Bearings

The trunnion blocks for the CA139 turret differed from those of the CA68 turret in that they were cantilevered above the gun girders without stiffeners or transverse tie rods. The inboard blocks serve as a common support for the two adjoining trunnions; each gun elevates independently. These trunnion blocks were simplified in the model but the geometric position of the points of support for the trunnion were located correctly with respect to the surrounding structure so that similitude of loading would be obtained.

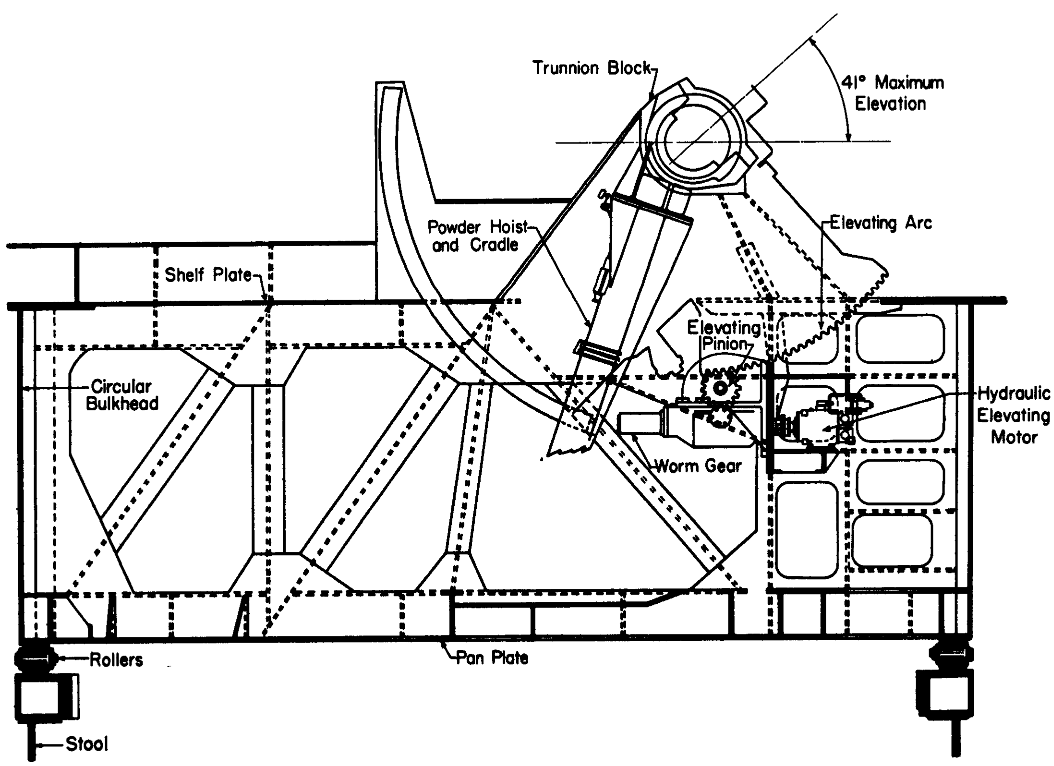


Figure 6 - Diagram of Elevating Gear Employed in CA139 Turret

This elevating arc-and-pinion system has previously been used only on smaller turrets; either ram or screw-and-nut drives have been previously installed on turrets of this size.

stress distribution and load-carrying capacity of the structure as a measure of the effectiveness of proportioning of material. Appropriate deflections were measured to determine the stiffness of the structure carrying the trunnion bearing blocks since large relative displacements of adjoining blocks might cause damage to the trunnion bearings, which were fitted with cylindrical and not self-aligning rollers.

Similar investigations of deflection were made of the elevating-gear mechanism since the meshing teeth of the elevating arc and pinion might be crushed if the distortions of the structure carrying the mechanism were excessive.

Details of the model tests are given below; these results are to be further confirmed by static and dynamic tests of a full-scale pilot turret.

MODELS OF THE CA139 TURRET

Two models of the CA139 turret were built at the Taylor Model Basin for these tests, a study model made of cardboard and wood and a test model made of furniture steel. Both models were built to 1/10 scale and duplicated all the rotating structure above the pan plate, except the armor and armor supports. The trunnions and trunnion blocks were simplified in both models, and except for the roller-path assembly, the structure was otherwise faithfully reproduced; the equivalent roller-track system employed in the model will be described subsequently in this section.

The cardboard and wood model was constructed to serve as a guide for the fabrication of the steel test model and for the design of test apparatus; it also served to verify the workability of the preliminary turret model drawings.

While the cardboard and wood model was being built, bending and compression tests were conducted with structural members of the same size as those proposed to be used in the trusses of the steel model, to compare their strength when welded with continuous joints and when welded with intermittent joints. The results indicated that the use of intermittent welding would not materially reduce the yield strength or alter the elastic behavior of the structure, but would appreciably change the mode of failure and the ultimate load-carrying capacity.

The steel model was fabricated with plating whose scaled-down thickness varied from 0.031 inch to 0.140 inch. Because of the impracticability of making steel welds to the 1/10 scale, this model was assembled with Everdur brazing rod. After consideration of possible difficulties in fabrication and of results of tests described above, intermittent beads were deposited wherever possible to reduce the distortions and residual stresses. Other necessary precautions were taken to reduce the amount of warping of the thin sheet steel but slight distortions did occur, particularly in the circular bulkhead. Because of the relative brittleness and the low melting point of Everdur welding material, no straightening, peening, or annealing was possible after fabrication. It should be noted that, whereas many other structural models had been constructed prior to this at the Taylor Model Basin, none were of this complexity nor were any to be used to obtain so much information regarding the elastic behavior of a full-scale structure. Figure 7 is a photograph of the completed assembly.

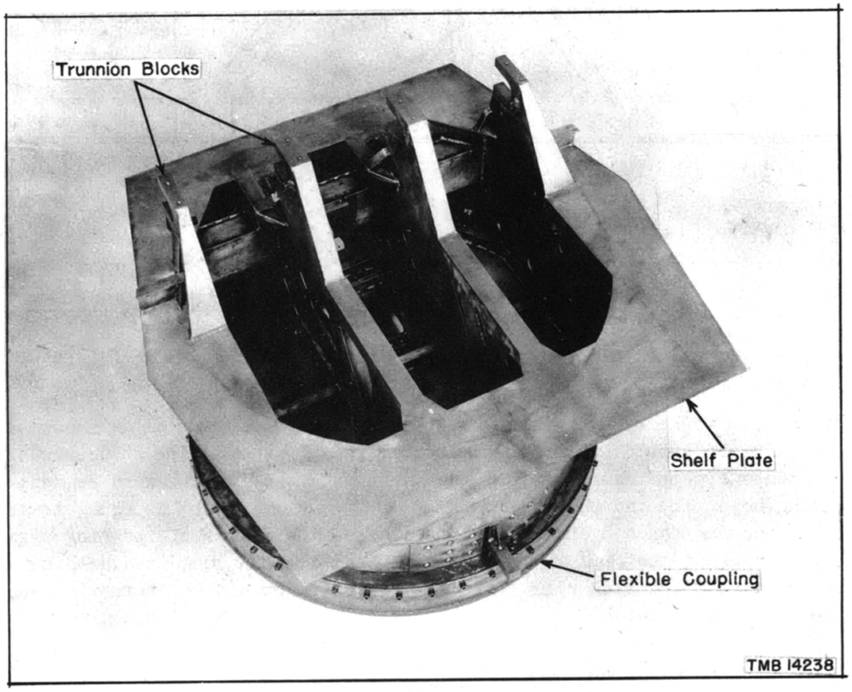


Figure 7 - Assembly of Steel Model of CA139 Turret

The model was built to 1/10 scale and duplicated all the rotating structure of the prototype except the armor and armor supports. The model was fabricated with Everdur brazing rod, and intermittent welding was employed wherever possible to reduce warping and residual stresses.

The roller track, stool, and other sub-structures that support the full-size turret were omitted from the model, and a steel flexible coupling was devised for mounting the model on the frame used for testing. The coupling was attached to the model at the position of the holding-down clips and roller track, and was designed to act as a split torsion spring whose stiffness and load-transmission characteristics were approximately equivalent to those of the foundation of the prototype. A section of the model illustrating the coupling is shown in Figure 8.

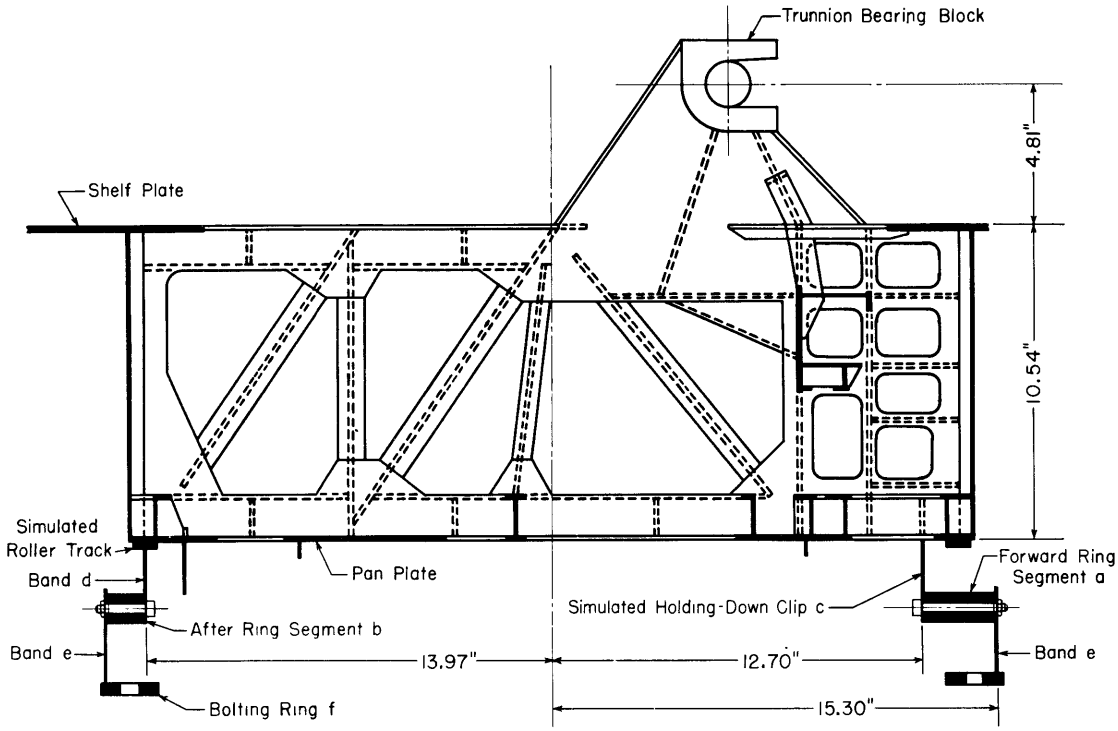


Figure 8 - Longitudinal Section of Steel Model Showing Details of Flexible Coupling for Mounting the Model

The coupling consists of two half-rings a and b which meet along a horizontal axis normal to that of the guns. The rings have their centers of arc at the centerline of the rotating structure. The outer radii of the two ring segments are the same, whereas the inner radius of the forward segment is equal to the radius of the holding-down clip and the inner radius of the after segment is equal to the radius of the roller track. Semi-circular bands c and d are bolted along the inside of the ring segments; band d is welded to the roller track at the rear of the model and band c to the simulated holding-down clip at the front. A circular band e and bolting ring f are welded to the outside of both ring segments and serve as a connection to the test frame.

The construction of the flexible mounting coupling was such that, when the model was subjected to horizontal forces representing recoil loads at 0-degree elevation, the external reactions perpendicular to the pan plate were applied in their proper locations and with approximately the same circumferential distribution as would have occurred if the roller track and elastic foundation had been present. Some lack of similarity of distribution probably existed, however, particularly with eccentric and lateral loading; this condition is discussed further on page 55.

The elevating-gear mechanism of the prototype is shown in Figure 6 on page 7. The arrangement for the center gun has been simplified in the test model, as shown in Figures 9 and 10, without any sacrifice of the geometric relationship between its various components. The elevating-machinery platform provided in the model is of exactly proportional size and shape.

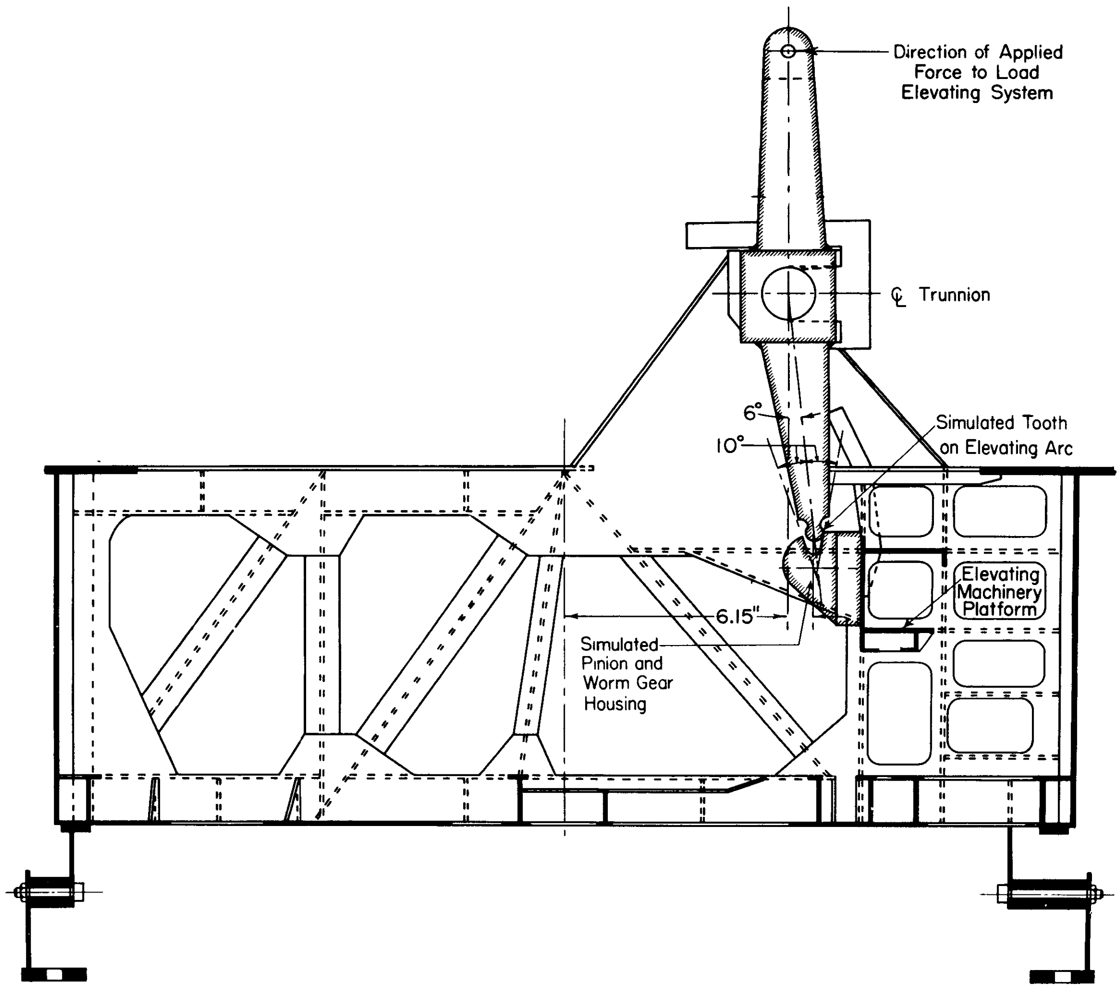


Figure 9 - Sketch Showing Simulated Elevating Pinion of CA139 Turret Model and Means for Loading

During operation of the turret, loads are transmitted between the elevating pinion and its arc either with gunfire or with elevation exercises of the guns. These loads produce distortion of the unsymmetrical elevating-machinery platforms and in turn a rotation of the axis of the pinion out of parallel with the axis of the arc. To determine the distortions to be expected in the prototype, the elevating-machinery platform of the model was loaded by a simulated arc and pinion so shaped and arranged that transmission of loads would be similar to that in the prototype.

TEST PROGRAM AND PROCEDURE

The tests of the steel model were conducted in three stages, depending on the type of load applied. The record is divided into three corresponding parts, as follows:

Part 1 - Tests with Forces Simulating Gun-Recoil Loads

Part 2 - Tests with Lateral Loading

Part 3 - Tests of Elevating-Gear Mechanism

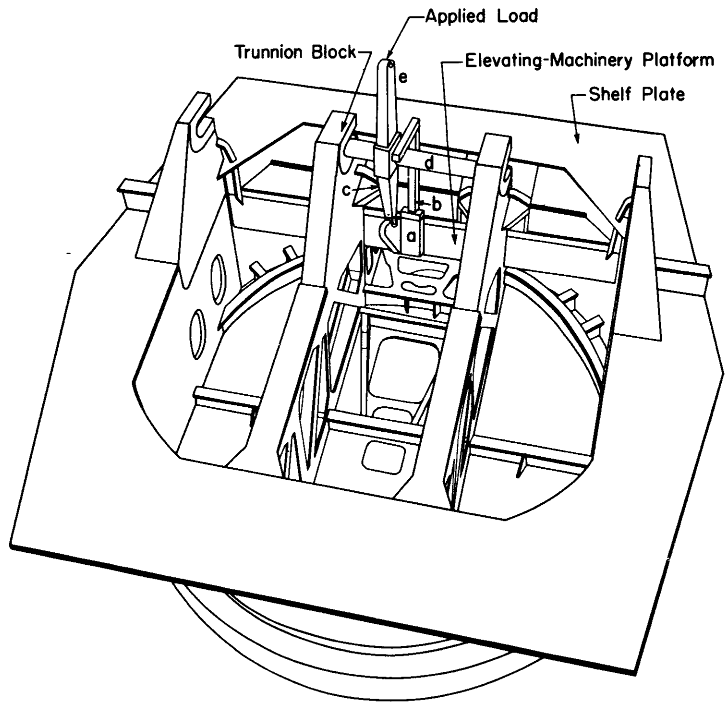


Figure 10 - Schematic Diagram of Turret Model Showing Elevating-Gear Mechanism

The elevating arc and gun slide have been represented by a round trunnion bar d to which is welded an arm c that terminates at its lower end in a tooth at the geometric position of one loaded tooth in the full-scale elevating arc. The worm-gear housing attached to the prototype machinery platform has been represented by a block a that includes an extension with a tooth recess to simulate the elevating-arc pinion. The recess engages the tooth of the arm c and thereby duplicates the meshing of the elevating arc and pinion at their contact point. The recess is shaped to ensure transmission of the load between the arm and the block along a line of action that is equivalent to the 20-degree obliquity that exists with the involute teeth of the prototype elevating mechanism. Further details are discussed on page 48.

In Part 1 the forces to simulate recoil loads were calculated as those which accompanied 1- and 3-gun salvos at 0-degree elevation. This direction of recoil loading was adopted since it would produce the maximum deformation of the turret. Maximum stresses that accompany loading at some other elevation have been found to be only slightly greater than those at 0-degree elevation (6).

In Part 2 the forces simulated the lateral components of the weight and the inertia of the guns as they bear against the trunnion blocks during a 30-degree roll of the ship, assuming a period of roll of 12 seconds.

In Part 3 the forces simulated those acting between the elevating arc and its driving pinion during operation of the elevating-gear mechanism and firing of the guns.

The several forces on the model which represented service loads on the prototype were of the following magnitudes, following the laws of similitude as laid down on pages 2 and 3.

1. The specified value of recoil load of 215,000 pounds per gun was represented by a force of 2150 pounds.* This value of the brake-recoil load is described by the Bureau of Ordnance as the maximum recoil load plus 25 per cent for peaking, but it does not include any factor which may be added in structural design procedures because of the dynamical type of loading.

2. The weight of each 8-inch gun and slide was 105,000 pounds and the lateral component during a 30-degree roll was represented by a lateral force of 525 pounds on the trunnion on the low side. To this should be added approximately 10 per cent of the weight of each gun to account for the acceleration effects of roll; thus the total scaled-down lateral force was 630 pounds.

3. The maximum load acting along the line of action of the elevating arc and pinion teeth was produced during firing of the guns and was limited to 53,000 pounds by the pull-out or slipping torque on the elevating-machinery brakes. The load was represented on the model by a force of 530 pounds applied at the corresponding point. No dynamic factor was specified for this type of loading.

No forces were applied to simulate gravity loading inasmuch as the stresses and deflections accompanying these loads were believed too small to be of interest. However, further studies of the absolute and flexural motions of ship structures, made subsequent to the date of planning these tests, indicates that below-keel or near-miss underwater explosions may impose severe acceleration effects and at least double or triple the gravity loads on structures of this kind. In the future a factor of this nature will have to be assumed for dynamic loading to be applied to gravity loads in turrets. This factor will further have to be embodied in turret and foundation designs and in model tests of this kind.

Strains were measured in Parts 1 and 2 of the test to determine the stress distribution and load-carrying capacity of the structure. Various deflection measurements were made in all three parts of the test to obtain the information required concerning the distortion of various elements of the structure. Descriptions of the particular test setup, instrumentation, and procedure are given in each of the following sections according to the type of loading and instrumentation employed.

* According to the laws of similitude, the scaled-down force varies as the square of the scale factor. The load on a 1/10-scale model is 1/100 the specified full-scale load; it produces stresses and angular deflections equal to those in the prototype, and deflections 1/10 those of the prototype.

PART 1 - TESTS WITH FORCES SIMULATING GUN-RECOIL LOADS

Part 1 of the tests was conducted to determine the strains in and deflections of the model when it was subjected to forces representing the brake-recoil load applied at 0-degree elevation. The tests were made in three series:

Series 1A, Load applied simultaneously to all three trunnions,

Series 1P, Load applied to port trunnion only, and

Series 1S, Load applied to starboard trunnion only.

The test setup is shown in the diagrams of Figure 11 and in the photograph, Figure 12. The turret model with its flexible coupling was bolted to the vertical plate of a test frame* so that forces could be applied in a direction parallel to the base of the model by the loading head of a universal testing machine pressing downward in a vertical direction. The load from the head of the testing machine was distributed equally by a ball, by levers, and by rollers to any selected combination of trunnions without variation of the load distribution induced by differences in deflection of the trunnion bearing blocks.

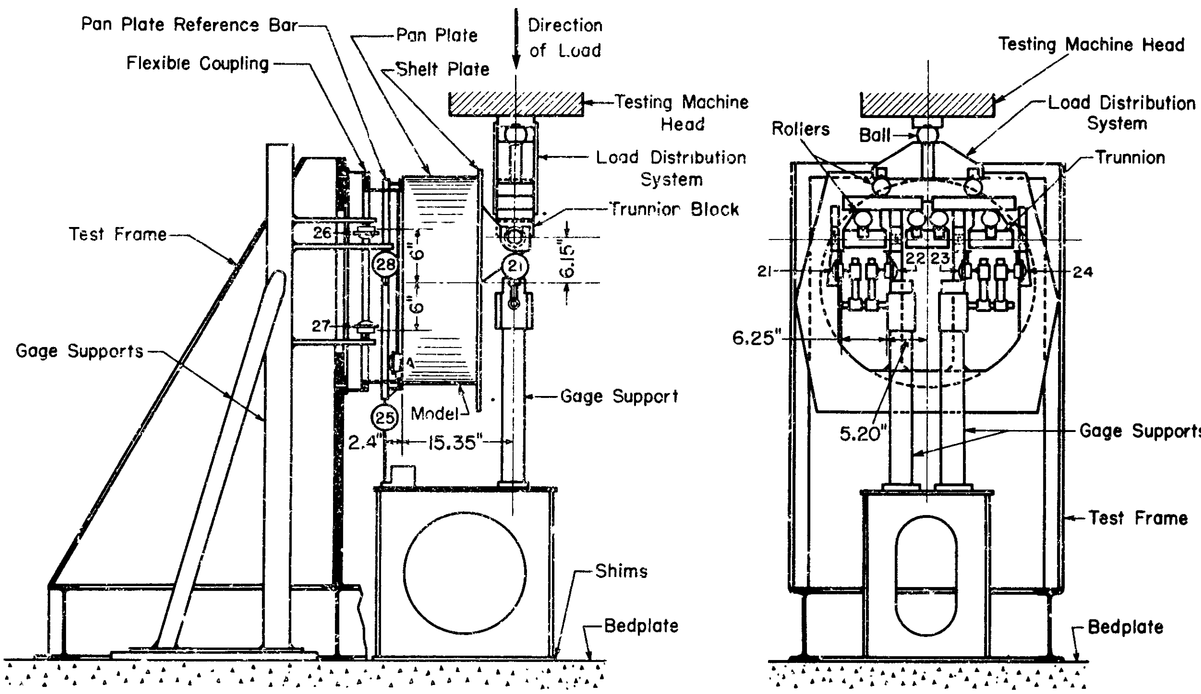


Figure 11 - Diagram of Test Setup

Dial Gages 21 through 24 are employed to measure deflections of the trunnion blocks relative to the testing machine table. Dial Gages 25 through 28 are installed to measure displacements of the base of the model relative to the bedplate.

* This frame is described in some detail in a report on model tests of a circular gun foundation (7).

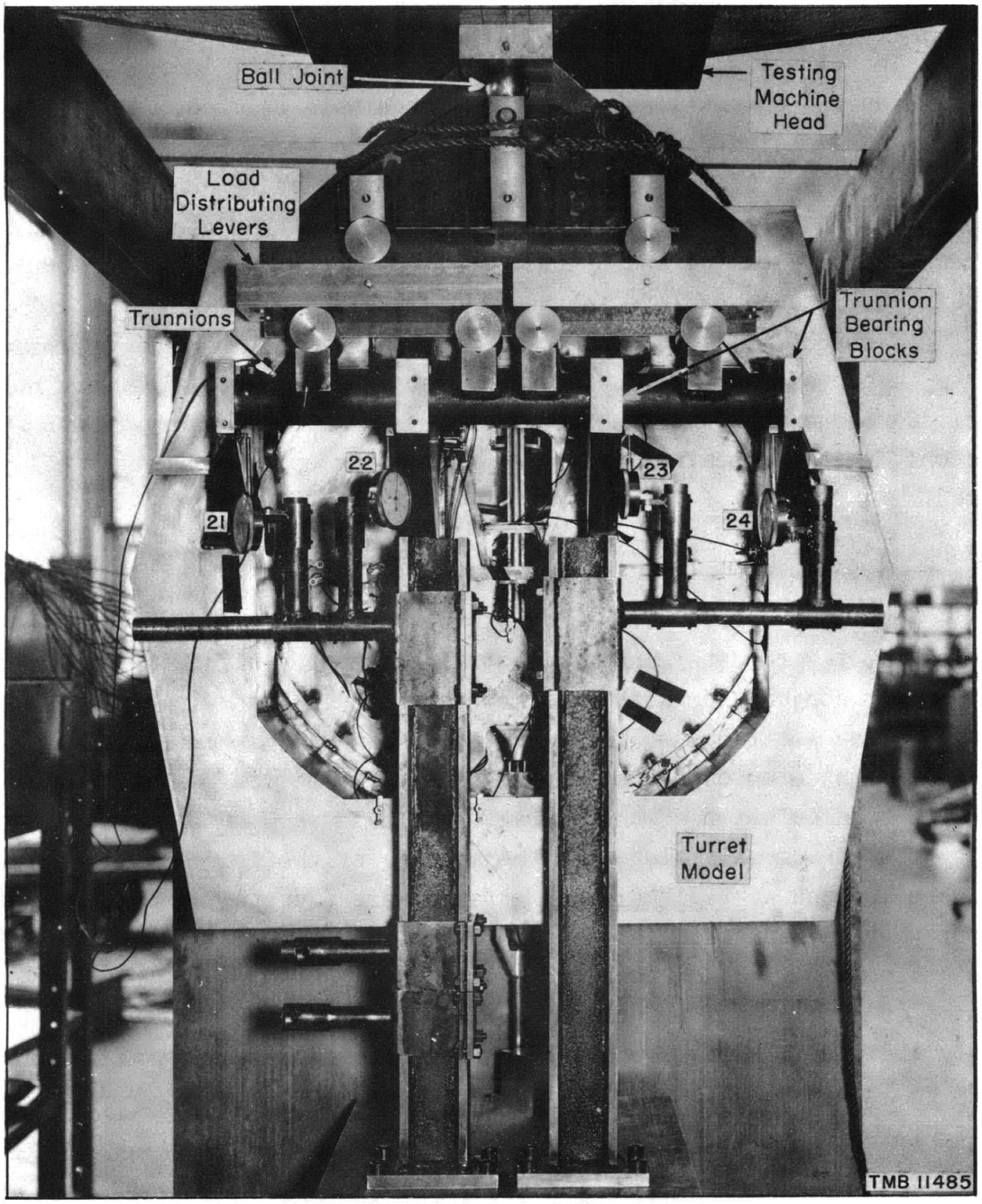


Figure 12 - Photograph Showing Load-Distribution System

The major service load on the prototype is that which accompanies gunfire. These forces have been simulated for the condition of 0-degree gun elevation by static loads applied at the trunnions. This photograph shows the test setup for Series 1A in which the load is applied to all three trunnions simultaneously. Dial gages are arranged to measure deflection of trunnion blocks relative to the testing machine table.

Details of the instrumentation for the strain and deflection measurements are grouped with the results according to the type of measurement.

In all tests, loads were applied in convenient increments until yielding occurred or until selected peak loads were reached. As stated previously, the scaled-down specified load on the model was 2150 pounds per gun. The model was loaded to 10,000 pounds in Series 1P and 1S, and to 25,000 pounds in Series 1A, at which load failure of the flexible coupling occurred both by yielding and by buckling. No further loading was employed to attempt to produce failure in the model itself.

Tests of previous structural models show that because of residual stresses, measurements made during the first application of load are nonlinear. Consequently, whereas observations were made at every load on the model, only results obtained after the preloading operation were finally analyzed.

STRAIN MEASUREMENTS

The load-carrying capacity of the turret model and the stress distribution in it were determined from strains measured with metalectric strain gages used in conjunction with a commercial Baldwin-Southwark SR-4 strain indicator. The locations of the gages are shown schematically in Figure 13. Gages were mounted on opposite flanges of each member of the port truss so as to permit calculation of the average strain in each member and from it the distribution of axial loads in the members of the truss. Additional gages were located at regions where strains were expected to be relatively high, or where a reduction in scantlings might be allowed if strains were sufficiently low. In each case, the gage was aligned in the anticipated direction of the maximum principal stress. Care was taken to mount the gages directly above stiffeners so that the effect of local bending in the thin plating would be negligible. The urgency of the test did not permit the complete exploration of stresses in the model by means of strain rosettes or additional single gages.

The observed strains were tabulated and then multiplied by an assumed modulus of elasticity, 30×10^6 pounds per square inch. The stresses thus derived are plotted as functions of applied load in Figures 14 through 16. If the stress for any gage was less than 500 pounds per square inch at the scaled-down value of specified recoil load, the results were not plotted.

The relationship between load and stress was assumed to be linear, and the straight line was drawn that best fitted the plotted points. In general, the divergence of points from such a line was less than 200 pounds per square inch except at the higher loads, when failure appeared imminent.

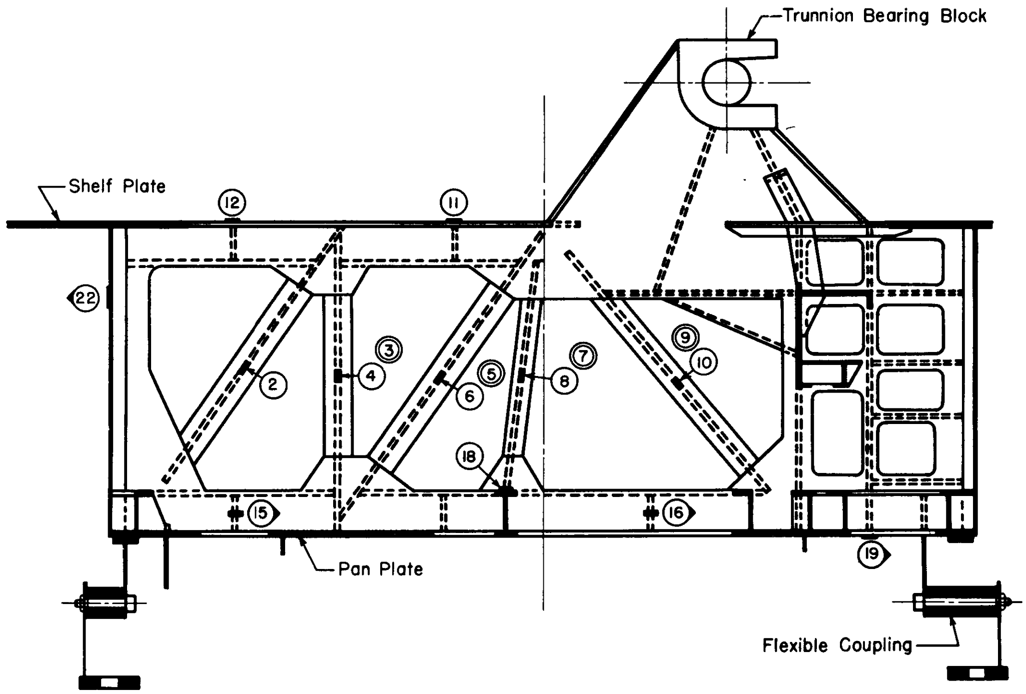


Figure 13a - Elevation of Port Truss, Showing Locations of Metalectric Strain Gages

(11) Indicates position of strain gage

(3) Indicates that a strain gage is on the far side of the member

(16) Indicates strain gage where shown but on opposite truss or girder

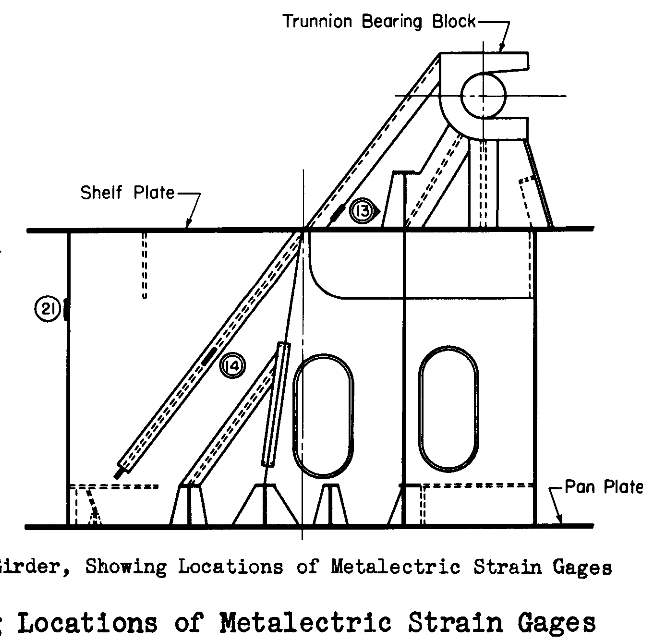


Figure 13b - Elevation of Starboard Girder, Showing Locations of Metalectric Strain Gages

Figure 13 - Diagram Showing Locations of Metalectric Strain Gages

Strains were measured in the turret model to determine the stress distribution, the safety of the structure, and economic proportioning of material.

Gage 17, not shown above, was located on the top flange of a radial roller-track stiffener alongside the starboard truss. All strain gages were of the A-7 type with a base length of 1/4 inch. Only one temperature-compensation gage was employed for all active gages. Selection of active gages for measurement purposes was accomplished with rotary switches so ganged as to minimize effects of contact resistance. The urgency of this test made prohibitive the use of as many strain gages as would be necessary to perform a complete experimental stress analysis.

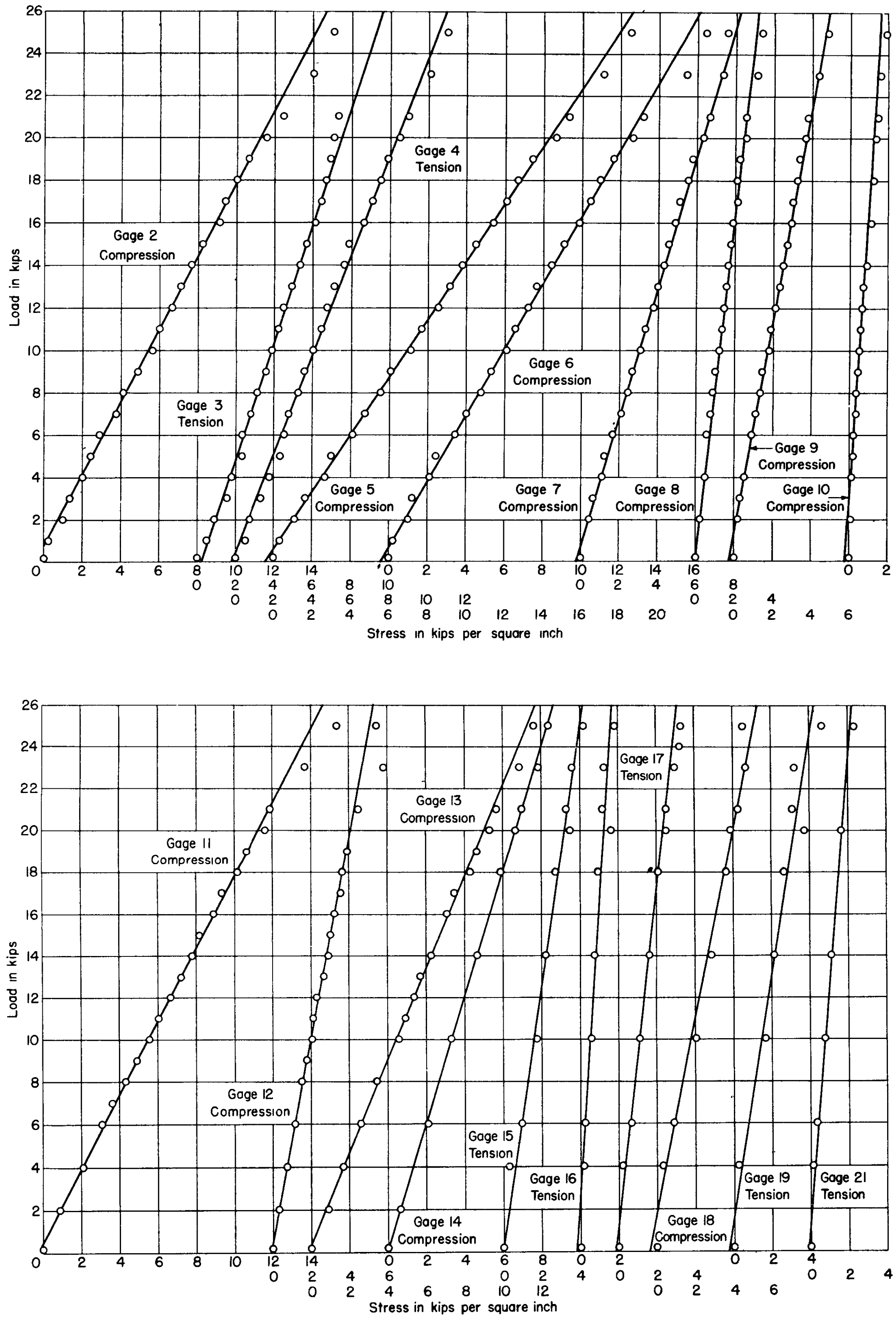


Figure 14 - Apparent Stresses in Model in Series 1A with Load Applied Simultaneously to All Three Trunnions

The locations of strain gages are given in Figure 13. The stresses were calculated by multiplying the observed strains by an assumed modulus of elasticity of 30×10^6 pounds per square inch. The ordinates are total load distributed equally among the three trunnions.

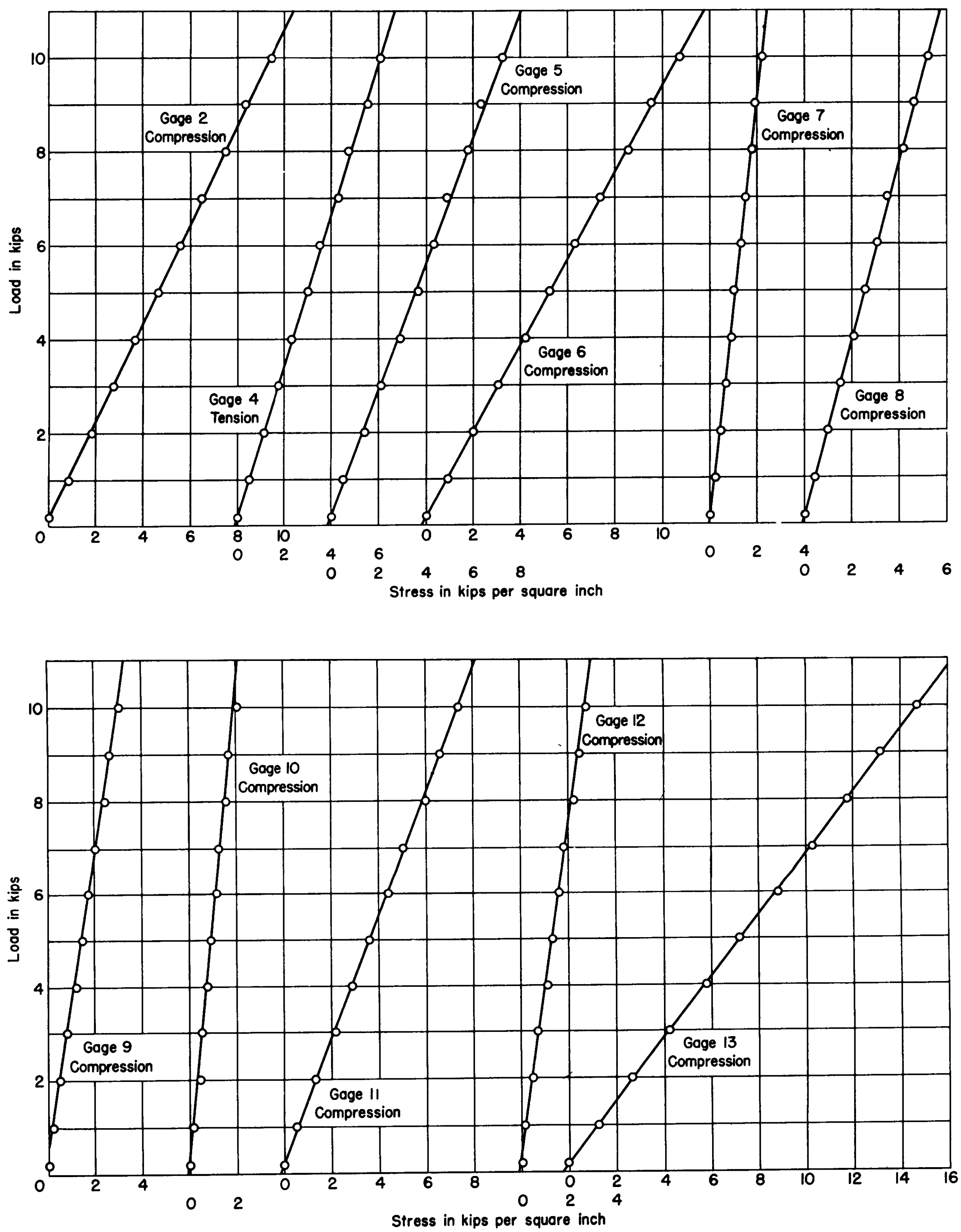


Figure 15 - Stresses in Model in Series 1P with Load Applied to Port Wing Trunnion

The locations of strain gages are given in Figure 13.

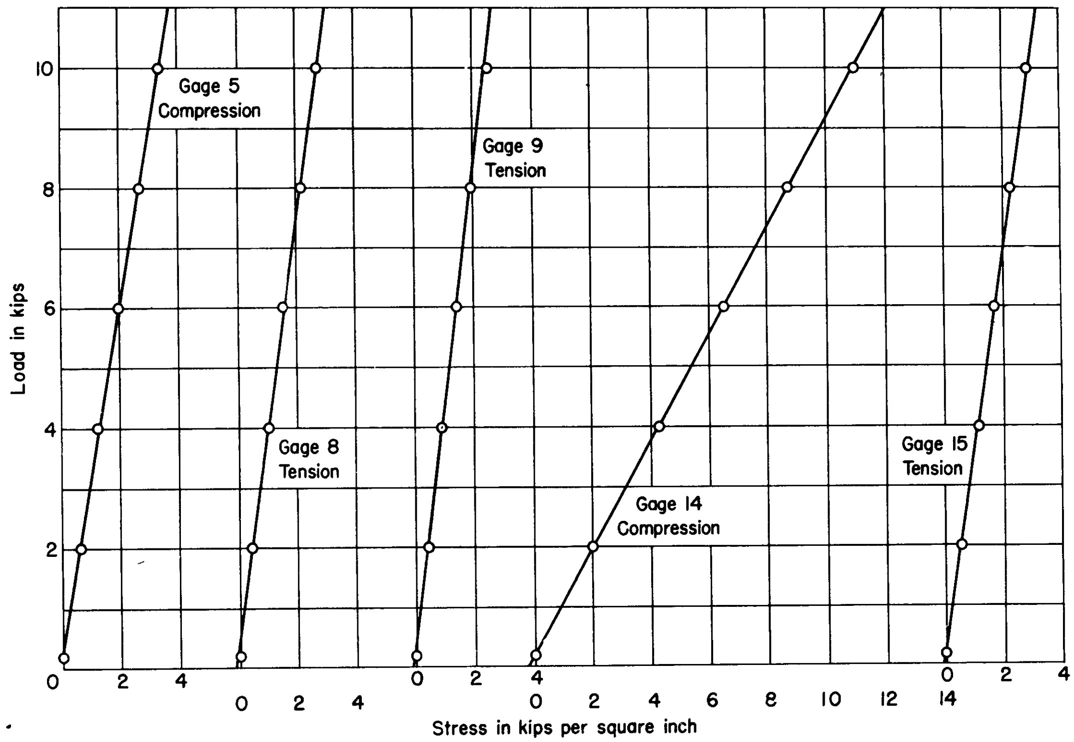


Figure 16 - Stresses in Model in Series 1S with Load Applied to Starboard Wing Trunnion

The locations of strain gages are given in Figure 13.

The slopes of these lines were calculated and the results were multiplied by the scaled-down value of the service load to obtain the apparent stress at each station for each type of specified loading. A summary of these results is given in Table 1. By the laws of similitude, the stresses in the prototype should be equal to those in the model at the scaled-down load for the same direction and type of loading. Inasmuch as the gun-recoil loading is transient, the dynamic effects are generally considered as producing strains and deflections greater than with static loading of the same magnitude (4). The observed apparent stresses have thus been multiplied by a arbitrary factor of 1.3* and listed in Table 1 as the stresses which may accompany full-scale performance with the dynamic loading characteristic of gunfire.

Some checks on the elastic behavior of the turret model can be made by a consideration of certain relationships that should exist between the strains at various gage stations during application of the several

* The magnitude of the dynamic factor as applied to that portion of the turret above the roller track is to be verified by tests of the 8-inch pilot turret.

TABLE 1

Apparent Stresses in Model of CA139 Turret at the Specified Values of Recoil Load

Gage locations are shown in Figure 13. Derived stresses, given in pounds per square inch, were calculated by multiplying the observed strains by an assumed modulus of elasticity of 30×10^6 pounds per square inch. Compressive stresses are indicated by a minus sign. Stresses designated by X were less than 500 pounds per square inch. According to the laws of similitude as applied to structural model analysis, stresses in the prototype should equal those in the model at the specified load, providing both loads are of the same type and direction.

Gage	Stresses Due to Recoil Loading, at the Specified Load of 2150 Pounds per Gun			Stresses Due to Recoil Loading, Increased by 30 Per Cent for Dynamic Loading		
	Series 1A 3-Gun Salvo	Series 1P Port Gun	Series 1S Starboard Gun	Series 1A 3-Gun Salvo	Series 1P Port Gun	Series 1S Starboard Gun
2	-3750	-2050	- X	-4875	2665	- X
3	2300	*	*	2990	*	*
4	2700	1350	X	3510	1755	X
5	-4750	-1600	- 800	-6175	-2080	-1040
6	-4100	-2300	X	-5330	-2990	X
7	-2100	- X	- X	-2730	- X	- X
8	- 800	- 700	600	-1040	- 910	780
9	-1300	- 700	550	-1690	- 910	715
10	- X	- X	- X	- X	- X	- X
11	-3700	-1650	- X	-4810	-2145	- X
12	-1350	- X	X	-1755	- X	X
13	-3000	-3250	X	-3900	-4225	X
14	-2150	X	-2400	-2795	X	-3120
15	1200	X	650	1560	X	845
16	600	- X	X	780	- X	X
17	850	X	X	1105	X	X
18	-1450	- X	- X	-1885	- X	- X
19	1050	X	X	1365	X	X
21	600	- X	X	780	- X	X
22	- X	- X	- X	- X	- X	- X

* Data for Gage 3 were unreliable after Series 1A.

service loads. For example, symmetrical behavior of the model is to be expected during the simultaneous application of equal loads to all three trunnions as in Series 1A. The members of the port truss should not be subject to bending out of the plane of the truss, and as a result, stresses should be equal at stations on opposite sides of each member.* In Table 1, the stresses at Stations 3 and 4, and at 5 and 6, show substantial agreement, whereas the results for Stations 7 and 8, and for 9 and 10, do not. However, the magnitude of these stresses is so small that the difference cannot be interpreted as an indication of unsymmetrical behavior.

In another comparison, the force on the port gun girder during Series 1P equals that during Series 1A. As a consequence, the stresses indicated by Gage 13 should be equal for both types of load. Similarly, the stresses for Gage 14 should be equal for Series 1A and 1S. Good agreement of results was found in both cases.

Inasmuch as the force acting on an inboard truss during loading of the wing trunnion alone is half that during simultaneous loading of all three trunnions, the stresses in all members of the truss should bear a similar relationship with these loads. For Series 1P, the stresses at Stations 2, 4, 6, 9, 10, and 11 are approximately half those observed during Series 1A. Similarly, the stresses at Stations 15 and 16 during Series 1S are approximately half of those observed during Series 1A. However, the stresses at Stations 5, 7, 8, and 12 for Series 1P do not have the proper ratio to those measured at these stations during Series 1A. This lack of agreement of results might accompany bending of the truss out of its plane, a mode of deformation that could be expected with unsymmetrical loading. Further evidence of this action can be found by examination of the stresses that were measured in the port truss, at Stations 5, 6, 7, and 8, during application of load to the starboard trunnion in Series 1S. Here the stresses on opposite sides of members of the truss were small and of opposite signs, a definite indication of bending of the truss out of its plane. This lack of agreement could also possibly result from interference of the intermittent welding with the uniform distribution of stress through the member, so that the local point at which strains were measured might not fully indicate the average stress at that section.

From the plot of the results, the load-stress relationships appear to be linear up to 20,000 pounds in Series 1A, and up to the peak loads of

* These stresses in each member are the result only of axial load inasmuch as the gages are located at the neutral axis in the plane of the web of the H-sections and thus would not indicate any bending of the members in the plane of the truss.

10,000 pounds in Series 1P and 1S. The nonlinear data observed during Series 1A for loads exceeding 20,000 pounds were found to accompany the erratic buckling of the flexible coupling that supports the model. It is believed that no yielding occurred in the model itself.

The maximum stress observed in the model at the specified load was 6175 pounds per square inch at Station 5 in the truss. Thus, if this were the most highly stressed fiber in the structure, a 3-gun recoil load of 34,180 pounds or more than 5 times the specified load would be required to produce a yield stress of 33,000 pounds per square inch at that fiber. The load-carrying capacity of the prototype may be even greater since yielding in the HTS members would not occur until the stresses were much greater than 33,000 pounds per square inch.

It should be emphasized that this extrapolation of results is not a reliable determinant of load-carrying capacity inasmuch as buckling failures would probably occur at loads less than those required to produce yielding. However, no elastic instability or yielding was detected in actual tests of the model with loads up to 5 times the single-gun load or 3 times the 3-gun load, so that the strength of the prototype can be guaranteed at least up to this load.

DISPLACEMENT MEASUREMENTS

To investigate the stiffness of the cantilevered structure which supports the trunnion blocks, various deflections of the blocks were measured during application of forces simulating recoil load. These measurements may be divided into two groups: (a) deflections of the blocks relative to the pan plate and in the direction of load, and (b) relative displacements of adjoining blocks in each pair supporting a trunnion. All deflections and displacements were indicated by dial gages.

Deflections of Trunnion Blocks Relative to the Pan Plate

The stiffness of the local turret structure supporting the trunnion blocks was determined by measuring the longitudinal deflection of each block with respect to the pan plate of the model. Because of the difficulties involved in observing these quantities directly, it was necessary to measure the deflections of the trunnion blocks with respect to the bedplate of the testing machine, and then with additional gages to compensate the gage readings for absolute displacements of the entire model relative to the bedplate. The complete arrangement of the dial deflection gages is shown in Figure 17.

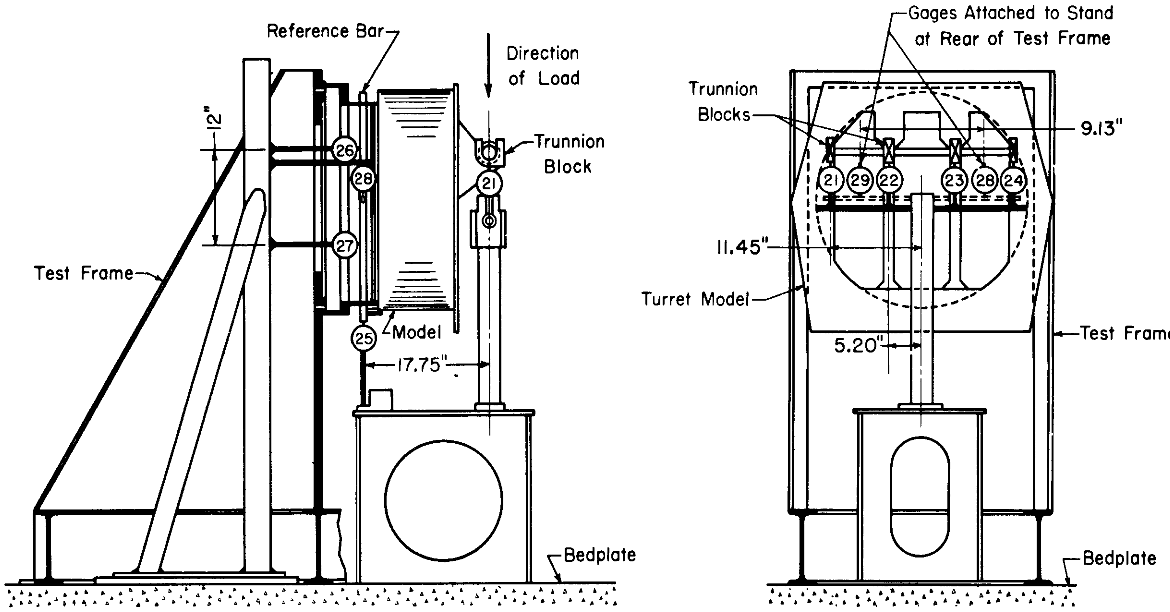


Figure 17 - Schematic Diagram Showing Location of Gages for Measuring Deflection of Trunnion Blocks Relative to Pan Plate

Gages 21 through 24 measure deflections of the trunnion blocks in the direction of load, Gages 26 through 29 measure rotation of the entire model, and Gage 25 measures displacement of the model in the direction of load. All measurements are relative to the base plate of the testing machine which can be regarded as fixed during the test. Deflections of the trunnion blocks relative to the pan plate were computed from deflections of model and blocks relative to the bedplate.

The vertical deflection of the trunnion blocks relative to the bedplate was measured along the line of action of the load with Gages 21 through 24. The vertical deflection of the pan plate relative to the bedplate was indicated by Gage 25. The motion of the pan plate was extended by reference bars to a plane slightly behind the model for ease of measurement. The displacement with respect to the bedplate was determined with Gages 26 through 29 as follows: Rotation about a transverse axis in the plane of the pan plate was measured with Gages 26 and 27, and rotation about an axis normal to the pan plate at its center was measured with Gages 28 and 29. This system of determining deflections of the trunnion blocks relative to the pan plate is shown graphically in Figure 18.

The deflections indicated by Gages 21 through 29 are plotted in Figures 19, 20, and 21 for the three groups of tests with loads simulating recoil of port, starboard, or all three guns. The deflections per unit load for all gages were computed from the slopes of the straight lines that best fitted the plotted data; they are given in Table 2. The values for Gages 21 through 24 were then compensated according to the process just described.

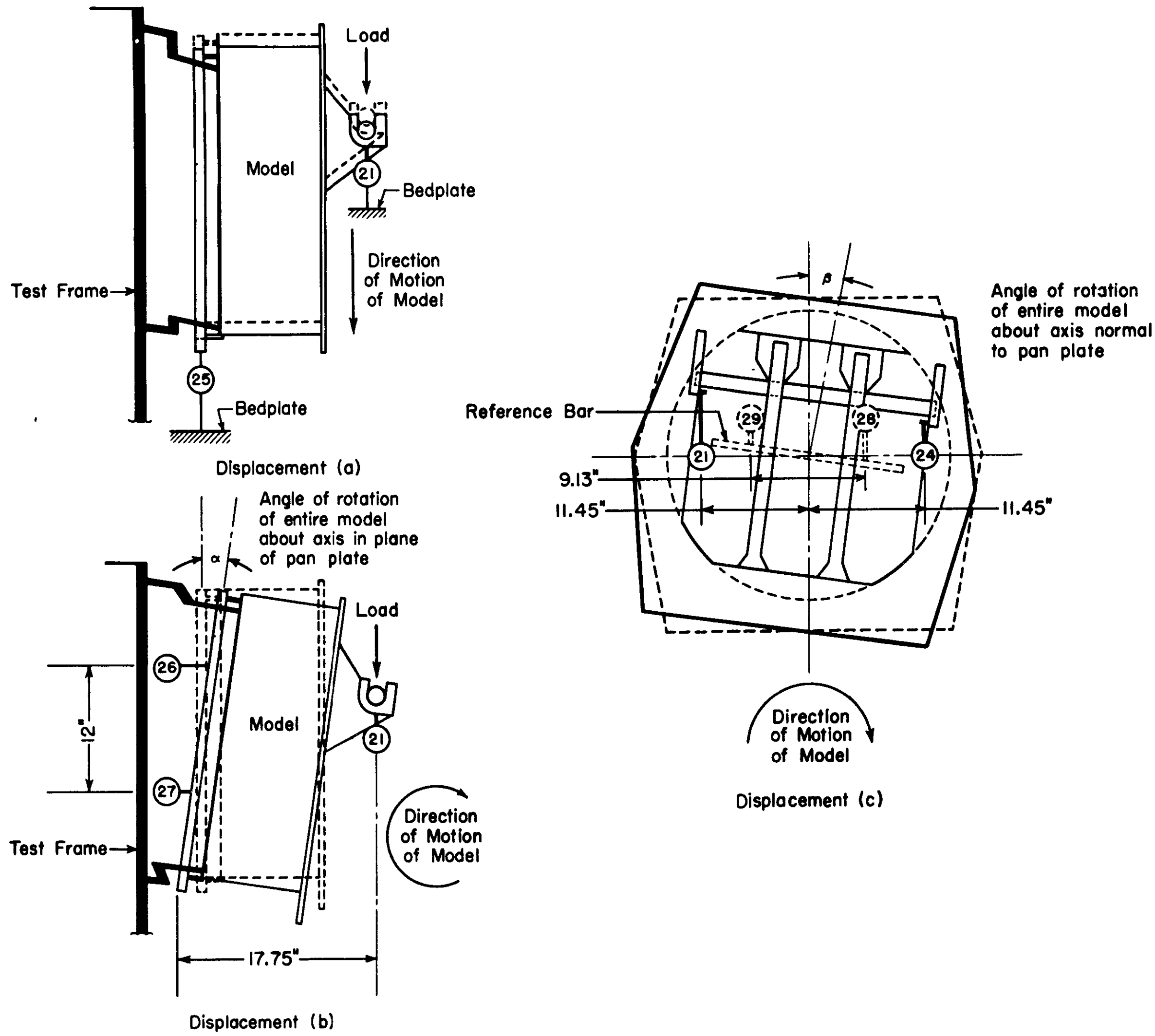


Figure 18 - Schematic Diagram Illustrating Various Modes of Displacement of Model during Application of Recoil Load

Gages are held in a fixed position by a stand resting on the bedplate. Displacement (a) is translation in the direction of loading. Displacements (b) and (c) are rotations about the two axes perpendicular to the direction of load.

The deflections of the trunnion blocks relative to the pan plate were computed as follows. The deflection relative to the pan plate of the port outboard trunnion block, for example, was found by subtracting the deflection given by Gage 25 from that of Gage 21, (a). This result was corrected for rotation of the model about a transverse axis by subtracting 17.75 times the angle of rotation α, where 17.75 is the distance from the trunnion block at Gage 21 to the pan plate at Gage 25. The angle of rotation α was computed from the difference in readings of Gages 26 and 27 divided by 12, the distance in inches between the gages, (b). A further correction was made for rotation of the model about an axis normal to the center of the pan plate, by adding to the earlier results 11.45 times the angle of rotation β where 11.45 is the distance from the axis to Gage 21. This angle was computed from the difference in readings of Gages 29 and 28 divided by 9.13, which is the distance in inches between the gages.

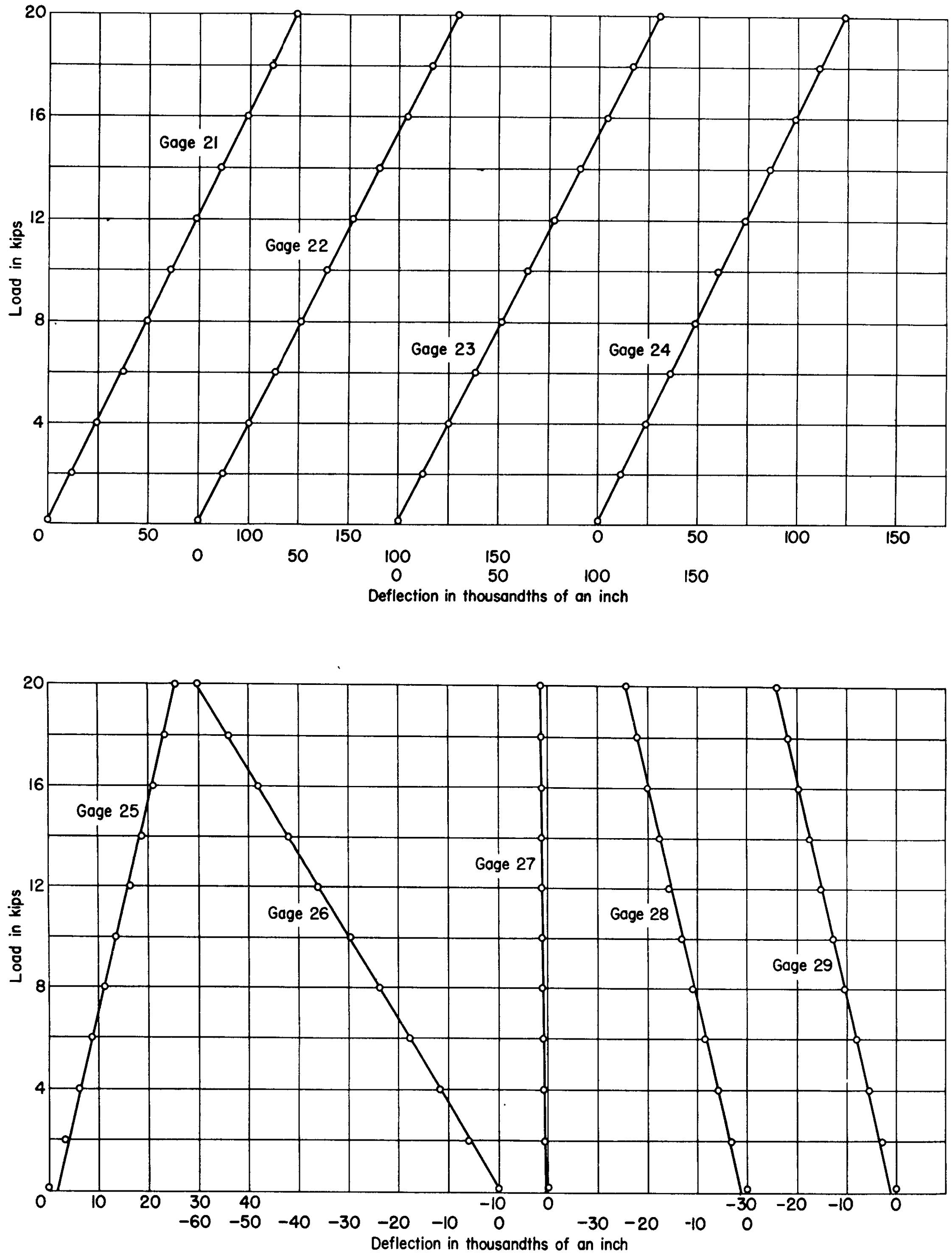
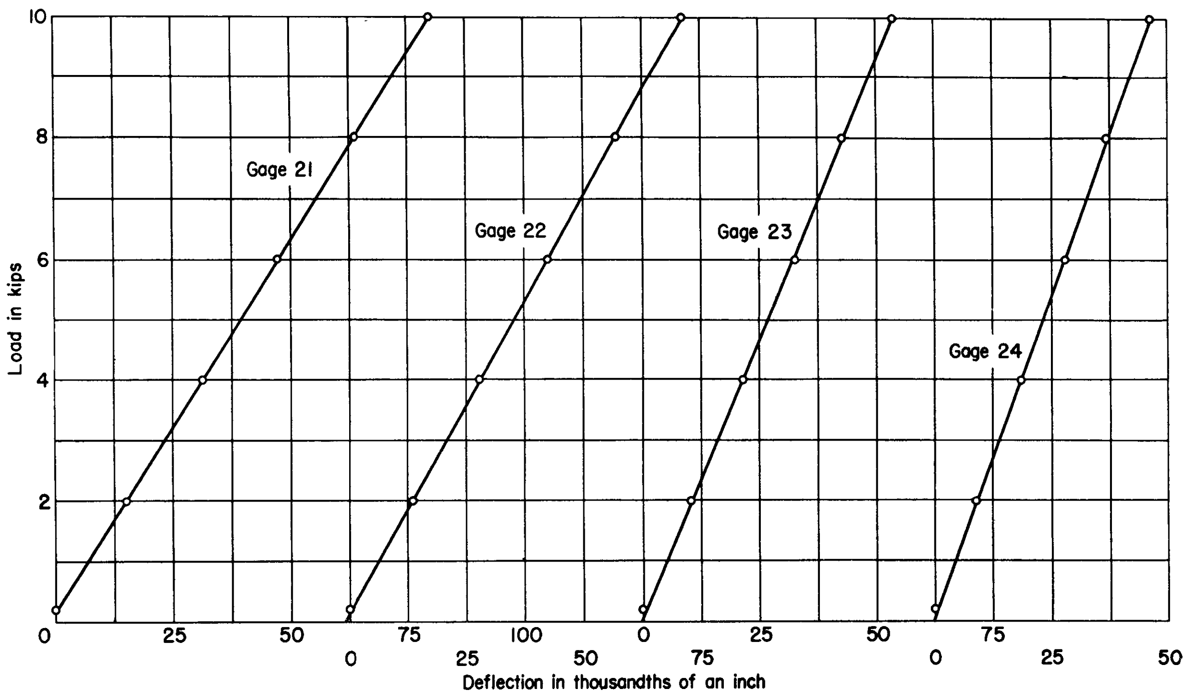


Figure 19 - Observed Displacements of Model in Series 1A with Load Applied Simultaneously to All Three Trunnions

Locations of gages are shown in Figure 17. The ordinate represents the total load which is equally distributed to all three trunnions.



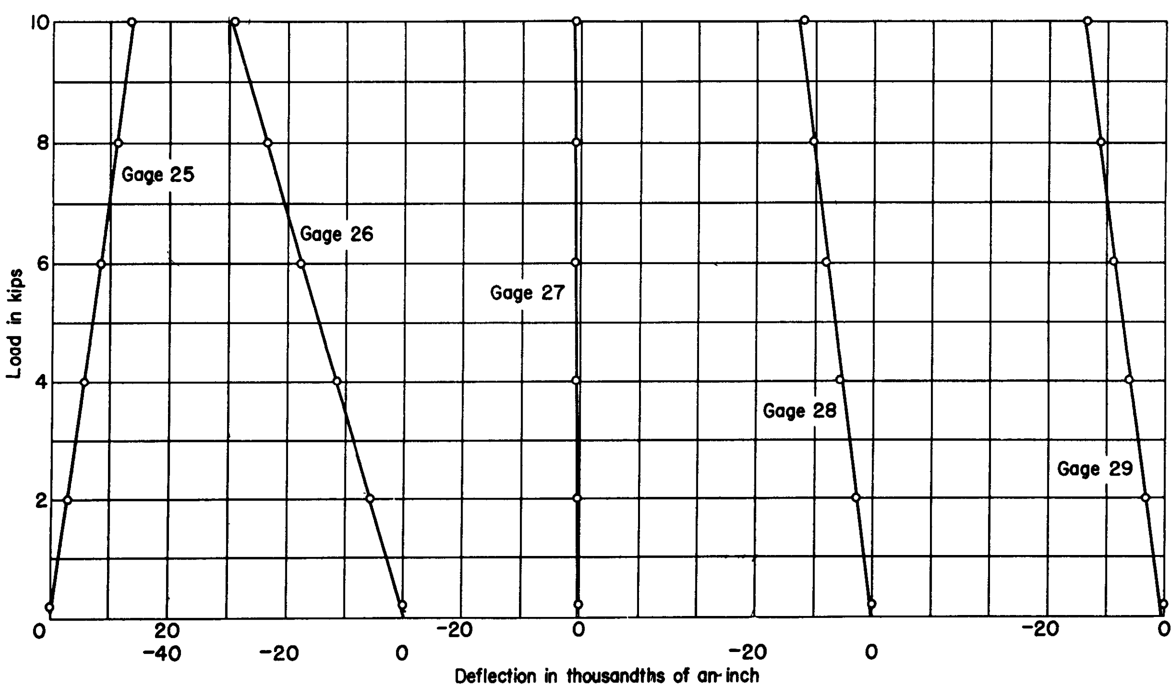


Figure 20 - Observed Displacements of Model in Series 1P with Load Applied to Port Trunnion

Gage locations are shown in Figure 17.

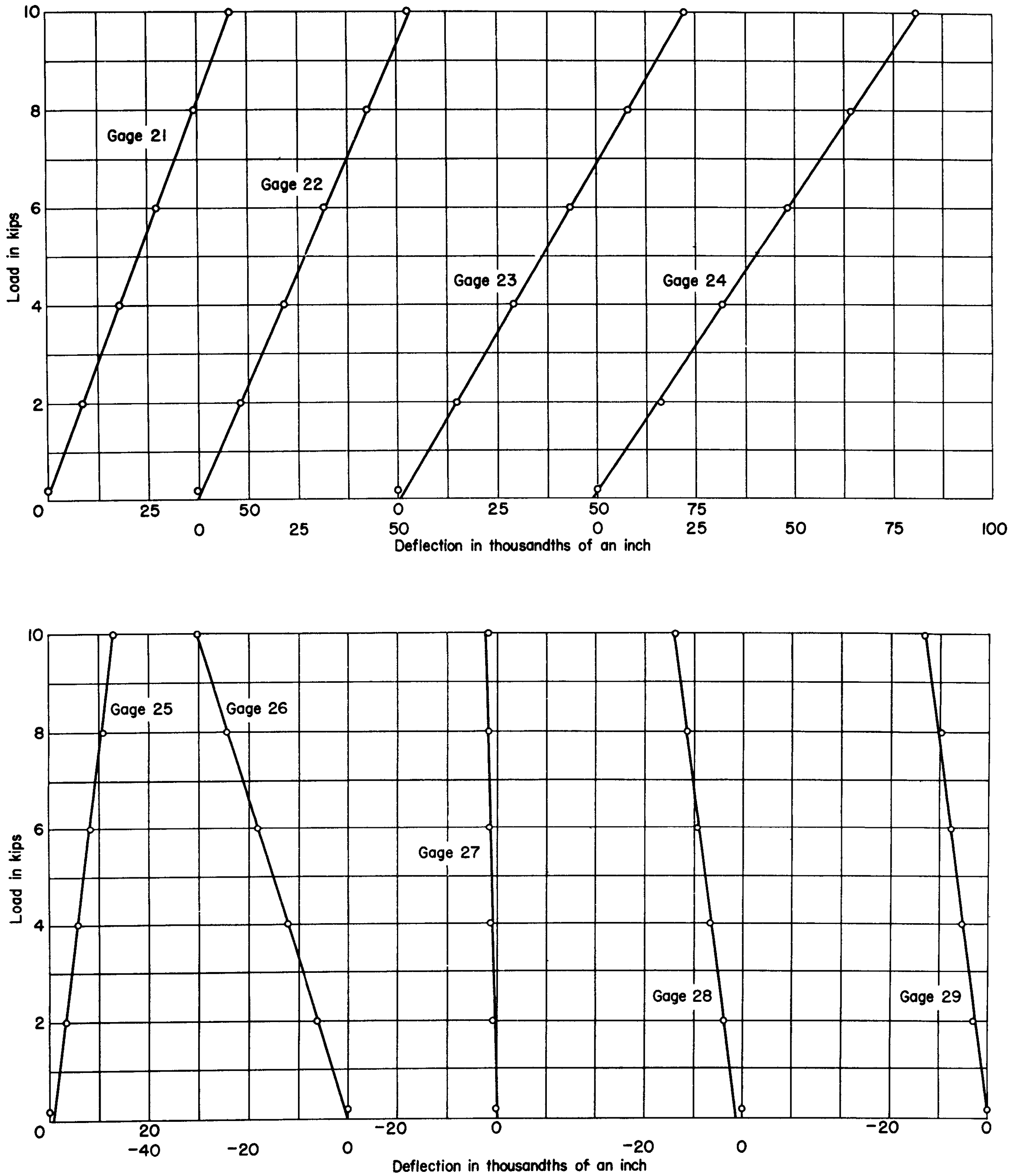


Figure 21 - Observed Displacements of Model in Series 1S with Load Applied to Starboard Trunnion

Gage locations are shown in Figure 17.

TABLE 2

Observed Deflections of Trunnion Blocks in Model of CA139 Turret, Accompanying Forces That Simulate Gun-Recoil Loads

Deflections are given in inches per pound × 10^{-8}.

Gage	Series 1A, Three Guns		Series 1P, Port Gun		Series 1S, Starboard Gun	
	Observed Deflections*	Corrected Deflections	Observed Deflections	Corrected Deflections	Observed Deflections	Corrected Deflections
21	+628	+58	+817	+237	+474	- 71
22	+657	+89	+732	+162	+546	- 9
23	+655	+89	+545	- 7	+734	+161
24	+623	+59	+472	- 70	+817	+234
25	+123		+124		+114	
26	-375		-294		-308	
27	- 2		- 1		- 6	
28	-112		-105		-116	
29	-114		-120		-101	

* Observed deflections are taken relative to the bedplate of the testing machine; the corrected values are those of the trunnion blocks relative to the pan plate.

The values thus corrected which represent the deflection per unit load of the trunnion blocks relative to the pan plate are also given in Table 2. The deflections of the trunnion blocks of the model relative to the pan plate were then calculated at the specified load by multiplying the deflections for unit loads from Table 2 by the scaled-down values of the forces. These are given in Table 3. As mentioned earlier in the report, the deflections of the model at the scaled-down load are 1/10 that of the prototype so that observed deflections have been multiplied by a factor of 10 to obtain equivalent deformations of the prototype. To include dynamic effects of recoil loading, these values were then arbitrarily increased by 30 per cent.

Because of the geometric symmetry of the turret model, certain relationships should be found to exist between deflections of the model at various points. For instance, with the simultaneous loading of all three trunnions in Series 1A, the deflections of the port girder relative to the pan plate should equal those of the starboard girder; again the deflections of the port truss should equal those of the starboard truss. Such agreement is indicated by the results given in Tables 2 and 3.

Further evidence of the symmetrical elastic behavior of the model should be found in the comparison of deflections of the girders and trusses

TABLE 3

Deflections of Trunnion Blocks Relative to Pan Plate at the Specified Values of Recoil Loading

Series	Type of Load	Magnitude of Recoil Load pounds		Calculated Deflections of Trunnion Blocks Relative to Pan, inches × 10^{-3}											
				Port Girder			Port Truss			Starboard Truss			Starboard Girder		
		Model	Prototype	Model	Prototype		Model	Prototype		Model	Prototye		Model	Prototype	
					Static	Dynamic*		Static	Dynamic		Static	Dynamic		Static	Dynamic
1A	Three Trunnions	6450	645,000	3.7	37	48	5.8	58	75	5.8	58	75	3.8	38	49
1P	Port Trunnion	2150	215,000	5.1	51	66	3.5	35	45	-0.2	-2.0	-3	-1.5	-15	-20
1S	Starboard Trunnion	2150	215,000	-1.5	-15	-20	-0.2	-2.0	-3	3.5	35	45	5.0	50	65

* Deformations of the prototype with dynamic loading are those for static loading increased by 30 per cent.

when the model was subjected to wing-trunnion loading. Here, the deflections of the girders and trusses during loading of the port trunnion, as in Series 1P, should be equal to those of the same members of opposite hand during loading of the starboard trunnion, Series 1S. The results given in Table 3 show such agreement.

From the data obtained during Series 1A, it can be seen that the deflections of the trusses were greater than those of the girders. This behavior suggests that the load-carrying capacity of the girders probably exceeds that of the trusses and that the stiffness of the entire turret is not exactly uniform.

A peculiar result of the eccentric loading of the trunnions is the twisting of the structure about an axis normal to the pan plate. This is indicated by the negative deflection of the unloaded trunnion blocks during Series 1P and 1S. If the effect of this twist is considered, the deflection of the outboard-loaded trunnion block in the direction of the horizontal load is $5.1 - 1.5 = 3.6$ inches × 10^{-3} which agrees well with the deflection of the block during Series 1A when the loaded girder was subjected to the same magnitude of force. Likewise the loaded truss during Series 1P and 1S deflected $3.5 - 0.2 = 3.3$ inches × 10^{-3} which is substantially half the amount observed during Series 1A when twice the magnitude of force was applied to the trunnion.

All the deflection data plotted in Figures 19 through 21 are linear functions of load, but the data recorded during initial loading showed considerable deviation from that straight-line relationship. This was found to be caused by uneven contact between the test frame and the base plate of the testing machine, an effect that was minimized by inserting shims between the frame and plate.

These deflection measurements of the trunnion blocks are difficult to interpret on a basis of their absolute magnitudes alone. However, an analysis of the results as an indication of the stiffness of the structure has been made by a comparison with results of a similar test conducted on a model of the CA68 turret. This is discussed on page 53. It is apparent, in any case, that information is lacking regarding deformations of turrets in service and also regarding the establishment of design criteria involving the allowable flexibility of various structural elements. Inasmuch as these tests constitute the first ones from which information was obtained regarding stiffness, the results may be utilized as a basis for future design criteria.

Relative Displacements of Adjoining Trunnion Blocks with Wing-Gun Loading

The relative displacements of adjacent trunnion blocks were measured during Series 1P and 1S only, since the unsymmetrical loading might produce relative block motions that would be sufficient to crush the trunnion bearings. These measurements were made by dial-gage extensometers held between reference bars welded to the trunnion blocks as shown in Figures 22 and 23. Gages 1 through 9 were used to measure relative displacements of the

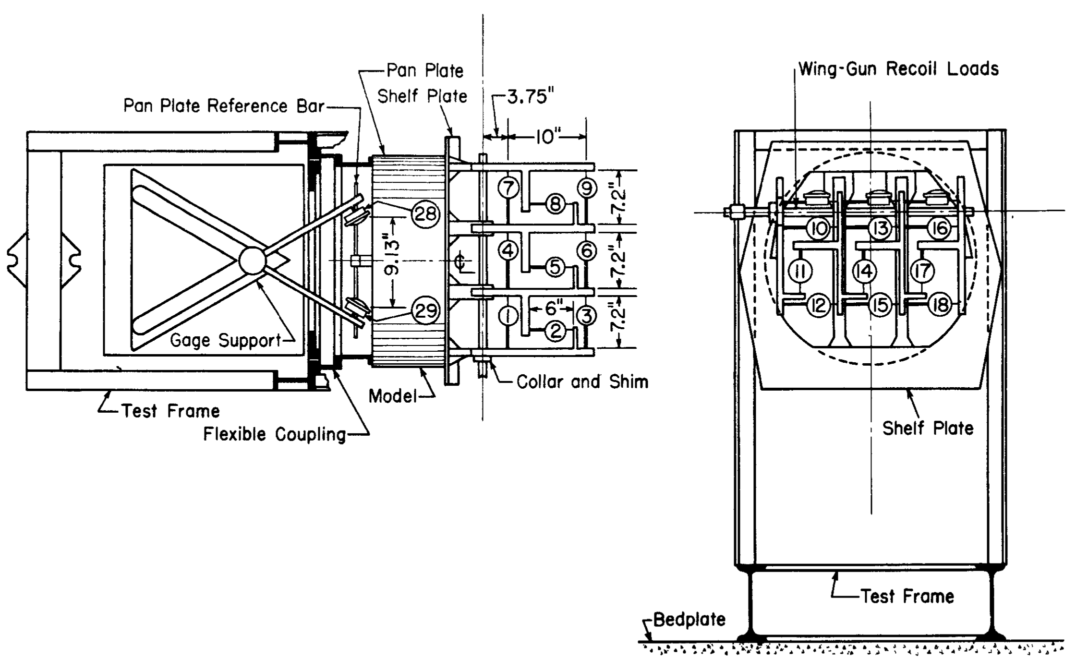


Figure 22 - Schematic Diagram Showing Arrangement of Dial Gages to Measure Relative Displacements of Adjoining Trunnion Blocks

These displacements were measured during wing-gun loading since the eccentricity of loading might produce excessive relative trunnion block motions, sufficient to crush the trunnion bearings.

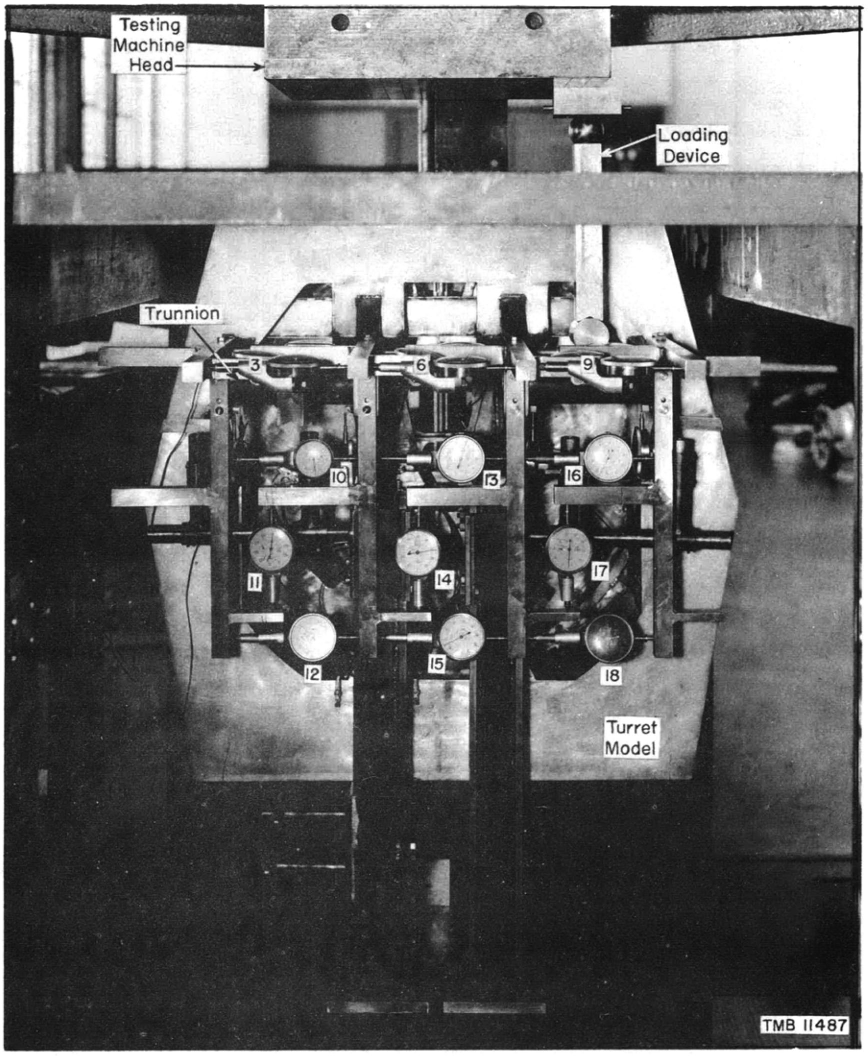


Figure 23 - Test Setup Showing System for Applying Recoil Load to Starboard Trunnion

Dial gages are arranged to measure relative displacements of trunnion blocks.

blocks in a plane normal to the pan plate. Gages 10 through 18 were used to measure displacements in a plane parallel to the pan plate. The extensometers were installed between adjacent trunnion blocks in groups of six. Since the operation of all gages in each group was similar, the procedure for calculating the relative displacements from the observed deflections will be described in detail only for the port trunnion block.

The relative displacements of adjoining trunnion blocks can be expressed in terms of relative angular deflections, relative lateral translations, and relative deflections in the plane which is parallel to the direction of load and normal to the pan plate. These various displacements are shown separately in Figure 24. To explain the method of calculation of the displacements from the observed deflections, the port outboard trunnion block was considered to be stationary, so that all relative motion was assumed to be performed by the port inboard trunnion block.

In the plane normal to the pan plate, the angle of rotation α_1 of the outboard block relative to the inboard block was found by subtracting the reading of Gage 1 from that of Gage 3, and then dividing this difference by 10 inches, the distance between the axes of the gages. The algebraic signs of the observed deflections were included in the calculations so that clockwise rotation would be indicated by a positive sign.

A similar calculation was made employing the readings of Gages 10 and 12 to obtain the relative rotation β_1 in the plane parallel to the pan plate. The results of the two calculations then were added vectorially to obtain the resultant angle formed between the adjacent blocks.

The lateral translation of the inboard block measured with respect to the outboard block was determined by first calculating from the average of the readings of Gages 1 and 3, the relative translation at a point midway between the gages. This value was corrected for relative rotation of the blocks by subtracting from the result the product of the angle of rotation α_1 times the distance from the midpoint of the gages to the point directly above the line of trunnions as shown in Figure 24. Inasmuch as the bars holding the gages were located 2.13 inches above the trunnions, the lateral translation at the level of the trunnions was obtained by adding to the previous result the product of the height, 2.13 inches, and the angle of rotation β_1 of the blocks. With due regard for the algebraic signs of the data employed in the calculations, a lateral translation of the blocks toward each other is positive.

The relative deflection of the trunnion blocks in the plane parallel to the direction of loading is the vector sum of the deflection indicated by Gage 2 and that indicated by Gage 11. The signs of the deflections are of no particular significance.

A sample calculation of the various relative displacements is given using results listed in Table 4.

From Figure 24, the distance between Gages 1 and 3 is 10 inches; the angle of rotation α_1 in the vertical plane is consequently

$$\frac{G_3-G_1}{10} = \frac{137-71}{10} = +6.6\times10^{-8} \text{ radians}$$

In the horizontal plane, the rotation β is

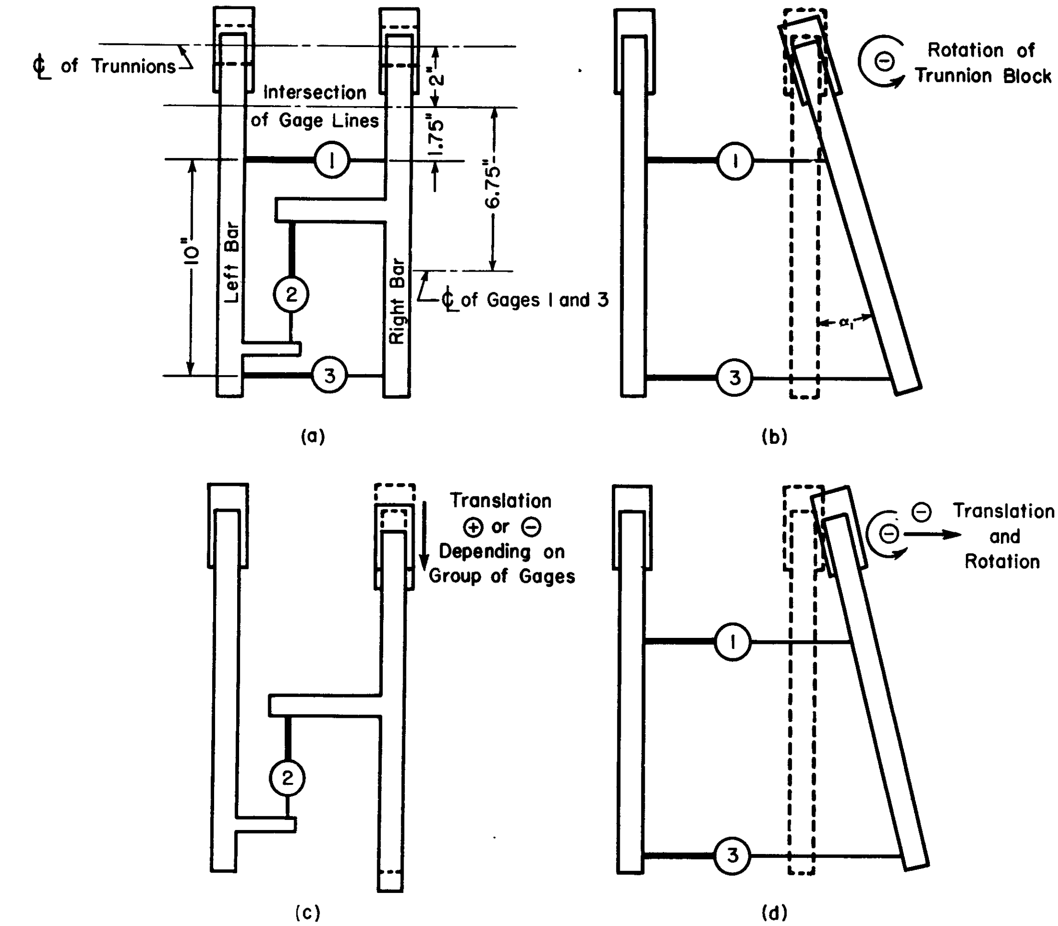


Figure 24a - Arrangement of Deflection Gages in Plane Normal to Pan Plate

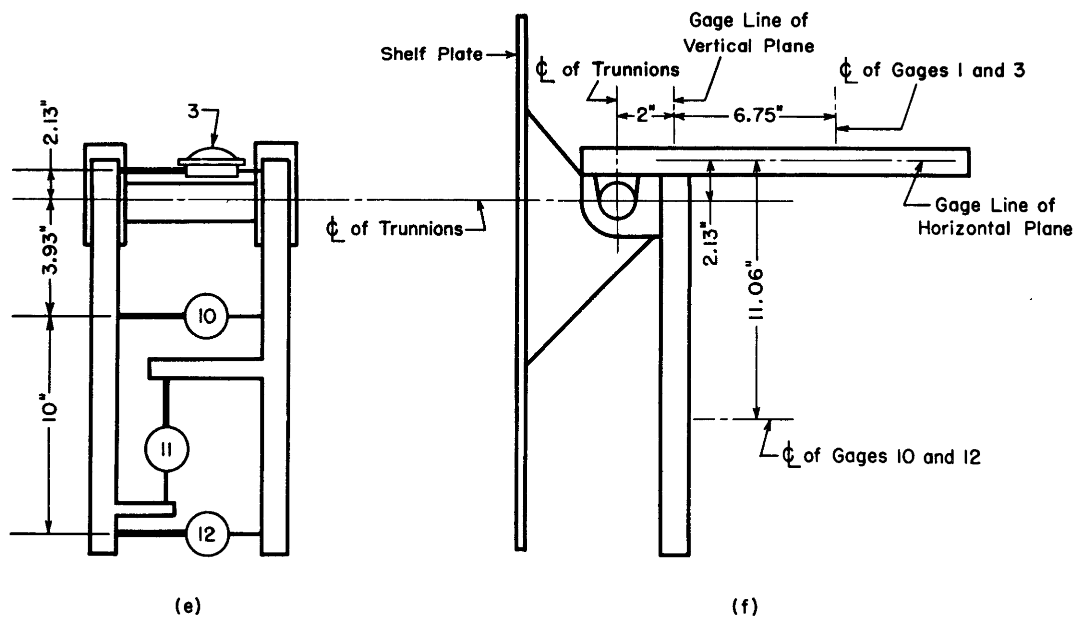


Figure 24b - Arrangement of Deflection Gages in Plane Parallel to Pan Plate

Figure 24 - Schematic Diagrams Showing Modes of Relative Displacements of Adjoining Trunnion Blocks

TABLE 4

Deflections per Unit Load Taken from Series 1S

Gage	Deflections per Unit Load inches × 10^{-8}
1	71
2	-30
3	137
10	69
11	110
12	76

$$\frac{G_{12} - G_{10}}{10} = +0.7\times10^{-8} \text{ radians}$$

The resultant angle formed between the blocks is $\sqrt{(6.6)^2 + (0.7)^2} = 6.63\times10^{-8}$ radians per unit load.

The relative lateral translation of the bars at a point midway between Gages 1 and 3 equals the average of the readings of the gages:

$$\frac{G_1+G_3}{2} = \frac{71+137}{2} = \frac{208}{2} = 104\times10^{-8} \text{ inches}$$

This value is corrected for rotation of the blocks by subtracting $8.75\alpha_1$ from this result. This gives the translation of the bars in the plane of the dial gages which is directly above the line of trunnions. Further correction of the translation to the level of the trunnions is made by adding 2.13β. The relative translation at the centerline of trunnions is thus

$$\frac{G_1+G_3}{2} - 8.75\left[\frac{G_3-G_1}{10}\right] + 2.13\left[\frac{G_{12}-G_{10}}{10}\right] = \frac{71+137}{2} - 8.75(6.6) + 2.13(0.7)$$

$$= 48\times10^{-8} \text{ inches per unit load}$$

The relative deflection of the blocks in the plane parallel to the direction of loading is the vector sum of the deflections indicated by Gages 2 and 11; that is, it is equal to

$$\sqrt{(-30)^2 + (110)^2} = 114\times10^{-8} \text{ inches per unit load}$$

The observed deflections for Gages 1 through 18 Series 1P and 1S are plotted in Figure 25. No plot was made of the data for a station if the deflection at peak load was less than 0.0025 inch. By considering the symmetry of the model, the data for gages located in the same position

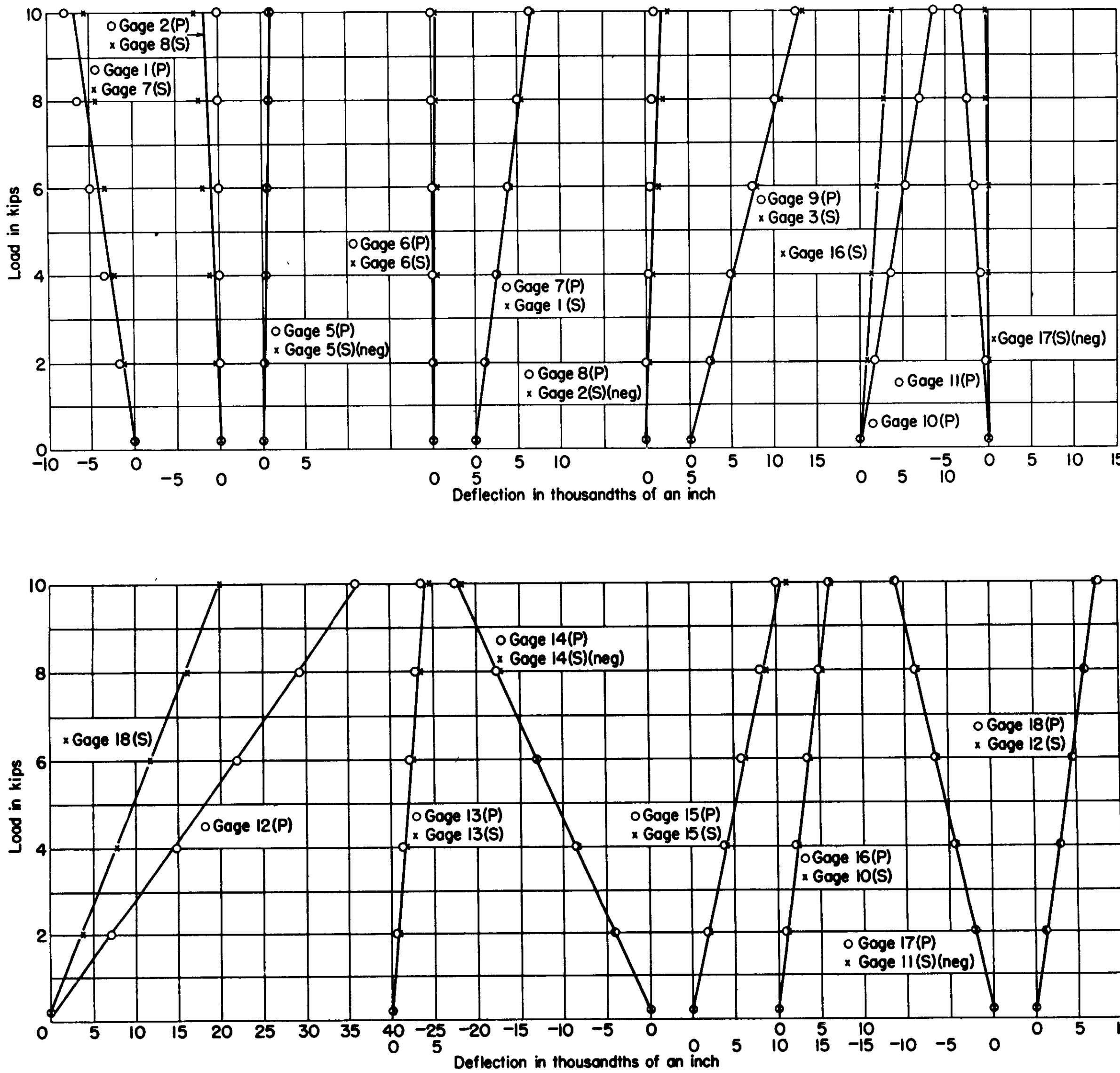


Figure 25 - Observed Deflections of Gage Bars during Application of Load to Wing Trunnions, Series 1P and 1S

Because of the symmetry of the model, deflections measured at stations in the same positions relative to the applied wing-gun recoil load are comparable, and thus can be plotted with the same origin. The results from Series 1P and 1S have been grouped as follows: the data are plotted with the sign corresponding to that observed during loading of the port trunnion; where the signs of data for loading of the starboard trunnion are opposite to those plotted, the gage designation is followed by "neg." The locations of the dial gages are given in Figure 22.

relative to the loaded trunnion were plotted with the same origin; that is, Gage 1 of Series 1P was plotted with Gage 7 of Series 1S, 3 with 9, and so on.

The deflections per unit load for Gages 1 through 18 were computed from the slopes of the straight lines that best fitted the plotted data. These values, given in Table 5, were used to calculate the relative rotations and deflections of the trunnion blocks according to the procedure described in the foregoing. The results are given for the specified value of recoil load in Table 6.

TABLE 5

Relative Movement of Gage Bars with Forces Simulating Wing-Gun Recoil Loads

Deflections are given in inches per pound × 10^{-8}.

Gage	Series 1P	Series 1S
1	- 78	+ 71
2	0	- 30
3	*	+137
4	*	*
5	+ 12	- 11
6	+ 3	+ 3
7	+ 68	- 54
8	+ 13	- 30
9	+129	*
10	+ 90	+ 69
11	- 37	+110
12	+369	+ 76
13	+ 39	+ 48
14	-224	+218
15	+105	+116
16	+ 65	+ 37
17	-112	+ 3
18	+ 81	+201

* These data were not plotted since the peak deflection was less than 25 × 10^{-4} inch. In the calculations, the deflections per unit load for these gages were assumed to be zero.

TABLE 6

Relative Displacements at Centerline of Trunnion of the Model at Specified Values of Recoil Load

Series	Specific Load of 2150 Pounds per Gun	Maximum Angle between Adjacent Trunnion Blocks minutes			Change in Lateral Displacement of Adjacent Trunnion Blocks inches × 10^{-3}			Relative Longitudinal Displacement of Adjacent Trunnion Blocks inches × 10^{-3}		
		Port Gun	Center Gun	Starboard Gun	Port Gun	Center Gun	Starboard Gun	Port Gun	Center Gun	Starboard Gun
1A	3-Gun Salvo									
1P	Port Gun	2.1	0.5	0.5	0.8	0.3	1.0	0.8	4.8	2.4
1S	Starboard Gun	0.5	0.5	1.3	1.1	0.4	0.8	2.4	4.7	0.6

Pure elastic behavior of a test model that does not distort appreciably under load should be accompanied by a linear relationship between the applied load and the deflections measured at each station; such relationships are apparent for the data plotted in Figure 25. Some of the observations from stations in corresponding positions relative to the loaded trunnion failed to coincide, and this condition is reflected in the lack of agreement of the angle formed between the port trunnion blocks for Series 1P and that between starboard blocks for Series 1S. However, good agreement of results can be found between the change in spacing between blocks and the relative longitudinal deflections by comparing the values in Table 6 at the loaded and the unloaded trunnions. When the results did not entirely coincide for all measured displacement, the tests were repeated, but generally identical results were obtained. This agreement upon repetition indicated that the observations were reliable and that the peculiar behavior was most likely due to lack of symmetry of lateral stiffness of the outboard gun girders of the model.

The method of calculation of the relative displacements of the trunnion blocks was found to be tedious, but no alternate system of measurement seemed practicable to obtain the information required. It is believed that the procedure adopted gave the best results for the measurements of displacements of such small magnitude. The test results presented in Table 6 are somewhat difficult to evaluate in terms of satisfactory performance of the prototype, and their significance lies primarily in a comparison with results from similar tests conducted on a model of the CA68 turret. This comparison is given on page 53.

PART 2 - TESTS WITH LATERAL LOADING

The second series of tests was conducted with lateral load applied to the model to simulate the acceleration effects and the transverse components of the weight of the guns which bear against the trunnion blocks during a 30-degree roll of the ship. Measurements were made of the resulting displacements of the trunnion blocks and of the strains in the turret to investigate the ability of the turret structure to sustain lateral service loads without distortions sufficient to damage the trunnion bearings.

The test setup for lateral loading is shown in Figure 26. The model was mounted in the test frame for recoil loading, and lateral forces were applied successively to each trunnion block by means of a screw jack attached to a column of the testing machine.

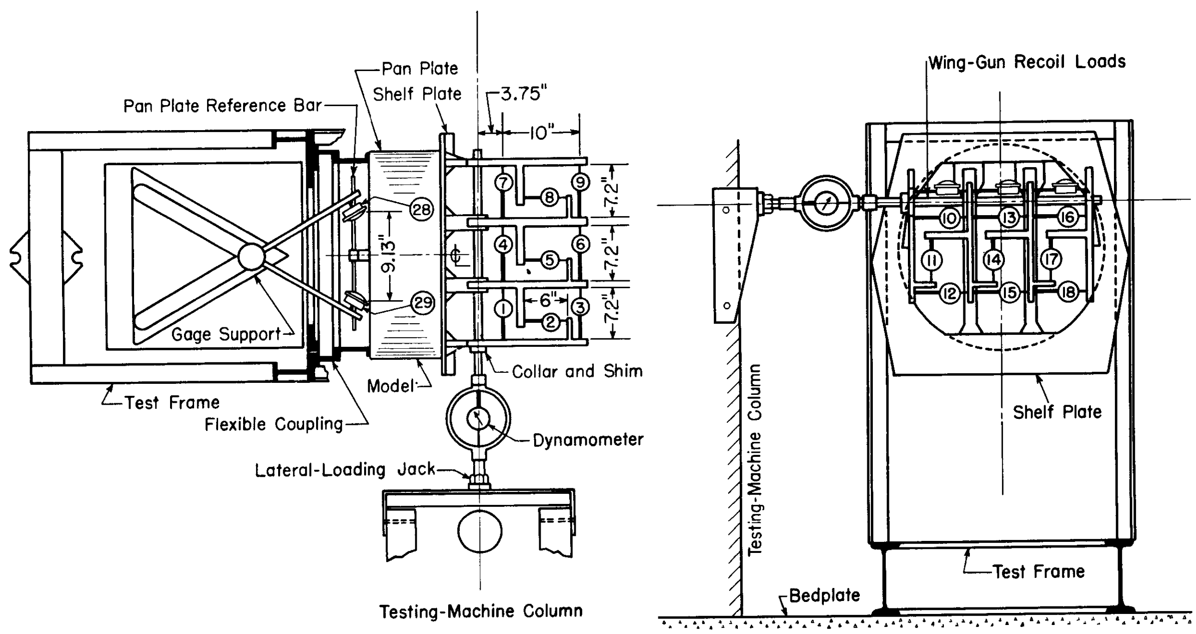


Figure 26 - Schematic Diagram Showing Setup for Tests of CA139 Turret Model with Lateral Loading

Lateral forces on the trunnion blocks of the prototype can be expected during the roll of the ship and are composed of the lateral component of the weight of the guns added to acceleration effects that accompany roll.

The dial gages shown are arranged to measure relative displacements of adjacent trunnion blocks. The loading system shown is for lateral loading on the port outboard trunnion block.

The lateral force was measured with a proving-ring type of dynamometer. A value of 630 pounds per gun was calculated as the model load scaled down from the lateral component of the weight of an 8-inch gun during a 30-degree roll added to the acceleration effects which accompany rolling.

In the tests, forces were applied in convenient increments to peak loads of 1600 pounds, which is approximately three times the specified load.

Inasmuch as the exact point of application of lateral load on the prototype during roll is unknown, two extreme positions for loading were chosen for the test, the top and the bottom of the trunnion bearings. Loads were applied to each block at these selected points by means of a collar and shim as shown in Figure 26.

Tests with lateral loading applied from the port side were conducted according to the following schedule:

Series:

- II-D Lateral load at the top of the port outboard trunnion bearing.
- II-E Lateral load at the bottom of the port outboard trunnion bearing.
- II-F Lateral load at the top of the port inboard trunnion bearing.
- II-G Lateral load at the bottom of the port inboard trunnion bearing.
- II-H Lateral load at the top of the starboard inboard trunnion bearing.
- II-J Lateral load at the bottom of the starboard inboard trunnion bearing.
- II-K Lateral load at the top of the starboard outboard trunnion bearing.
- II-L Lateral load at the bottom of the starboard outboard trunnion bearing.

The behavior of the turret with lateral loading produced by three guns simultaneously was calculated by superposing the results of the tests in which loads were applied to three adjacent trunnions. Thus Series M consisted of calculations for the simultaneous loading of three trunnions at the top of the blocks; the calculations were made by adding algebraically the results of Series F, H, and K. Series N consisted of calculations with load at the bottom of the blocks and was determined by adding the results of Series G, J, and L.

STRAIN MEASUREMENTS

Strains were measured during application of lateral load in the manner described on page 16. The observed values have been multiplied by the assumed modulus of elasticity and the results are plotted in Figure 27. If the stress at any gage was less than 500 pounds per square inch at the

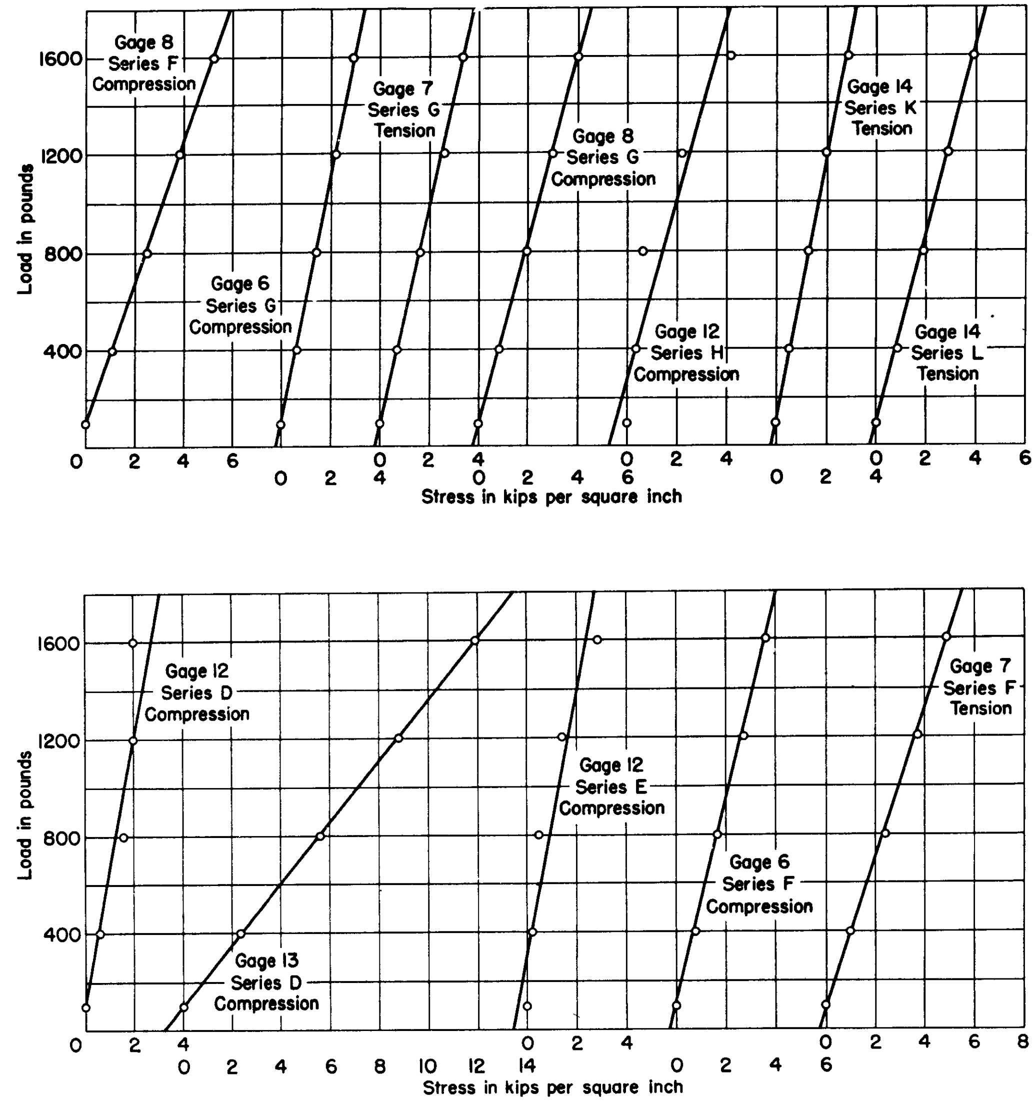


Figure 27 - Apparent Stresses in Model of CA139 Turret with Lateral Loading, Series II

The apparent stresses were calculated from the observed strains by multiplying each reading by an assumed modulus of elasticity of 30×10^6 pounds per square inch. No stresses were plotted if the value at the specified load of 630 pounds was less than 500 pounds per square inch.

specified value of lateral load, no plot was made of the data. The apparent stresses at specified load were computed as before, using the slope of the straight line drawn through the plotted data; these stresses are given in Table 7.

The load-strain relationships were linear for all plotted data except those of Gage 12 for Series D, E, and H. Here the observed compressive stress was not directly proportional to the load, probably because of local buckling which produced nonlinear bending stresses in the sheet at

TABLE 7

Apparent Stresses in Model of CA139 Turret at the Specified Values of Lateral Load

According to the laws of similitude as applied to structural-model analysis, stresses in the prototype should equal those in the model at specified load. The specified load on the model is 630 pounds to simulate the components of weights during 30-degree roll added to acceleration effects of roll.

Gage locations are shown in Figure 28. Stresses are given in pounds per square inch and were calculated by multiplying observed strains by an assumed modulus of elasticity of 30×10^6 pounds per square inch. Compressive stresses are indicated by a minus sign. Stresses designated by X were less than 500 pounds per square inch.

Gage	Port Girder		Port Truss		Starboard Truss		Starboard Girder	
	Series II-D Top*	Series II-E Bottom*	Series II-F Top	Series II-G Bottom	Series II-H Top	Series II-I Bottom	Series II-K Top	Series II-L Bottom
2	X	X	X	X	X	X	X	X
3	**							
4	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X
6	X	X	-1500	-1350	X	X	X	X
7	X	X	2050	1400	X	X	X	X
8	X	X	-2050	1600	X	X	X	X
9	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X
11	X	X	X	X	X	X	X	X
12	-1150	-1200	X	X	-1750	-X	X	X
13	-4900	X	X	X	X	X	X	X
14	X	X	X	X	X	X	1200	1600
15	X	X	X	X	X	X	X	X
16	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X
18	X	X	X	X	X	X	X	X
19	X	X	X	X	X	X	X	X
21	X	X	X	X	X	X	X	X
22	X	X	X	X	X	X	X	X

* "Top" and "Bottom" refer to the point of application of lateral load on the trunnion block.

** Data for Gage 3 were unreliable after Series 1A.

the station. The maximum stress at the specified lateral load as calculated from the observed strains was 4900 pounds per square inch. This stress occured during Series D at Station 13, which is located on the port girder at the level of the shelf plate as shown in Figure 28. In other cases of

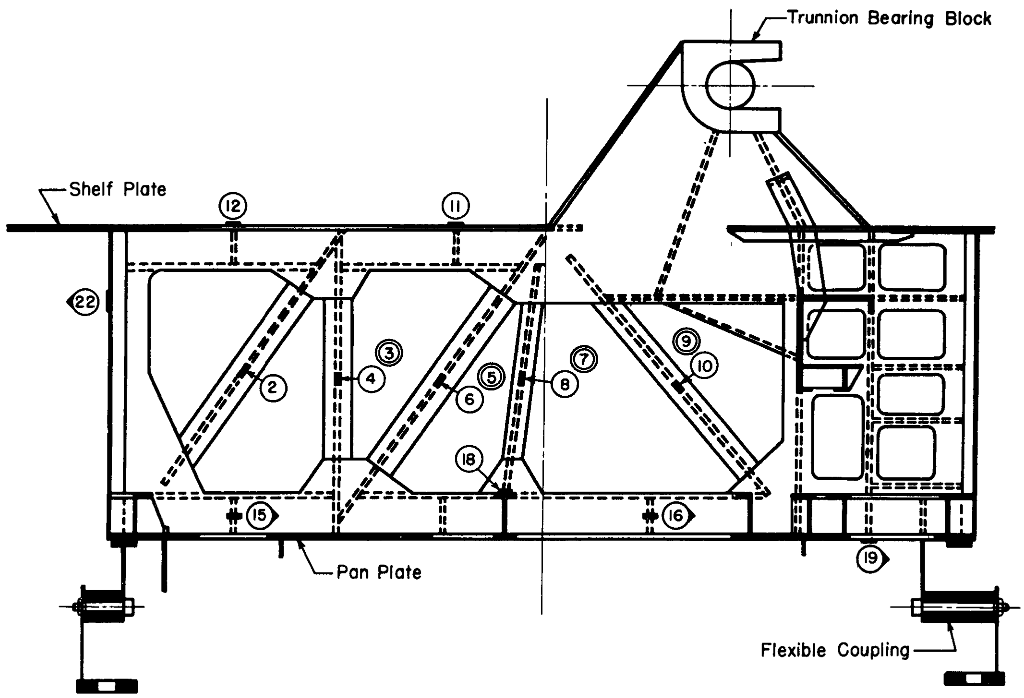


Figure 28a - Elevation of Port Truss

(11) Indicates position of strain gage

(3) Indicates that a strain gage is on the far side of the member

(16)▶ Indicates strain gage where shown but on opposite truss or girder

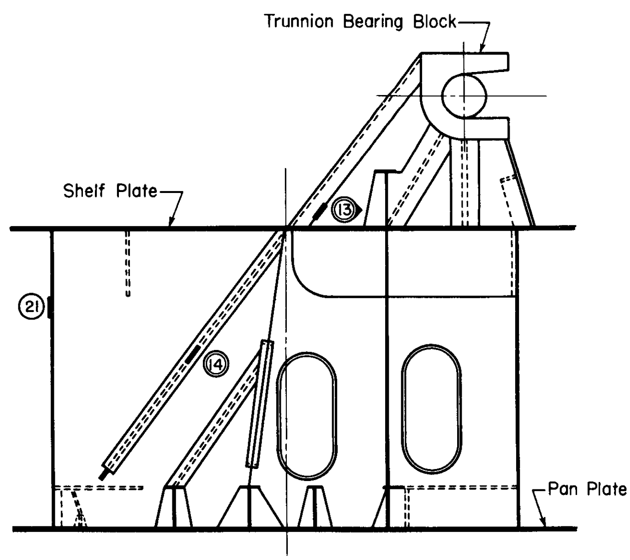


Figure 28b - Elevation of Starboard Girder

Figure 28 - Schematic Diagram Showing Location of Metalectric Strain Gages

lateral loading, the stresses observed at all stations were extremely low. According to the laws of similitude, discussed previously, stresses in the prototype structure should be equal to those in the model at the scaled-down value of load.

DISPLACEMENT MEASUREMENTS

With lateral loading, relative displacements between adjacent trunnion blocks were measured by means of dial gages arranged as in Series 1P and 1S. This array of gages is shown in Figure 26. For simplicity in analysis, the observed deflections of pairs of gages in the same positions relative to the loaded trunnion were averaged, and the results are plotted in Figure 29. No data for a gage were plotted where the deflection at peak load was less than 25×10^{-4}. The deflections per unit load were calculated from the slopes of the straight lines drawn through the plotted data, and are given in Table 8. The relative displacements of adjoining blocks were computed as before, and the results are given for the specified value of lateral loading in Table 9.

TABLE 8

Observed Displacements of the Trunnion Blocks with Lateral Loading, Series II

Deflections are given in inches per pound $\times 10^{-6}$.

Gages	Average Deflections of Series G and J	Average Deflections of Series F and H	Average Deflections of Series E and L	Average Deflections of Series D and K
1, 7	-23	-35	26	48
3, 9	-45	-76	45	105
10, 16	-24	-31	13	23
12, 18	-29	-35	- 3	4
2, 8	8	18	8	24
4, 4	21	34		
6, 6	44	76		
13, 13	22	29		
15, 15	28	32		
5, 5	9	15		
14, 14		2		
11, 17			10	12

TABLE 9

Relative Displacements of Adjoining Trunnion Blocks at Specified Values of Lateral Load

Series	Lateral Loading: Specified Load of 630 Pounds per Gun	Maximum Angle between Adjacent Trunnion Blocks minutes			Change in Lateral Displacement of Adjacent Trunnion Blocks inches × 10^{-3}			Relative Longitudinal Dispalcement of Adjacent Trunnion Blocks inches × 10^{-3}		
		Port Gun	Center Gun	Starboard Gun	Port Gun	Center Gun	Starboard Gun	Port Gun	Center Gun	Starboard Gun
II-D	Top of outboard port trunnion block	13.7	0	0	12.0	0	0	17.6	0	0
II-E	Bottom of out-board port trunnion block	5.5	0	0	8.8	0	0	8.2	0	0
II-F	Top of port truss block	9.1	9.1	0	-13.1	11.6	0	11.2	9.5	0
II-G	Bottom of port truss block	4.8	4.8	0	-10.1	10.0	0	5.0	5.6	0
II-H	Top of starboard truss block	0	9.1	9.5	0	-11.6	13.1	0	9.5	11.2
II-J	Bottom of star-board truss block	0	4.8	4.8	0	-10.0	10.1	0	5.6	5.0
II-K	Top of starboard girder block	0	0	13.7	0	0	-10.0	0	0	17.6
II-L	Bottom of star-board girder block	0	0	5.5	0	0	-8.8	0	0	8.2
II-M	For 3 guns simul-taneously, com-puted from sum of Series F, H, and K; load applied at top of trun-nion blocks	9.1	0	6.5	-13.9	0	0.8	11.2	19.0	27.6
II-N	For 3 guns simul-taneously, com-puted from sum of Series G, J, and L; load applied at bottom of trunnion blocks	4.8	0	4.8	-10.1	0	1.3	5.0	11.2	15.7

Both the deflection data and the calculated relative displacements of adjacent trunnion blocks indicate symmetrical elastic behavior of the model. An examination of the results shows that the displacements accompanying the lateral load applied at the top of the trunnion blocks were always greater than those with the load at the bottom. However, when the prototype structure deforms during a roll, the transverse component of the weight of the guns is probably carried at the bottom of the trunnion bearings so that the model-test results for load applied at that point is of greater significance. The

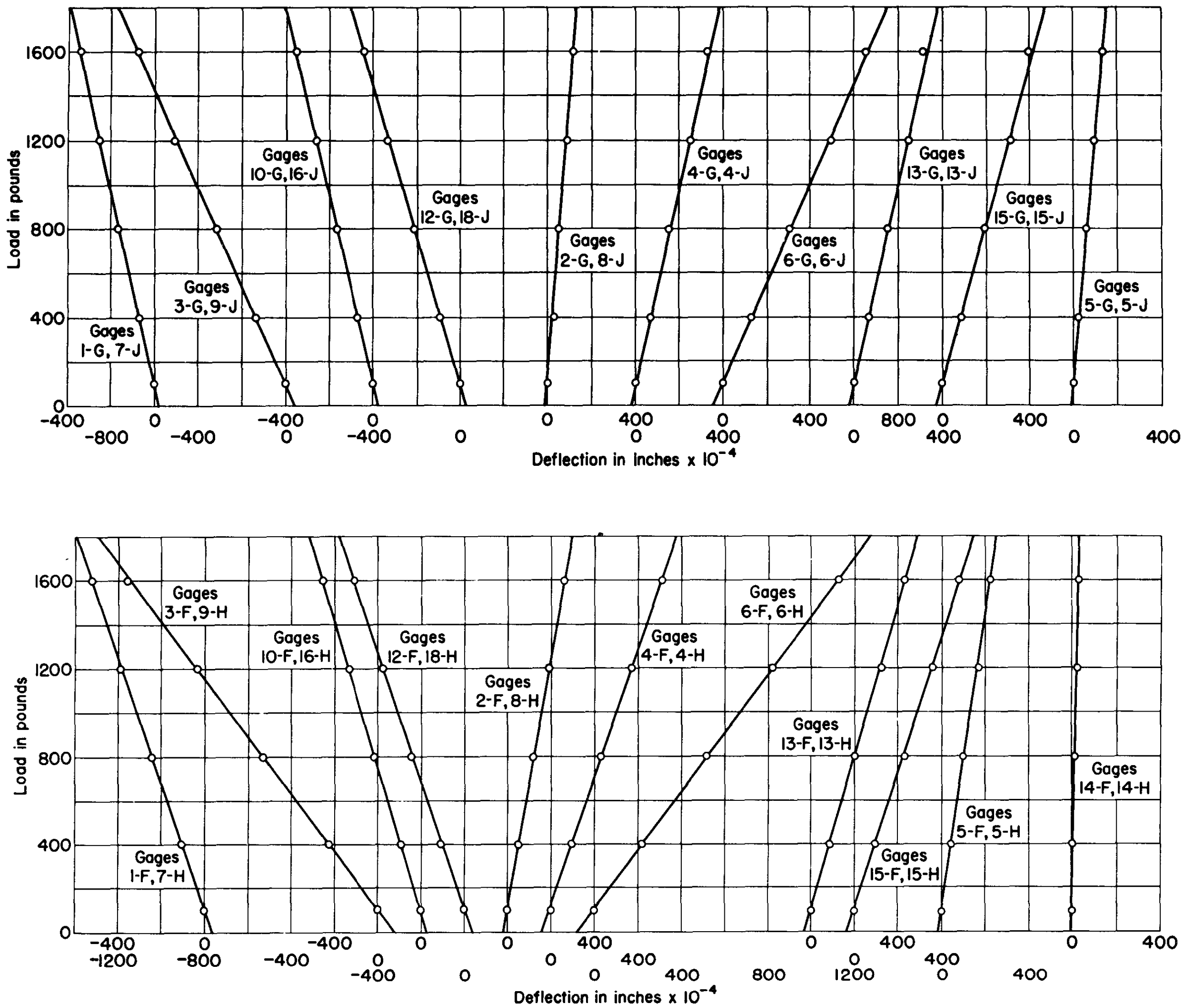
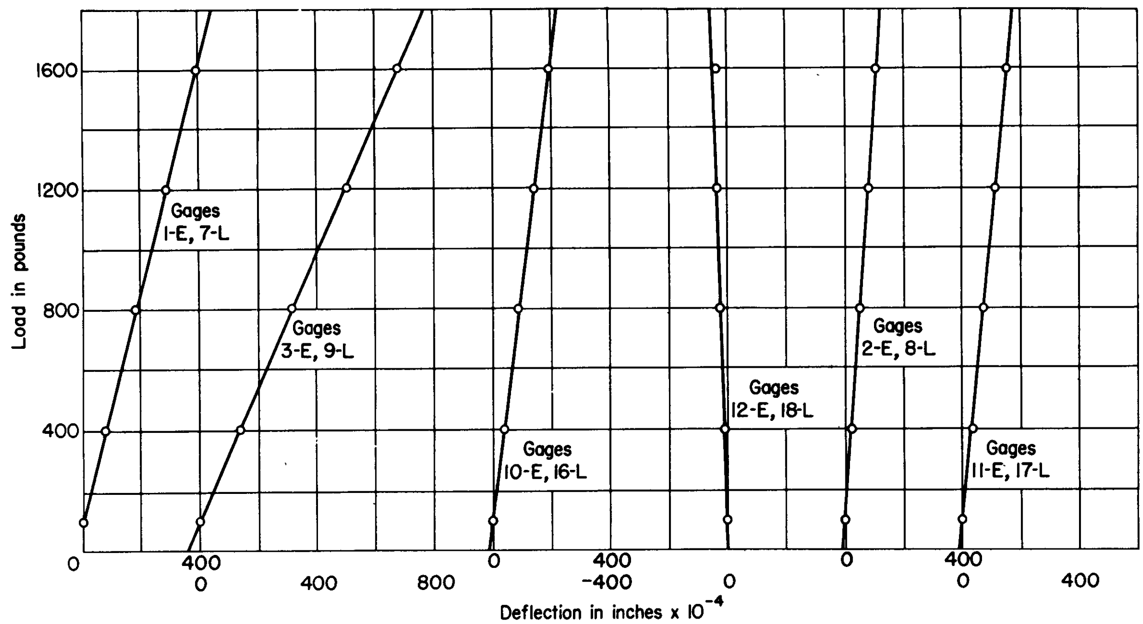


Figure 29 - Relative Deflections of Adjacent Trunnion Blocks with Lateral Loading of CA139 Turret Model, Series II

The number corresponds to the gage, and the letter to the series designation.

Data from gages in the same position relative to the loaded trunnion have been averaged. The sign of the plotted deflection corresponds to that for data of the gage noted first on each curve.



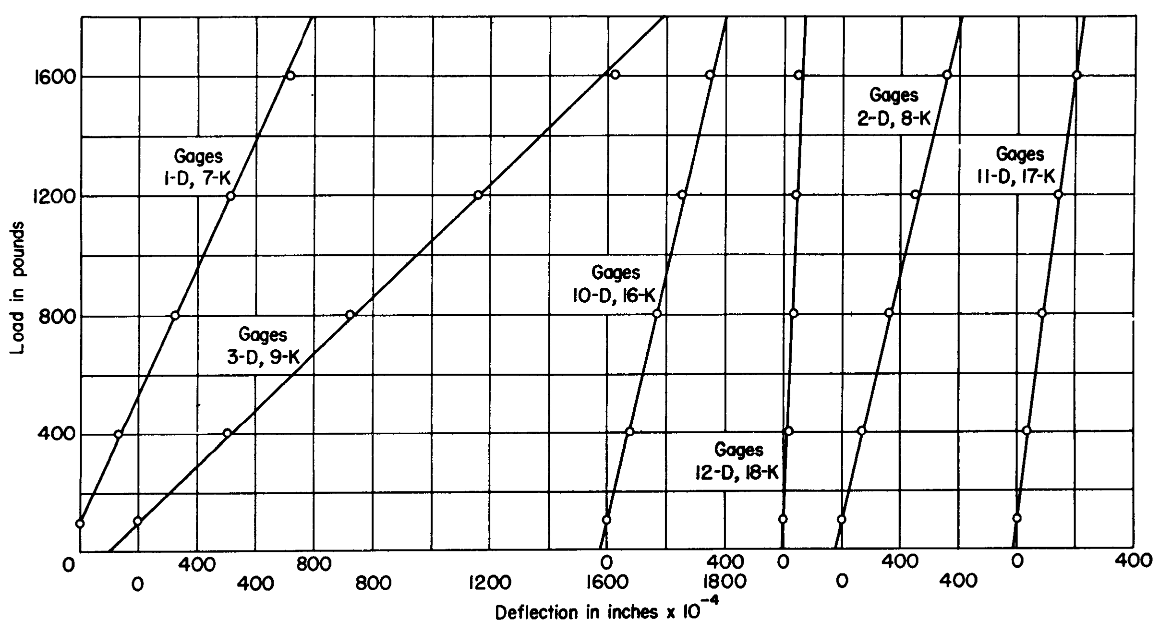


Figure 29 - Continued

displacements for the girders and trusses were substantially equal, which indicates that the lateral stiffness of the two different types of gun-supporting structures was approximately the same.

Although it is possible to predict prototype behavior from these results, the primary value of the measurements lies in the comparison with similar results from tests of the CA68 model, which permits a comparison of stiffness of the two types of turrets.

PART 3 - TESTS WITH LOADS ON ELEVATING-GEAR MECHANISM

The third group of tests with the turret model were conducted to determine any departure from mesh of the elevating arc and pinion that might accompany the service loads transmitted by the mechanism. Such behavior, which may result from distortions under load of the elevating-machinery platform, can be inferred from the change in parallelism of the axis of the pinion and the axis of the trunnion carrying the arc.

Only as much of the elevating-gear mechanism as was necessary for the test was duplicated in the model. This structure is described on page 10, and a schematic diagram showing the various components is given in Figure 30. The force between the elevating arc and pinion was applied through a lever **e** extending from the bar **d** that represents the gun slide and trunnion, and the proportions of the system were so chosen that load applied to the lever equaled that on the tooth at the end of arm **c**. This force was transmitted from the tooth in arm **c**, which represents the elevating arc, to the groove in piece **a** which represents the elevating pinion. The shapes of the tooth and the groove were chosen to ensure transmission of load at the 20-degree angle of obliquity found in the prototype. A schematic diagram of the test setup is given in Figure 31.

The forces operating on the full-scale elevating-gear mechanism are a combination of effects of the acceleration of the guns coming into firing position and forces due to gun recoil. The magnitude of force is limited to 53,000 pounds by the maximum torque imposed on the pinion by the braking effect of the hydraulic system. This force was applied on the model by means of a screw jack, and was measured with a proving-ring type of dynamometer. Loads were applied in convenient increments up to 1100 pounds, which was approximately twice the scaled-down specified load of 530 pounds.

DEFLECTION MEASUREMENTS

The change in parallelism between the axis of the pinion and that of the trunnion which carries the elevating arc was determined as follows:

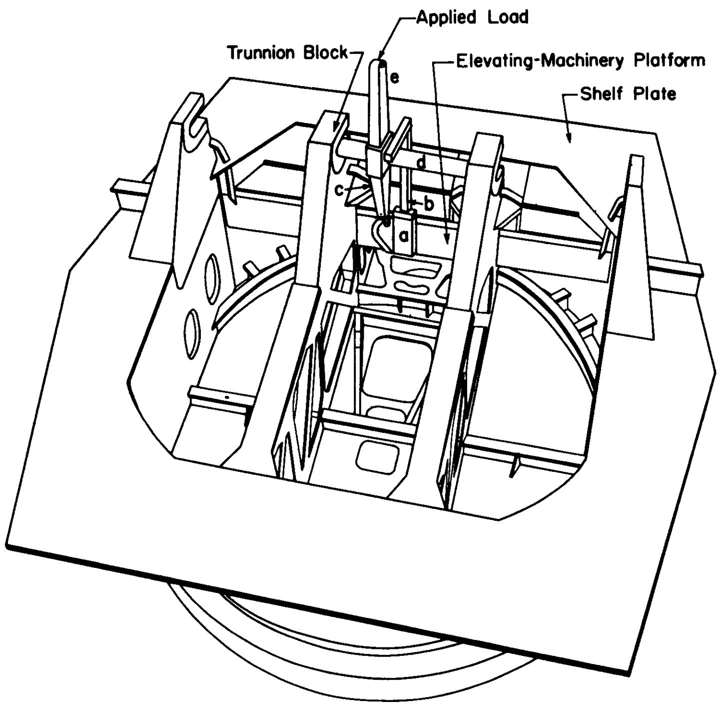


Figure 30 - Schematic Diagram of Turret Model Showing
Simulated Elevating-Gear Mechanism

The elevating arc and gun slide have been represented by a round trunnion bar d to which is welded an arm c that terminates at its lower end in a tooth at the geometric position of one loaded tooth in the full-scale elevating arc. The worm-gear housing attached to the prototype machinery platform has been represented by a block a that includes an extension with a tooth recess to simulate the elevating-arc pinion. The recess engages the tooth of the arm c and thereby duplicates the meshing of the elevating arc and pinion at their contact point. The recess is shaped to ensure transmission of the load between the arm and the block along a line of action that is equivalent to the 20-degree obliquity that exists with the involute teeth of the prototype elevating mechanism. Further details are discussed on page 48.

The displacement of the worm-gear housing relative to the elevating pinion was extended to the level of the trunnions by means of an L-shaped bar b, shown in Figure 31. The outboard trunnion blocks which were not subjected to any external load were assumed to be fixed and therefore were considered the determinant of the original centerline of all three trunnions. The angle of rotation between the axis of the pinion and the axis of the elevating arc of the center gun was assumed the same as that between the bar b and the centerline of the outboard trunnion blocks. This angle was determined by adding the measured changes in angle between the bar and the inboard blocks to the changes in angle between the inboard and the outboard blocks. These deformations were indicated by the dial gages as shown in Figure 31. The angle between the bar and the inboard port trunnion block was computed from the difference in deflections indicated by Gages 31 and 32 divided by 4, the distance in inches between the gages. The angle between inboard and outboard

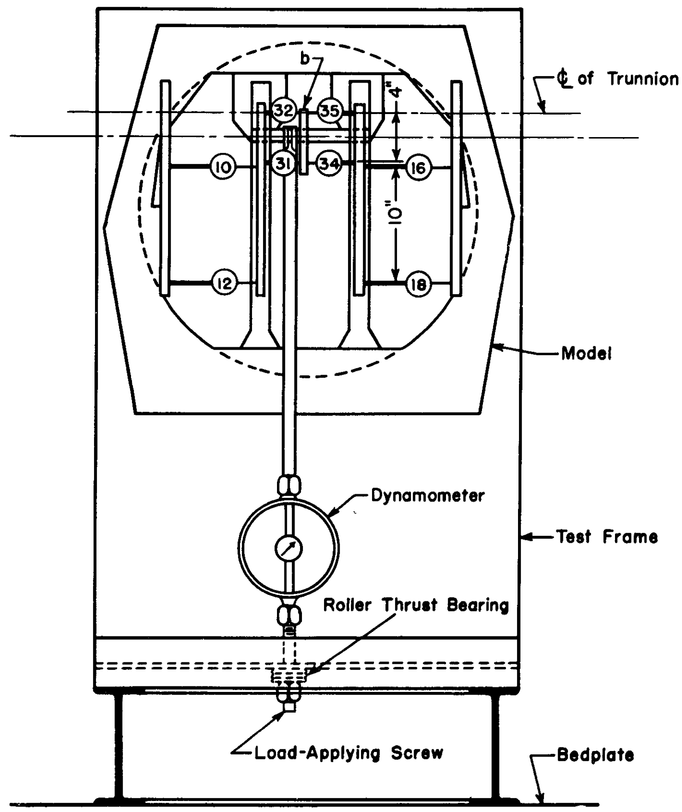


Figure 31 - Arrangement for Tests with Load Applied to Elevating-Gear Mechanism

Load was applied to the elevating-gear mechanism with a screw jack and measured with a ring dynamometer. Dial gages were employed to measure the deflections of the elevating-machinery platform relative to the outboard trunnion blocks which are assumed fixed. These deflections were then analyzed to determine the variations from parallelism of the axis of pinion and the axis of arc.

blocks was computed from the difference in deflections indicated by Gages 10 and 12 divided by 10, the distance between the gages. Similarly, the angles on the starboard side were computed from deflections indicated by Gages 34, 35, 16, and 18.

The measured deflections indicated by these gages are plotted in Figure 32.

The angles were found for a unit load from the slopes of the straight line that best fitted the plotted results, and the angles at the specified load were calculated by the product of 530 times the unit rotations. The results are given in Table 10 for the observed rotations measured separately with respect to the port and the starboard outboard girders, both of which were regarded as stationary. As indicated in Table 10, the rotations were extremely small.

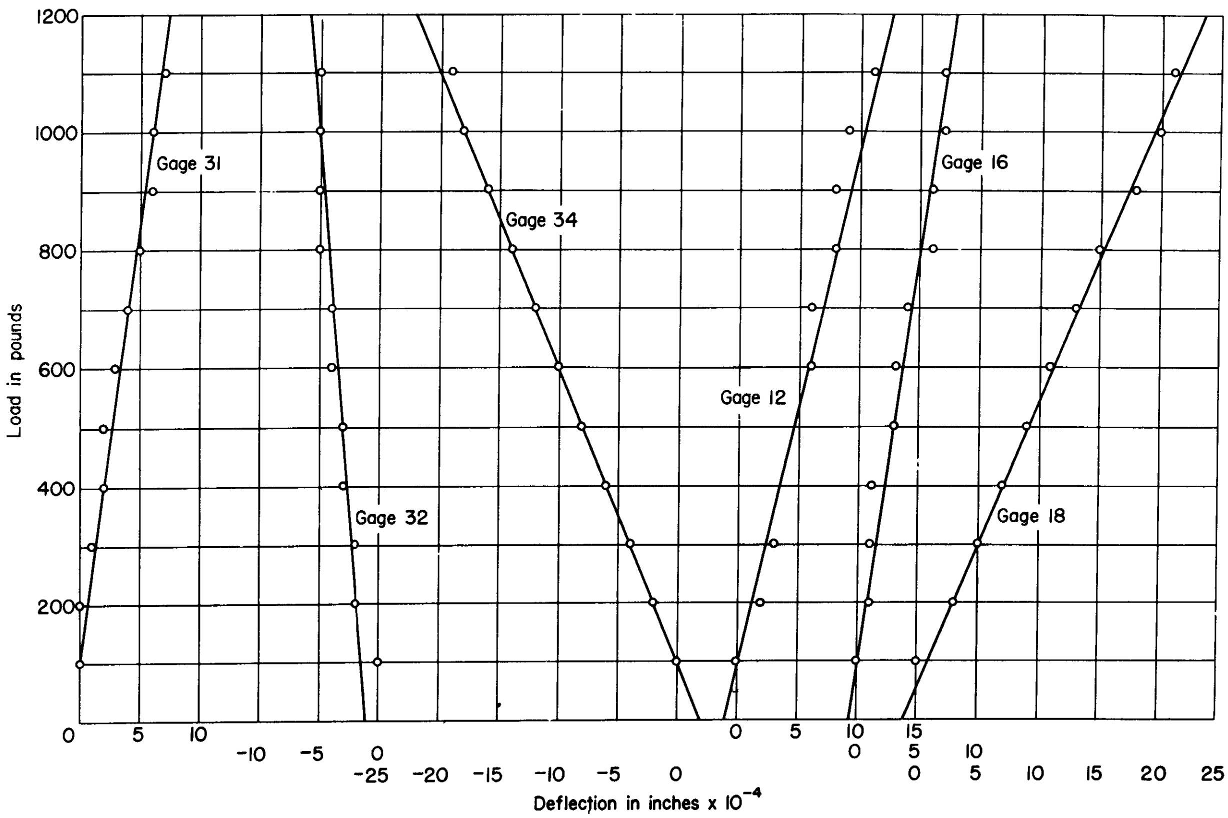


Figure 32 - Deflections of Outboard Trunnion Blocks and Elevating-Gear Mechanism with Elevating-Gear Loading

No data were plotted for Gages 10 and 35 since their deflections at peak load were less than 0.0005 inch.

TABLE 10

Rotations of Elevating-Gear Pinion Relative to the Line of Trunnions at Specified Load

Angle between Gage Arm *b* and Port Girder minutes	Angle between Gage Arm *b* and Starboard Girder minutes
0.68	0.64

SUMMARY OF RESULTS OF TESTS ON MODELS OF CA68 AND CA139 TURRETS

The experimental results previously discussed have been summarized in terms of specified loading for (a) deflections of the trunnion blocks, (b) maximum apparent stress in the structure, (c) load-carrying capacity, and (d) angular deflection of elevating arc relative to the pinion. All these results are summarized in Table 11. A summary of results of similar tests conducted

TABLE 11

Summary of Test Results for 1/10-Scale Models of CA139 and CA68 Turrets

	Model of CA139 Turret	Model of CA68 Turret
Part 1 - Series 1A		
Specified value of 3-gun recoil load, in pounds	6450	6450
Maximum applied horizontal load, in pounds	25,000	25,000
Minimum load-carrying capacity determined by test from ratio of maximum applied load to specified load	3.9	3.9
Maximum observed stress at specified load, in pounds per square inch	4750	2710
Ratio of observed maximum stress and yield stress of steel in model	6.3	11.0
Deflection, at specified load in direction of recoil load of outboard trunnion blocks with respect to pan plate, in inches $\times 10^{-3}$	4	4
Deflection, at specified load, in direction of recoil load of inboard trunnion blocks with respect to pan plate, in inches $\times 10^{-3}$	6	4
Part 1 - Series 1P and 1S		
Specified value of wing-gun recoil load, in pounds	2150	2150
Maximum applied wing-gun recoil load, in pounds	10,000	10,000
Maximum observed angular deflection of adjacent trunnion blocks at specified load, in minutes	2.1	1.0
Part 2		
Specified value of lateral load, in pounds	630	630
Maximum applied lateral load, in pounds	1600	1600
Maximum observed angular deflection of adjacent trunnion blocks, at specified loading, in minutes	5.5	5.5
Part 3		
Specified value of tangential load applied to elevating-gear tooth, in pounds	530	
Maximum tangential load applied to elevating-gear tooth, in pounds	1100	
Angular deflection of elevating arc relative to pinion at specified load, in minutes	0.7	Estimated 1.0

on a model of the CA68 turret also is given in Table 11 for purposes of comparison. A full account of these latter results will be given in a subsequent report.

COMPARISON OF RESULTS OF TESTS ON CA68 AND CA139 TURRET MODELS

As has already been mentioned, the almost complete absence of standards for the stresses and deformations of turret structures rendered impracticable an independent analysis of results of tests on the CA139 turret model. Consequently, similar tests were performed on a model of the CA68 turret which has operated successfully in service, so that some measure of the acceptability of the new turret could be inferred from a comparison of results of the two model tests. The summary as given in Table 11 can be used for a brief comparison.

The comparison of stresses suggests that the load-carrying capacity of the CA68 turret probably exceeds that of the CA139 turret. However, this does not indicate any weakness of the CA139 structure inasmuch as its load-carrying capacity was proved by tests to be satisfactory since it was more than three times the specified value of 3-gun recoil load. On the contrary, these test results show an improvement over the earlier turret of the distribution of material throughout the new structure.

The deflections in the direction of loading of the trunnion blocks relative to the pan plate as given in Table 11 show that the stiffnesses of both turrets in the direction of gun loading are substantially the same. This is of considerable interest inasmuch as the structure supporting the trunnion blocks of the CA139 turret was much lighter in weight than that of the CA68. This, again, is evidence of improved structural design.

A comparison of the relative displacements of adjacent trunnion blocks shows that the displacements accompanying wing-gun loading were larger for the CA139 model. This may result from the greater cantilevered heights of the trunnions above the shelf plate. Agreement between deformations in the two turret models with lateral loading indicates that the absence in the CA139 turret of the tie rod that joins the trunnion blocks of the CA68 turret does not decrease the structural strength and stiffness.

DISCUSSION OF TEST RESULTS

The interpretation of the results of static tests on turret models, in the prediction of prototype behavior, generally depends on three factors: the reliability of the measurements, the accuracy with which the behavior of the model represents that of the prototype under the same conditions of loading, and the consideration of the dynamic character of the prototype loading.

The existence of these factors and their importance in this test are discussed in the following sections.

ACCURACY OF TEST RESULTS

Deflections of the model and the test frame were measured with dial gages which were graduated to 0.0001 inch. The gages had a precision, determined from calibration, of plus or minus 0.001 inch. However, this gage error was usually accumulated gradually in readings over the entire range, so that for small deflections the error was generally less than 0.0005 inch. Errors in observation were reduced by repeating the loading operation several times and averaging the results. The effectiveness of this procedure can be found from an examination of the observed deflections. The plotted deflections for the various applied loads show but a small degree of scatter from a linear relationship. Likewise, the excellent agreement of results from gages located in corresponding positions relative to the load for the various series of tests may be considered indicative of the precision of the gages and of the accuracy of observations.

The strains were measured with metalectric strain gages used in conjunction with a Baldwin-Southwark SR-4 Strain Indicator. The strains were read to the closest 5 microinches per inch, and the overall error of the gages and indicator was less than 5 per cent. The departure of plotted data from a linear relationship to load was very small and demonstrated the reliability of the observations.

The observed strains were multiplied by an assumed modulus of elasticity of 30×10^6 pounds per square inch before plotting, and the product gives apparent stress that would be valid only if the gage were aligned in the direction of a uniaxial stress at the point of measurement. This relationship probably exists with gages located on the members of the trusses but only to an approximate degree at other stations. The maximum principal stresses and shearing stresses could have been determined only if gages had been arranged in rosettes of three. However, with the care taken in orienting the gages, it is unlikely that the principal stresses would have greatly exceeded the ones calculated with the assumption of uniaxial stress.

ADEQUACY OF TURRET MODEL

The test model was fabricated of furniture steel which has approximately the same modulus of elasticity as the steel used in the prototype. Thus, with the same type of loading, the strains, deflections, and elastic stability of the prototype should be related to those of the model entirely on a basis of the geometric similarity of the structures. According to the laws of similitude when the model is loaded to the specified value of 1/100 the full-scale load, the model should have stresses and angular deflections equal to those in the prototype, and deflections one-tenth as great as those in the prototype. If the dynamic character of the prototype loading is neglected, only the departure of the model from geometric similitude should interfere with these basic relationships, and the differences that did exist are discussed in the following paragraphs.

The model was equipped with a flexible coupling that replaced the roller track and foundation, and moreover prevented the comparatively rigid test frame from constraining the elastic behavior of the model. Sometimes, however, the distribution of reactions was dissimilar to that in the prototype. In particular, the coupling transferred horizontal loads to the roller track at the side of the turret, whereas these loads would have been transmitted by the full-scale roller flanges at the front and rear. Further variation of distribution occurred with unsymmetrical recoil loading and lateral loading. In every case, however, it was probable that the elastic behavior of the model was affected only in the direct vicinity of the pan-plate level and not at the trunnions where measurements were made. It should be emphasized that the exact distribution of load transmitted by the roller track of a turret has never been adequately measured. Therefore, since the elastic similitude of the boundary conditions of the model could not be verified, it was not appropriate to design a complex roller track to scale for use in the test; the coupling appeared to be a satisfactory substitute.

The lack of fairness of the circular bulkhead and the use of intermittent and slot welding were not believed to have had any appreciable effect on the stress distribution of the model, but these factors would have adversely affected the load-carrying capacity of the model if the loads had been increased sufficiently to produce damage. In all probability, the measured deformations are greater than if the structure had continuous joints, but this lack of similitude is on the safe side.

The difference between yield stress of the furniture steel utilized in the model and that of the high-tensile and special-treatment steels employed in the prototype does not permit an exact prediction of the load-carrying capacity and mode of failure of the full-scale turret. The full-scale values cannot be deduced entirely from the ratio of the yield strengths of the two materials inasmuch as elastic instability might occur at stresses greater than the yield stress of furniture steel and less than that of high-tensile steel. In any case, the load-carrying capacity of the prototype as predicted by the model tests should be on the safe side.

LOADING

The forces that were applied to the model to simulate service loads on the prototype turret structure have been fully discussed in this report. Some lack of similitude of loading did exist however, and this interfered with an exact prediction of prototype behavior. The primary differences in loading were

a. the omission of loads to simulate the dead weight of the guns,

b. the omission of loads to simulate gun firing at elevations other than 0 degree,

c. the static character of the loads on the model in contrast to the dynamic loads of the prototype.

The first factor has generally not been considered important in tests to determine the acceptability of turret structures inasmuch as the dead weight of the guns is but a fraction of the recoil load; and the distribution of load is such that the stresses and deformations in the structure are negligible. However, recent experience with naval vessels damaged by underwater explosions indicates that the structures are subjected to forces of 10 to 20 times the gravity loads as a result of the accelerations accompanying the explosions. This factor is not now considered a design condition, but more attention must be given to these loads in the future. The effect of the chance occurrence of gunfire with a 30-degree roll of the ship can be determined by superposing the results from the two parts of the model test in which the service loads were separately applied.

Forces on the model simulating recoil loads at gun elevations other than 0 degree were omitted since stresses and deflections of the structure at other angles of gun elevation would be only slightly greater than those at 0 degree.* The exact angle productive of maximum stresses is unknown.

The static loads applied to the model produce strains and deflections that differ from those produced by dynamic loads of equal intensity. The exact relationship is still to a great extent unknown, particularly for portions of the structure near the points of application of load. Present design procedure based on results of tests (4) indicates that the dynamic effect of the gun firing would produce stresses and deflections approximately 30 per cent greater than those accompanying an equal static load, and prediction of prototype behavior must take this factor into account. Thus all results of the part of the test that employed forces simulating recoil loads

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* The stresses accompanying inclined recoil loading were found from tests on the CL144 turret model to be generally not more than 5 per cent greater than the stresses with horizontal loading (6).

have been increased by that amount. The dynamic effects involved with the lateral loading are negligible since the accelerations accompanying rolls of the ship are generally only a fraction of 1 g. The dynamic character of the load involved in the braking of the elevating-gear mechanism is believed to be productive of effects similar to recoil loads so that the measured value might require a slight increase in predictions of prototype behavior.

ANALYSIS OF RESULTS

Upon completion of preliminary tests on the model of the CA139 turret on 23 March 1944, a conference was held (8) (9) at the David Taylor Model Basin with representatives of the Bureau of Ships, Bureau of Ordnance, Philadelphia Naval Shipyard, and Bethlehem Steel Company for the purpose of determining the final scantlings of the turret. On a basis of the model-test results, it was agreed that the stresses were sufficiently low and that the load-carrying capacity was sufficiently high that minor reductions in scantlings might be allowed. In any case, the proposed structure was considered safe and acceptable.

The values for deflection of the trunnion blocks were adjudged to be satisfactory, and the Bureau of Ordnance did not favor any reduction in size of structural members that might decrease the rigidity of the trunnion-block supports. It was agreed that since no definite standard for the deformations of the trunnion blocks exists, these model-test results, which are to be confirmed by tests on the full-scale structure, can serve as a guide in design of turrets where some consideration must be given to allowable deformations.

CONCLUSIONS

1. On a basis of the test results and their comparison with results from tests on a model of the CA68 turret known to be satisfactory in service, the stresses and deflections of the CA139 turret are considered to be within safe limits. Better proportioning of structural members was evident in the new turret.

2. The structural models, test setup, and procedure adopted for these model tests appear to be adequate and can be employed in the future for similar investigations of elastic behavior of structures as a check on design equations, safety, and economy of distribution of material.

3. On a basis of these test results, better design criteria can be established for the stress distribution and deformations of turret structures.

RECOMMENDATIONS

In order to add to the available information concerning the accuracy of structural model tests, it is recommended that predicted prototype behavior be checked by measurements made during full-scale firing trials.

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