636

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COMPRESSION TESTS OF SHIP-STRUCTURE ASSEMBLIES

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48

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Introduction

A considerable amount of testing has been done at the U.S. Experimental Model Basin on the strength of flat plates and Tee stiffeners when loaded in compression. Tests on simple elements do not, however, reveal all the elastic interactions developed by a compound ship section, hence it appears valuable to test such structural assemblies and to check their performances against predictions based on the simple elements alone.

In a preliminary way this has been done by building to scale four structural assemblies which represent parts of typical sections of a recent destroyer and cruiser. The analysis of the test results are presented and discussed in this report.

Test Models

The models tested were scaled from plans obtained from the Bureau of Construction and Repair. The scale ratio was largely influenced by the (1) availability of the material from which to make the different scantlings, (2) the matching of the proper physical properties, and (3) the size and capacity of the testing machine. The general characteristics of the assemblies tested are given in Table I, and seen in Figs 1-14.

Fabrication of Models

Assembly of the closed section or box type models nos. 1 and 2 was originally made with both spot welding and solder; see Fig. 1. The transverse floors were flanged and provided with lightening holes, but accessibility inside the box was very much restricted; and this largely contributed to the very poor internal connections. Spot welding proved quite unreliable, tearing loose at bulges in the plate and causing the solder to shear off. When this occurred the transverse floors, in turn, became detached and thus a premature failure of the model was accelerated. Models exhibiting premature failures were subsequently repaired, however, and reinforced with arc welding and with plug welding where possible.

Assembly of the open section models nos. 3 and 4 was made with arc welding throughout. No particular difficulties were experienced here since all the connections were readily accessible for welding. Satisfactory welding was obtained with material 0.073 in. thick. The size of the bead* was kept as close as possible to the thickness of the plating, and no warping of the plate was noted.

All angles, and channels for models nos. 1, 2 and 3 were formed by bending

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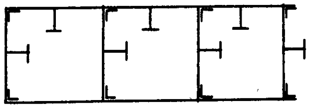
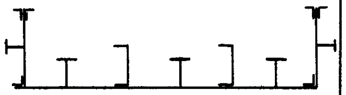
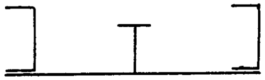
*Thickness through throat.

TABLE I

Model No.	Ship	Section	Scale Ratio	Material	Overall Length in.	Total Width in.	Method of Assembly
1	Light Cruiser CL46-48	Same as in Model No. 2 Length covers 3 belt frame spacings. Double bottom in way of machinery space. Longs. No. 1 to No. 4.	1:3.65	Furniture Steel t = .05" t = .079" t = .083" Mild Steel t = 0.184"	75.0	35.4	Tee stiffeners soldered to inner bottom plating and longitudinals. Transverse floors were flanged and soldered. Angles spot welded to longitudinal plates. Reinforced later by continuous arc welding at the 4 corners and plug welding at angles.
2	Light Cruiser CL46-48	 Length covers distance between two bulkheads in way of machinery space.	1:6.30	Furniture Steel t = .045" t = .033" t = .109"	78.0	21.0	Same as above. No reinforcement was applied to this model.
3	USS MAHAN DD364	 Midship section from Long. No. 2 to Long. No. 5. Length covers 3 transverse belt frame spacings.	1:2.25	Furniture Steel t = .073" t = .109"	71.4	35.1	Intermittent chain welding on the Tee stiffeners, angles and channels. The backs of the angles were joined with continuous arc welding.
4	USS MAHAN DD364	 Midship section from Long. No. 3 to Long. No. 4. Length 1 ft. less than 1 belt frame spacing.	1:1	Mild Steel t = 1/4" 9" x 2-7/16" x 13.4 lbs. [	72.0	27.0	Continuous arc welding throughout.

flat sheets. The Tee sections were assembled by soldering. The members in model no. 4 were rolled sections.

Method of Testing

After assembly, the loaded ends of the models were machined parallel. For testing, soft aluminum bearing plates were placed between the ends of the models and the heads of the testing machine. This helped eliminate the effects of end irregularities and made the load distribution more nearly uniform. The models were placed so that the gravity axis of the section coincided with the center line of the testing machine.

Longitudinal and transverse strains were measured at different loads. Normal deflections of the plating were measured also at 1 in. intervals along the longitudinal center line.

The open section, model no. 3, as seen from Fig. 10 was supported by means of angle bars at two points whose distance apart represents the transverse belt frame spacing. This type of support establishes points of inflection corresponding somewhat to those induced by the actual transverse belt frames.* In the closed section, box type models nos. 1 and 2, no external support was necessary because here the points of inflection were determined by the transverse diaphragms or floors equally spaced; see Figs. 4 and 6. Model no. 4, which represents a full scale section (Fig. 13) was tested with flat ends, the heads of the testing machine furnishing the only transverse support.

Results and Discussion

The test results are given in Table II. It is to be noted that for the open type sections, models nos. 3 and 4, the maximum load at failure agrees with the predicted value within 1 per cent. This is an unusual case; ordinarily estimates within 5 per cent are all that can be reasonably expected. (See Appendix for detailed computation). The box type sections, models nos. 1 and 2, however, show very large discrepancies which can be explained only by faulty connections at the longitudinals resulting in inadequate support of the plating.

The predicted load is computed by calculating the loads carried by each panel on the basis of the average stress as taken from Fig. 12a** and adding these to the loads carried by the Tee stiffeners as computed on the basis of Figs. 4&5 of EMB Report No. 445.+ This is permissible since the Tee stiffeners used in these assemblies

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* Because of the limited height of the testing machine, the upper and lower bays of this model were made shorter than the middle in order to keep the correct scale ratio for the middle bay.

**Supplement to Progress Report No. 2, "The Strength of Hull Plating under Compression."

+ The Ultimate and Critical Compressive Strength of Tee Stiffeners.

TABLE II

Model No.	Ship Section	Area Section sq. in.	Max. Load Obtained lbs.	Average Stress at Failure lbs/sq. in.	Yield Stress of Material lbs/sq. in.	Predicted Max. Load lbs.	Ratio of Observed to Predicted Load
1	Light Cruiser CL46-48	14.37	317000	22000	33 to 47000	437000	.73
2	Light Cruiser CL46-48	5.20	131000	25200	38000	151000	.87
3	USS MAHAN DD364	8.45	292000	34600	36 to 40000	294000	.99
4	USS MAHAN DD364	15.56	572000	36700	40000	576000	.99

were stable and had sufficient rigidity to support the plating adequately. The assumptions in this method of computation are that the individual panels are simply supported at the longitudinal edges by stiffeners of adequate stability and rigidity, and that the load carrying capacity of each simple element remains the same whether it is tested alone or in combination with other structural elements. Recent tests with stiffened plates tested together tend to show that the error from these assumptions is negligible for narrow panels, (b/t = 60). With wider panels the elastic interaction between stiffener and plate, however, may be appreciable and this effect is being studied experimentally at present. Estimates of the ultimate predicted loads are not made on nominal quantities, but rather on the actual yield point and thickness of material used in the structural assembly, these values being determined by physical tests.

In interpreting the results from models nos. 1 and 2, it must not be inferred that these assemblies cannot develop more than the load given in Table II. The discrepancy between actual and predicted loads is very large, but a plausible explanation can be found in the fact that the premature failures of these models left the internal structure in a badly damaged condition which weakened the whole assembly. The attachment of the double bottom longitudinals was never regarded as satisfactory in either model no. 1 or no. 2.

The results of these tests indicate that if the elements of the structural assembly are adequately attached, as in models nos. 3 and 4, the load carrying capacity of the assembly can be closely predicted by summing the load carrying capacity of the individual elements. The correctness of this estimate depends, however, upon the knowledge of the division of load between the panel and stiffener. As indicated earlier, this division is being experimentally investigated.

The analysis of the strain and deflection data will not be included in this report because it is planned to report later on the general question of stress distribution. Omission of this analysis here does not affect the most important conclusions of the tests.

Modes of Failure

Model No. 1

This model represents a section of the double bottom of light cruisers CL46-48, in way of the machinery space, including longitudinals nos. 1 to 4. The scale ratio was 1:3.65, and the length was equivalent to 3 belt frame spacings. The model was salvaged twice and tested three times. Figures 2 to 5 show the different phases of the test. In the first test the spot welding at the corners and at the inside angles joining the longitudinals to the outer bottom plating gave away at a load of 210,000 lbs., damaging the internal structure. The model was subsequently repaired by running a bead of arc welding at the corners and by plug welding the angles of the longitudinals to the shell plating for the middle 3/4 length; see Fig. 3. The remainder of the length was tack welded from the inside through the lightening holes of the transverse floors. Holes were cut in the shell plating to straighten and reinforce some of the damaged internal structure, after which the cut out section was welded into position as shown in Fig. 2. This repair work, however, was unsatisfactory because when the model was tested the second time (see Figs. 2 and 3), the buckles of the plate were not stopped at the longitudinals but actually extended over them. In this second test the model carried an ultimate load of 303,000 lbs. The assembly was then further salvaged by cutting off one end of it which was in good condition; see Figs. 4 and 5. The salvaged portion represented a length equal to two belt frame spacings and was internally subdivided by two transverse floors. The ultimate load carried was 317,000 lbs. The final test was not considered satisfactory since the plate buckles were not stopped within the width of the panel, as shown by Fig. 5.

Model No. 2

This represents the same section as model no. 1 but with a scale ratio of 1:6.30. The equivalent length corresponds to the length between two bulkheads in way of the machinery space. The model was tested three times, in each test the total length being different. Spot welding was used throughout in assembling the longitudinal members except in the Tee stiffeners which were attached with solder. The first failure occurred at a load of 110,000 lbs., and as seen from Fig. 6, the longitudinals stood up much better than the intermediate Tee stiffeners. The solder used to join the Tees to the inner bottom tore loose, and the stiffeners became ineffective. This is evidenced by the deep bulges which spanned the Tee stiffeners and which were stopped only at the longitudinals. The lower half of the model, not having shown any signs of failure, was cut off and prepared for test as shown in Fig. 8. At a load of 127,000 lbs., the spot welding tore loose at the corners, and the test was discontinued. A remaining piece was again salvaged and tested as shown in Fig. 9. The model here still represented a length equal to three belt frame spacings, and was internally subdivided by two transverse floors. In this final test, the model failed at a load of 131,000 lbs, and its performance cannot be regarded wholly satisfactory. Some panel buckles were stopped within the width of the panel, while others were carried across the longitudinals. Local tearing of the solder in some of the Tee stiffeners was a secondary effect, being induced only after pronounced bulges had appeared.

Model No. 3

This model represents the midship section of the U.S.S. MAHAN from longitudinal no. 2 to no. 5, corresponding to a length of 3 belt frame spaces. The scale ratio was 1:2.25. This model, mounted in the machine ready for testing, is shown in Fig. 10, and the details of construction are more clearly seen in Fig. 11. The performance of this model was satisfactory. Failure took place at the middle bay, the plate bulging alternately in and out, with each bulge stopping at the longitudinal stiffeners; see Fig. 11 and 12. The Tee stiffeners retained their shape and did not bend over. Local wrinkling, however, developed at the web and flange in line with the bulges in the shell plate. One of the channels bent over but the transverse frame prevented the bending from extending into the other bays. The unsupported length between welding fillets caused local wrinkling. The small intermediate Tee stiffeners attached to the deep webs of the built-up longitudinals, nos. 2 and 5, effectively supported the deep web plates.

The type of support used with this model offers high resistance to normal displacement at the points of support, but negligible torsional rigidity. The middle bay with six panels, therefore, becomes elastically supported both in length and width and is practically free from the unknown restraining effects present at the loaded ends. This makes the structure more nearly comparable with the actual ship under compressive loading.

Model No. 4

This model represents to full scale the midship section of the U.S.S. MAHAN including longitudinals no. 3 and no. 4, except that the length is 1 ft. less than one belt frame spacing. The test was satisfactory, and the same general type of failure was noted here as in model no. 3; see Fig. 14. The intermediate Tee stiffener effectively supported the plating, dividing it into two separate panels. Bulging of the panels was alternately in and out. At high loads, however, there was visible deformation of the Tee and the channels, with the channels giving evidence of "laying over" before the web plate of the Tee stiffener buckled locally.

Although this model was 1 foot shorter than the actual frame spacing of 7 feet, it is believed that this discrepancy in length has no appreciable effect on the ultimate load carried.

Conclusions

The conclusions from these tests are grouped into two headings: specific and general. Specific conclusions are derived from the experimental tests proper, while general conclusions are derived mainly from the design features of the ships from which the structural assemblies were scaled.

Specific

1. Models nos. 3 and 4, which were assembled with arc welding, developed an ultimate average stress that is in very good agreement with the plate strength predicted from Fig. 12A of the supplement to Progress Report No. 2. The average collapsing stress of the models was close to 90 per cent of the yield stress of the material.

2. In constructing future box type models, the elements of the structural assembly should be securely attached with electric arc welding or riveting. Solder and spot welding have proven unreliable for operations in inaccessible quarters.

3. Continuous arc welding should be preferred to intermittent welding in order to prevent local wrinkling between increments. Such failures were noted on model no. 3.

General

1. The designs tested and reported here are considered adequate for longitudinal compressive strength. With effective attachment of the stiffener to the plating, and proper width of plating ($b/t = 60$) the structure can develop very high compressive stresses. Reducing the panel width to $b/t = 50$ would increase the panel strength about 10 per cent. The effect of hydrostatic loading on the plating has not been considered here.

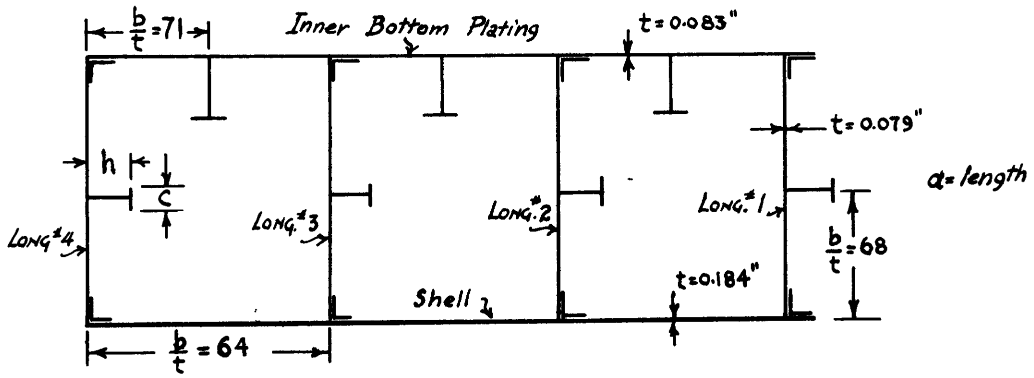
2. The total compressive load carried by structural assemblies of the type tested can be very closely predicted from laboratory tests on simple elements – flat plates and stiffeners.

3. All Tee stiffeners, including the small ones attached to the double bottom longitudinals nos. 1 to 4 of models nos. 1 and 2, are sufficiently stable and rigid to support the panels adequately.

4. Channel sections, being unsymmetrical, tend to "lay over" more readily than Tee sections when loaded in compression. These unsymmetrical sections could be safely replaced by Tee stiffeners of less weight and equal effectiveness.

APPENDIX

The method of arriving at the estimated ultimate compressive load that a structural assembly will carry is illustrated in the following example. Model no. 1 here has been considered in detail. Similar procedure was followed in ascertaining the predicted maximum loads given in Table II.



Note that no allowance is made for the angles in reducing the b/t ratios of the panels. The tests indicated that no such reduction is permissible, as wrinkling extended over the full panel width between the webs of the longitudinals. Since the edges of the panels are stressed to the yield at failure, the angles are considered loaded to the yield stress also. The strength of the Tee stiffeners is taken from E.M.B. Report No. 445, and the strength of the plating is taken from Fig. 12A of Supplement to Progress Report No. 2. The analysis is tabulated in Table III.

TABLE III

Scantling	Number	Dimension	Yield stress lbs. per sq. in.	Area of scantling sq. in.	Strength of plating from Fig. 12A lbs/sq. in.	Load carried by panels lbs.	Strength of Tees from E.M.B. Report No. 445 lbs/sq. in.	Load carried by Tees and Angles lbs.
Shell plating	3 panels	b/t = 64	46600	6.52	35000	228000		
Inner bottom plating	6 panels	b/t = 71	33000	2.93	24000	70400		
Longitudinals no. 1–4	8 panels	b/t = 68	33100	3.38	25500	86300		
Tees on inner bottom	3	h/t = 46 c/t=16.8 a/h = 10	34000	0.47			34000	16000
Tees on Long. No. 1–4	4	h/t = 22 c/t=12.4 a/h = 21	34000	0.344			34000	11700
Angles*	8	1.0"x.8" x .05"	34000	0.72				24400
						384700		52100
						52100		
				14.36	Total load	436800 lbs.		

*Assumed stressed to yield point.

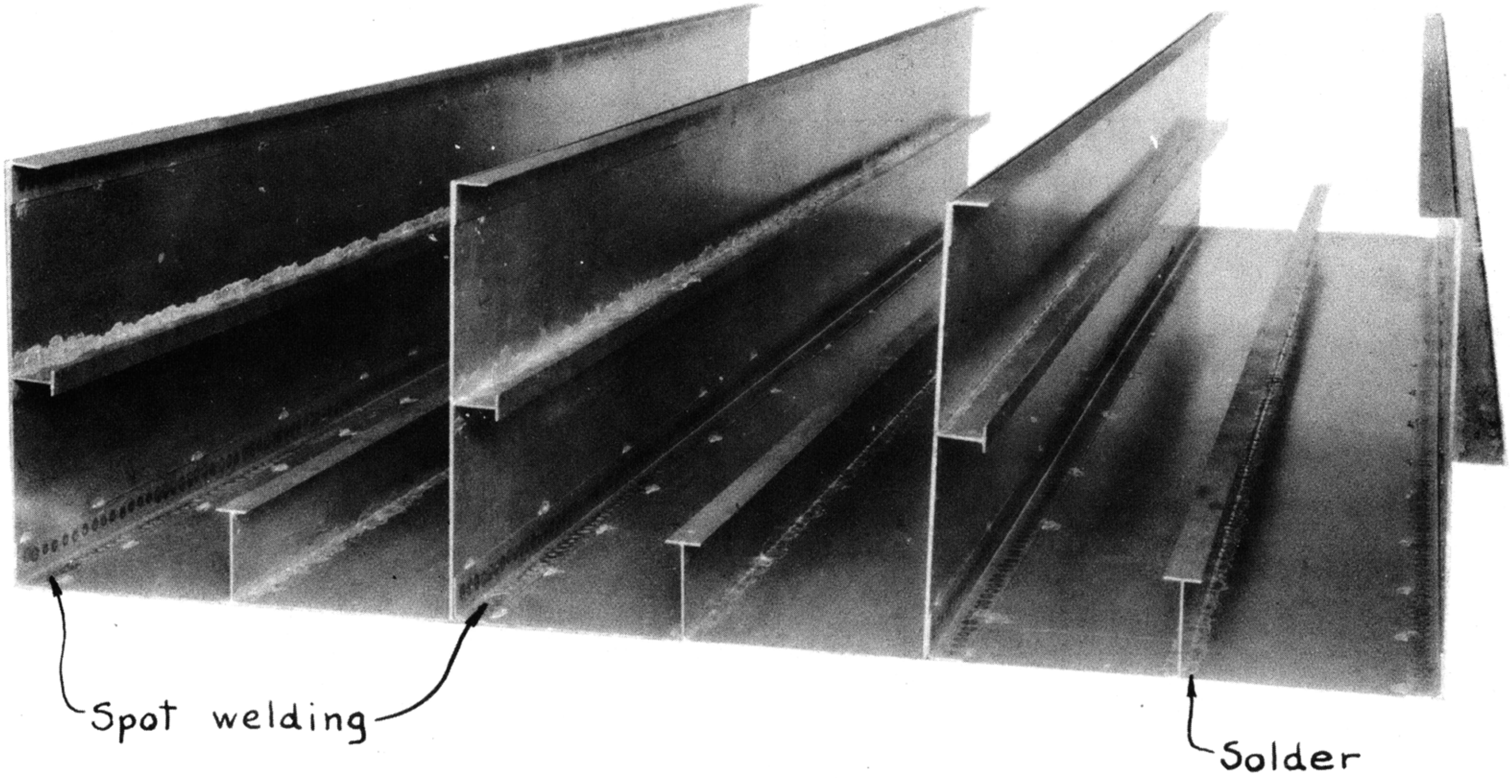
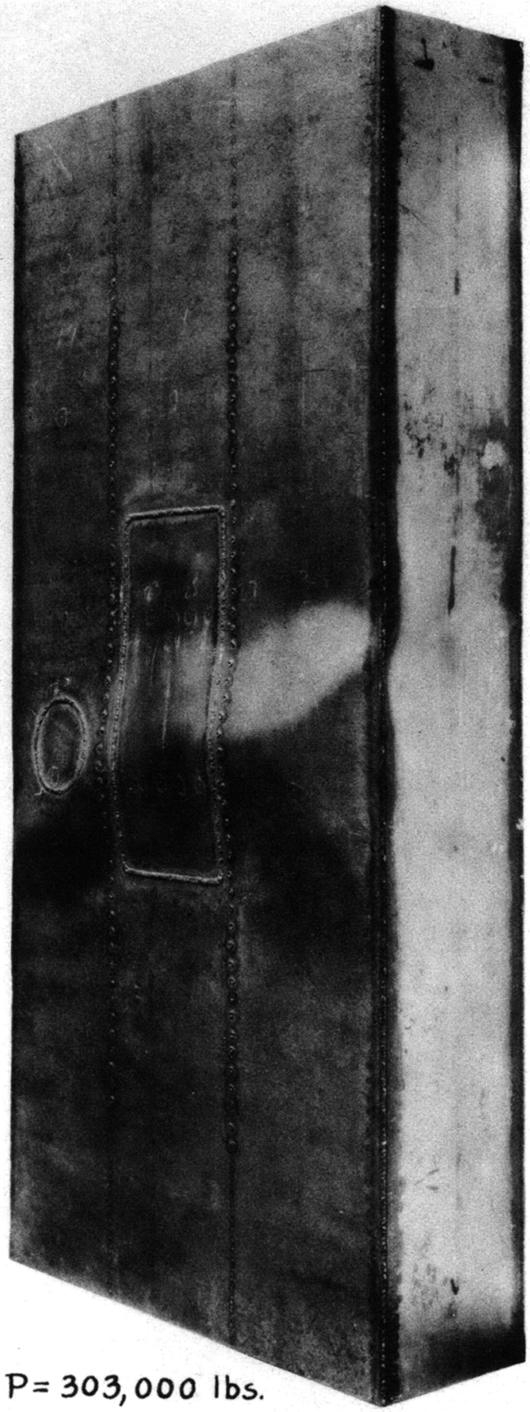


FIG. 1

Model No. 1 – Process of Fabrication

View of Longitudinals and Inner Bottom Plating

Scale 1:3.65



P= 303,000 lbs.

FIG. 2

Model No. 1

View of Shell Plating   Patched after Premature Failure

Damaged Internal Structure

Scale 1:3.65

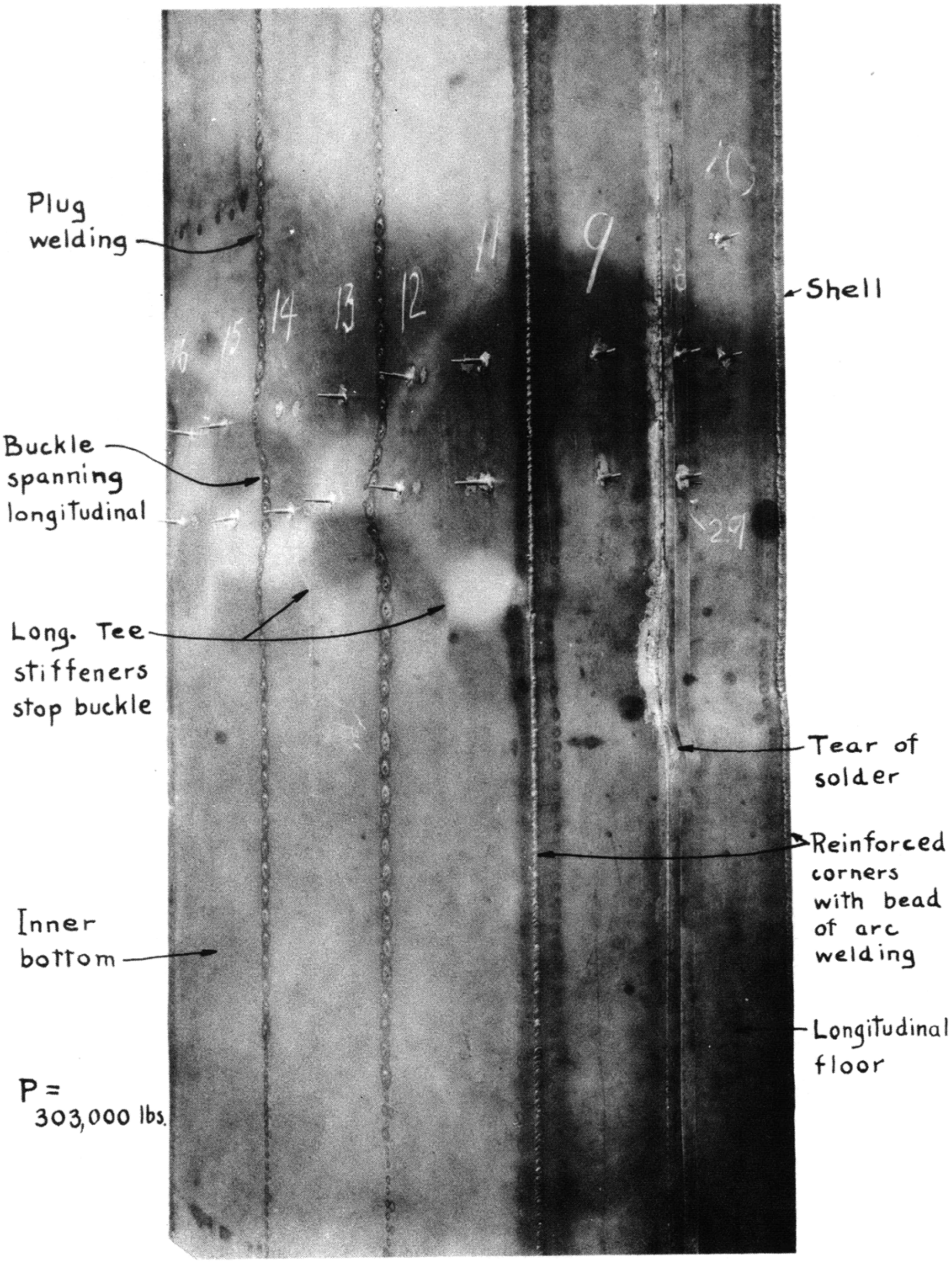


FIG. 3
Test Model No. 1 after Reinforcement
View of Inner Bottom Plate Buckles
Scale 1:3.65

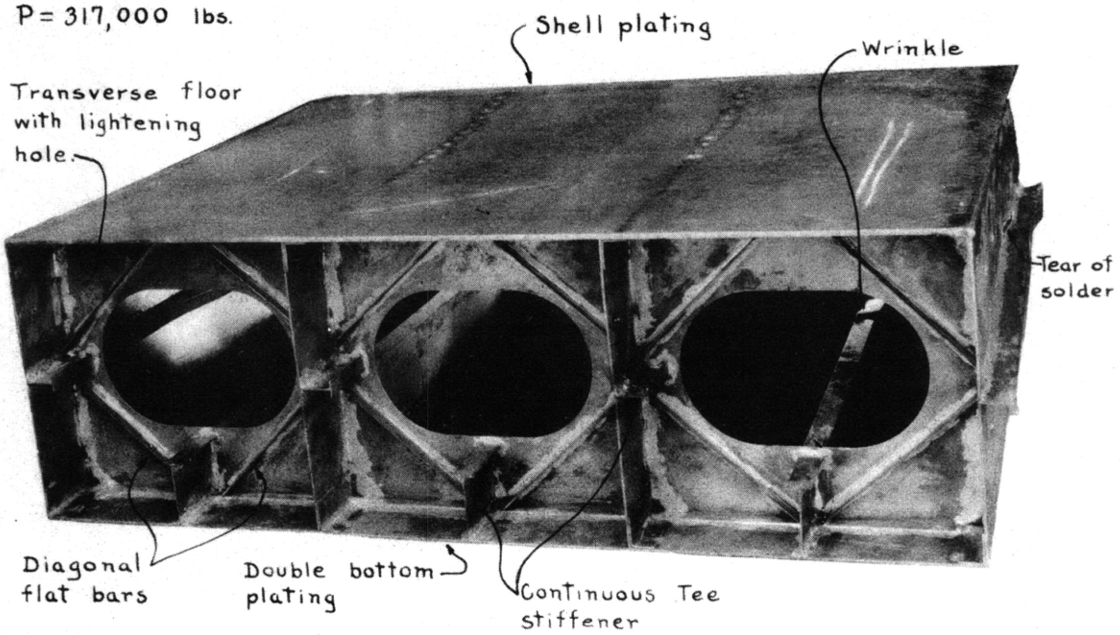


FIG. 4

Part of Model No. 1 (Salvaged and Retested)

Scale 1:3.65

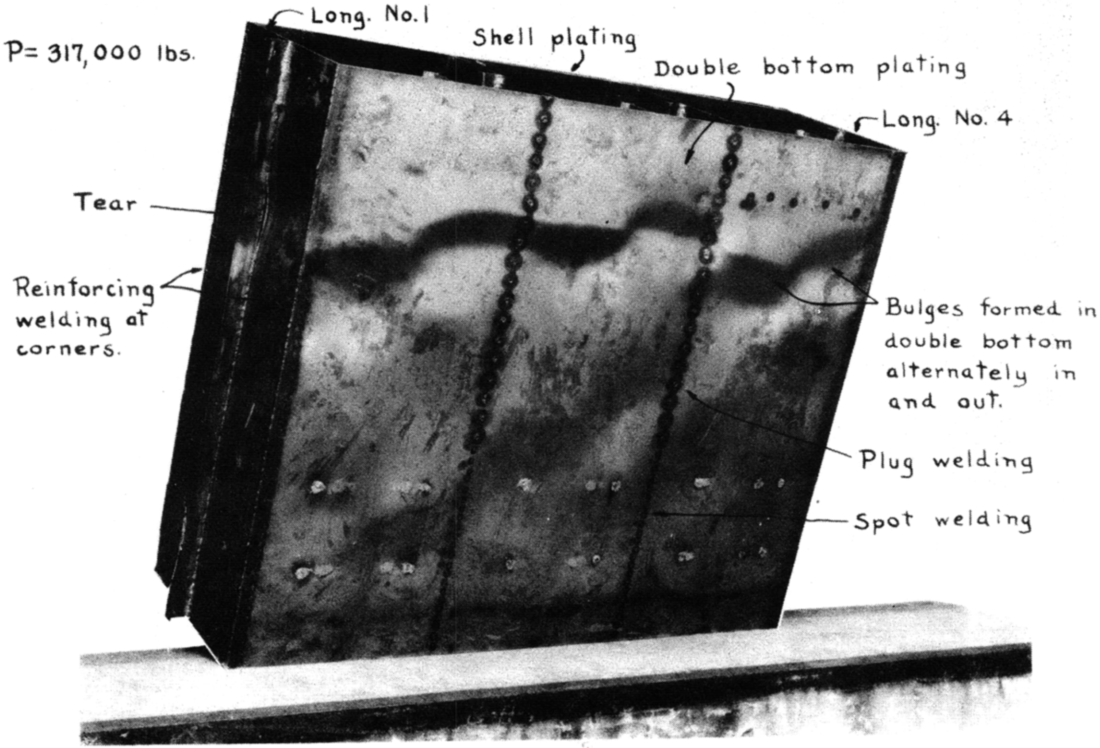


FIG. 5

Part of Model No. 1 (Salvaged and Retested)

Scale 1:3.65

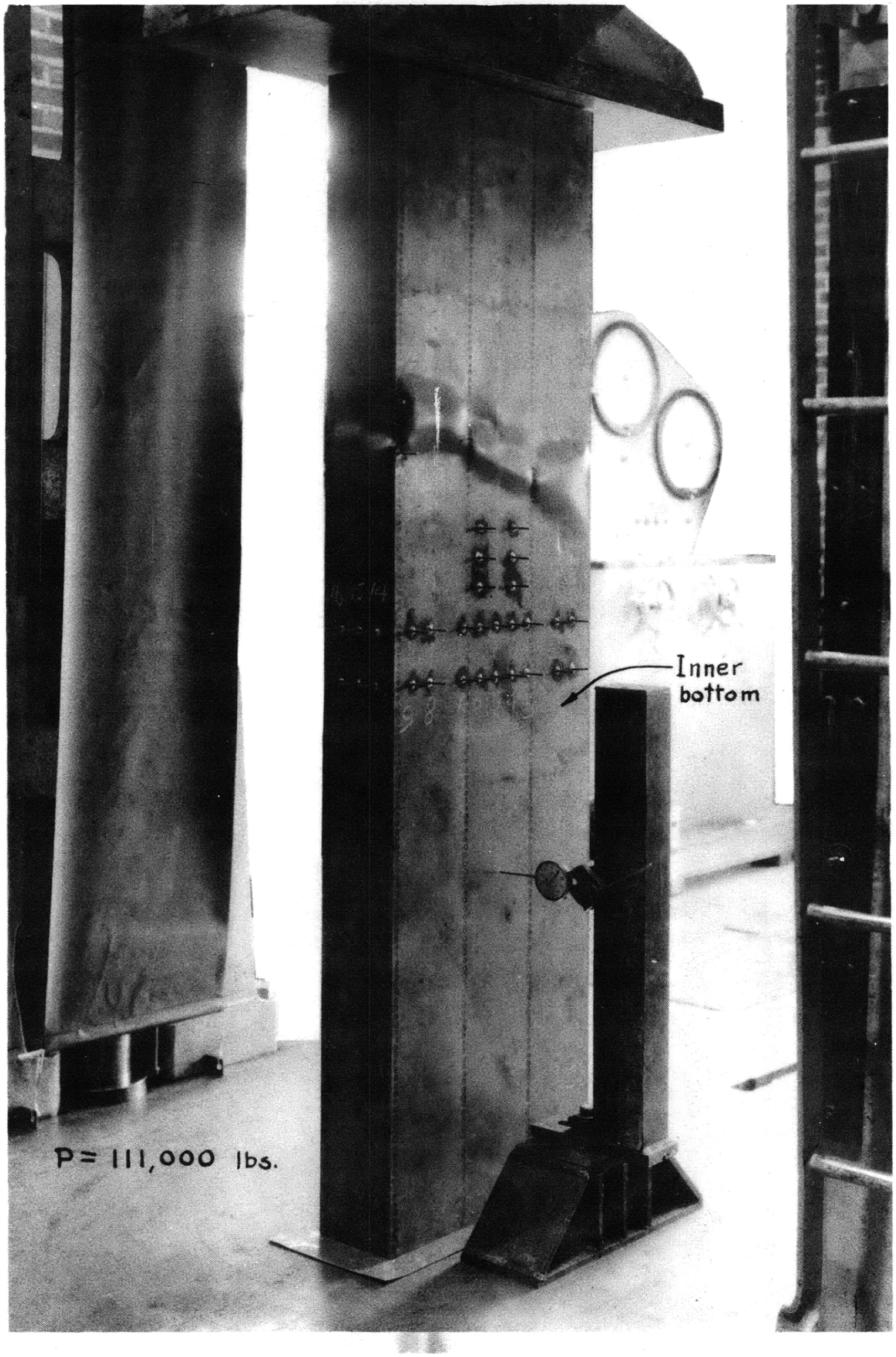
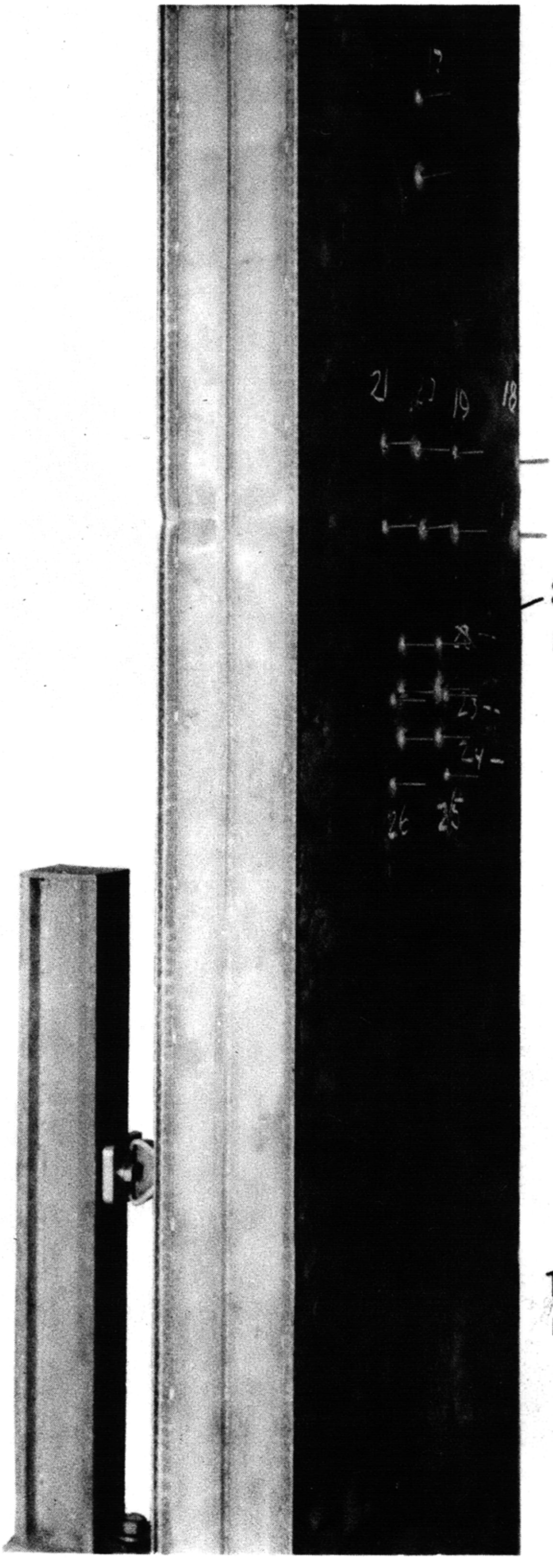


FIG. 6
Model No. 2 - Scale 1:6.30



Shell plating

P= 111,000 lbs.

FIG. 7
Model No. 2 – Scale 1:6.30

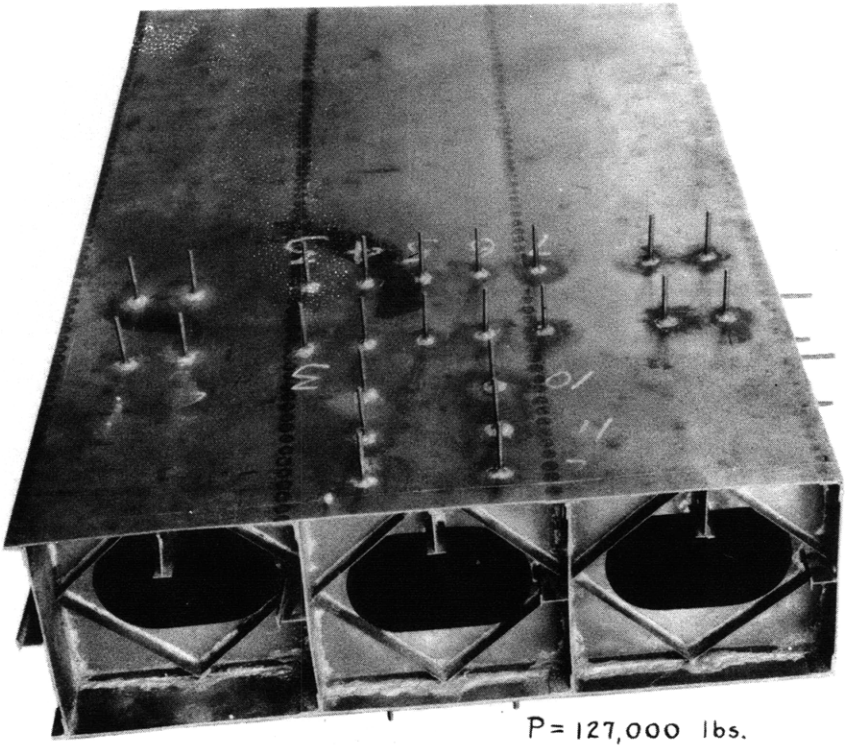


FIG. 8
Part of Model No. 2 – Top View (Salvaged End Before Test)
Scale 1:6.30

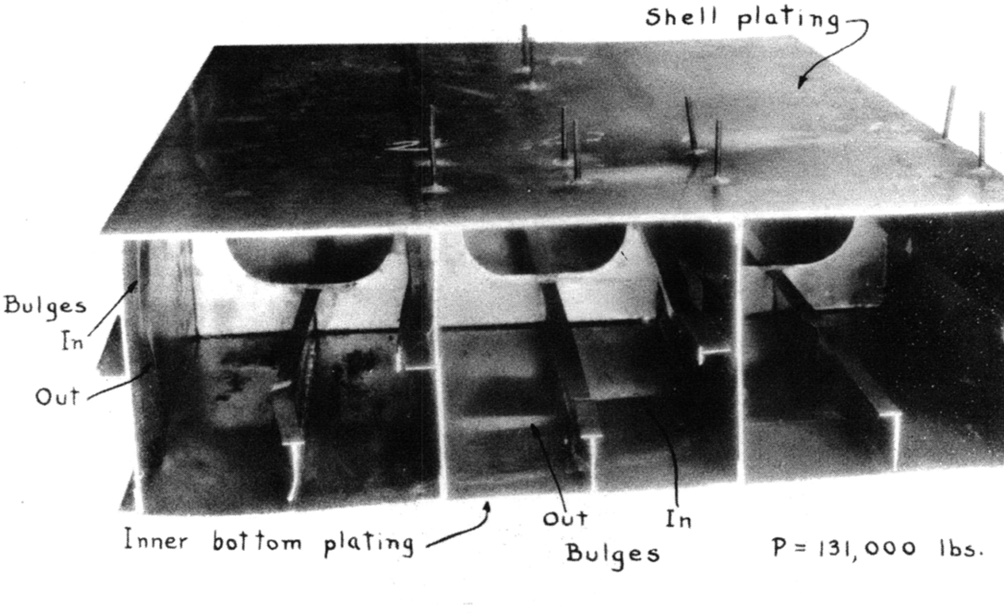


FIG. 9
Part of Model No. 2 (Salvaged End)
Scale 1:6.30

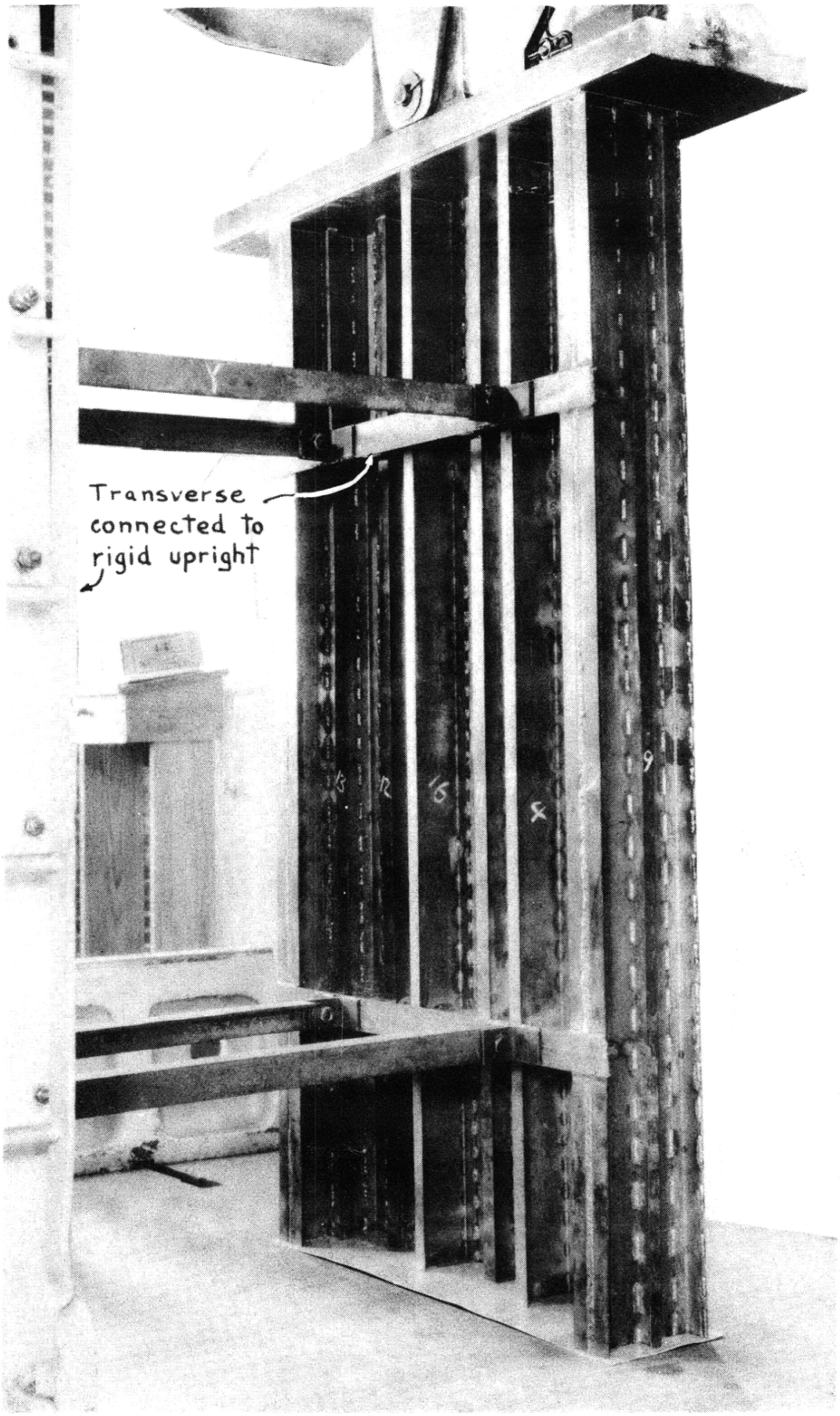


FIG. 10
Model No. 3 - Ready for Test
Scale 1:2.25

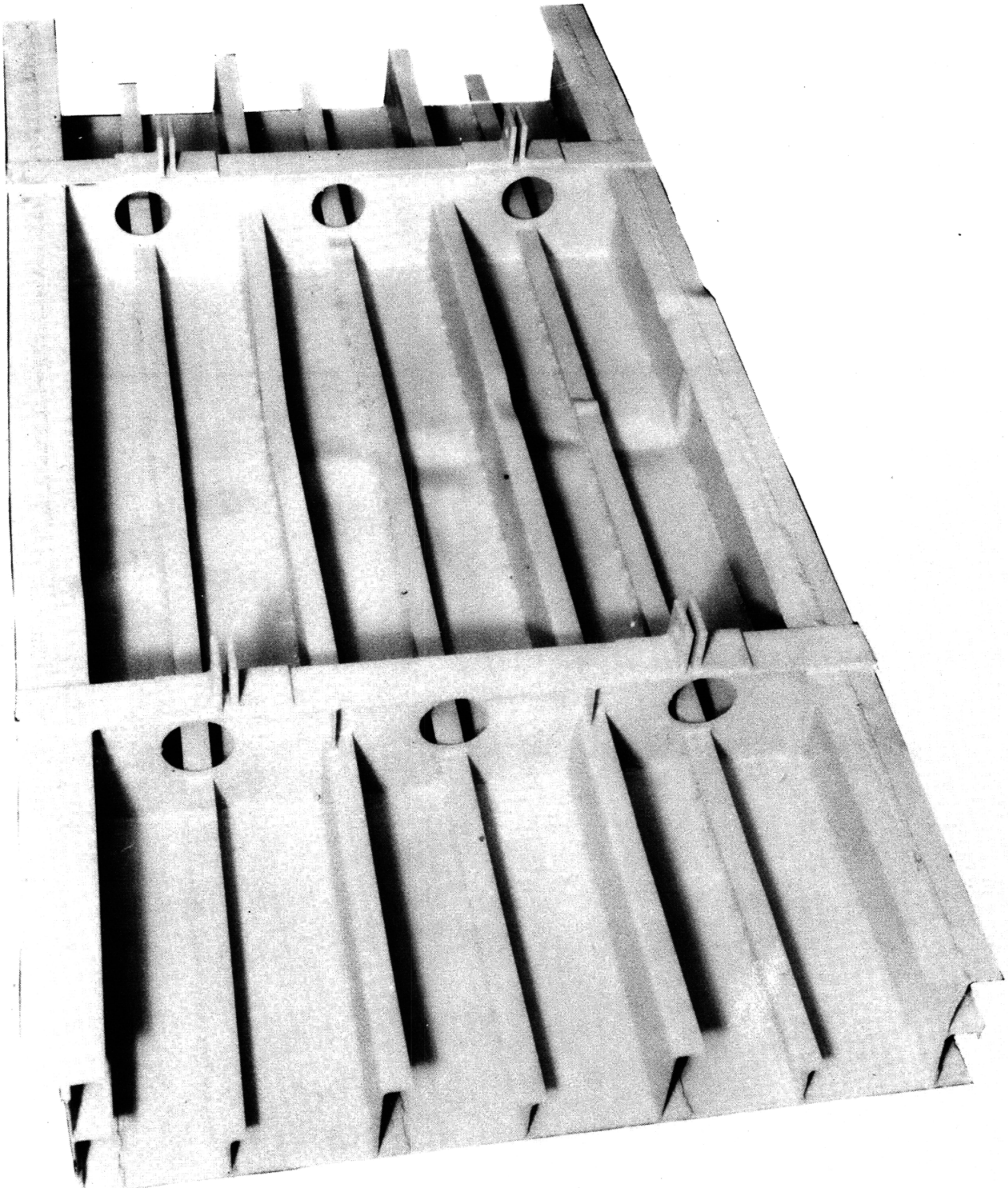


FIG. 11
Model No. 3 – Inside View
Scale 1:2.25

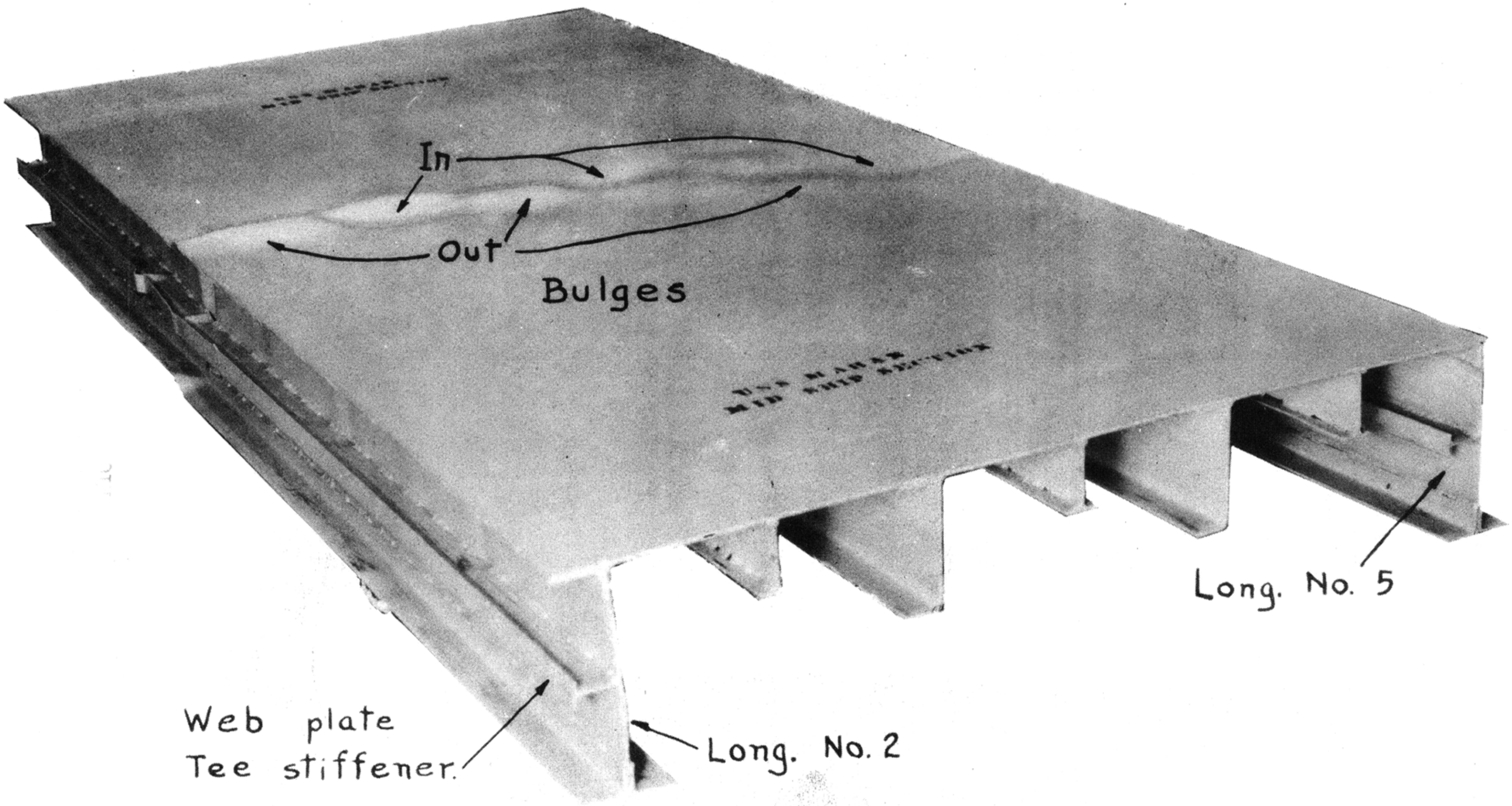


FIG. 12
Model No. 3 – Outside View
Scale 1:2.25

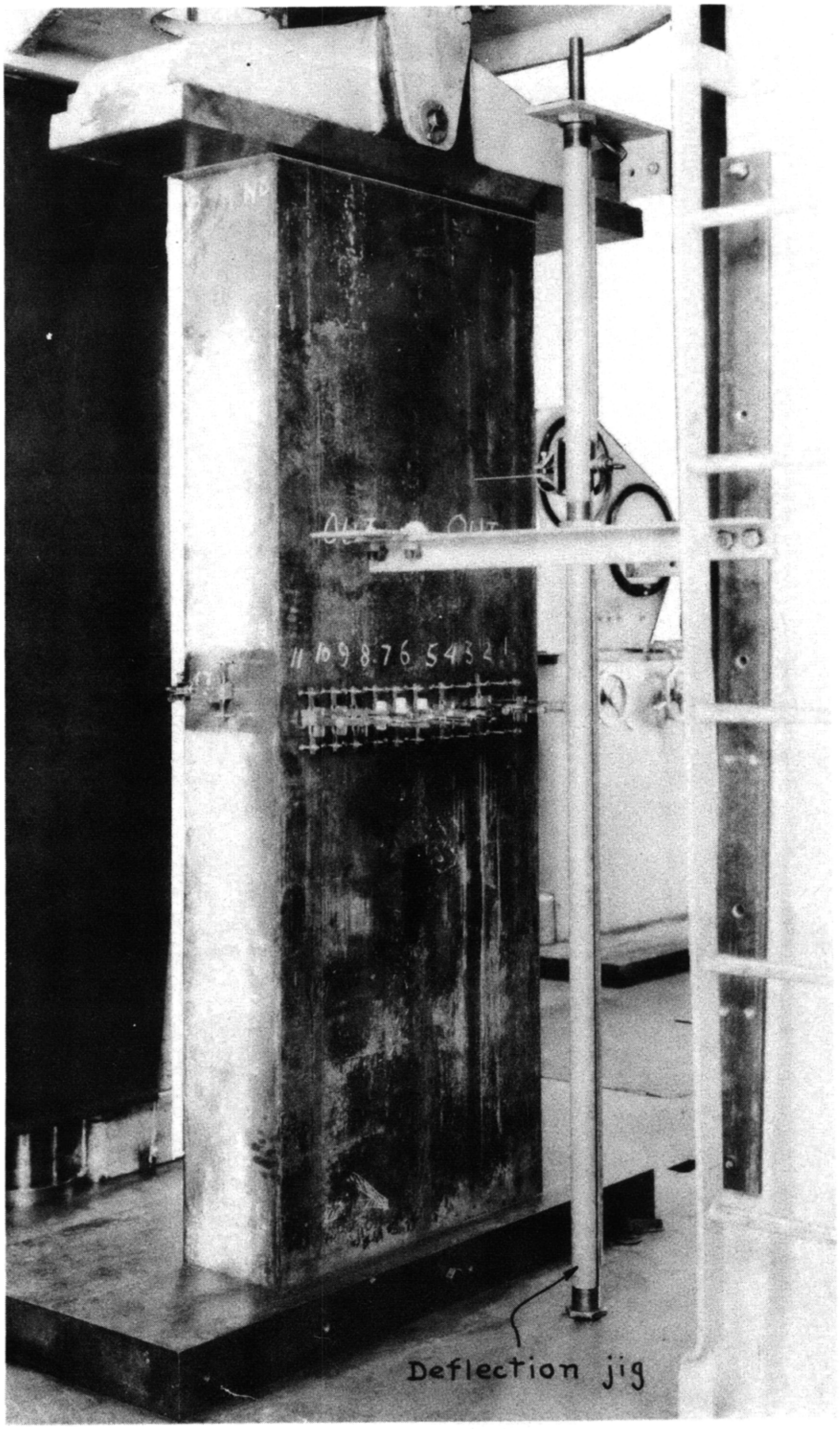


FIG. 13

Model No. 4 – Back View Ready for Test

Strain Gages Attached

Full Scale

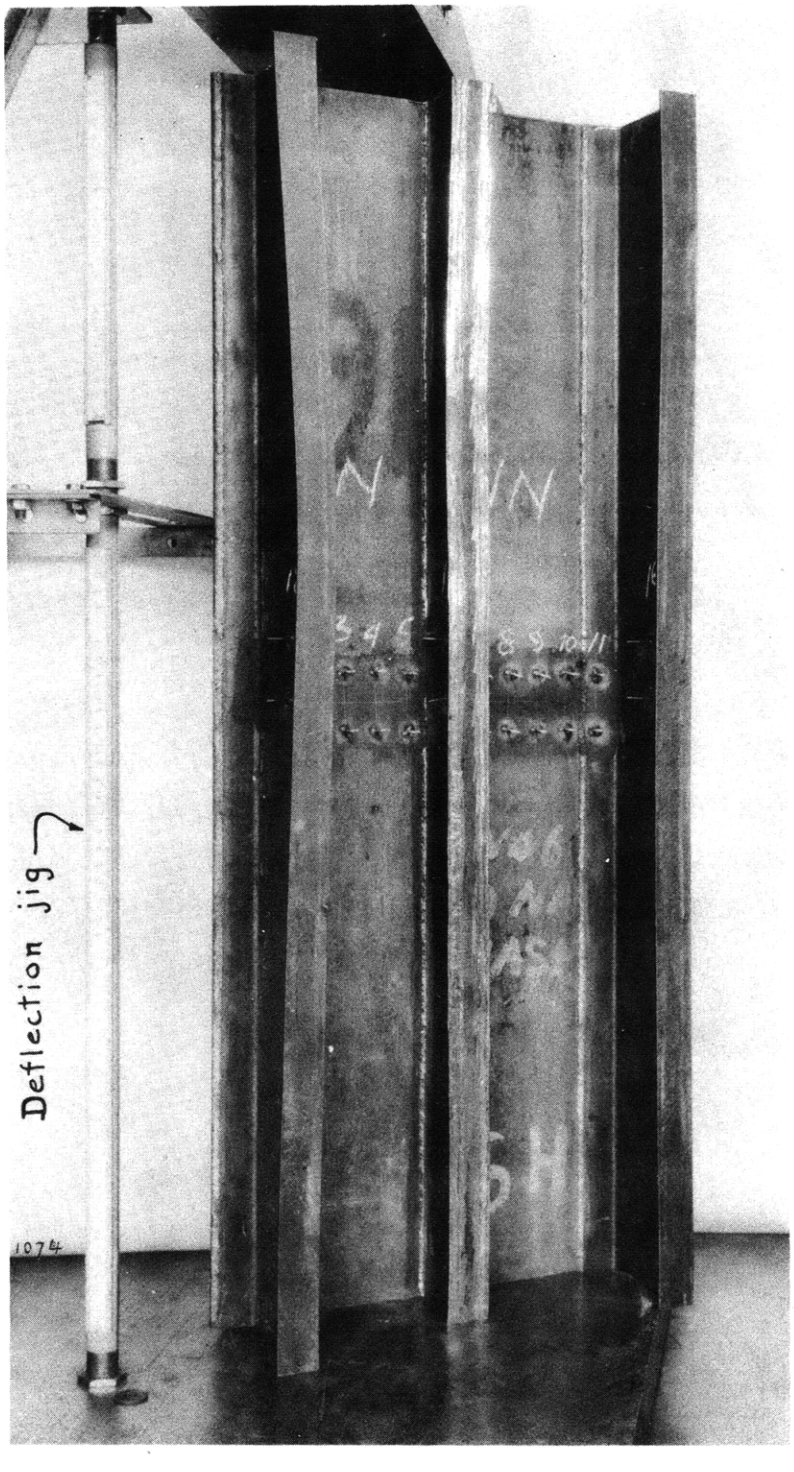


FIG. 14
Model No. 4 – Front View – Model Failed
Full Scale