SERIAL NO. SSC-67

FINAL REPORT

(Project SR-121)

on

MODEL TESTS ON HULL-DECKHOUSE INTERACTION

by

LYNDON CRAWFORD and WILLIAM J. RUBY

Reed Research, Inc.

Under Bureau of Ships Contract NObs-54509

(BuShips Project NS-731-034)

for

SHIP STRUCTURE COMMITTEE

Convened by

The Secretary of the Treasury

Member Agencies—Ship Structure Committee

Bureau of Ships, Dept. of Navy
Military Sea Transportation Service, Dept. of Navy
United States Coast Guard, Treasury Dept.
Maritime Administration, Dept. of Commerce
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Address Correspondence To:

Secretary
Ship Structure Committee
U. S. Coast Guard Headquarters
Washington 25, D. C.

SERIAL NO. SSC-67
BuShips Project NS-731-034

JANUARY 17, 1955

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ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

January 17, 1955

Dear Sir:

As part of its research program related to the improvement of the hull structure of ships, the Ship Structure Committee sponsored an experimental investigation at Reed Research, Inc., Washington, D. C., to verify theoretical studies of the contribution of a ship's superstructure to the strength of the hull girder. Herewith is a copy of the Final Report, SSC-67, of the investigation, entitled "Model Tests on Hull-Deck House Interaction" by Lyndon Crawford and William J. Ruby.

Any questions, comments, criticism or other matters pertaining to the Report should be addressed to the Secretary, Ship Structure Committee.

This report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Yours sincerely,

K K Cowart

K. K. COWART
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

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ABSTRACT

Purpose: To check a theory and formula proposed by H. H. Bleich on stress relationship of hull and house for vessels fitted with long deckhouses. Theory based upon concept of separate house and hull bending. Interaction strongly dependent upon vertical stiffness of support of house.

Program: Nine tests performed upon a single 20-ft. aluminum model with three separate houses, fitted for simple variation of underdeck stiffness.

Model: Hull of double-cell construction, connected by fitted bolts and high-torque bolts. Houses 160 and 80 in. in length. Demountable main deck equipped with simulated deck beams. Design based upon proportionality of elastic action of ships and model. Midship proportions in general conformance with passenger vessel practice. Range of Bleich u value for nine tests representative of ship values to be expected. Model loaded to give constant hogging moment throughout length of house.

Discussion.

Discussion supported by results in the following categories:

Midship Stresses:

(i) Distinct agreement of test and theory for standard deck beams (2-in. spacing) and for heavily bulkheaded long houses.

(ii) With outsize deck beams (at 14-in. centers), house shirked predicted stresses.

(iii) Extra high stresses (in excess of Navier formula) clearly observed at house top for cases

with bulkheading heavily concentrated amidships.

(iv) Short house, even with extensive bulkheading, showed incomplete participation with main hull.

Deviation Factor: Graph of Φ, based on measured strains and calculated u values, shows rather good correlation with theoretical curve at extreme values of u, but considerable scatter at median values.

Deflections: Counter-flexure pattern clearly shown for houses with flexible vertical support at the main deck.

Longitudinal Variation of Stresses: For stresses in the housetop, fair correlation between theory and experiment shown, with the zone of "midship effectiveness" fairly well maintained in the midship half length of the long houses.

Longitudinal Connecting Shear: Most plots do not show expected peaking of values at house ends. Average value of shear markedly increased, for all houses, with increase of vertical rigidity.

Overall Stress Patterns: Slight rise shown in main deck stress level toward house ends. Some non-linearity of hull bending adjacent to loading bars may be reason for no greater increase.

Shear Lag and Deck Bending: Complex pattern of stresses on main deck observed, but distinct trends with varying test conditions discernible. Both shear lag and plate bending believed to have been present.

Principal Stress Patterns: Rosettes fitted to house sides--particularly at ends--did not show clear trends. Sharp fluctuations appeared at extreme ends. Considerable biaxial stress prevailed.

Conclusions.

The essential theory proposed by Bleich is believed to be correct for cases of relatively uniform foundation modulus--applicable to midship half-length of house.

The proposed averaging process for deck stiffness is somewhat questionable in view of results in the sensitive, middle range of u. It is believed further that more elaborate stiffness tests should be made before drawing a firm conclusion.

Multiple, lateral bulkheading well connected to house invites full participation of longer houses as predicted.

Connection between house and vertical supports could be made more complete than in some cases observed on shipboard.

Moderately localized "extra stress" is a real possibility with concentrated bulkheading amidship.

Present test technique is believed to be very useful in gaging effects of major design practices.

<u>Recommendations for Further Study</u>:

More tests believed necessary to validate theory completely. Applicability of proposed formula to actual ships still in question.

Following specific needs pointed up:

(a) Test study to determine foundation stiffness for realistic structures, particularly widely spaced stiff structures.

(b) Application of parabolic bending moment.

(c) Analytical studies on isolated bulkhead effect, variable moment of inertia, hull shear stiffness, variable foundation stiffness.

(d) Correlation of full-scale ship tests and model tests, with snalytical predictions.

(e) Studies of specific shipboard practices: expansion joints; house-end shear reinforcement and vertical support.

(f) Study of short erections.

Auxiliary Tests.

Fasteners. Series of high-torque bolted plates tested in special test rig. This showed slippage to occur all at once as "yield" type action. Factor against slippage considerably more than two in model design. Spot checks throughout testing showed no slip.

Stiffness. Various conditions of the deck framing system below house tested by loading along line of house-hull intersection, measuring difference between deflections of hull sides and line of house sides. Results:

Standard Deck Beams. Appeared much stiffer than predicted, with load applied to single beam. Results believed misleading due to excessive fore-and-aft stiffness of deck sheet.

Outsize Deck Beams. Very good correlation with predicted stiffness.

Partial Transverse Bulkheads. Actual stiffness much less than that predicted.

Bare Hull Tests.

Stresses and deflections correlated with simple beam theory.

Test Rig.

Test performed within double, longitudinal truss rig. Constant bending moment applied by twin equalizers, loaded by center screw jack. Each equalizer pivoted off transverse at end of truss. Vertical loads at each end of model applied by flat bars hung from twin transverse yokes attached to fore-and-aft equalizers. End loads from model taken off through pin connections to twin channels separating the two trusses at lower ends of rig.

Instrumentation:

Dynamometer. Calibrated tensile test specimen equipped with two SR-4 strain gages in series below screw jack. Total load and loading symmetry at four load points checked very well during tests.

Strain Gages: Type A-1 gages and AR-1 gages (rosettes) used; gave excellent performance as to linearity and drift.

Dial Gages: Lines of gages along both house and hull sides showed good performance.

I. INTRODUCTION

The most significant finding of the structural tests on the passenger vessel S.S. "President Wilson" was the unusual transverse distribution of longitudinal bending stresses--particularly in the midship area. When a longitudinal bending moment was statically applied to the vessel, a plot of stresses in the midship area showed a straight-line distribution from the bottom of the hull to the promenade deck. At this deck the principal longitudinal bulkheads of the superstructure* were transversely recessed from the sides, and above this deck the stresses diminished approximately linearly to the navigating bridge level--the topmost significant deck. The detailed results of this test series were reported in References 2 and 3. Theoretical studies to explain the above action are contained in References 4 and 5. The present report concerns a model-test program to check the validity of a general formula developed by Bleich in Reference 4.

The theoretical work ascribes the non-linear stress distribution to a semi-independent beam action of hull and superstructure. Because of the flexibility of the support of the longitudinal bulkheads of the superstructure, it is presumed that the house can deflect somewhat differently from the main hull. Under this presumption the house receives longitudinal shearing forces from the deck at the top of the main hull and

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*In this report the words deckhouse and superstructure are used interchangeably.

vertical loads from the supports beneath. Specifically, Bleich's formula expresses the stress condition as follows:*

$$\sigma = \sigma_N + \Phi\Delta\sigma$$

where

σ = Predicted stress at any point on the cross section.

σ_N = Stress based on beam theory if both house and hull are considered to act together. ($=Mc/I_{total}$)

$\Delta\sigma$ = Stress correction if vertical rigidity of house support is neglected.

Φ = "Deviation Factor"--a factor to take into account the vertical stiffness of house support (K) and certain geometrical properties of the house and hull. (Values of Φ, for constant bending moment, are shown by the curve of Fig. 17.)

Bleich has made a rather complete mathematical demonstration of the above formulation for house and hull of constant cross section, with constant running stiffness of support for the house, for the cases of constant and parabolic bending moment distributions in the region of the house. Thus, numerical predictions can be made for specific cases which follow the above conditions. The tests reported here were performed on configurations of constant cross section (both house and hull), with constant bending moment over the house region.

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*Appendix 4 summarizes the theory and notation.

Bleich suggested that the stiffness constant, K, be obtained by dividing the force required to deflect one bulkhead (or beam) by the spacing, it being assumed that there would be at least five bulkheads spaced reasonably equally over the length of the house(4).

Since actual vessels possess some irregularity in the supporting structure under the house, it is necessary to follow an averaging procedure. Therefore, the tests were performed with both regular and irregular distribution of framing.

The following sections describe the preliminary considerations leading to design of the experiments, construction, component tests, instrumentation and prove-out, and the nine basic tests required by the contract(1). Discussion and recommendations follow. The results of the tests are reported in the Appendices.

II. MODEL DESIGN

Survey. The contract required a check of the theoretical conclusions of Bleich. The model to be tested was to be greatly simplified as to cross section and loading. Nevertheless, it was desired that the configurations selected be as nearly representative of actual vessels as possible. Therefore, a brief period was reserved at the outset of the program for a general survey of practices existent on American and European passenger vessels. Tables I and II (Appendix 6) report on certain basic properties of representative vessels and of the model tested, as well as those of an "Alcoa" model and certain hypothetical models.

Selection of Vessels For Comparison. Particular attention focused on the two vessels, S.S. "President Wilson" and S.S. "America." These were both built in this country, and working drawings for them were available. The "Wilson" was an obvious selection because of the aforementioned structural tests. She represented a vessel whose house is relatively short and whose framing beneath the promenade deck appears lighter than the average for larger U. S. vessels. It seemed wise, therefore, to select the "America" too due to her extremely rigid system of partial bulkheads and framing in general.

S.S. "President Wilson" and "S.S. America" Features. Aside from general considerations of length, breadth, depth, and so forth, interest centered on approximations of those quantities which influence the Bleich prediction. The factor Φ in the equation,

$$\sigma = \sigma_N + \Phi \Delta \sigma$$

previously mentioned, is a complex function of a variable, u (Appendix 4). u, in turn, depends upon the relationships between the house and hull, and K, the stiffness of the foundations under the principal longitudinal bulkheads of the house. With the exception of this stiffness, all the above quantities can be readily obtained. Stiffness deserves special consideration at this point.

Foundation Stiffness on Ships. The precise definition of foundation stiffness* has been stated by Bleich: "K is defined as the force per unit length of deckhouse required to produce a relative deflection (between house and hull) equal to one unit of length."[4] If all vertical support of the house were furnished by structures concentrated at specific frame stations (the deck otherwise being considered infinitely flexible), one could calculate the deflection produced by a unit concentrated load at each of these isolated structures; and if at each station these deflections were equal and the spacings between these points were equal along the length of the house, then the inverse of these deflections divided by the spacing would be the value of K. Actually, the above assumptions are not strictly true. The spacing of principal structural bulkheads is irregular on any vessel, and their stiffnesses vary. Even for a particular bulkhead, stiffness

*Present theory has been worked out only for the case of constant foundation stiffness.

at the point of intersection of the house longitudinal bulkhead and transverse bulkhead is difficult to estimate. On the "America" a typical bulkhead, No. 103, extended the full depth of the vessel from the promenade deck. Each side was first considered to be a cantilever shear web of average thickness 0.323 in. For a bulkhead spacing of 37.5 ft. (to bulkhead No. 89), the derived K was 65,200 lb. per sq. in. In addition to this, the stiffness of the average deck beam (analyzed as a continuous member), divided by the average beam spacing, gave a K value of only 136 lb. per sq. in. This is obviously negligible if it is merely to be added to the K value for the bulkheads. Similar operations performed for the "President Wilson" gave similarly high values of K; but this seems not in accord with the stresses determined by experiment--presuming the Bleich theory to be correct. Working backwards from the "Wilson" test data, we deduced a K value of only 1490 lb. per sq. in. It was then assumed that a calculation based on shear of bulkheads alone was not a fair measure of K. Two factors support this:

(a) Under the house longitudinal bulkheads at many transverse bulkhead stations, were doors and other openings. Local deformation of the structure immediately above the doors may have been appreciable.

(b) There were no continuous structural ties at these points (i.e., no vertical stiffeners or chocks below). The boundary angle for the longitudinal bulkhead would presumably pad out the load into the deck and thence into the transverse bulkhead webs.

It should be noted that the test program was intended, among other things, to check the general validity of averaging for ascertaining the K value when the basic support for the house is furnished by rather isolated transverse bulkheads; the very concentration of the support from a transverse bulkhead could possibly be responsible for the relatively low values of house stress measured on the "President Wilson".

For the "America" calculations were performed to obtain K values based on various overlapping assumptions. These values are as follows:

Basis of Computation	K	u
Typical Deck Beam	136	1.19
Full Single Shear of Transverse Bulkhead	60,000	5.59
Local Deformation Due to Door in Bulkhead Below	24,650	4.39
Crushing of Transverse Bulkhead Below--Distributed Load (3 1/2 in. Loading Zone)	11,100	3.59
Crushing of Transverse Bulkhead--Concentrated Load	3,536	2.70

Selected Range For Parameter, u. On the basis of the survey briefly described above, it seemed that a suitable range for the parameter, u, would be 0.5 to 5.0. The contract stated that in one case the calculated value of u should duplicate that of one other test but be achieved by a different arrangement. The results of our survey reinforced the wisdom of this stipulation. The range of u was discussed with and approved by the Project Advisory Committee at its first meeting during the course of the project.

Selection of Geometrical Configurations For Test. The length, breadth, and height of the model hull, together with house dimensions, could be determined prior to assignment of scantlings. It had been decided that one symmetrical model hull would serve as a base for all tests. This was to be a box configuration of constant cross section. The final proportions, L = 240 in., B = 30 in., H = 24 in. (See Fig. 1, Appendix 5), seemed in general harmony with typical vessels, as reported in Table I. Preliminary considerations of section properties, in view of the range of u desired for the nine specified tests, indicated that three houses would suffice, with variations in the main hull to alter stiffness of house support. Two lengths of house, 80 in. and 160 in., were selected. The shorter house was taken as a probable minimum for which the coupled beam action could be expected to hold, while the longer dimension was taken to be sufficiently generous to check the theory. The heights of the two long houses were, at an early date, fixed at 6.0 in. and 7.5 in; 7.5 in. was also taken as the height of the shorter house. For comparative purposes it was decided that the house breadth should be held constant at 16 in. for all three houses. Thus we could virtually change single variables. In further support of a constant breadth of house, it was argued that a narrowing of the house would have no important effect other than diminishing the value of K (due to greater offset from the hull sides) and this could be handled otherwise. House breadth was a second order variable whose consideration here would have confused the program.

It was decided to add an intermediate, phantom deck near the neutral axis for reasons of dimensional and structural stability during the changes required in testing. Further design considerations were deferred pending a general study of the similitude problem and the choice of material.

Similitude. The designer of a structural model of an entire ship is faced with difficult, special problems. Principally, his prototype is very large and of extremely complicated configuration and detail. While complete scaling down of all structural features, including connections, would theoretically satisfy the requirements of a static test, it was obviously impractical. There was no need for multiple decks, inner bottom, etc., to achieve the action desired. Since the theory has not yet incorporated cut-out effects, section property variations, transverse tiering of houses, and the like, the overall geometry could be kept simple.

Plating thickness of hull deck and sides play a part in the problem, but a scaled step-down of thickness would have led to impractically thin sheet gages. Consequently, materials of lower elastic modulus were considered. A composite model was ruled out as conducive to thermal stresses and other complicating features, so a decision was reached to build the entire model of unclad aluminum alloys, 24ST and 14ST. With differences in material between model and prototype, we were forced to compromise on basic similitude. For example, because the thickness of the deck of the model was not scaled down in the ratio of the other dimensions, its stiffness as a plate was not proportionate to its contribution to the flexural stiffness of the hull as a whole. We were finally led to a design based on certain premises of proportionality, rather than on strict dimensional analysis. These premises are as follows:

(a) The ratio of shearing to bending stiffness should be the same on ship and model.

(b) The ratio of deck-beam to hull stiffness should be the same on ship and model.

(c) The ratio of house to hull stiffness should be the same on ship and model.

(d) At the line of the house longitudinal bulkheads, the ratio of stiffness of the deck as a plate to the stiffness of the deck beams should be approximately the same on ship and model. (Excessive vertical stiffness created by outsize top sheet should be avoided.)

These premises are stated mathematically in Appendix 4, together with certain formulae which follow logically. A tabulation of final selections for the model is shown on Table II, alongside ship values as calculated. The model design satisfies the above premises, within the limits of the required general realism.

Loading. An advantage in the selection of aluminum was that stresses could be kept low; the same precision of strain readings could be maintained as with steel stresses three times as great. Stresses in the model could be kept below 8,000 lb. per sq. in. For compressive stability and fastener stiffness, as well as for loading, this was an advantage.

It was decided at an early date that all tests should be performed in hogging. It would have been exceedingly difficult to maintain panel stability and necessary similitude in the sheet structure on the top of the model if compression had been permitted there, and there seemed very little counter advantage to be gained by sagging the model.

Section Properties. Fig. 1 shows the cross sections of hull and houses finally selected, and Table III summarizes their properties. The flexural stiffness of "proportionately equivalent" deck beams was based on S.S."America" promenade deck beams. Values were adjusted for simply supported ends at the hull sides and for the elimination of stanchion supports. Correction was also made for the proportionately greater beam spacing on the model. It was then considered that the running stiffness of the deck, along the line of the house longitudinal bulkheads, was in conformance with our requirements.

Elastic Stability. On a structural model with considerable indeterminancy, it is necessary that there be very little question as to the effectiveness of material. Consequently, unlike aircraft design, the present structure required complete stability of all its members under axial or shearing loads. For this reason, it was necessary to place three longitudinal stringers along the bottom to divide the hull into stable panels. Deep, transverse floors, running from the bottom to the phantom deck, were placed every 16 in. At the bottom of the hull sides, combined shear and compressive action demanded the placing of a stringer 5 in. up from the bottom. Vertical side stiffeners, spaced every 8 in., were placed on the inside, above and below the phantom deck, to avoid any tension-field action due to shearing instability. Some concern was felt for possible shearing instability in the house sides, particularly at the ends where considerable concentration of longitudinal shear was expected. Therefore, closely spaced, vertical stiffeners were placed there. The bottom stringers were checked against column failure over their unstabilized spans, and all fastener pitches were checked for possible interbolt buckling of the sheet.

Fasteners. The requirement for interchangeability in the model made the fastener problem a critical one. Among the fasteners considered were bolts with dimpled sheet, expansible internal nuts, fitted bolts, Dill nuts, cycle weld, Rotoloc, Cameloc, and Nelson stud welding. All of these were extremely expensive, and for many the tolerances required were almost prohibitive. Therefore, consideration was given to the use of normal steel bolts applied under extra high torque. It was felt that these might provide sufficient friction due to clamping action to take the necessary shearing loads. Slippage tests, described in Appendix 1, were performed on the two sizes of bolts which were used. On the basis of these tests, the decision was made to use high torque bolts for all fastenings except the angle connections at the bottom, the side-to-angle connection at the top, and the deck-to-angle connection at the ends of the house. In these locations, fitted bolts were used. No. 10-32 and 1/4-28 bolts were used throughout, except at the heavy, loading plates. It was decided that in no case should the factor of safety be less than two based on the slippage tests. Actually, this factor was exceeded by a considerable margin.

Structural Features. Simple support at the ends of the model required special considerations in order to permit rotation and to provide a proper load funnel for the highly concentrated loads. For this purpose heavy steel end plates were fitted, as shown in Fig. 5. Pin connections, fore-and-aft and athwartship, were provided. Full-height trunnion plates for load application were fitted to the hull sides beyond the ends of the longer houses, both inside and outside the hull. At each end of the model, these plates received the loads from loading rods and distributed them through a generous array of quilting bolts.

For tests in which transverse bulkhead action was planned, special partial bulkheads were designed. (See Figs. 1 and 6.) These extended from the phantom deck to the main deck, and from the hull side to the house side only. They were placed clear of transverse floors below, so that their stiffness, as installed, could be more readily calculated. Each bulkhead was connected to a vertical side stiffener, and on its inboard side was attached to an angle whose fore-and-aft leg was brought through the top deck and attached to the house side. This step was taken in order to minimize any uncertainty as to the load path, and to predict local stiffness for the .020-, .040-, and .064-in. gages designed* for this application.

Predictions. Fig. 7 shows the configurations finally chosen for test. Test No. 10 was on an arrangement requested by the Project Advisory Committee after testing had commenced. (A third, short-house test, with irregular bulkheading, had been planned.) The value of K for the deck was computed by calculating the stiffness of the deck beams with effective deck sheet and dividing by the beam spacing. Similarly, the shear stiffnesses of the partial bulkheads were computed. For each array stiffness was divided by the mean spacing to give K for bulkheads alone. The theoretical total k was taken as

*Actually, the .064-in. bulkheads were not used in the program as later modified.

the sum of deck and bulkhead K values. Stiffness data are tabulated on Table IV for each of the tests.

The value, $\Delta\sigma$, depends only upon the section properties. u can be expressed as $u = C\sqrt[4]{K}$, where C is also a function of section properties alone. Values of $\Delta\sigma$ and C, for each of the three houses, have been calculated on Table III. The values of u, combining section properties with the K values, have been developed on Table IV. Values for the deviation factor, Φ, for constant bending moment, were taken from Table 1 of Reference 4, interpolating for the various values of u. Values of K based on deck stiffness tests (see Appendix 1), and the corresponding values of u and Φ are also included in Table IV. Thus, the Bleich correction to the Navier stresses is applied from both theoretical and experimental determinations of K. Table V lists stresses for the nine basic tests predicted on the above bases. The designations σ_T and σ_X have been used to differentiate the Bleich formula stress predictions based upon K deduced theoretically and experimentally, respectively.

III. MODEL CONSTRUCTION

Material. A considerable delay occurred in the procurement of aluminum alloy for construction of the structural model. This was notwithstanding cooperation from the Aluminum Company of America. It was partly attributable to delays to be expected in times of emergency; sheet lengths were outsize and demanded special schedules. (Splices would have been undesirable in the extreme.) It was necessary to adhere rather closely to initial selections of rolled and extruded shapes. Unclad sheet was demanded because the action of cladding material might have been indeterminate; in 24ST alloy sheet the demand is normally for cladding, so this also may have been a factor in the delay. All long elements were cut to size in the mill and conformed in all respects to our requirements when finally delivered.

Fabrication. Machine-shop accuracy, rather than sheet-metal-shop practice, was maintained throughout, and as a result no spoilage occurred. All holes were drilled from steel templates fitted with hardened bushings. Since most connections depended upon friction, hole diameters were made .002-in. to .003-in. oversize. All matching elements were drilled together, great care being taken to avoid any lateral or fore-and-aft dissymmetries or built-in warpages.

Assembly. The illustrations in Appendix 5 show the basic constructions of the model. Examination will show that there were only two lines of blind fastenings: the attachment between floors or bulkheads and the phantom deck, and that between the partial bulkheads and the top deck. These were accomplished by riveting on a "gang" strip with fine-threaded holes for screws to be attached from the top. Assembly was a straightforward operation. Nuts were run up to within a few inch-pounds of the desired torque by automatic nut runner, the final desired torque being applied by hand torque wrench. There were approximately 8000 fasteners in the final hull assembly, including the main deck. The model showed complete rigidity, even with main deck uncovered, and no built-in warpage or other stress condition was discernible.

IV. TEST TECHNIQUES

This section deals with the main testing of the structural model. In sequence, the following tests were performed:

TEST NO.	SIZE OF HOUSE (inches) LENGTH	HEIGHT	SUPPORTS (in addition to standard beams)	u (See Table IV) from theoretical stiffness	from experimental stiffness
1	---	---	bare-hull test	---	---
2	160	6	none	1.41*	2.36
3	160	6	outsize deck beams, spaced 14 in.	2.06*	2.58
4	160	6	3 Bhds., 1020 in. thick-- one at each end of house and one amidship	3.59	2.79*
5	160	7.5	none	1.32*	2.21
6	160	7.5	5 Bhds., .040 in. thick-- one at each end of house, one amidship, one 32 in. fwd. and one 32 in. aft of amidship	4.73	3.10*
7	160	7.5	5 Bhds., .040 in. thick-- one at each end of house, one amidship, one 16 in, fwd. and one 16 in. aft of amidship	4.73	3.10*
8	80	7.5	none	0.66*	1.10
9	80	7.5	7 Bhds., .040 in. thick-- one amidship, and pairs 16 in., 32 in., and 48 in. from amidship	2.98	1.87
				1.82*	
10	160	7.5	2 Bhds., .040 in. thick, one at each end of house	3.36	2.53*
11	---	---	bare-hull test	---	---

*Preferred values--see "Stiffness Tests", Appendix 1.

The bare-hull test (test No. 1) provided a run-in of the test program, and, together with a concluding bare-hull test, a check of overall drift of model and instruments. The model was loaded at all times for tension on top, since this region was not designed against compressive instability; but the model was loaded and unloaded several times before any reported data were taken. Strain readings were checked at random for repetition before the first actual test.

Virtually all major tests were made during the evening, when electrical disturbances, vibration, and other disturbances were minimized, and thermal conditions were steadier. No test lasted more than ten hours--seven hours being the average duration. Temperature was measured before and after each test. The first readings were always made after a small load was applied; this set was taken as "zero". The standard maximum bending moment was 720,000 in-lb. This was arrived at in four increments of load of about 180,000 in-lb. each The model would then be unloaded to a bending moment of about 360,000 in-lb and thence to the original zero. At each step, readings of all gages were taken, and differences were observed for an on-the-spot linearity check. The loadings for the various tests did not exactly correspond, for it was the practice not to back off any load on the way up. For each reading it was necessary to double check switch point and switch bank, which were coded for recording the raw data--both active gage readings and those of the associated dummy gages. Dynamometer readings were taken before and after the other gage readings on each load increment. The model was observed closely as the load was slowly taken up toward the maximum for any sign of shear instability in the house end region, as well as in the critical, combined-stress area in the lower side panels of the main hull. No sign of either shear or compressive instability was observed.

Changes between tests constituted a vital part of the program. The time for change varied from one to three working days, depending upon the extent. The distribution panel (Fig. 75) was a great help for house changes. It was found that deck stiffness changes could be made without unwiring; leads were kept slack, and the deck was pivoted on the edge adjacent to the panel. Naturally, rebolting practice followed the same rules as in the basic model construction with all final torques being applied by torque wrench.

V. DISCUSSION

Midship Stresses. The nine basic tests are reported on Figs. 8-16. In discussing these, attention is invited to the difference between stresses predicted on the bases of experimentally estimated stiffness (σ_x) and theoretical stiffness

(σ_T). Both of these are pertinent to the main objectives of the contract, but the authors favor σ_x for the tests with bulkheads and σ_T for tests without. The reasons for preference are brought out in the discussion of the deck stiffness tests, Appendix 1.

In all tests the stress distribution lines, as determined from measured strains, show a discontinuity at the main deck. In Fig. 8, for example, fairing was guided by the following evidence:

(a) The consistency of the gages below the main deck virtually determined the deck intercept.

(b) The readings of the four gages on the house indicated a house stress line having a lower intercept at the main deck.

(c) The spread between gages 13 and 16, on centerline, can be attributed to deck bending--a phenomenon explained by Bleich. Their median point, taken as the sheet-membrane (mid-plane) stress, indicates deck lag.

(d) Gage 15 was erratic in most tests, so little reliance is placed in its readings.

Although there was no net vertical shear force in the model as a whole between load points, shear stresses must be present in the deck to transfer the load from hull to house. (See plots of longitudinal shear in the house, Figs. 40-42). Local shear distortion demands for compatibility a variation in strain across the deck. This may explain the apparent shear lag between hull side and house side.

Fig. 8 shows the midship results of test No. 2, the long, low house with standard deck beams only. Correlation between measured strains and σ_T is extremely good. Diminishing stresses toward the housetop are unmistakable. Predictions based on experimentally determined stiffness (σ_x) were too high, but it is believed that this stiffness was not a true measure of the deck action. We can conclude, then, that test No. 2 is a good check of the theory.

Midship stresses for test No. 3, with long, low house supported by outsize beams, are reported on Fig. 9. Stresses at the housetop were much lower than predicted values, both σ_x and σ_T. Although there was agreement between experimental and calculated stiffness for the outsize beams, when the stiffness of the standard beams was added, different stress values were obtained. As for test No. 2 then, σ_T is preferred. Deviation from theory is still considerable, and this has not been satisfactorily explained.

Test No. 4 is reported on Fig. 10. The effect of even three bulkheads is very pronounced. More than "full participation" of the long, low house is clear. The midship stresses even exceeded those predicted by theory. The measured stiffness of bulkheads was less than that calculated, but this fact did not affect the deviation factor, Φ , which is rather insensitive to changes in values of u greater than 3. (See Fig. 17.)

Test No. 5 results, plotted on Fig. 11, show a pattern very similar to that of test No. 2, as should be expected with the long, but higher house, with standard deck beams. Again, σ_T agreed closely with experiment, and σ_x was far too high for top-of-house stresses.

Test No. 6 was performed with the long, high house with five rather evenly spaced bulkheads. In this case the experimental values (Fig. 12) were slightly less than those predicted, both σ_x and σ_T .

Test No. 7, reported on Fig. 13, was run with the same nominal foundation stiffness as test No. 6, but with the three central bulkheads more concentrated. In this test the increase in midship stress at the top of the house was somewhat more pronounced than in test No. 6.

Test No. 8, for which the midship stresses are reported on Fig. 14, was one of two run with the short, high house-- this one with standard deck beams only. Theory and experiment are in very close agreement. Test No. 8 represented the lowest value of u for the program. (As shown in Fig. 17, the curve of Φ flattens out as u approaches zero.)

Test No. 9 (Fig. 15), was performed on the short house with seven rather uniformly spaced bulkheads. Here the completely theoretical prediction (σ_T) was far in excess of experiment; even the preferred prediction, based on experimental stiffness, was too high.

Test No. 10 (Fig. 16) repeated test No. 7 but with only the end bulkheads. Constant stress appeared to prevail in the house. "Predicted" stress for the housetop was much higher, but foundation conditions did not even remotely approximate the theoretical uniform stiffness. The two rigid members could exert a bending moment on the house only by acting in conjunction with the standard deck beams in between. Hence it is not surprising that test No. 10 results fall roughly midway between those of test No. 5 on the one hand, and tests No. 6 and No. 7 on the other.

Deviation Factor. The equation of the Bleich theory can be rewritten as follows:

$$\Phi = \frac{\sigma - \sigma_N}{\Delta\sigma}$$

If we assume that the value of $\Delta\sigma$ is correct, it is possible to determine "experimental" values of Φ , taking for σ the experimental stresses at top of house. On Fig. 17, two sets of such values have been plotted against u , together with the theoretical curve of Φ . One set of points represents the nine experiments of the program with u determined from the calculated values of K, while the other set is based upon the experimental K values. For reasons discussed in Appendix 1, less confidence is placed in the experimental stiffness of the standard deck beam array than in its calculated stiffness, whereas for bulkheads the reverse is true. In all cases the lower value of K, and hence of u, is considered more accurate. Test No. 10, with bulkheads only at the ends, is obviously unfair to the theory. With these reservations we find exceedingly good correlation with theory at low values of u, where the foundation is uniform (tests No. 2, No. 5, and No. 8). Comparison of tests No. 2 and No. 5 shows that moderate changes in house section properties had little effect on results--in accord with theory.

It will be noted that test No. 3 (long house with outsize deck beams) and test No. 9 (short house with numerous bulkheads) lie close to each other (Fig. 17) but somewhat to the right of the theoretical curve. Test No. 9 was the only one in which the house ends landed between bulkheads. Lack of rigidity at these critical points may have caused the house to act as though K were reduced. This suggests a need for further study of the averaging process for determining the foundation modulus, K.

With a long house and increased bulkheading, as in test

No. 6, conformance with theory is shown to be rather good. For such cases the determination of K is a less critical factor. It will be noted that the theory predicts negative values of Φ. This means "extra stressing" of the upper elements of the structure, even when the deck is uniformly stiffened. The only tests which actually show "extra stresses" are those where bulkheading provided essentially three-point support (i.e., tests No. 4 and No. 7). Figs. 36 and 37 show that these "extra stresses" were quite localized.

Deflections. Deflections are reported on Figs. 18--26. Their patterns seem entirely consistent with the midship stress patterns discussed above. In particular, the separate bending of house and hull is manifest. Tests No. 2 and No. 5, with long houses resting on standard deck beams only, show strong counter flexure of the house. Test No. 3, with outsize deck beams, shows a considerably diminished counter flexure, as does test No. 8, with the short house on a flexible foundation. The flat deflection pattern of test No. 9 is consistent with the constant stress pattern observed amidship. Test No. 9 also shows that even the presence of numerous bulkheads cannot force deflection compliance with the main hull although the unexpected slackness of these bulkheads may have been in part responsible for this. The same flat pattern is obvious in test No. 10, with the long house and end bulkheads only, but the end deflection of the house more nearly coincides with that of the main hull. Test No. 6, with uniformly spaced bulkheads under a long house, shows very close conformance between house and hull, as might be expected, while tests No. 4 and No. 7, with greater concentration of bulkheading amidship, show more distorted house deflection patterns, with increased curvature amidship. The slight knuckle in the main hull deflection line just forward of the house end in certain tests is believed to be real since it was indicated by symmetrical gages and repeated in similar tests.

Longitudinal Variation of Stress. The deviation factor, Φ, as a function of distance from amidships, is shown in Fig. 10 of Reference 4 for values of u as follows: 1.0, 1.844, 4.0, and 6.0. Using factors for the midship station as a basis for interpolation, Φ values were estimated for stations along the house. Approximate theoretical house-top stresses for tests No. 2 and No. 6 were computed and plotted on Figs. 36 and 37. Examination of Fig. 36 reveals very close correlation between the predicted and experimental curves for test No. 2, for the whole length of the house except at the extreme ends. Test No. 6 shows lower stresses amidship than expected, but the general pattern of stresses seems to be consistent with theory along the whole length of the house. The zone of relative effectiveness of the house was approximately the same as that predicted by theory.

Longitudinal Shear Stress. As inferred from most theoretical work, including the Bleich report[(4)] it was expected that with constant bending moment on the whole house the shear stresses would peak to extremely high values at the ends of the house-hull connections. Strain measurements were taken 1 1/4 in. above the main deck, which was the closest that it was feasible to place gages. Longitudinal shear stresses were computed by the formula:

$$\tau_{xy} = G\left[(\epsilon_1 + \epsilon_3) - 2\epsilon_2\right]$$

where ϵ_1, ϵ_2, and ϵ_3 are strains in the longitudinal, 45°, and vertical directions, respectively. The results of these measurements are reported on Figs. 40--42. It will be noted that none of these plots shows more than a gentle rise at the ends except possibly for test No. 7. (The curve for test No. 9 actually shows a sharp reduction at the extreme ends.) To a degree this may be due to the fact that it was impossible to take readings exactly at the intersection between house and hull; also, it may be partially due to the difference between bolted and welded connections. In the Bleich theory, it is presumed that the longitudinal shear at the connection when there is no vertical support will be highly concentrated at the ends. However, it should be noted that equation(r) of the

Appendix to Reference 4 expresses the shear stress as follows:

$$\tau_{xy} = \frac{1}{t}\cdot\frac{dT}{dZ} = \frac{EI_A}{dt}(\alpha_1 y_1''' + \alpha_2 y_2'''),$$

showing shear to be dependent on the third derivative of the house deflection. Now if we examine the longitudinal variation of housetop stresses, we notice that the curves tend to flatten out toward the ends. This implies that the rate of change of house curvature is rather low at the ends. Thus, low shear is consistent with the above formula.* It might be pointed out that neither the Alcoa model tests[9] nor the "President Wilson" data showed any sharp peaking of shear stresses. Thus, as might be expected, the actual shear stress seems a function of the zone of effectiveness of beam action--which is a matter not covered by the present theoretical treatments. A detailed study of end conditions is recommended as a separate study. (See Section VII.)

Overall Stress Patterns. Figs. 27--35 are plots of fore-and-aft distribution of stresses in the bottom, main deck, and top deck of the model. These should be considered as indicative of trends, whereas Figs. 36--38 show more exaggerated, faired

*Also, since loading was close to the house ends, the bending moment was hardly developed in this locality, and this may have contributed to the apparent action.

plots of the housetop stresses only. Both sets show that the stresses were fairly constant over the midship half-length of the long houses. Exceptions to this were tests where bulkheads were concentrated amidship. In the short house, even when heavily bulkheaded, the top-of-house stress diminished very rapidly from the midship value.

A rise in main-deck stresses toward the house ends is generally discernible. It might be expected that this trend would be more pronounced. However, in the region adjacent to the load points, hull stresses did not vary linearly with distance from the neutral axis. A greater share of the bending moment was carried by the hull sides, with a corresponding reduction in main deck stresses. This tendency is clearly shown in the bare hull tests, reported in Appendix 1. (See Fig. 71.) In the tests with houses, it may have counteracted, to some extent, the gradual loss of house participation. On shipboard, of course, the total bending moment itself tends to fade toward the house ends, and therefore, for different reasons, a large increase in main deck stresses fore-and-aft would not be expected.

Shear Lag and Deck Bending. The strains for the main deck, for the entire test program, show a very complex pattern. Most other strains show a rather regular pattern. It is believed that the irregularity at the main deck is not accidental. There seems to be a definite pattern of performance, but the exact nature of this action has not been satisfactorily explained. Some shear lag in the main deck is shown for the tests with houses. This can be inferred from the house and hull side stress distribution, as well as from gages placed on and under the deck. With the complex shear pattern across the deck, together with shear transfer from hull to house (even with constant bending moment), it would be indeed difficult to calculate the exact extent of lag. There is also clear evidence of the effects of plate bending in the deck--likewise of a rather complex order.

Principal Stress Patterns. Figs. 43 to 51 show the magnitudes and directions of principal stresses derived from rosette data. Most of these gages were located in the end zones of the houses or just above the house-hull connecting angles. Their performance was somewhat irregular. The program was not aimed at investigating the two-dimensional stress distribution in the end area, and consequently, the model was not instrumented sufficiently to plot stress contours. However, the following statements can be made:

(a) Vertical stresses in the long houses were higher along the connection lines for the tests with only standard deck beam support (tests No. 2 and No. 5).

(b) The trend of vertical stresses for most tests was toward high values at the ends, reduced stresses in the house quarter-length region, increasing again amidship.

(c) With bulkheads below, vertical shear connections tended to reduce the vertical stresses in the houses along the connection lines.

(d) In test No. 4, with bulkheads amidship and at ends only, considerable longitudinal tensile stresses were built up at the house ends.

(e) The distribution of principal stresses at the house ends shows sharp fluctuations and even reversals with rather localized, high compression, and tension values.

XI. CONCLUSIONS

It is believed that the theory proposed by Dr. Bleich is inherently valid for cases of quite uniform foundation modulus (as presumed by Bleich). Three tests, Nos. 2, 5, and 8, were run with standard deck beams (i.e., cases of almost constant deck stiffness). All these tests were in the relatively sensitive regions encompassed by the Bleich theory. All correlated well with theoretical predictions. Three houses are represented by these three tests, a long, low house; a long, high house, and a short, high house.

Furthermore, as Bleich predicted, a long house with numerous well connected and stiff transverse bulkheads below can be expected to participate with virtually 100 per cent of the strains predicted by the Navier theory in approximately its midship half-length. This is suggested by the results of tests Nos. 6 and 7.

For long houses with relatively flexible support furnished by moderately spaced web frames or bulkheads (i.e., the sensitive region of the Bleich theory) there is some question on the averaging process suggested in the Bleich report, even when more than five major supports are present. Test No. 3, with outsize deck beams at 14-in. centers, testifies to this.

Short houses with rigid framing below appear also to lie in the sensitive region of the Bleich theory when the properties are calculated, and here again a question is raised in the application of the theory--at least with regard to the method of estimating the stiffness value, K. Test No. 9 illustrates this difficulty.

To be added to this evidence are the analytical efforts, made during the course of this program, at estimating stiffness of deck foundation for the "President Wilson" and at correlation of the Bleich theory with the results of tests on that vessel. Under none of four overlapping assumptions for computation of K could correlation be achieved.

It appears that the underlying action of deckhouse and hull has been explained by the theory. Furthermore, the "pure" theory (i.e., with virtually constant foundation stiffness) is apparently correct mathematically. The exceptions to the extended application of the theory stated in the preceding paragraphs should, in the first place, be taken as tentative, since the test program was not sufficiently extensive for full exploration. In the second place, logic suggests that the exceptions center on just what is the effective measure of K under these various circumstances. In Reference 4 the hope was expressed that with five or more bulkheads, under most conditions, a fair estimate of K could be made by computing the stiffness of the prominent supports and dividing by the spacing of these supports. Bleich hoped, it seems, that a constant K could be so derived for the vessels described by this program and applied in the full theory for fairly accurate prediction. Evidence so far produced does not support this extension.

As to the techniques used in the test program reported here, the writers are quite satisfied on the whole. It was found that, with the convenient addition or removal of rather small sheet metal members on a single base model, radically different overall stress patterns were to be found. In some cases these were of the type observed on shipboard. Model testing is deemed to be a useful tool in estimating overall stress distributions under various major design practices.

The model is not a tool for examination of detail design features; it was not so designed. For simulating various conditions of underhouse support, the outsize deck-beam technique is probably superior to the partial bulkheads also used during the program--both in simplicity and predictability. It appears that the entire interesting range of stiffness could be further explored by this technique.

The algebraic presentation of Reference 4 should not be taken as exhaustive of the theory itself. It represents a simplification of conditions which is quite consistent with a preliminary presentation, and provides a guide for pilot testing. With improved understanding of the effect of more realistic foundation conditions, there is no reason now to believe that algebraic applications of the intrinsic theory cannot be refined to correct the difficulties so far exposed. "Side-by-side" model testing should make such refinement most efficient and meaningful.

Conclusions as to practice in ship design are somewhat outside the scope of this program. It may be said that even overall numerical calculations for actual vessels would be questionable for the present. This condition may not persist with improvements in understanding suggested above and in the next section. Qualitative effects for certain vessels may be predicted; for example, the likelihood of more or less constant stress conditions in vessels with short houses with heavy framing, or (from test No. 4) the possibility of semilocalized stresses higher than the Navier stresses in vessels with long houses and a concentration of underhouse framing (say, machinery room casings) in the midship region. The relatively high longitudinal and vertical stresses measured at the house ends seem to support the generally held opinion that special reinforcement in these areas is advisable.

XII. RECOMMENDATIONS FOR FURTHER STUDY

The structural action of house and hull is a complex, three-dimensional phenomenon. Nine tests are rather few for thorough examination, and certain distinct questions remain. It is believed that the intrinsic theory has been shown to be valid, and that there is justification for pursuing the matter further. This work would breed increasing <u>insight</u> into real ship problems even if the numerical determination of shipboard stiffness has not yet been finally resolved.

These remarks point to the following needs:

(a) More model tests aimed at determining correct stiffness formulations. (This should include more elaborate stiffness tests than possible in this program.) Outsize deck beam technique might prove most useful.

(b) Application of parabolic bending moment to present model.

(c) Further analytical study of problem, including:

  (i) Effect of singularities (i.e., isolated bulkheads);

  (ii) Inclusion of variable I (for instance, by finite difference method);

  (iii) Inclusion of hull shear stiffness effect;

  (iv) Variable foundation modulus.

(d) Coordinated Full-Size Ship Tests, Analysis, and Model Tests

It is believed that the present model could be arranged to show overall structural patterns simulating actual vessels. A three-way program which would include close examination of ship's foundation stiffness and examination of ship test results matched against model findings would be significant.

(e) Experimental study of specific practices used aboard ship:

  (i) Use of expansion joints;

(ii) House-end practices--shear reinforcement, underdeck holddown structure, etc.

(f) Study of short erections:

(i) Theoretical treatment of stress-field problem;

(ii) Special welded specimen tests;*

(iii) Short erections on present 20 ft-0 in. model;

(iv) Photoelastic tests.

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*The tensile and bend testing of flat plates with short, high, vertical flat bars is suggested here.

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APPENDIX 1

AUXILIARY TESTS

Fasteners. A series of tests was run early in the course of the project in order to determine the effectiveness of bolted connections accomplished with relatively high wrenching torque. These tests, which were reported in some detail in a special report to the Project Advisory Committee, are described below.

(a) Specimen Description. The specimens were made of 24ST aluminum clad strips, 2 in. wide, 0.051 in. thick, and sufficiently long to take the prescribed number of bolts at the given spacing. Oversized holes were match-drilled to insure definite clearance for the bolts. Two sizes of steel bolts were used, No. 10-32 and 1/4-28, with aluminum washers. To assure a friction connection, considerable care was exercised to see that the tightened bolts did not bear on the aluminum strips. End clamps were fixed to the specimens, allowing the use of very simple pin connections for placing the elements in the test machine.

The majority of the tests were conducted with either one or three bolts. When three bolts were used, all were tightened to the same specified torque. Various wrenching torques were used on each size bolt to bracket what was felt to be a usable value. This was governed to some extent by actually torque-loading a group of bolts to failure.

(b) Equipment. A small, hydraulically operated tensile test machine was used to apply the load, which was measured indirectly by strain gages fixed to a standard tensile specimen. The strain, which is proportional to load, was recorded by a Brush, Model BL 302, Strain Amplifier and Recorder. In addition to providing a permanent record, this showed the inception of appreciable slip. The relative displacement of two reference points, approximately 16 in. apart, was measured with a machinist's telescope gage. The wrenching torque was applied by a 0-300 in-lb capacity torque wrench. A universal-type linkage was incorporated in the system to assure axial loading of the specimens. Fig. 52 will give the reader a more detailed impression of the test apparatus.

The strain-load curves were checked with a hydraulic gage attached to the loading jack. The combination of jack and hydraulic gage was taken to the National Bureau of Standards for calibration. (See Fig. 53.)

(c) Results of Tests.

Torque-Failure Tests. Five bolts of each size were tightened to failure. The failure torques and types of failure were as follows:

Bolt Size 10-32			Bolt Size 1/4-28		
Trial No.	Torque Req'd for Failure in. lbs	Type of Failure	Trial No.	Torque Req'd for Failure in. lbs	Type of Failure
1	80	Bolt threads	1	235	Bolt sheared
2	85	Bolt threads	2	300	Bolt threads
3	80	Bolt threads	3	235	Bolt sheared
4	80	Bolt threads	4	200	Bolt threads
5	85	Bolt threads	5	230	Bolt threads

Slippage Tests. The results of eight representative tests are reproduced, in small scale for convenience, in Figs. 54-61. The sloping straight line on each graph represents the estimated elastic elongation line for the 16-in. gage length used.

The specimen number gives the pertinent information for each test in the following way: the first number is the number of bolts; the second is the bolt size; the letter distinguishes individual, similar specimens; and the last number is the torque in inch-pounds.

Examination of the area surrounding the bolt hole after test showed no sign of damaging scores on the sheets;

however, in some cases the aluminum washers were unsuitable for further use. Other tests (not reported here) were run but were not carried through to a condition of bolt bearing on sheet.

(d) Analysis and Conclusions. A general conclusion that can be drawn from the slippage tests is that the clamping action produced by high-torque bolts (in sheet metal) yields a rigid type joint for certain load ranges. Slip appears to be a "yield type" action, occurring after rather complete elastic performance.

For the majority of tests reported, torques were modest and the "rigid range" showed some considerable variation, but the influence of high torque is clear from Fig. 59. With 2-1/4 in. bolts wrenched up to 200 in-lbs, elastic performance continued until the loading reached about 1000 lbs. per bolt. For 1/4-in. bolts torqued to 125 in-lbs, a conservative estimate of load at slip inception is 400 lbs. per bolt.

In order to assess the meaning of these tests to the major program, the maximum shear flows for the model were computed. For tentatively assigned pitches (and bolt diameters) individual bolt loads could then be compared to the slippage test results.

The connection between the deck and top side angle will serve as an example of a major interchangeable connection. At this location static moment, $Q = 14.3$ in.^{3}; moment of inertia, $I = 1653$ in.^{4}; and total shear, $V = 20{,}000$ lbs. (for bare-hull test). Unit shear, $q_o = VQ/2I = 20{,}000 \times 14.3/2 \times 1653 = 86.5$ lb/in.

For bolt spacing of two in., bolt load, $P_b = 2 \times 86.5 = 173$ lbs. One-fourth-in. bolts with 200 in-lbs torque were used, giving a factor of safety of 1000/173 = 5.8.

It was concluded that high-torque bolts would assure, for almost all fastening lines, sufficient joint rigidity for proper simulation of shipboard shear action. However, it was decided to use fitted bolts for two major, not usually interchanged fastening lines--those between the upper and lower angles and the hull side. While even here friction type fastenings would probably have held, this precaution is believed to have been wise.

The house end attachment offered a special fastener problem. Present ship design practice usually provides for a high order of rigidity, both in shear structure and in vertical support. The current superstructure theories do not cover this action, but generalized theory suggests high longitudinal shears. Therefore, bolt spacing at the house ends, for a region of approximately three times the height of house, was closed up to the minimum spacing for 1/4-in. bolts (125,000 lb. T.S.).

In certain cases inter-bolt buckling of sheet, rather than fastener strength, provided the criterion for pitch.

Stiffness Tests. The purpose of these tests was to obtain some measure of the stiffness, under actual test conditions, of model and house. These tests were not performed until after the main program, due to the long delay in model fabrication and the need for adherence to schedule. Unfortunately, time and contract resources permitted only the limited tests reported here. Since underdeck stiffness is a dominating parameter in the Bleich theory, a more elaborate program is needed for adequate evaluation of the averaging procedure used.

Fig. 62 is a photograph of the adjustable loading bar and dynamometer used for deck stiffness testing. Load was measured by double strain gages on the small dynamometers. Differential deflection between house side connection and hull side was measured by dial gages.

In each test a load was applied simultaneously on each side of the model. In the case of tests on deck beams--both standard and outsize--vertical "up loads" were applied through temporary eye bolts attached through the deck and beams. When the stiffness of a transverse bulkhead was tested, loads were applied to the fore-and-aft legs of the inboard bulkhead angles, which had been cut off at the main deck. Loads were also applied between deck beams and at deck beams adjacent to bulkheads. Results are plotted in Figs. 63--65. Principal findings of these tests were:

(a) Under concentrated load, the stiffness of a standard deck beam was higher by a factor of about eight than that predicted for a simply supported beam. This, however, deserves qualification. Fore-and-aft bending rigidity of the deck sheet undoubtedly contributed greatly to the apparent stiffness. With load distributed fore and aft, sheet bending would be minimized, and the assumption of simple bending of the deck as a series of beams appears justified. In the overall action of model hull and house, with standard deck beams only, there was excellent correlation between measured strains and stresses predicted from Bleich's theory on the basis of computed stiffness.

(b) There was no discernible difference between stiffness measured under loads directly on a beam and stiffness measured between beams. This supports the conclusion that the load was distributed among several beams by the deck sheet.

(c) The stiffness of outsize deck beams correlated almost exactly with that predicted. The preponderant lateral stiffness of these beams overshadowed the effects of fore-and-aft stiffness of the deck sheet.

(d) The stiffnesses of both the 0.020 and 0.040 bulkheads were lower by a factor of about six than those predicted on the basis of single shear for each partial bulkhead.

Qualitative, separate tests made upon these bulkheads showed some indication of interbolt buckling at the loads corresponding to the stiffness tests. Also, dial gages placed across the step between house and hull sides indicated some deflection across the bend radii of the bulkhead's flanges. Deck shear tended to stiffen the action only after some initial bending. The blind threaded connections at main and phantom decks may have contributed to some "slop" in the shearing action. However, high as this factor of error is, the full-scale tests correlated with theory rather well. The factor, u, depends upon only the fourth root of the stiffness. Moreover, the curve of Φ is rather flat in the range of u corresponding to most of the tests with bulkheads as supports. (See Fig. 17.)

(e) Stiffness of deck and beams adjacent to partial transverse bulkheads or outsize deck beams decreased very rapidly to approximately the value for deck and standard deck beams alone. This was not unexpected. It had been previously felt that the existence of a bulkhead constituted a very singular situation.

Bare Hull Tests. Midship distribution of longitudinal stresses shown by Figs. 66 and 67 correlate well with simple beam theory. Fig. 70 shows longitudinal variation of primary stresses for main deck and bottom, matched against theory. It is well known that the stress distribution cannot possess the sharp knuckle predicted by simple theory, and the rounding off near the load points conforms with findings of similar tests. It is gratifying to note, on these figures, that fixity at the ends was reduced to almost zero. Figs. 68-69 illustrate the deflection for both bare hull tests, and show good correlation with the theoretical. Fig. 71 shows stress distribution at station 76, near a load point, and emphasizes the non-linear distribution which must exist in this region. On both bare hull tests it will be noted that there was considerable spread in the gage readings for the main deck. In view of the consistency of gage readings elsewhere, and since very similar trends can be detected at stations 20 and 36 for these tests, this spread is believed to be more than coincidental. However, it cannot be definitely established that it was due to shear lag, since in both tests 1 and 11 the faired stress line more or less bisects the stress points No. 13 and No. 16, which are the inside and outside gages on the centerline. It would appear that some bending, in the deck plating, rather than shear lag, occurred even in the bare hull tests. For these tests the reason for this is not clear; the Bleich theory explains it in the case of tests with houses attached.

APPENDIX 2

TEST RIG DESIGN AND CONSTRUCTION

At the outset of the test program it had been hoped that the two-story framing arrangement of the main laboratory building of Reed Research Inc. might form the basis of a test rig. However, it was soon decided that a self-contained frame would be necessary. A rig with two longitudinally disposed trusses was settled upon. Fig. 72 indicates the method of construction. It will be noted that constant bending moment was applied to the model by two fore-and-aft box beams pivoted at each end of the truss and loaded by a screw jack at the center. All members of the equalizer system were pinned and well balanced. Tolerances in the construction of the test rig were kept to 1/16-in.: 240 in., or better, and major parts were fabricated in pairs. No eccentricities resulted, and there were no "out fits" in either truss. Symmetry of loading was thus achieved, as discussed in Appendix 3. The special stiffness test rig has been described in Appendix 1.

APPENDIX 3

INSTRUMENTATION

The principal instruments used in the tests were SR-4 type electrical resistance strain gages and dial deflection gages. The major objective of the project, a check of the theory formulated by Bleich, governed the disposition of the instruments.

Dynamometers. The loading method has been described in Appendix 2. It had been planned that the main dynamometer be of the ring-electrical type. However, this type gage was unavailable, and a deflection type gage was considered unsatisfactory for the purpose. On advice from the David Taylor Model Basin and the National Bureau of Standards, it was decided to use a tensile type specimen as a load gage. Drill-rod steel was used, and carefully machined to a diameter of 0.619 inch. This load gage was thoroughly calibrated in the range, 0--10,000 lbs., at the National Bureau of Standards. One SR-4 gage (Model A-1) was cemented on each side of the bar and rubber-taped for moisture-proofing throughout the program. These gages were connected in series to eliminate any bending effects. A piece of the same steel was used for application of two dummy gages. No difficulty arose in this connection, as attested by the linearity of virtually all the other strain gage readings (samples in Figs. 78 and 79), including 16 gages on the individual loading bolts which are discussed below.

At each of the four loading points, on the two transverse yokes, the vertical loading flat bar was attached by two one-inch diameter bolts. Each of these bolts was fitted with two SR-4 strain gages as a check for symmetry of loading and, incidentally, as a crude check on the main dynamometer. Their performance was quite reassuring as indicated in the sample, Table XI. They showed both transverse and longitudinal symmetry within about one per cent, and while the bolts were not intended as dynamometers or machined as such, the apparent total end load checked the main dynamometer reading within about three per cent.

The load measurements for slippage and foundation stiffness tests have been described in Appendix 1.

Strain Gages. Fig. 77 shows the location of all electrical strain gages used in the tests. Some of the gages shown were employed only for particular houses.

All of the gages on the hull and the single-wire gages on the houses were Baldwin, Model A-1. Three-wire rosettes on the houses (designated by the symbol, R, in Fig. 77) were Baldwin, Model AR-1. Prior to application they were checked for resistance range. Surfaces in way of gages were cleaned and roughened and application was made with Duco cement. Pressure was applied with small, portable clamps, and the gages were then moisture-proofed. Aluminum patches were attached to the model adjacent to the active gages and single-wire dummy gages of the same type were affixed. Approximately one dummy was used for every three gages. On the inside of the model one dummy was used for each active gage. Wiring was run from the model to junctions on a distribution panel attached to the front truss. Two multipoint switches were used. Each was made up of six banks of twenty-six contacts each, one being common to all. The points on these gages were gold-plated after delivery; variations due to variable contact resistance had been observed before this was done. One of these switches served the dummy gages, and the other served the active gages. Wiring was run from the distribution panel to the switches, which were connected to a Baldwin Type L strain analyzer. Selection of gage was made by punching appropriate keys on the seitches, with switch bank number controlled through a separate plug board. Readings were made by manual balance, individual readings being possible in 10-20-second intervals. All electrical equipment was carefully protected against moisture when not in use.

Since the theory is most complete for stresses at the midship station, with fall-off of stress in the house area expected fore and aft of this section, a considerable cluster of gages was placed amidship. Stations* 20, 36, and 56 were taken as representative of other stations where the Bleich double-beam theory should still hold, and sufficient gages were placed at these locations for full distribution of stresses. Numerous gages were also placed at station 76 since this was close to the point of load application. This station and station 36 were selected as useful points to check deck shear lag action. Longitudinal shearing stresses along the house-hull connecting line are vital, and a continuous line of rosettes was place just above the connecting angle. Since the zone of applicability of the theory is significant, a modest number of rosette gages were placed on the sides of each house in the end regions in order to ascertain directions and magnitudes of principal stresses. Stations 20, 36, and 76 were chosen for sampling of longitudinal symmetry of stresses. Station 100 was chosen for check of bottom shear lag. It is felt that there were adequate checks for transverse symmetry.

Through the entire program it could not be said that any single gages should be absolutely disregarded. A very few gages gave some difficulty as to general consistency. The instrumentation was planned, insofar as possible, to provide more than one inference as to general trends; occasionally one gage reading was disregarded because of a combination of other inferences.

---

*Stations are identified in inches forward or aft of amidship.

The overall performance of the gages is considered to be excellent. Figs. 78 and 79 show a brief sampling. Checks were made all during the tests by observing linearity as the loads were increased. Linearity was the almost universal rule, and virtually all gages seemed to zero out excellently. Instrument drift under load was hardly noticeable. The close correlation between bare hull tests before and after the main program provides overall assurance of gage reliability. Accuracy of measured strains is indicated by their close agreement with simple beam theory.* (See Figs. 66-67.)

<u>Dial Gages</u>. Deflection readings were made during all tests with Ames Model #282 dial gages. Thirteen gages were placed along the line of the hull side and ten gages measured deflections along the line of the house longitudinal bulkhead. A sufficient number were used to check symmetry. Since there must obviously be some deflection of the test rig, readings commenced at station 120--the extreme end. Tables VIII and IX report these readings. Before each test, the gages were checked for "stickiness", but no trouble was experienced. During the bulkhead stiffness tests, a single Sprague Model #2X(1/10,000) dial gage, of very high accuracy, was used to check against bulkhead deflections measured by the other instruments.

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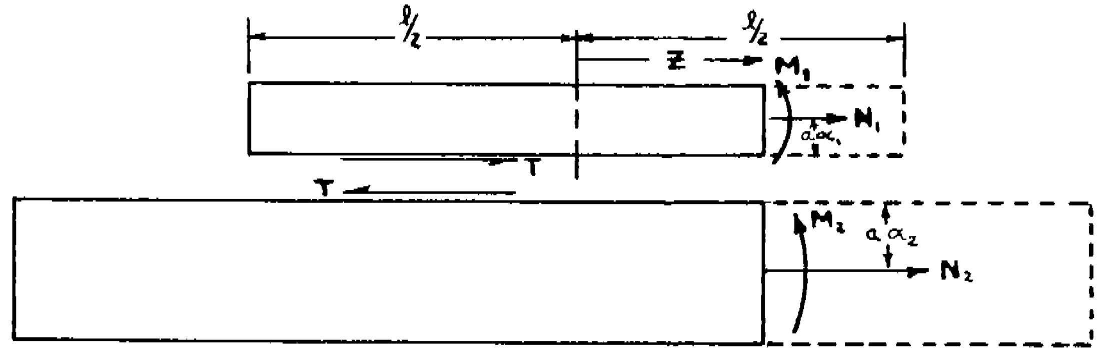
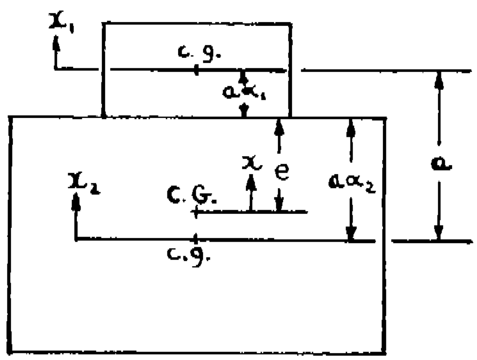
*Based on $E = 10.6 \times 10^6$ lb. per sq. in., as recommended by ALCOA for both 24ST and 14ST aluminum alloy.

APPENDIX 4
NOTATION CHART and THEORETICAL SUMMARY





$$\sigma = \sigma_N + \Phi \, \Delta\sigma_{1,2}$$

$$\Phi_1 = \frac{\sin u \cosh u + \cos u \sinh u}{\sin u \cos u + \sinh u \cosh u}$$

(DEVIATION FACTOR FOR CONSTANT BENDING MOMENT)

$$u = \frac{l}{2}\sqrt[4]{\frac{K}{4E} \cdot \frac{(1+\mu)}{(\alpha_2 I_1 + \mu\alpha_1 I_2)}}$$

$$\Delta\sigma_1 = \frac{\Delta N_1}{A_1} - \frac{\Delta M_1}{I_1} x_1 \qquad \Delta\sigma_2 = \frac{\Delta N_2}{A_2} - \frac{\Delta M_2}{I_2} x_2$$

(STRESS CORRECTIONS IF HOUSE HAD NO VERTICAL SUPPORT)

$$\Delta N_1 = -\Delta N_2 = \frac{M I_A}{a} \cdot \frac{\mu(\alpha_1 - \mu\alpha_2)}{(1+\mu)(\alpha_2 I_1 + \mu\alpha_1 I_2)}$$

$$\Delta M_1 = -M I_1 \frac{\mu}{(1+\mu)(\alpha_2 I_1 + \mu\alpha_1 I_2)}$$

$$\Delta M_2 = M I_2 \frac{\mu^2}{(1+\mu)(\alpha_2 I_1 + \mu\alpha_1 I_2)}$$

$$\sigma_N = -\frac{M}{I} x \qquad \mu = \frac{I_1 + \alpha_1 I_A}{I_2 + \alpha_2 I_A} \qquad I_A = a^2 \frac{A_1 A_2}{A_1 + A_2}$$

PROPORTIONAL BEHAVIOR

	Ship	Model	Relationship Model/Ship
LENGTH	L_S	L_M	λ
BEAM	B_S	B_M	λ
DEPTH of HULL	H_S	H_M	λ
DEPTH of HOUSE	h_S	h_M	λ
LENGTH of HOUSE	ℓ_S	ℓ_M	λ
NEUTRAL AXIS LOCATION	Y_S	Y_M	λ
LOAD	P_S Equiv.	P_M	π
DEFLECTION of HULL	δ_{HS}	δ_{HM}	Δ_H
BENDING DEFL. of HULL	δ'_{HS}	δ'_{HM}	Δ'_H
SHEAR DEFL. of HULL	δ''_{HS}	δ''_{HM}	Δ''_H
DEFLECTION of DECK BEAM	δ_{BS}	δ_{BM}	Δ_B
DEFLECTION of DECK PLATE	δ_{PS}	δ_{PM}	Δ_P
DEFL. of SUPERSTRUCTURE	δ_{SS}	δ_{SM}	Δ_S
STRESS	σ_S	σ_M	Σ
DECK BEAM or PLATE LOAD	Q_S	Q_M	π
HULL SIDE PL. THICK.	t_{HS}	t_{HM}	T_H
MAIN DECK PL. THICK.	t_{MS}	t_{MM}	T_M
SUPERSTRUCTURE PL. THICK.	t_{SS}	t_{SM}	T_S
HULL FLEXURAL INERTIA	I_{HS}	I_{HM}	Φ_H
DECK BEAM FLEX. INERTIA	I_{BS}	I_{BM}	Φ_B
RUNN. D'K. BEAM FLEX. INER.	i_{BS}	i_{BM}	φ_B
HOUSE FLEXURAL INERTIA	i_S	i_M	Φ_S
DECK BEAM SPACING	S_S	S_M	λ_S
HOUSE TRANSVERSE STEP	d_S	d_M	λ
YOUNGS MODULUS	E_S	E_M	$\xi(\ )$
MODULUS of RIGIDITY	G_S	G_M	$\xi(\ )$

FUNDAMENTAL REQUIREMENTS

(1) $\dfrac{\Delta'_H}{\Delta''_H} = 1$ SHEAR BENDING PROPORTIONALITY

(2) $\dfrac{\Delta_B}{\Delta'_H} = 1$ DECK BEAM - HULL PROPORTIONALITY

(3) $\dfrac{\Delta_S}{\Delta'_H} = 1$ SUPERSTRUCTURE - HULL (BENDING) PROPORTIONALITY

(4) $\dfrac{\Delta_P}{\Delta_B} = 1$ PLATE/BEAM STIFFNESS RATIO (APPROX.)

BASIC PROPORTIONALITIES

$$\delta'_H = k_1 \frac{PL^3}{EI_H}$$

$$\delta''_H = k_2 \frac{PL}{GHt_H} = k'_2 \frac{P}{E_H t_H}$$

$$\delta_S = k_3 \frac{QL^3}{E_s i} = k'_3 \frac{PL^3}{E_s i}$$

$$\delta_B = k_4 \frac{QB^3}{E_B I_B} = k'_4 \frac{PL^3}{E_B I_B}$$

$$\delta_P = k_5 \frac{Qd^2}{E_p t_M^3} = k'_5 \frac{PL^2}{E_p t_M^3}$$

DERIVED RELATIONSHIPS

$$\Delta'_H = \frac{\delta'_{HM}}{\delta'_{HS}} = \frac{k_{1M}\dfrac{P_M L_M^3}{E_M I_{HM}}}{k_{1S}\dfrac{P_S L_S^3}{E_S I_{HS}}} = \frac{k_{1M}}{k_{1S}} \; \frac{\pi \lambda^3}{\xi \Phi_H} = \frac{\pi \lambda^3}{\xi \Phi_H}$$

$$\Delta''_H = \frac{\delta''_{HM}}{\delta''_{HS}} = \frac{k'_{2M}\dfrac{P_M}{E_M t_{HM}}}{k'_{2S}\dfrac{P_S}{E_S t_{HS}}} = \frac{k'_{2M}}{k'_{2S}} \; \frac{\pi}{\xi T_H} = \frac{\pi}{\xi T_H}$$

$$\Delta_B = \frac{\delta_{BM}}{\delta_{BS}} \doteq \frac{k'_{4M}\dfrac{P_M L_M^3}{E_M I_{BM}}}{k'_{4S}\dfrac{P_S L_S^3}{E_S I_{BS}}} = \frac{k'_{4M}}{k'_{4S}} \; \frac{\pi \lambda^3}{\xi \Phi_B} = \frac{\pi \lambda^3}{\xi \Phi_B}$$

$$\Delta_S = \frac{\delta_{SM}}{\delta_{SS}} = \frac{k'_{3M}\dfrac{P_M L_M^3}{E_M i_M}}{k'_{3S}\dfrac{P_S L_S^3}{E_S i_S}} = \frac{k'_{3M}}{k'_{3S}} \; \frac{\pi \lambda^3}{\xi \Phi_S} = \frac{\pi \lambda^3}{\xi \Phi_S}$$

$$\Delta_P = \frac{\delta_{PM}}{\delta_{PS}} = \frac{k'_{5M}\dfrac{P_M L_M^2}{E_M t_{MM}^3}}{k'_{5S}\dfrac{P_S L_S^2}{E_S t_{MS}^3}} = \frac{k'_{5M}}{k'_{5S}} \; \frac{\pi \lambda^2}{\xi T_M^3} = \frac{\pi \lambda^2}{\xi T_M^3}$$

Let $\eta = \frac{\Phi_H}{\lambda^2}$

MULTI CELL FACTOR

from (1) $\Delta'_H = \Delta''_H$

$$\frac{\pi \lambda^3}{\xi \Phi_H} = \frac{\pi}{\xi T_H} \quad \text{OR} \quad \frac{\lambda^3}{\eta \lambda^2} = \frac{1}{T_H}$$

(A) $\underline{\eta = \lambda T_H}$

from (2) $\Delta_B = \Delta'_H$

(B) $$\frac{\pi \lambda^3}{\xi \Phi_B} = \frac{\pi \lambda^3}{\xi \Phi_H} \quad \text{OR} \quad \underline{\Phi_B = \eta \lambda^2}$$

from (3) $\Delta_S = \Delta'_H$

(C) $$\frac{\pi \lambda^3}{\xi \Phi_S} = \frac{\pi \lambda^3}{\xi \Phi_H} \quad \text{OR} \quad \underline{\Phi_S = \eta \lambda^2}$$

from (4) $\Delta_P = \Delta_B$

(D) $$\frac{\pi \lambda^2}{\xi T_M^3} = \frac{\pi \lambda^3}{\xi \Phi_B} \quad \text{OR} \quad \underline{T_M^3 = \eta \lambda}$$

THIS GIVES:

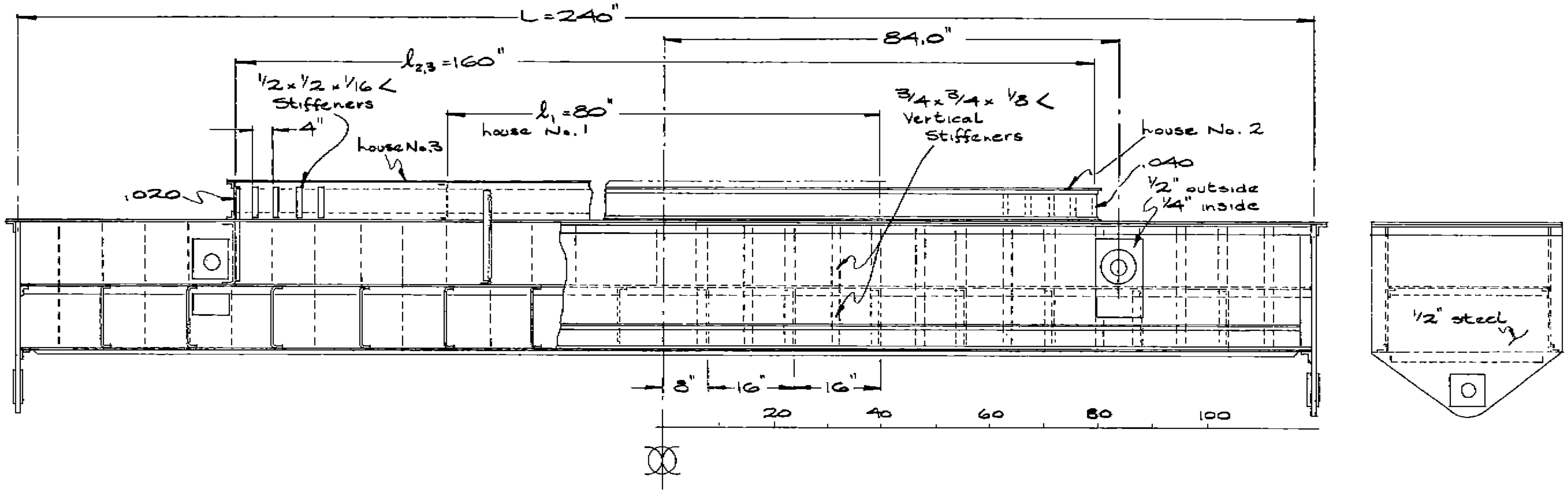
$$\eta = \lambda T_H = \frac{\Phi_B}{\lambda^2} = \frac{\Phi_S}{\lambda^2} = \frac{T_M^3}{\lambda}$$

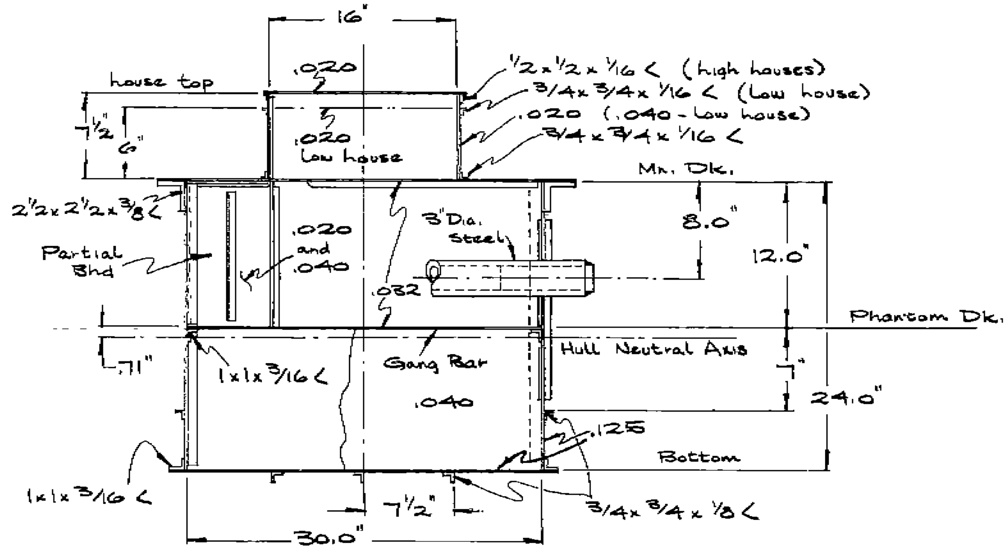
OR USING:

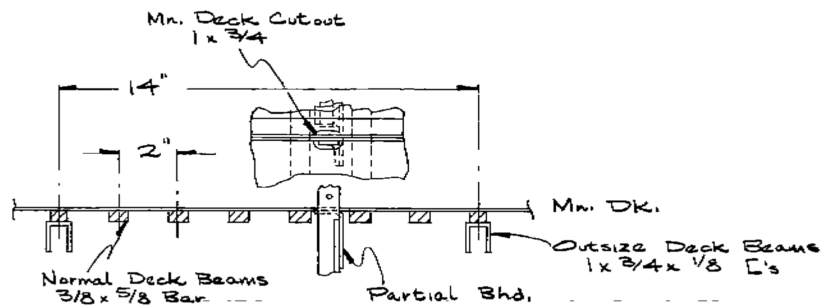
$$\Phi_H \cong \eta \lambda^2 \qquad \eta \cong \frac{\Phi_H}{\lambda^2}$$

$$\frac{\Phi_H}{\lambda^2} = \lambda T_H = \frac{\Phi_B}{\lambda^2} = \frac{\Phi_S}{\lambda^2} = \frac{T_M^3}{\lambda}$$

(E) $$\boxed{\Phi_H = \lambda^3 T_H = \Phi_B = \Phi_S = \lambda T_M^3 = C}$$







NOTE:
ALL SHEET - AL-AL 24ST (UNCLAD)
ROLLED and EXTRUDED SHAPES - AL-AL 14ST
See Table (III) for SECTION PROPERTIES.

FIG. 1-EXPERIMENTAL MODEL
HULL-SUPERSTRUCTURE TESTS

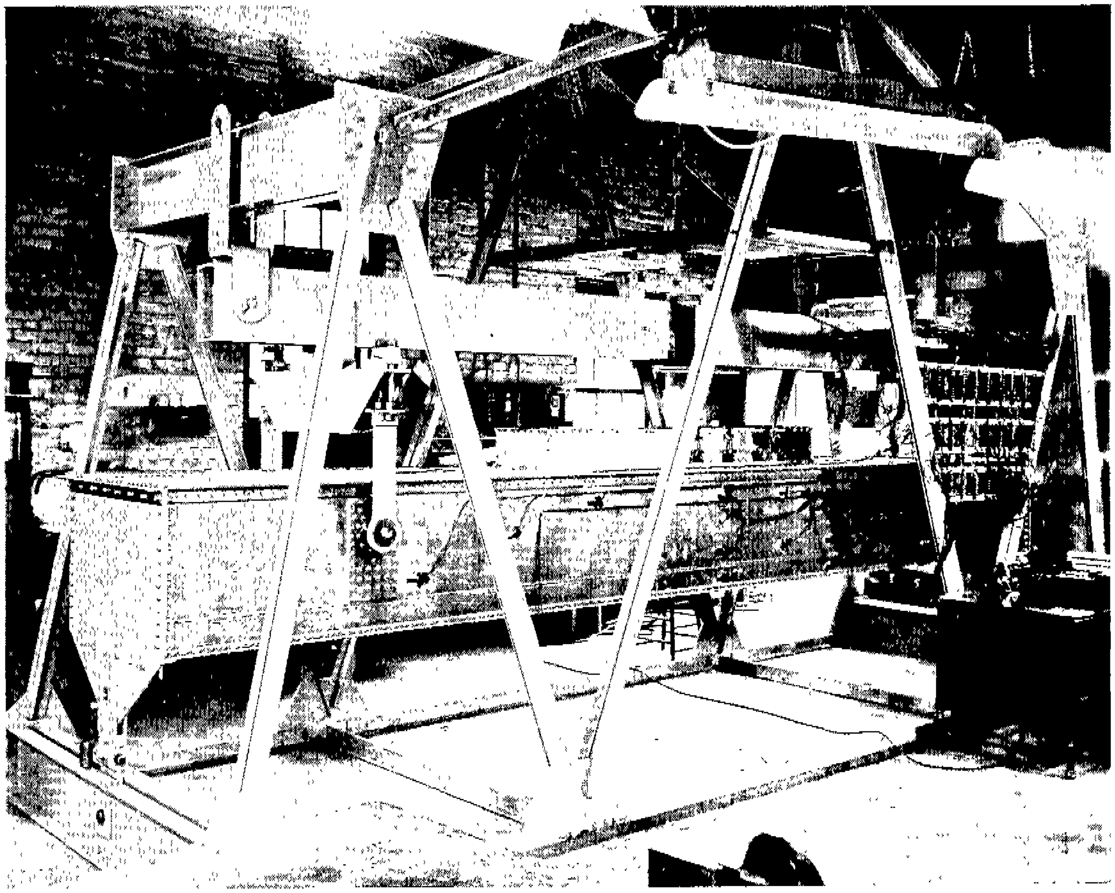


FIG. 2 - GENERAL VIEW OF MODEL - SHORT HOUSE

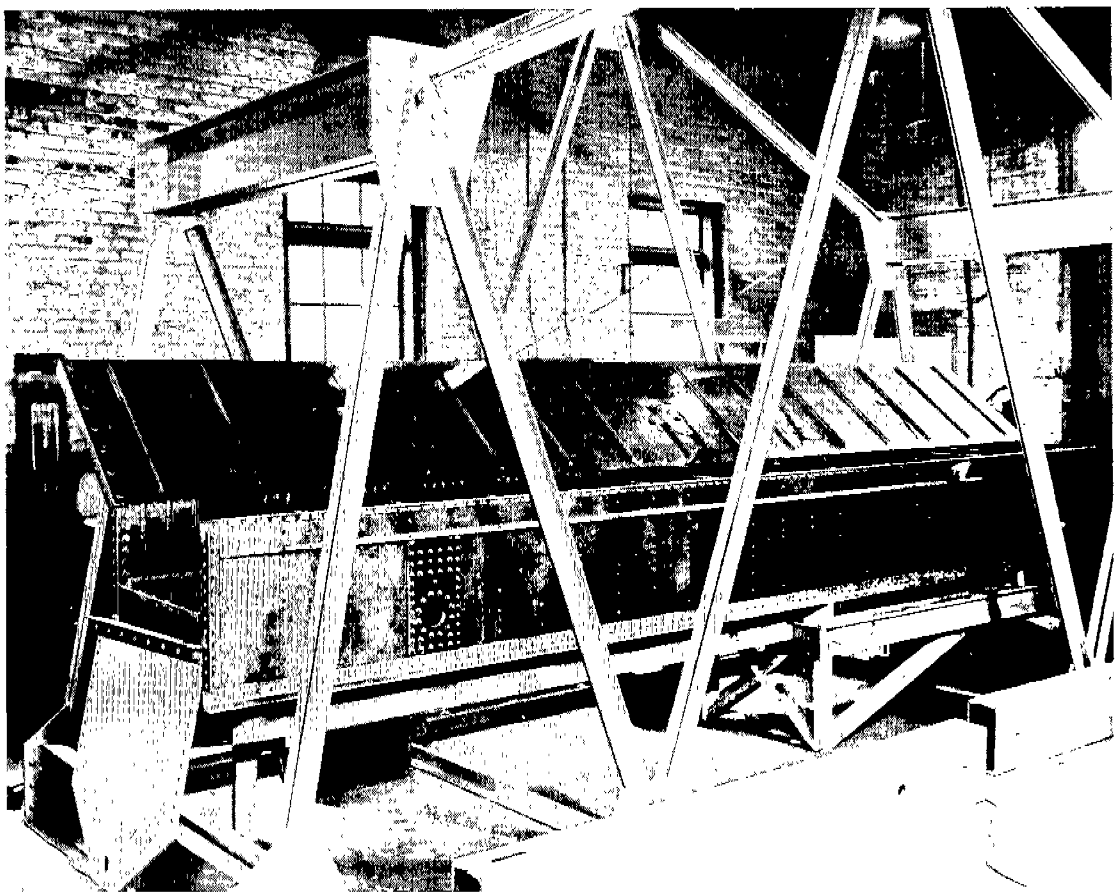


FIG. 3 - ASSEMBLY - BOTTOM STRUCTURE

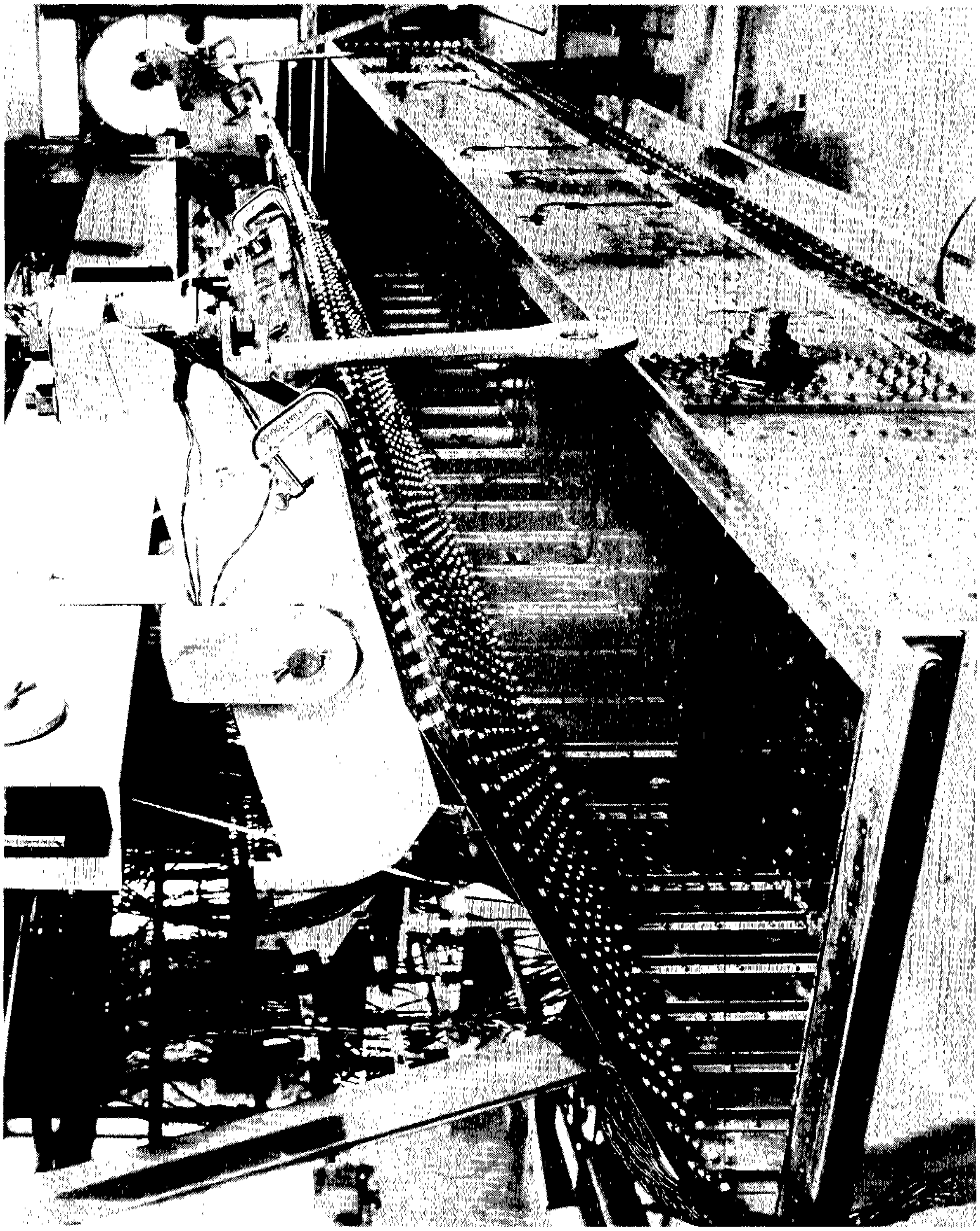


FIG. 4 - PHANTOM DECK LOOKING DOWN

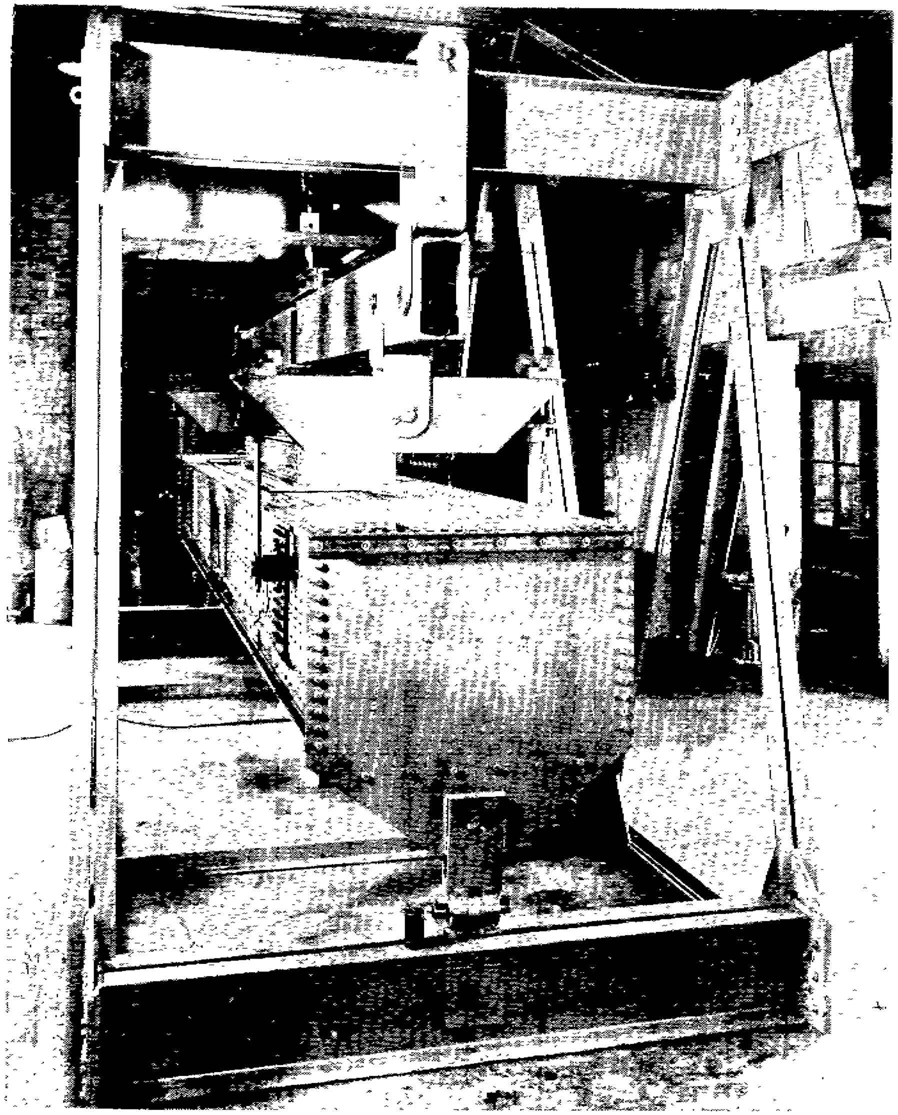


FIG. 5 - END VIEW OF MODEL - SHORT HOUSE

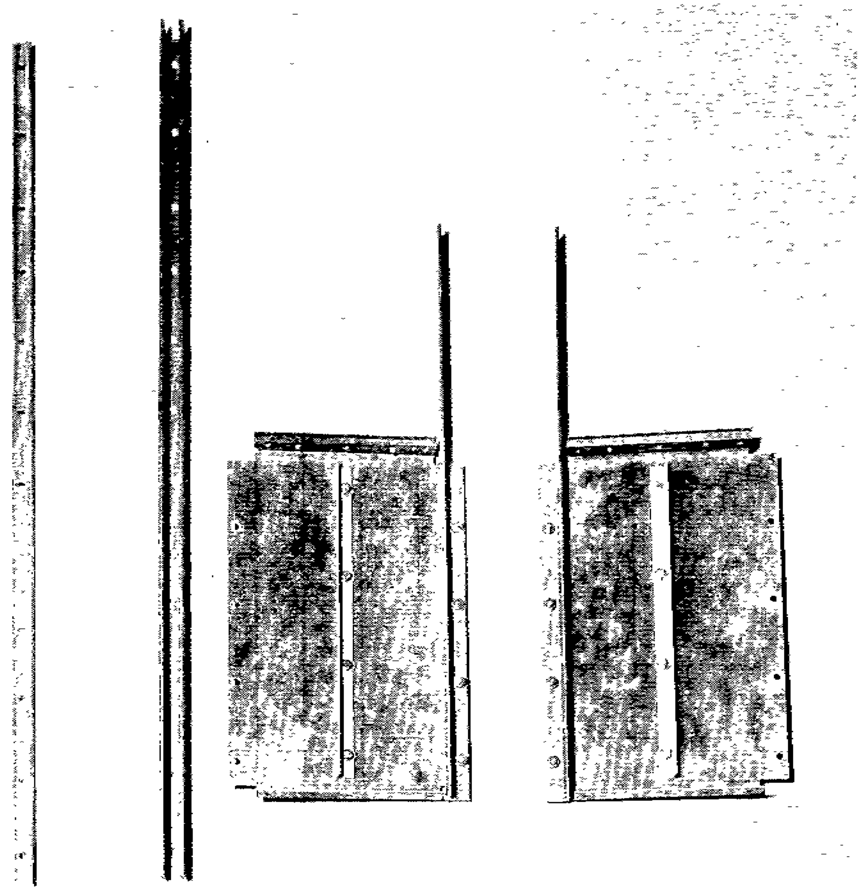


FIG. 6 - TYPICAL BULKHEAD AND DECK BEAMS

Fig. 7-ARRANGEMENT OF DECK HOUSE AND SUPPORTS - TESTS 2-10
(TESTS #1 and #11 WERE BARE-HULL TESTS - SEE APPENDIX 1.)

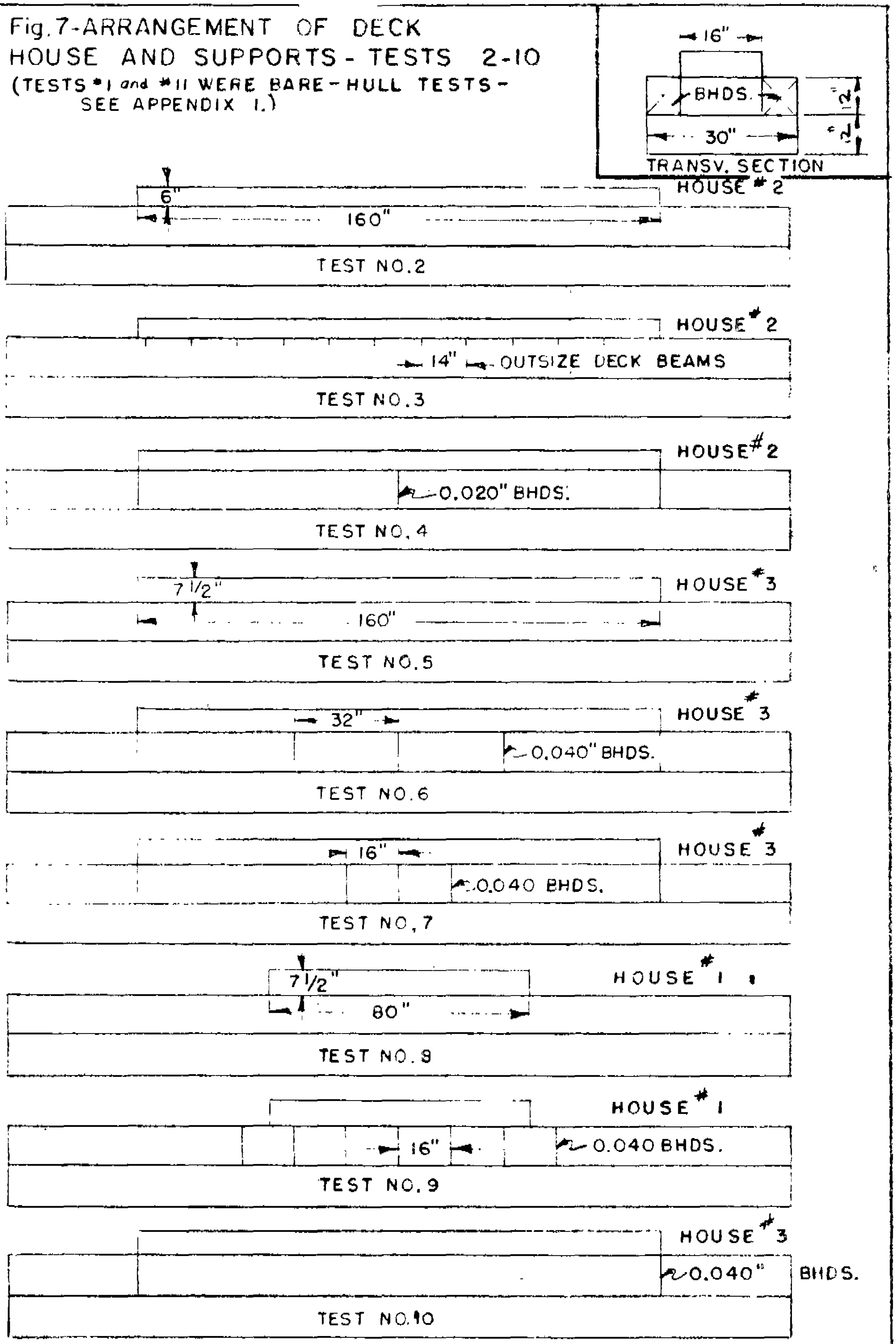


FIG. 8 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 2

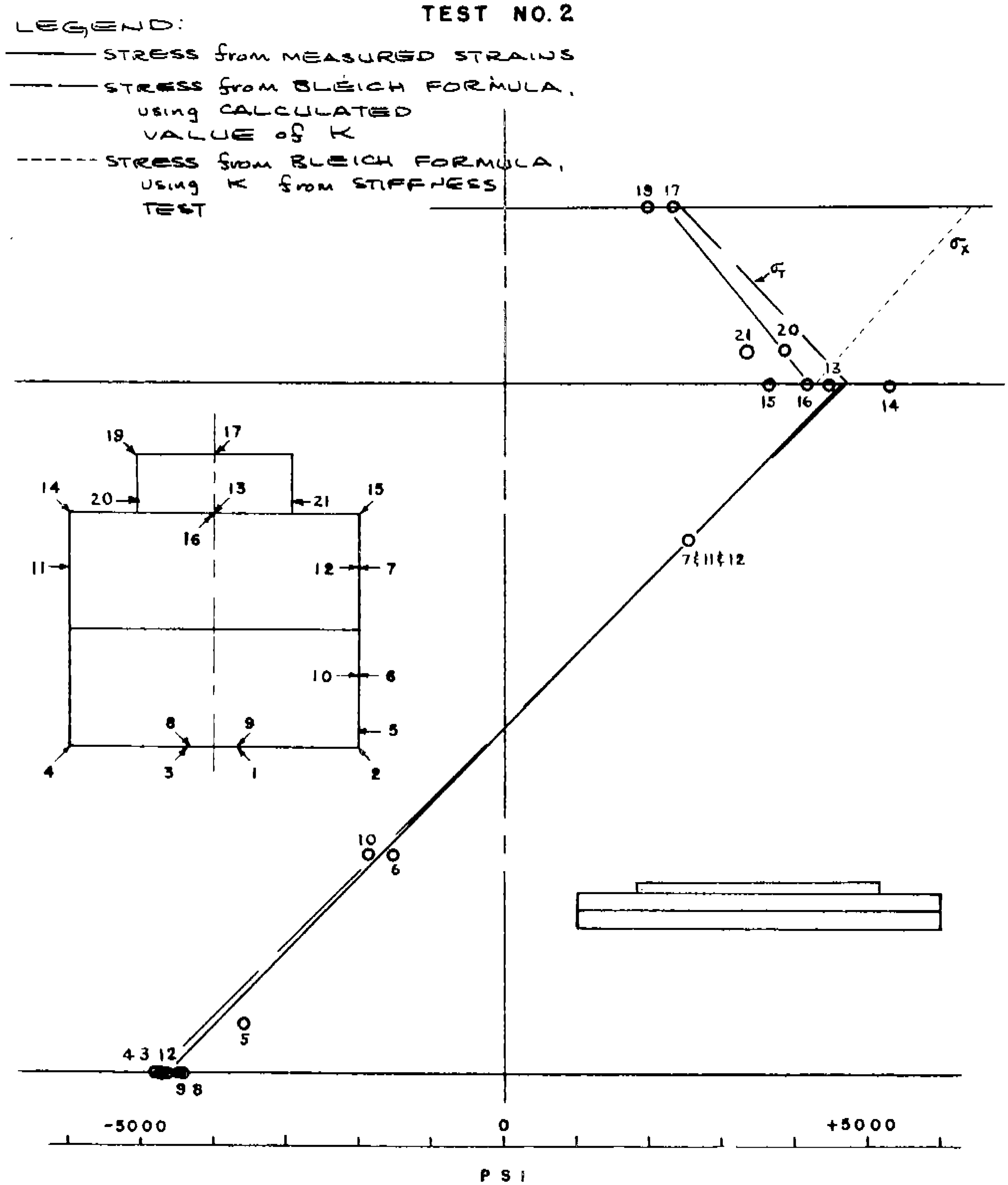


FIG. 9 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 3

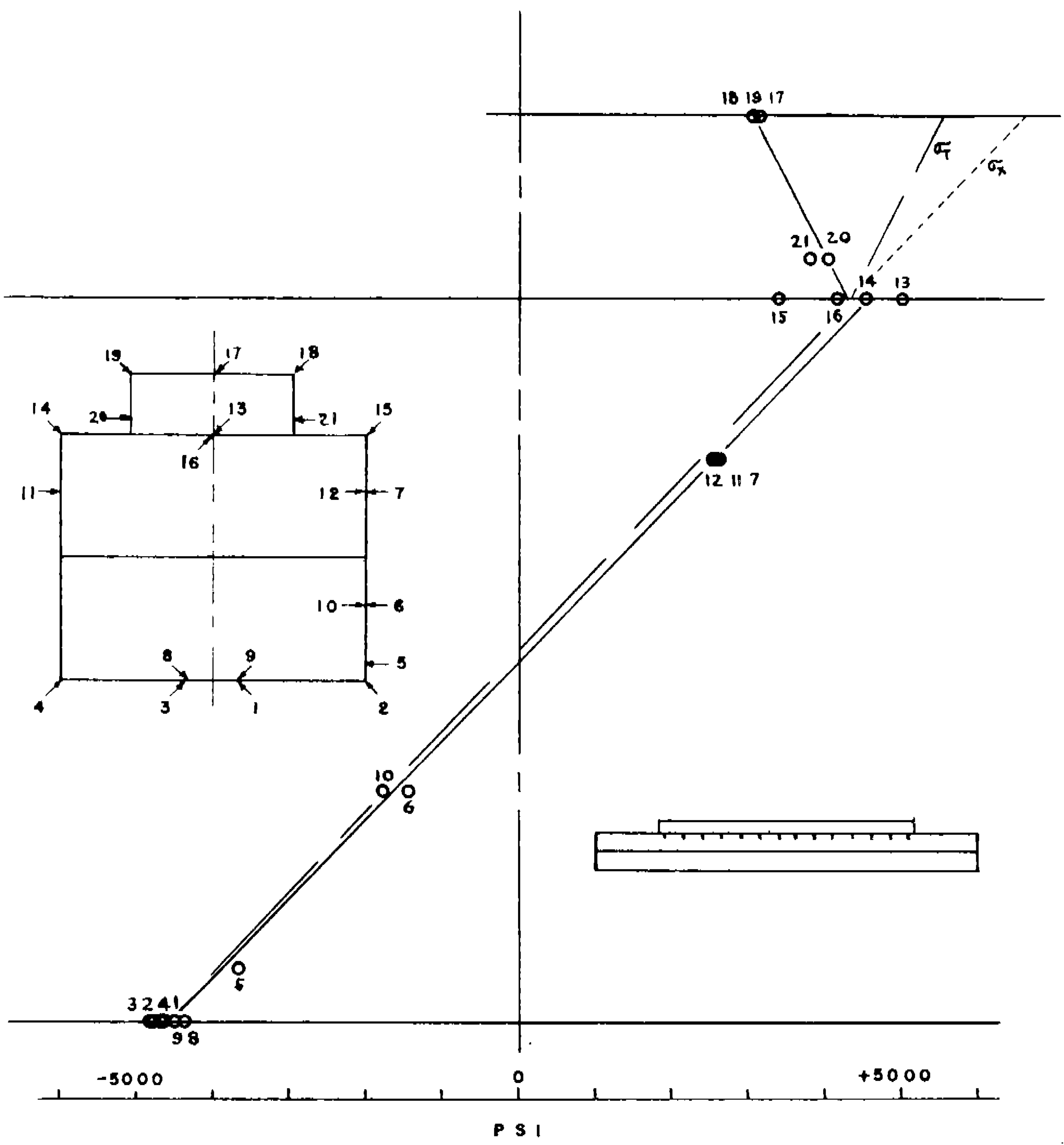


FIG. 10 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 4

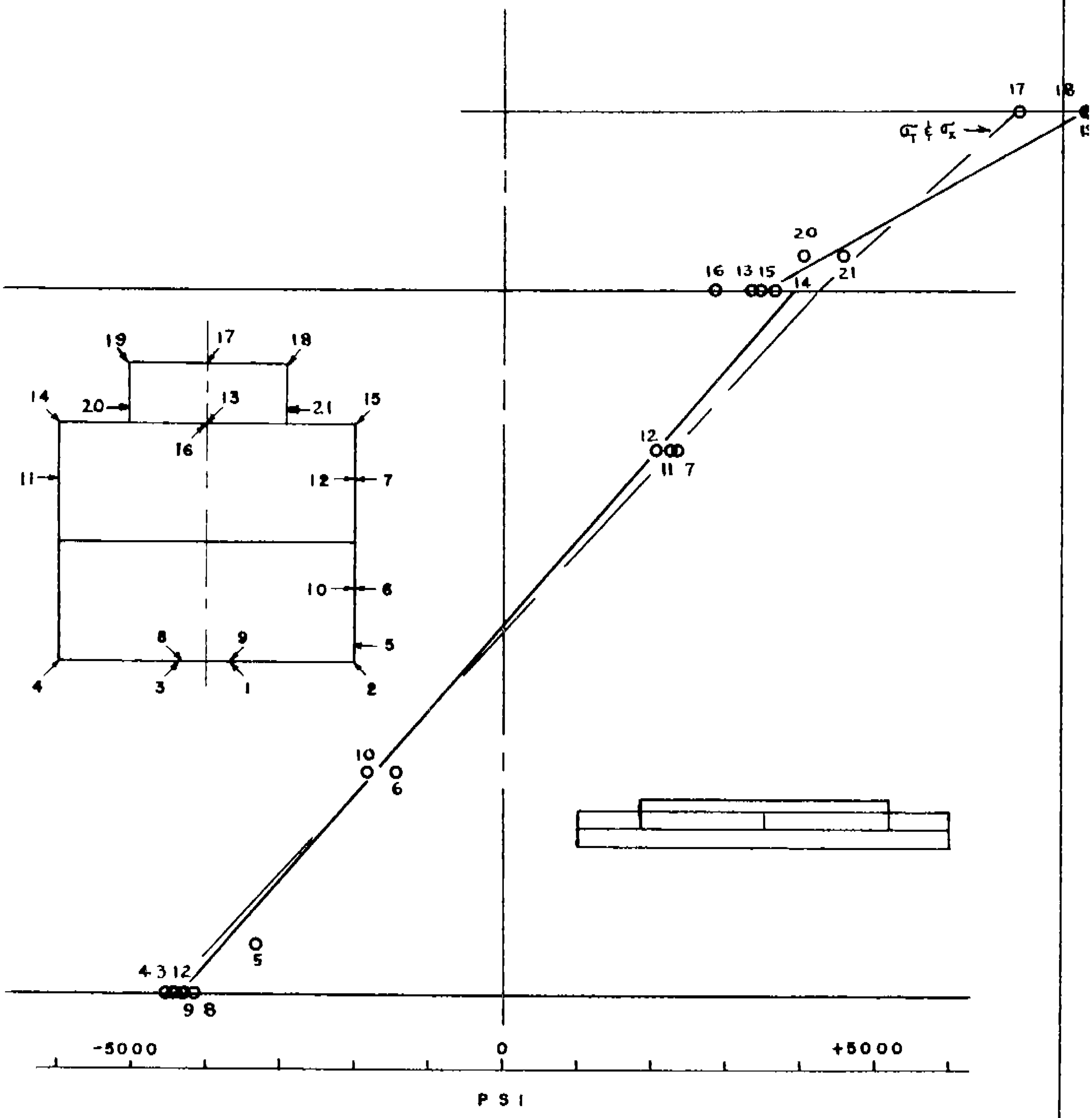


FIG. 11 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 5

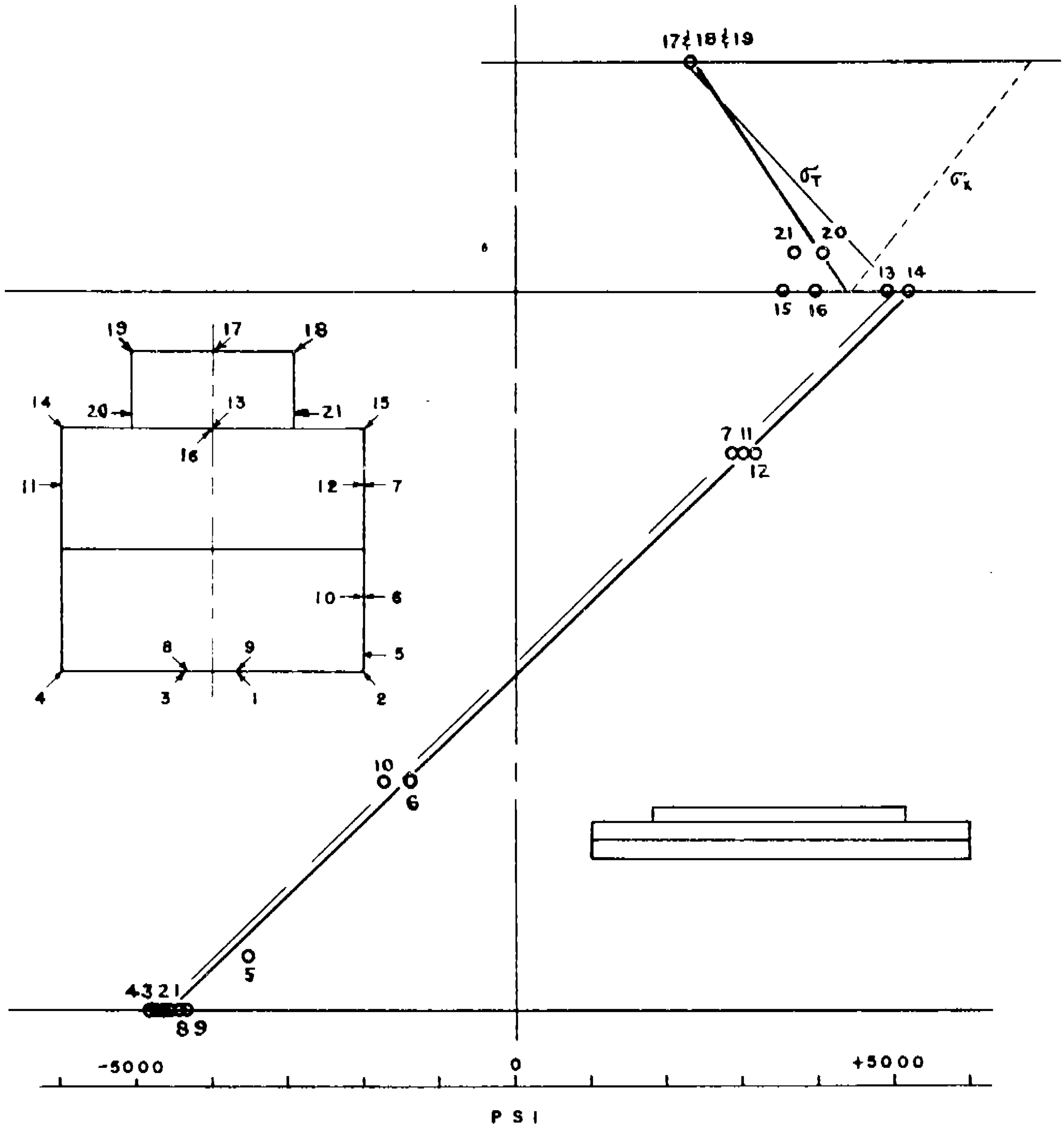
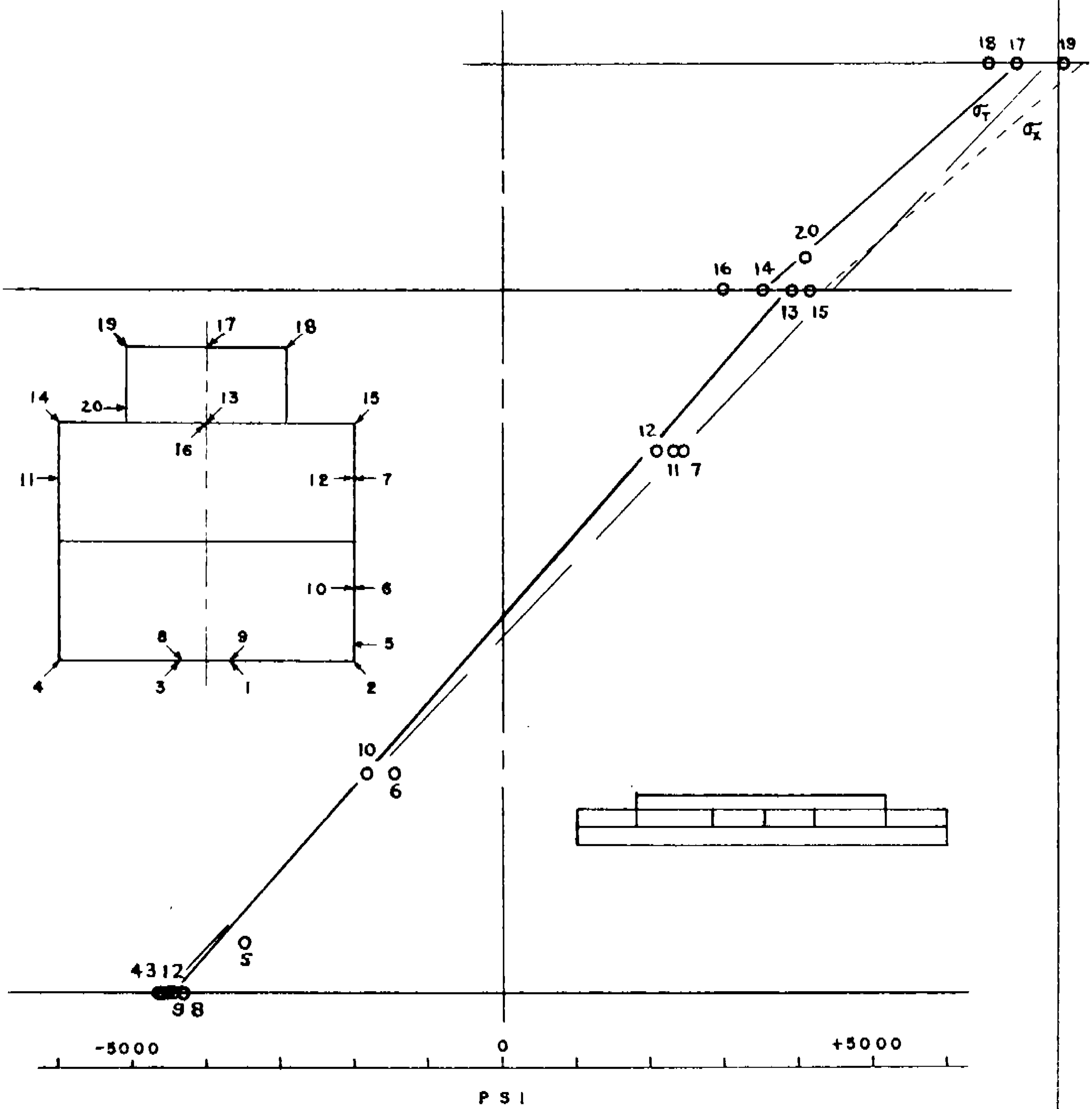


FIG. 12 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 6



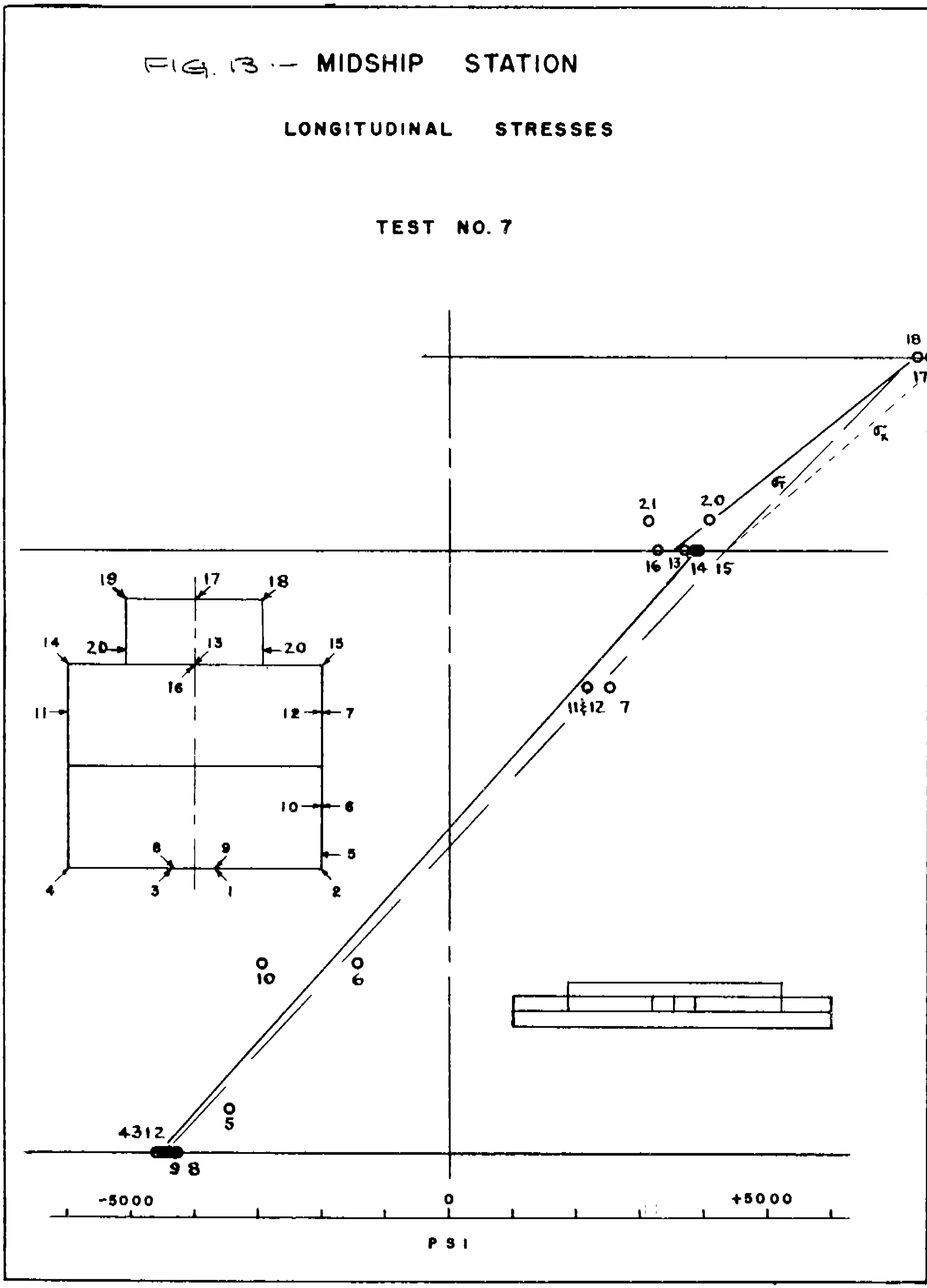


FIG. 13 — MIDSHIP STATION
LONGITUDINAL STRESSES
TEST NO. 7
18
17 & 19
σ_x
σ_T
21
20
16
13
14
15
19
17
18
14
20
13
20
15
16
11
12
7
10
6
8
9
5
4
3
1
2
11 & 12
7
10
6
5
4 3 1 2
9 8
-5000
0
+5000
PSI

FIG. 14 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 8

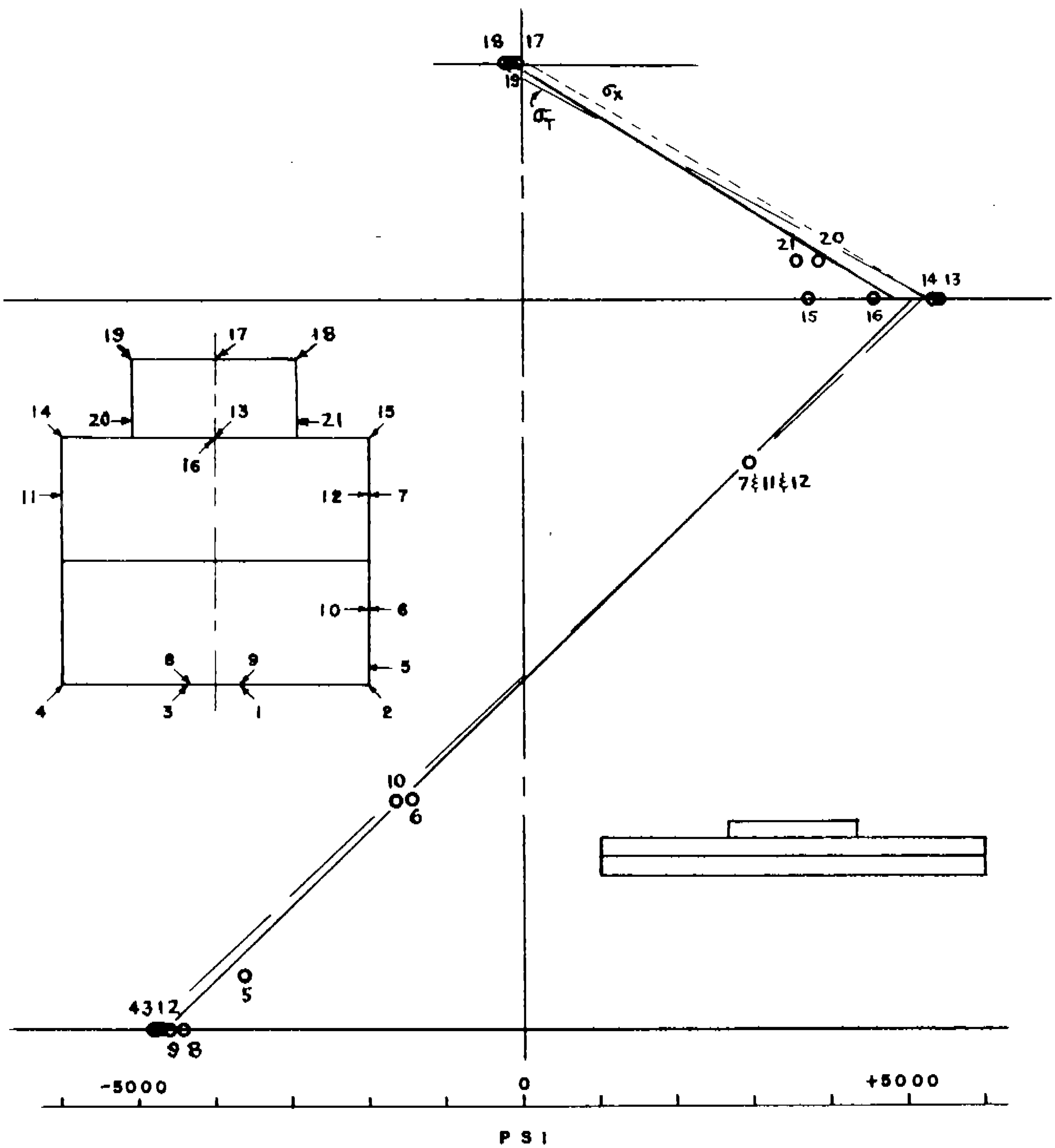


FIG. 15 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 9

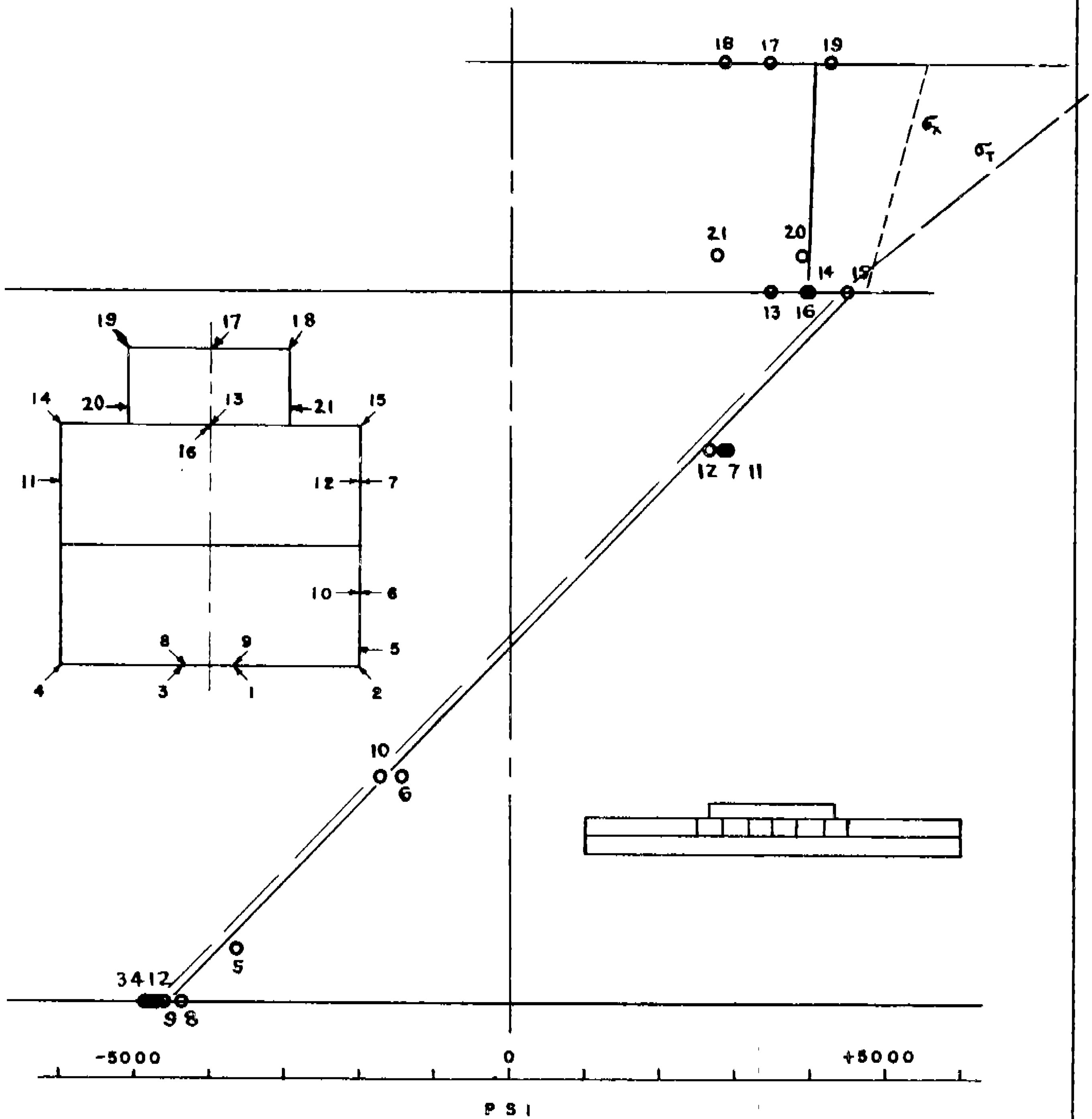
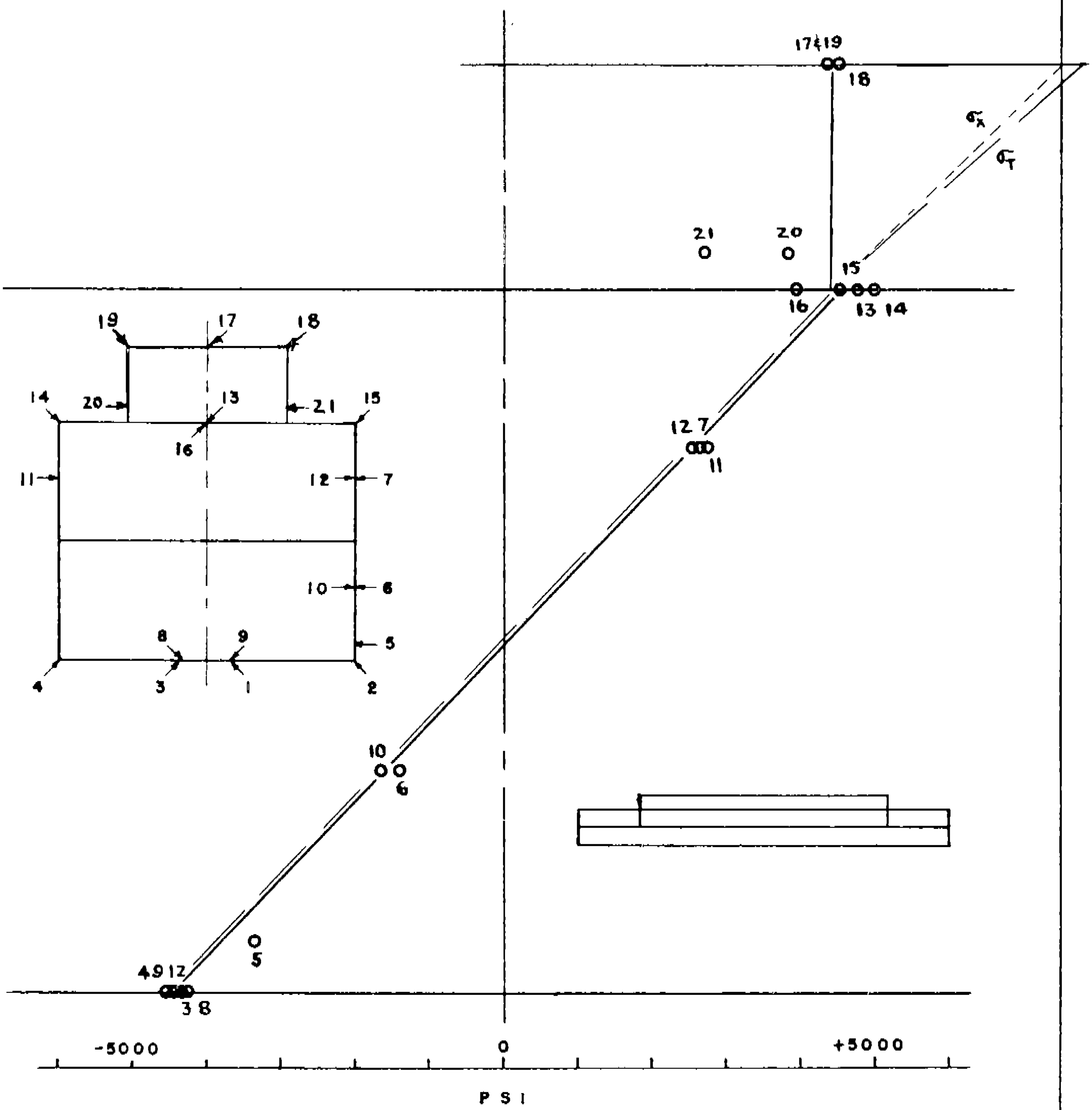


FIG. 16 - MIDSHIP STATION

LONGITUDINAL STRESSES

TEST NO. 10



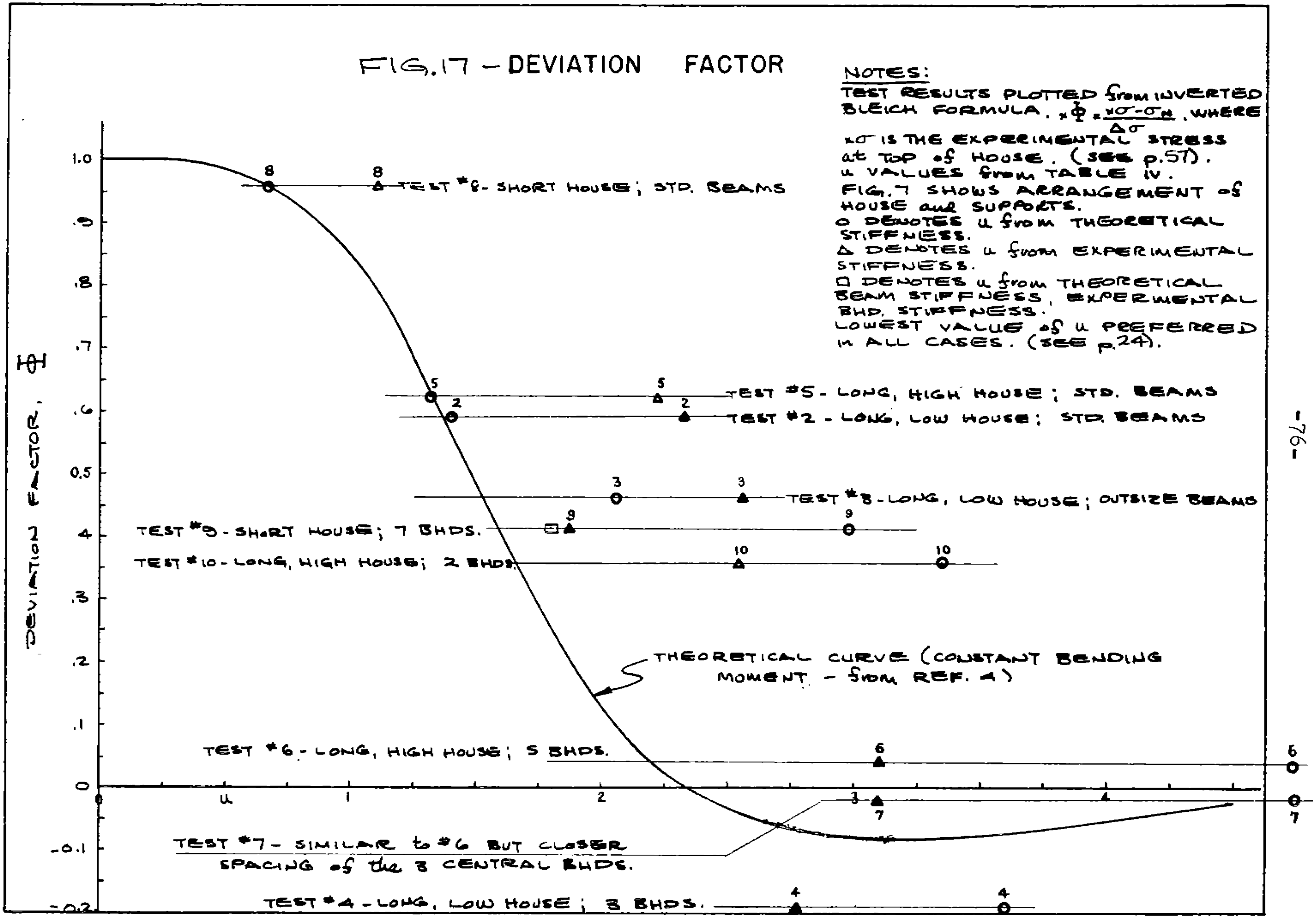


FIG. 17 - DEVIATION FACTOR

FIG. 18 - DEFLECTIONS
HOUSE & HULL

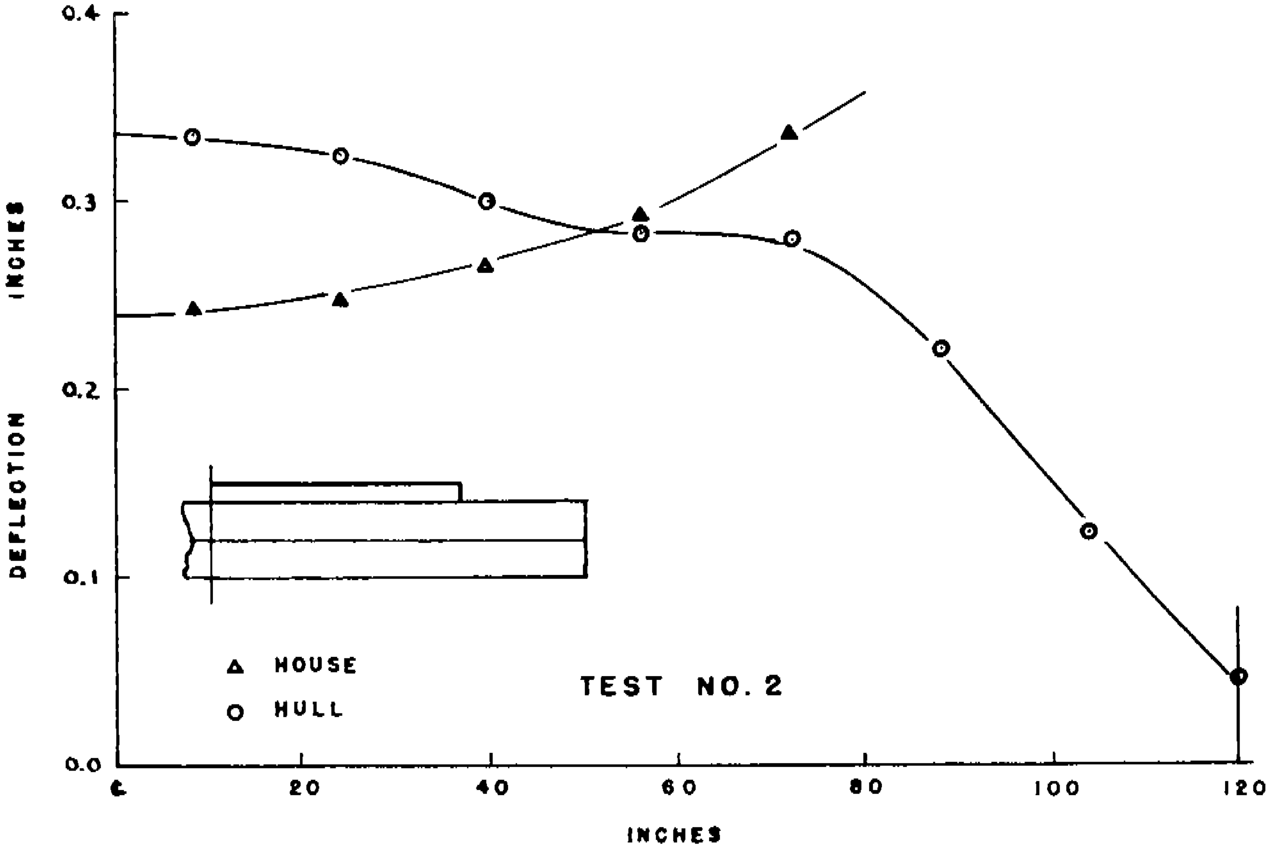


FIG. 19

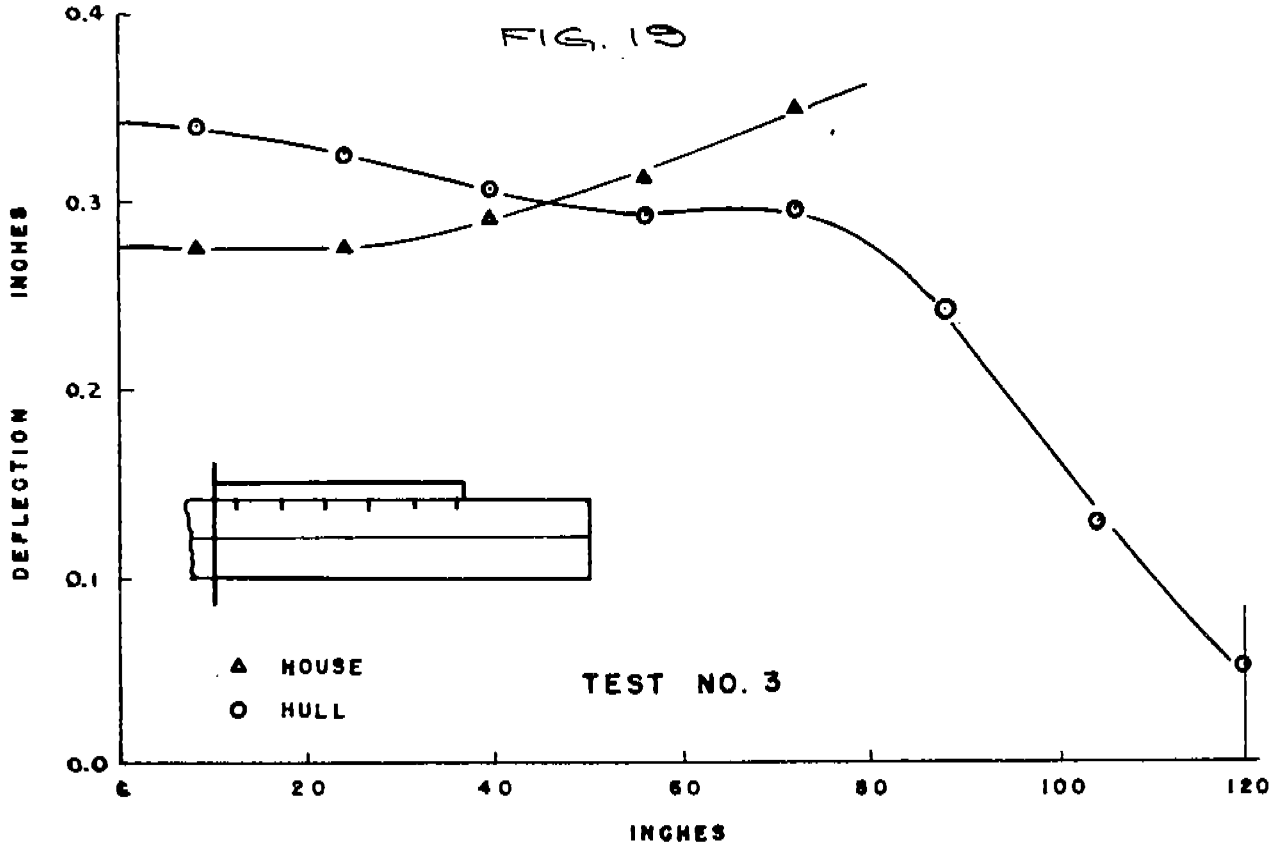


FIG. 20 - DEFLECTIONS
HOUSE & HULL

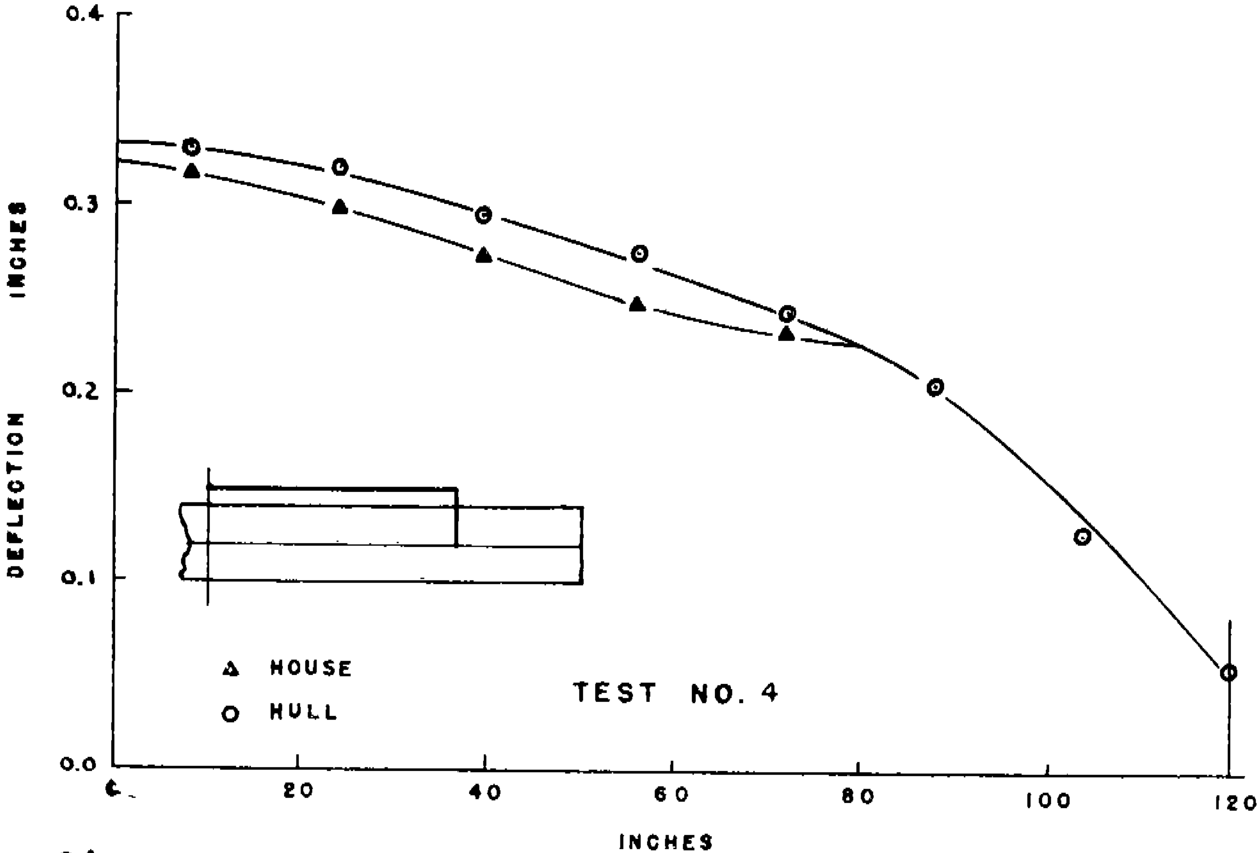


FIG. 21

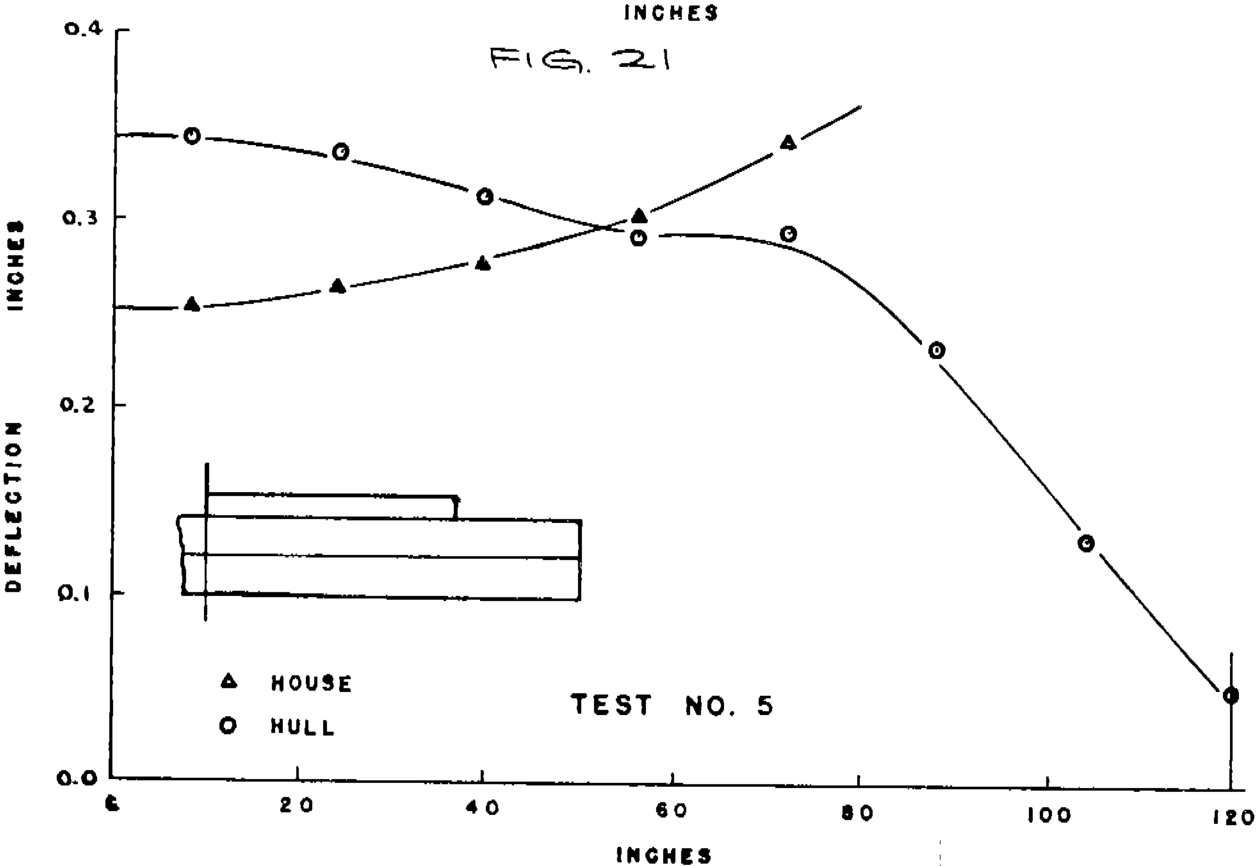


FIG. 22- DEFLECTIONS

HOUSE & HULL

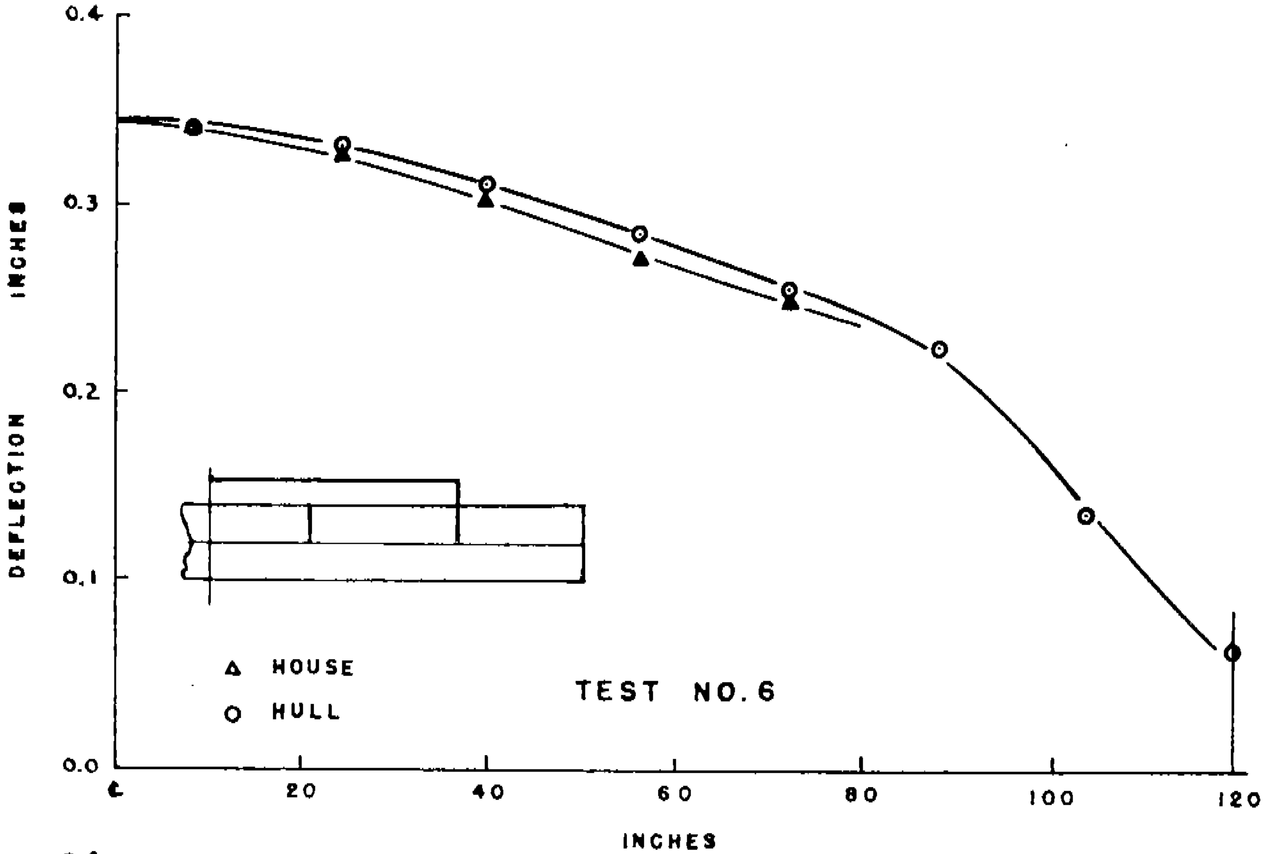


FIG. 23

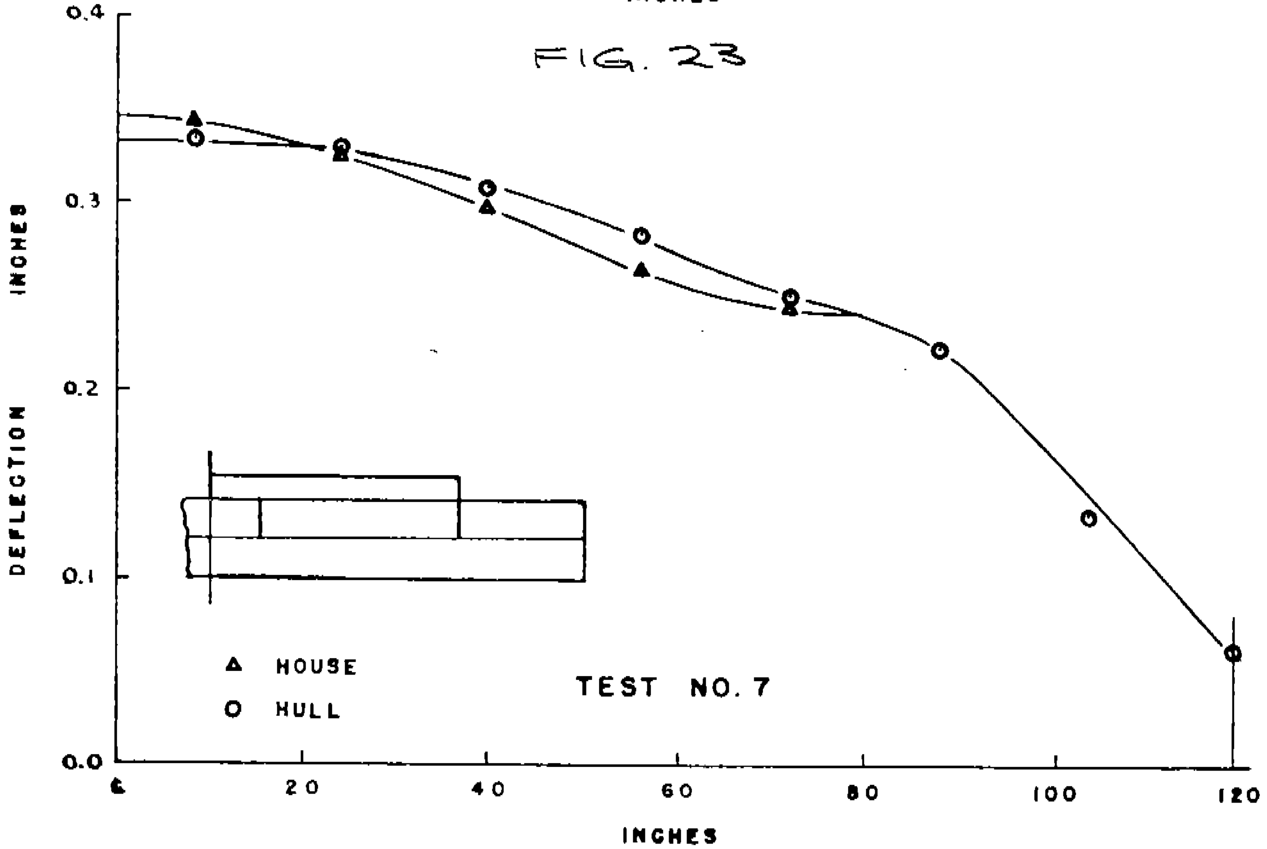


FIG. 24 - DEFLECTIONS
HOUSE & HULL

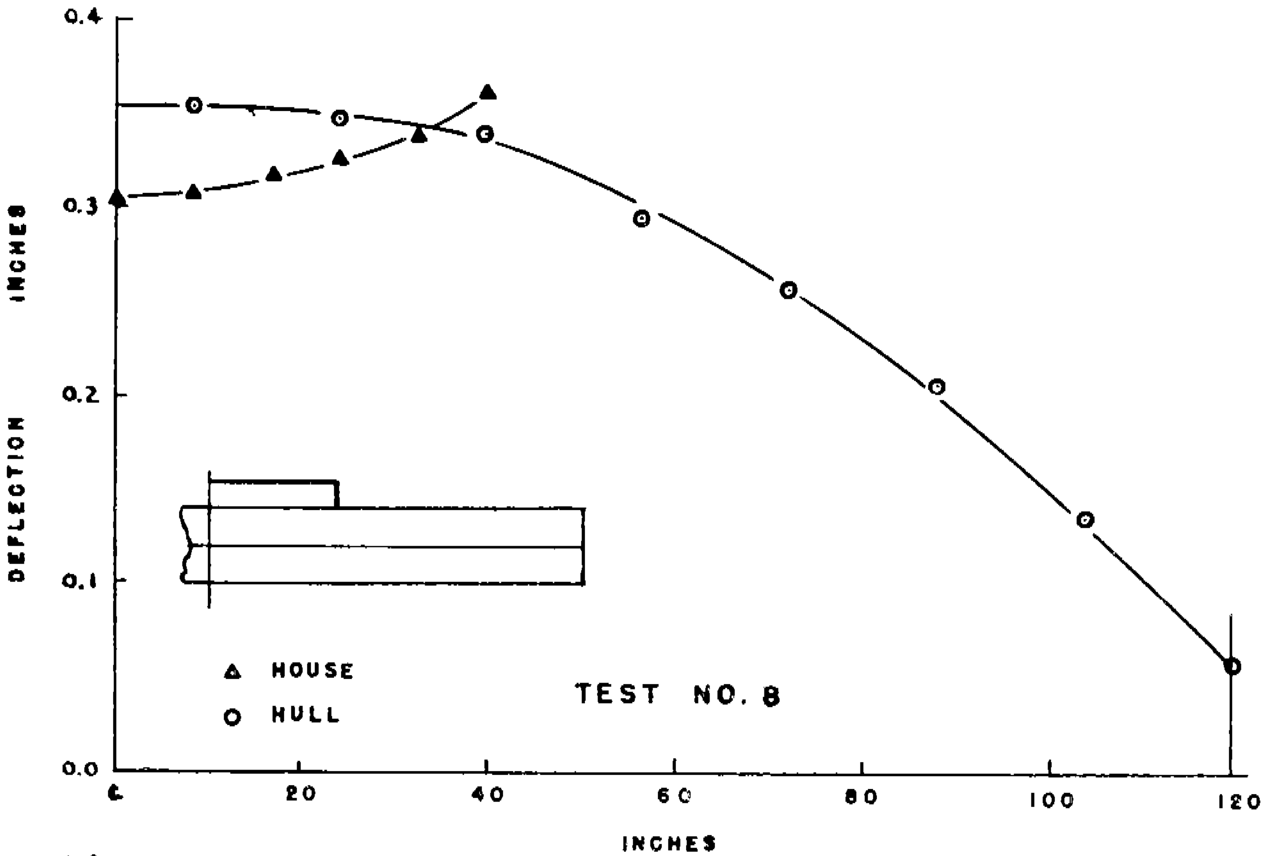


FIG. 25

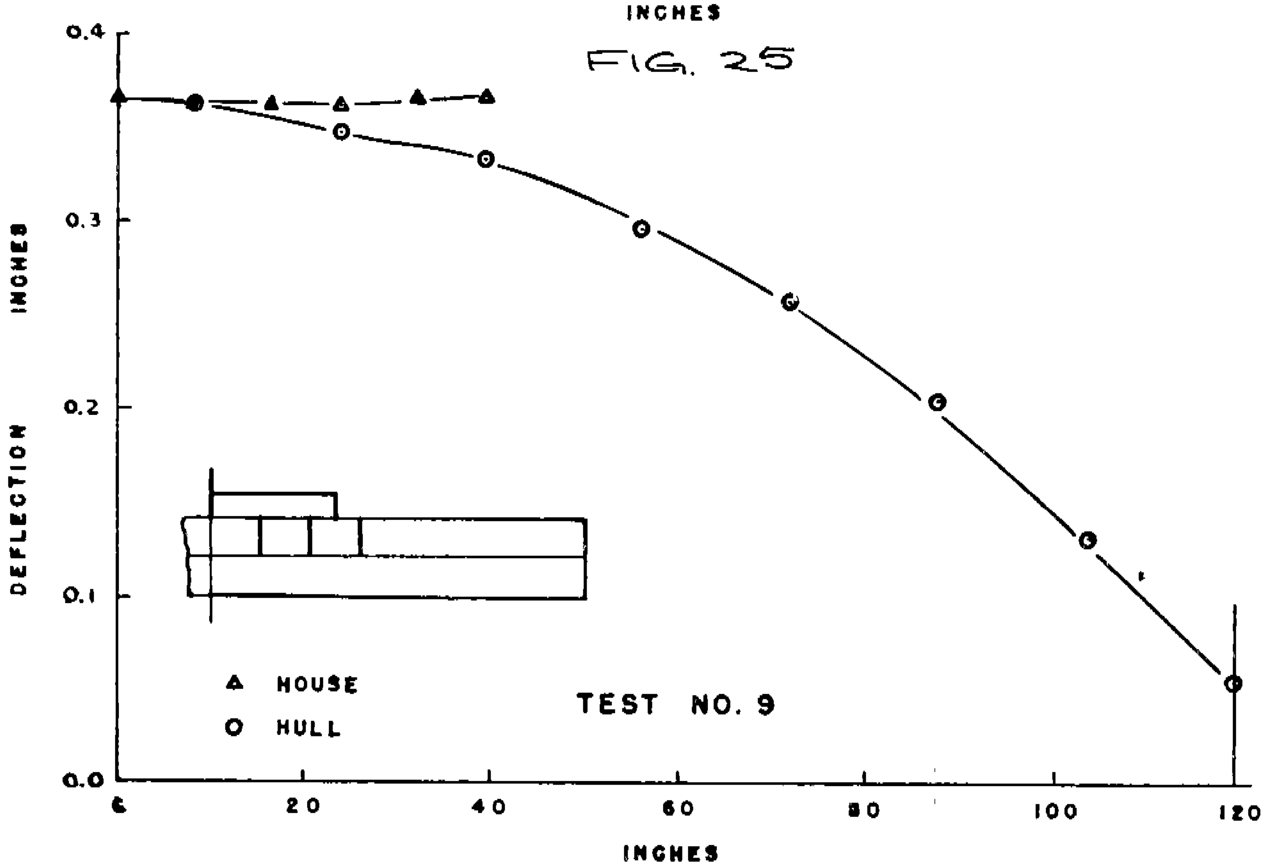
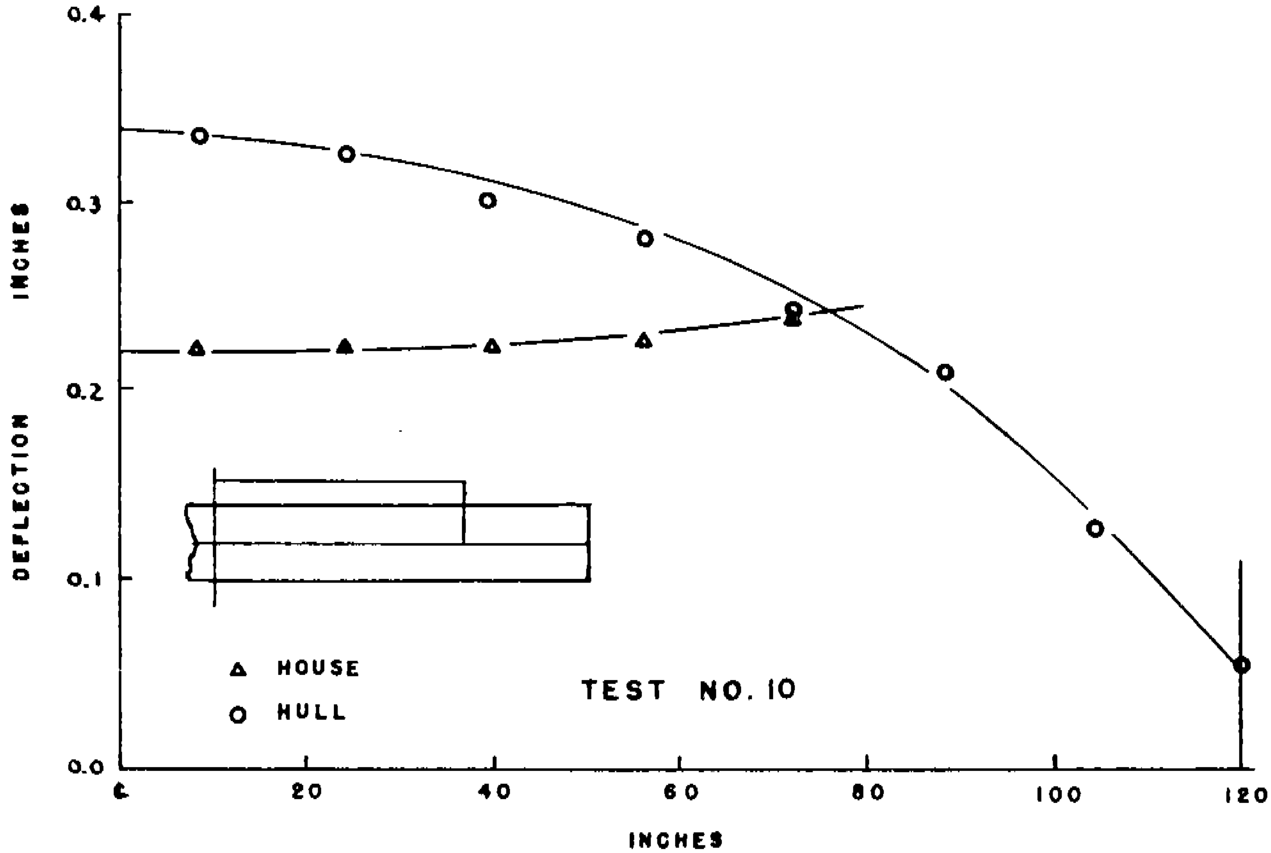


FIG. 26 -DEFLECTIONS
HOUSE & HULL



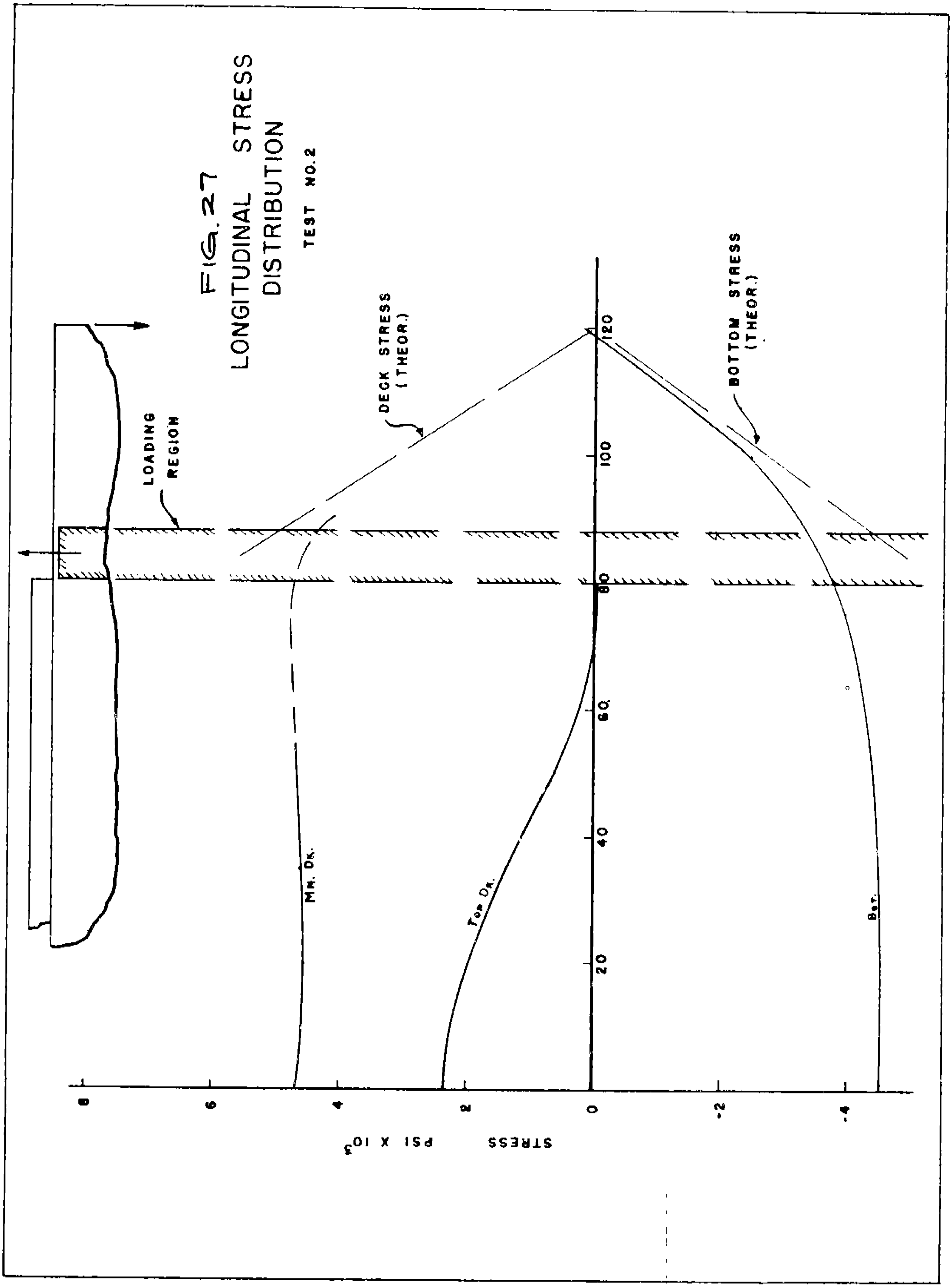


FIG. 27
LONGITUDINAL STRESS DISTRIBUTION
TEST NO. 2

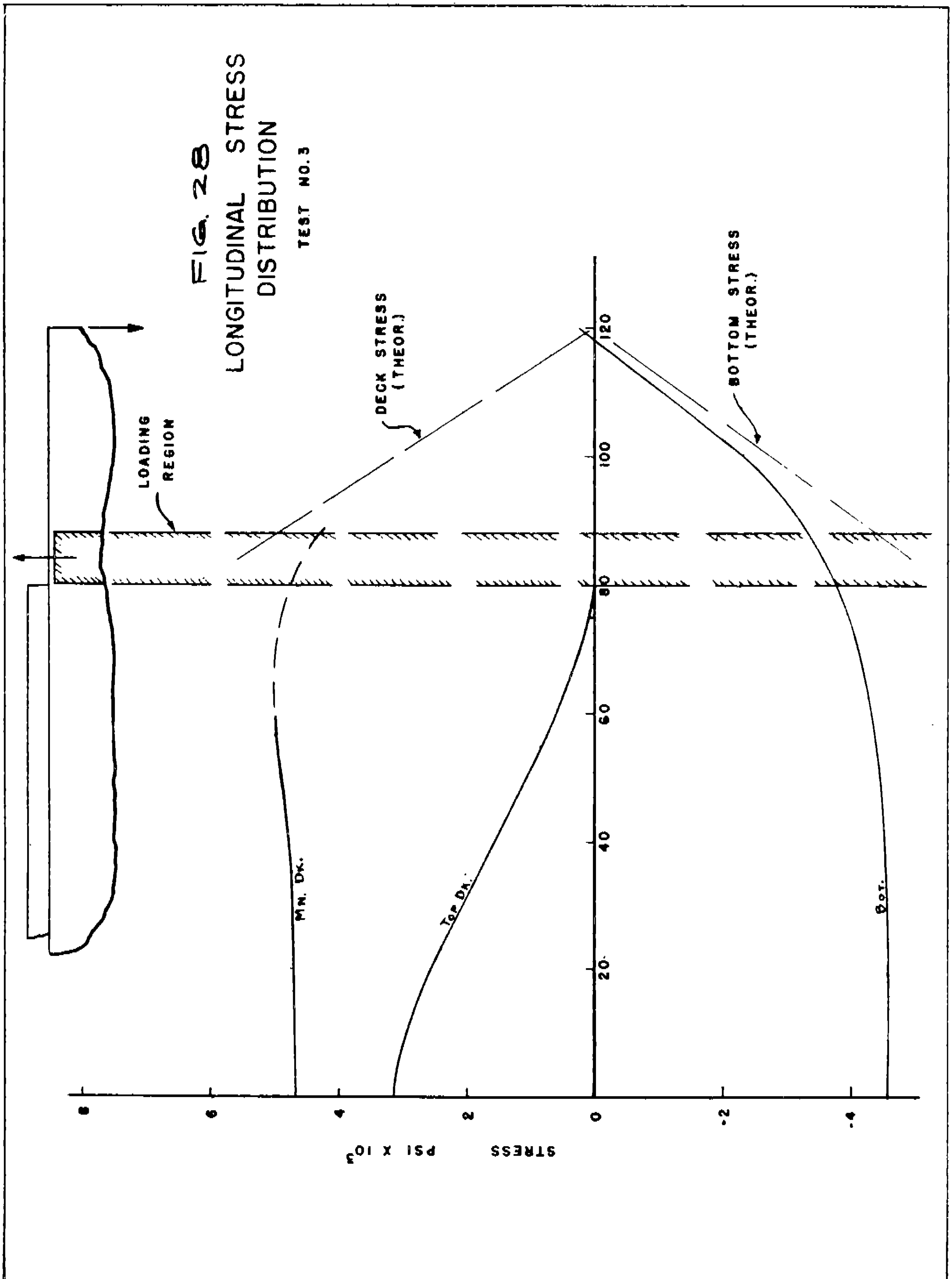


FIG. 28 LONGITUDINAL STRESS DISTRIBUTION
TEST NO. 3

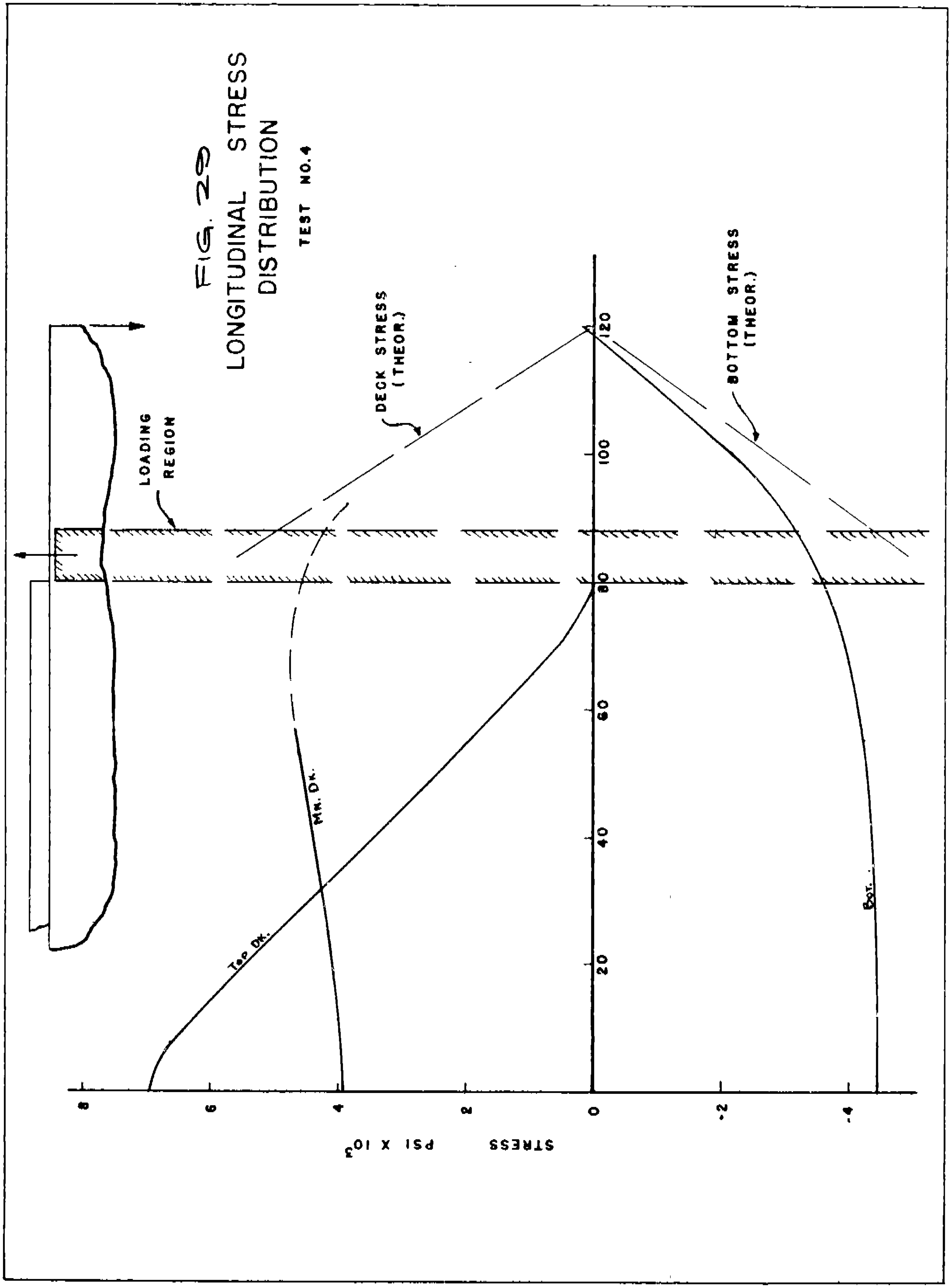


FIG. 29
LONGITUDINAL STRESS DISTRIBUTION
TEST NO.4
LOADING REGION
DECK STRESS (THEOR.)
BOTTOM STRESS (THEOR.)
Top Dk.
Mn. Dk.
Bot.
STRESS PSI X 10³
8
6
4
2
0
-2
-4
20
40
60
80
100
120

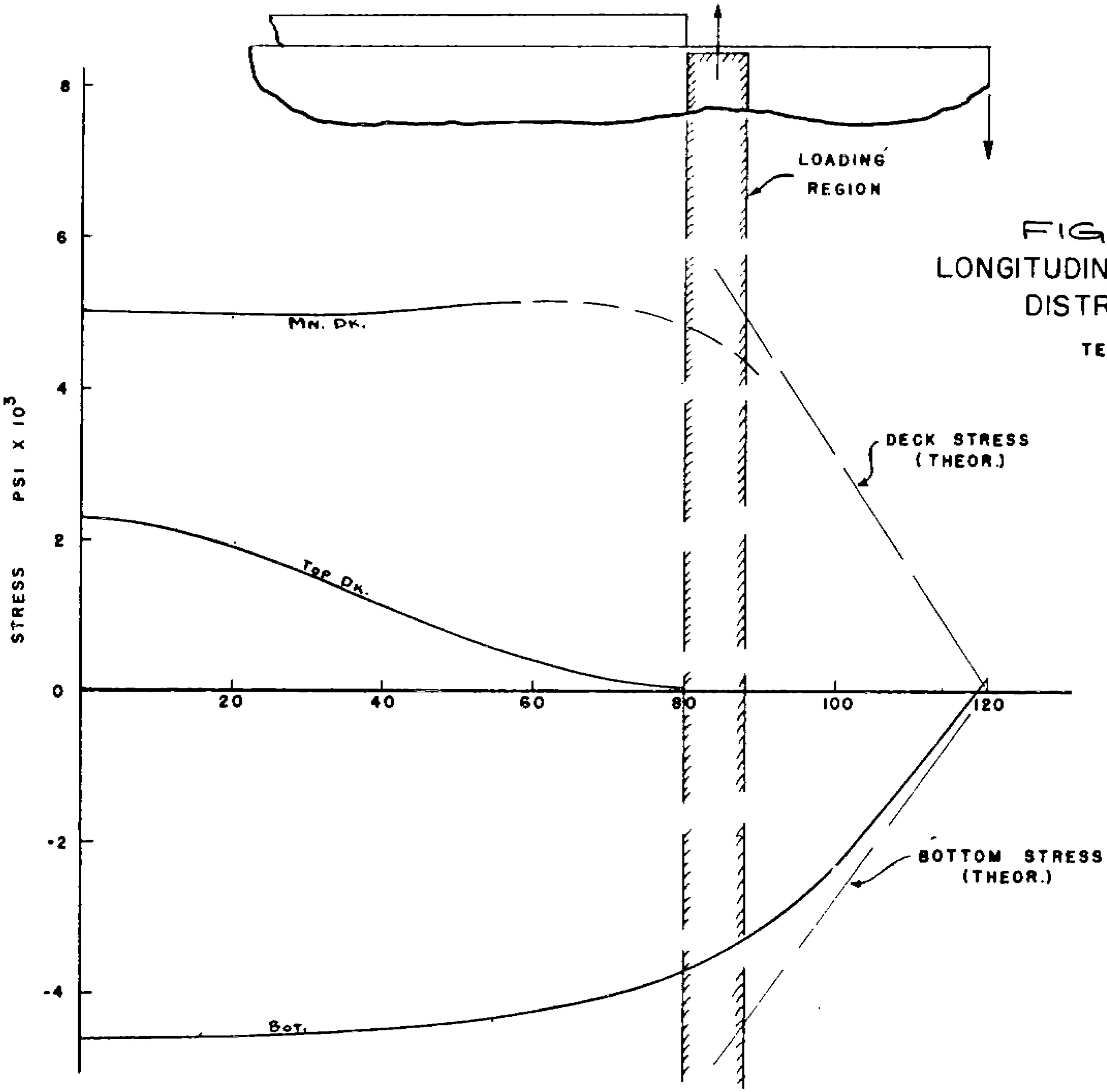


FIG. 30
LONGITUDINAL STRESS DISTRIBUTION
TEST NO.5

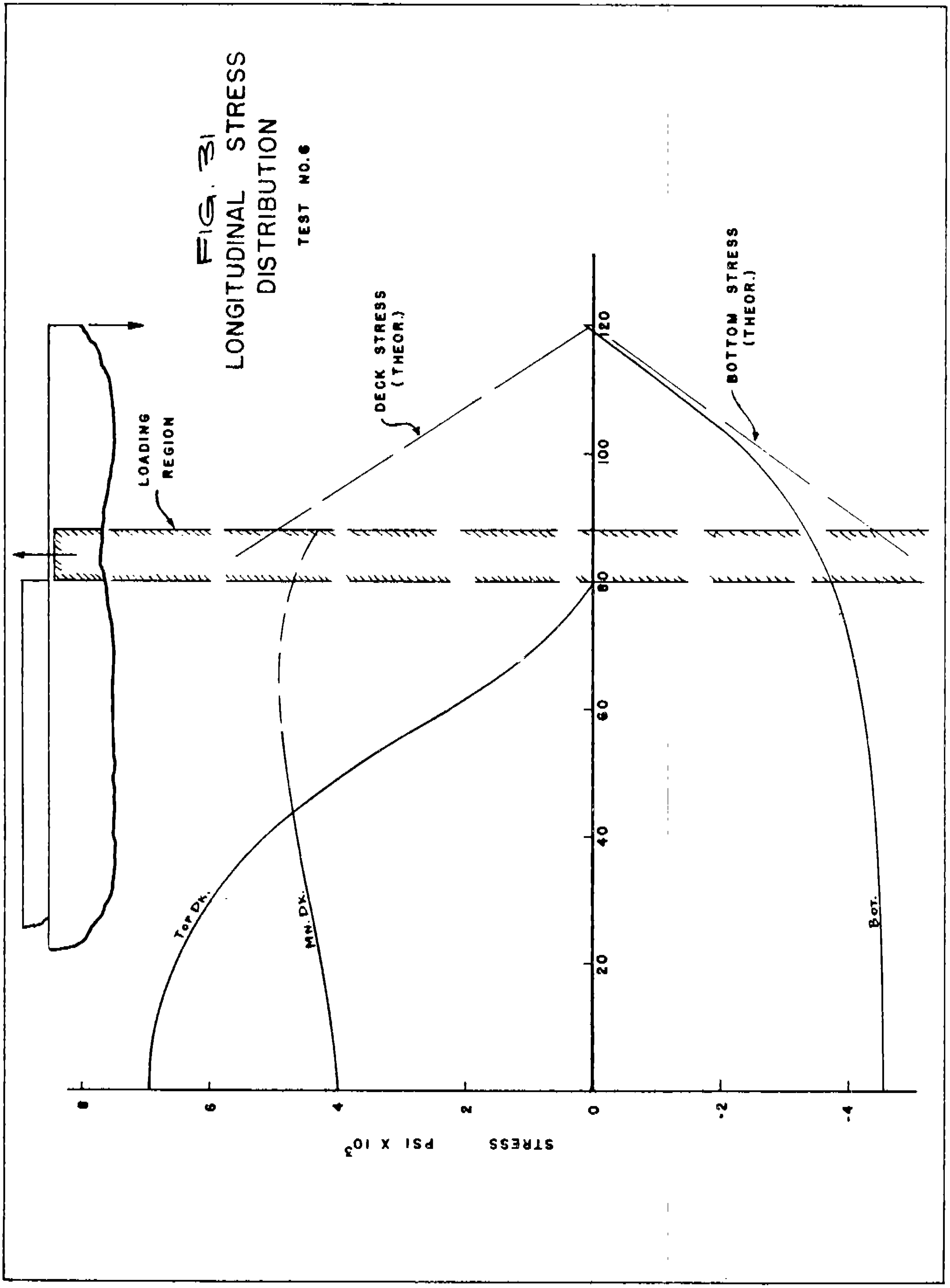


FIG. 31 LONGITUDINAL STRESS DISTRIBUTION

TEST NO. 6

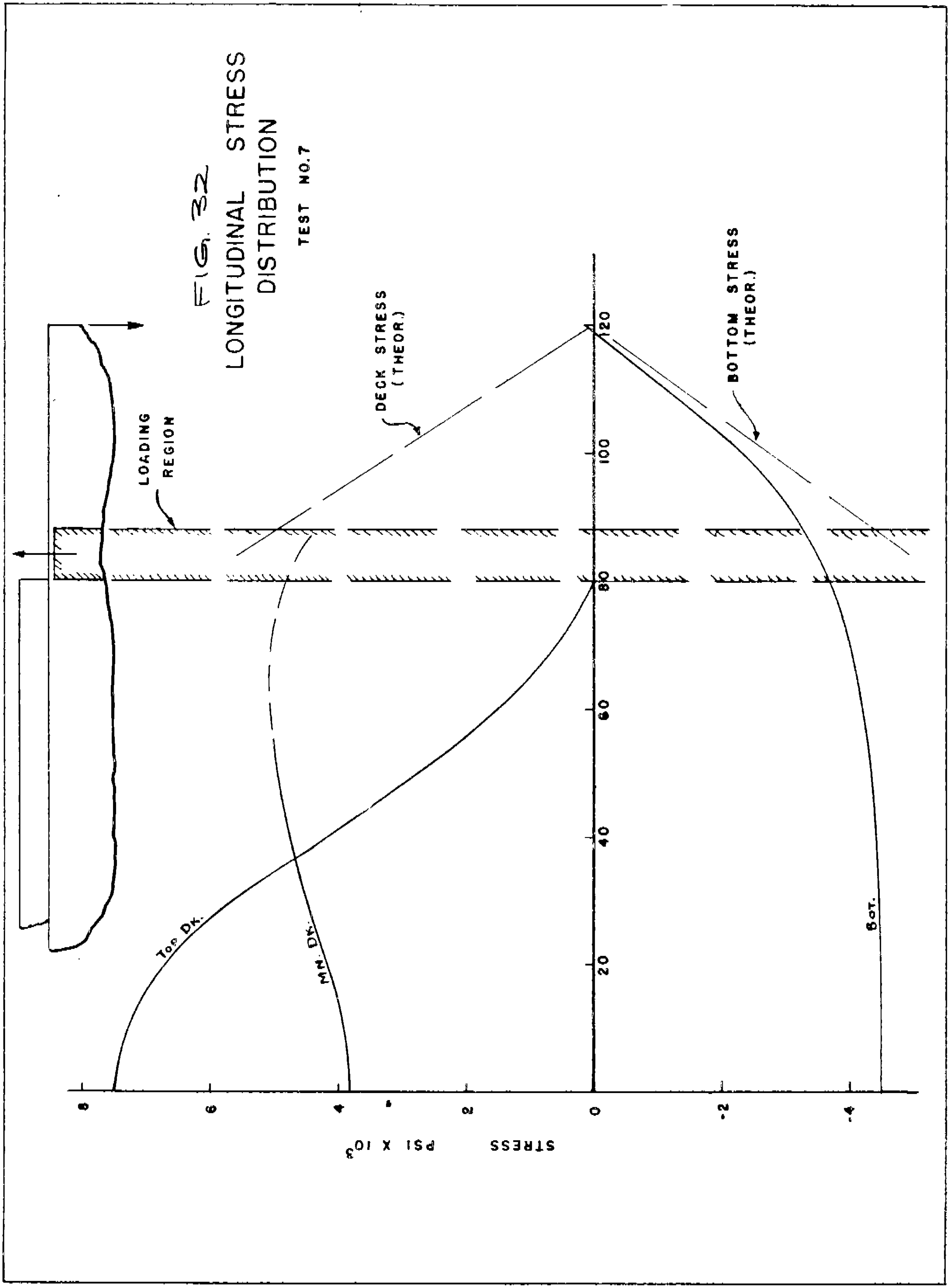


FIG. 32
LONGITUDINAL STRESS DISTRIBUTION
TEST NO.7

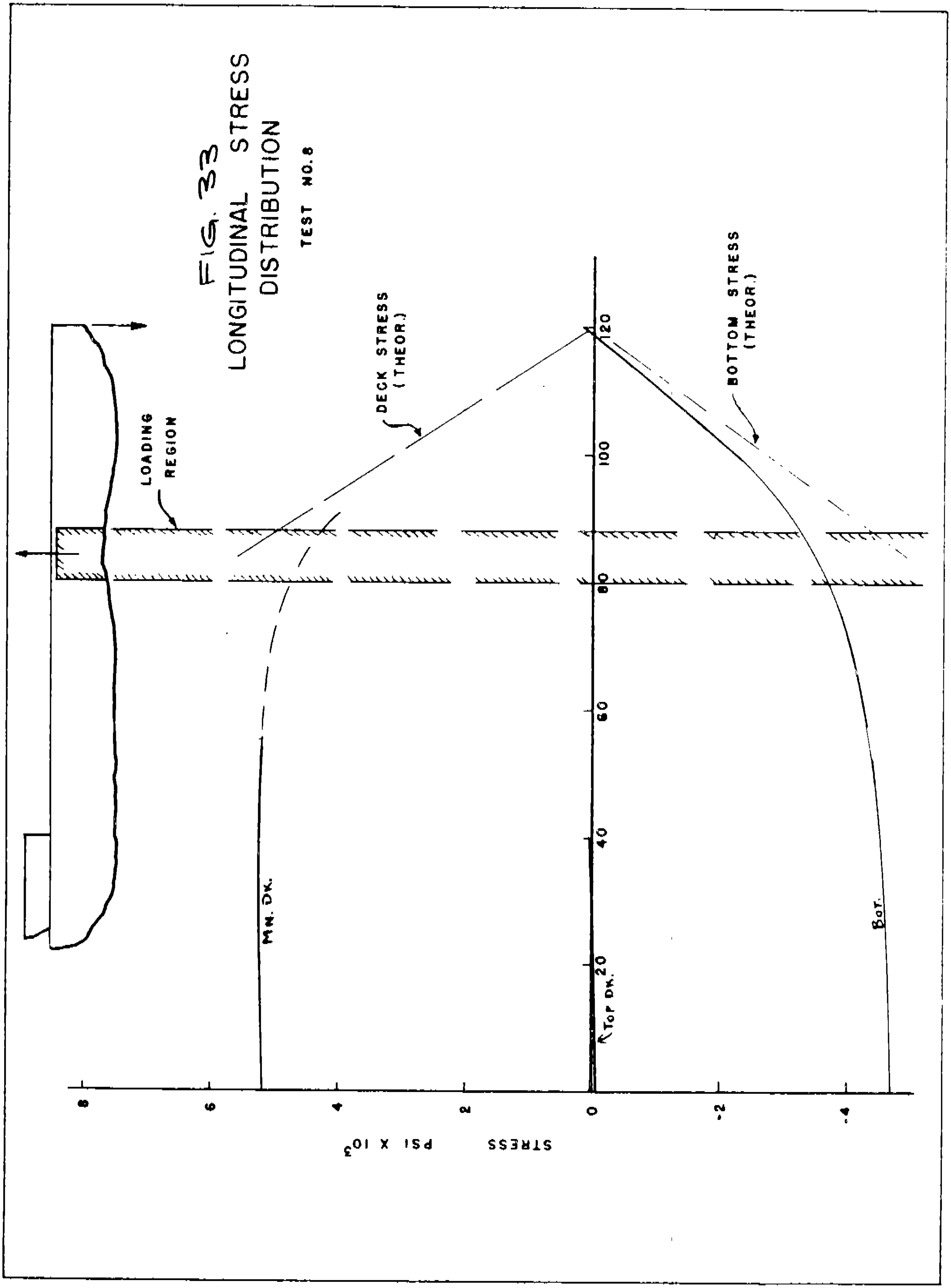


FIG. 33 LONGITUDINAL STRESS DISTRIBUTION

TEST NO. 8

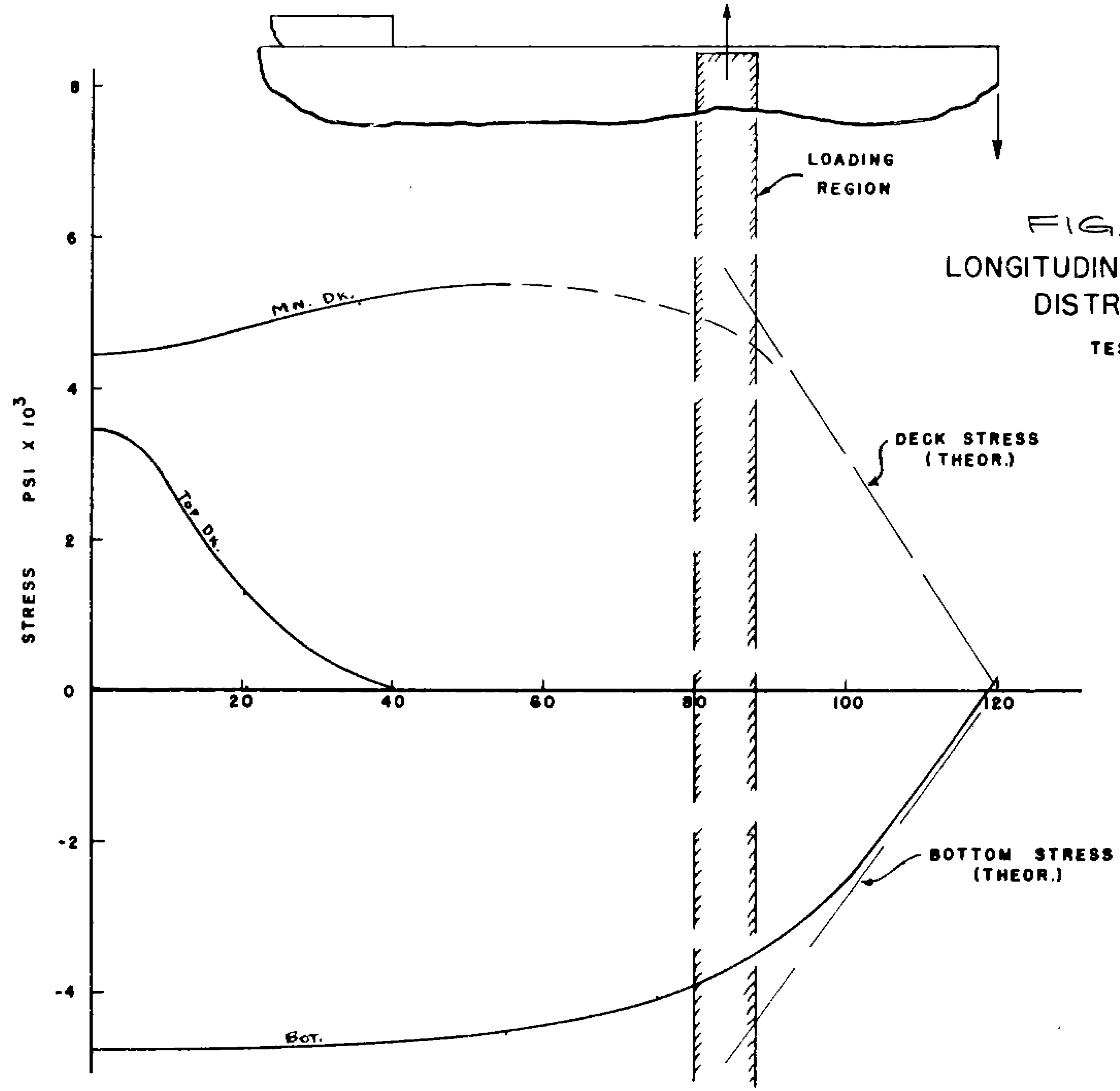


FIG. 34
LONGITUDINAL STRESS
DISTRIBUTION
TEST NO. 9

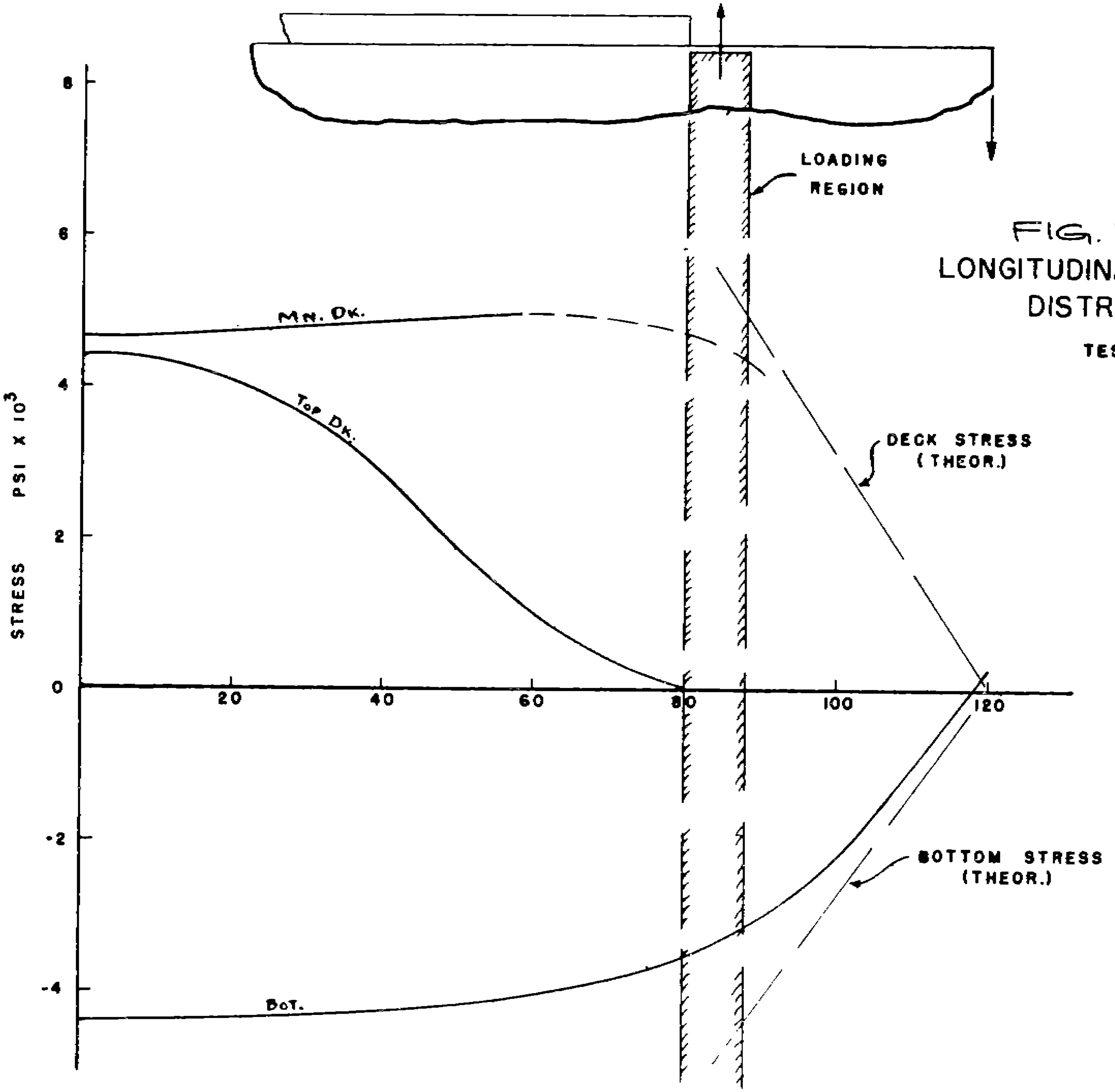


FIG. 35
LONGITUDINAL STRESS DISTRIBUTION
TEST NO. 10

FIG. 36

LONGITUDINAL STRESSES

HOUSE TOP
LONG, LOW HOUSE

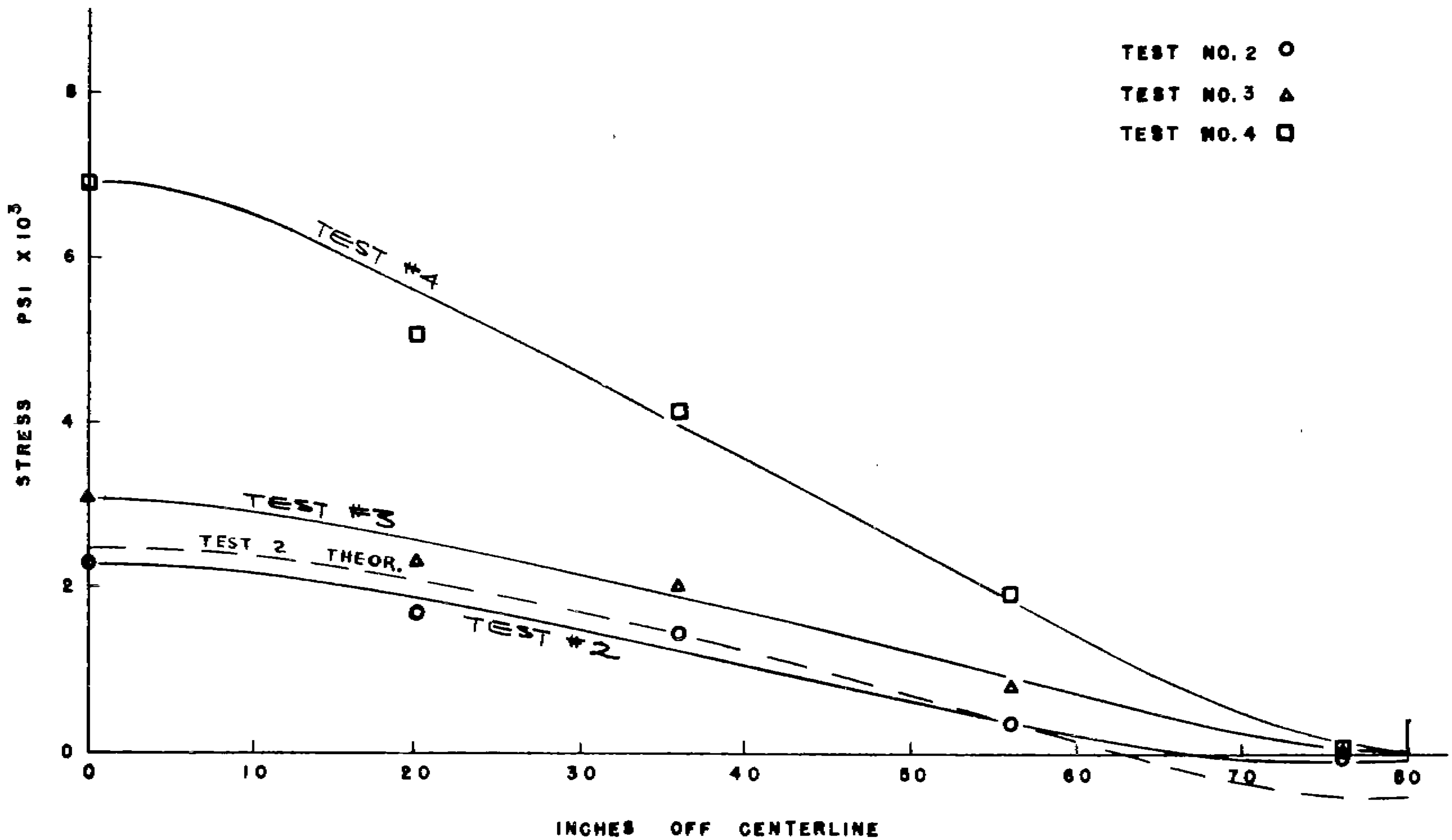


FIG. 37

LONGITUDINAL STRESSES

HOUSE TOP

LONG, HIGH HOUSE

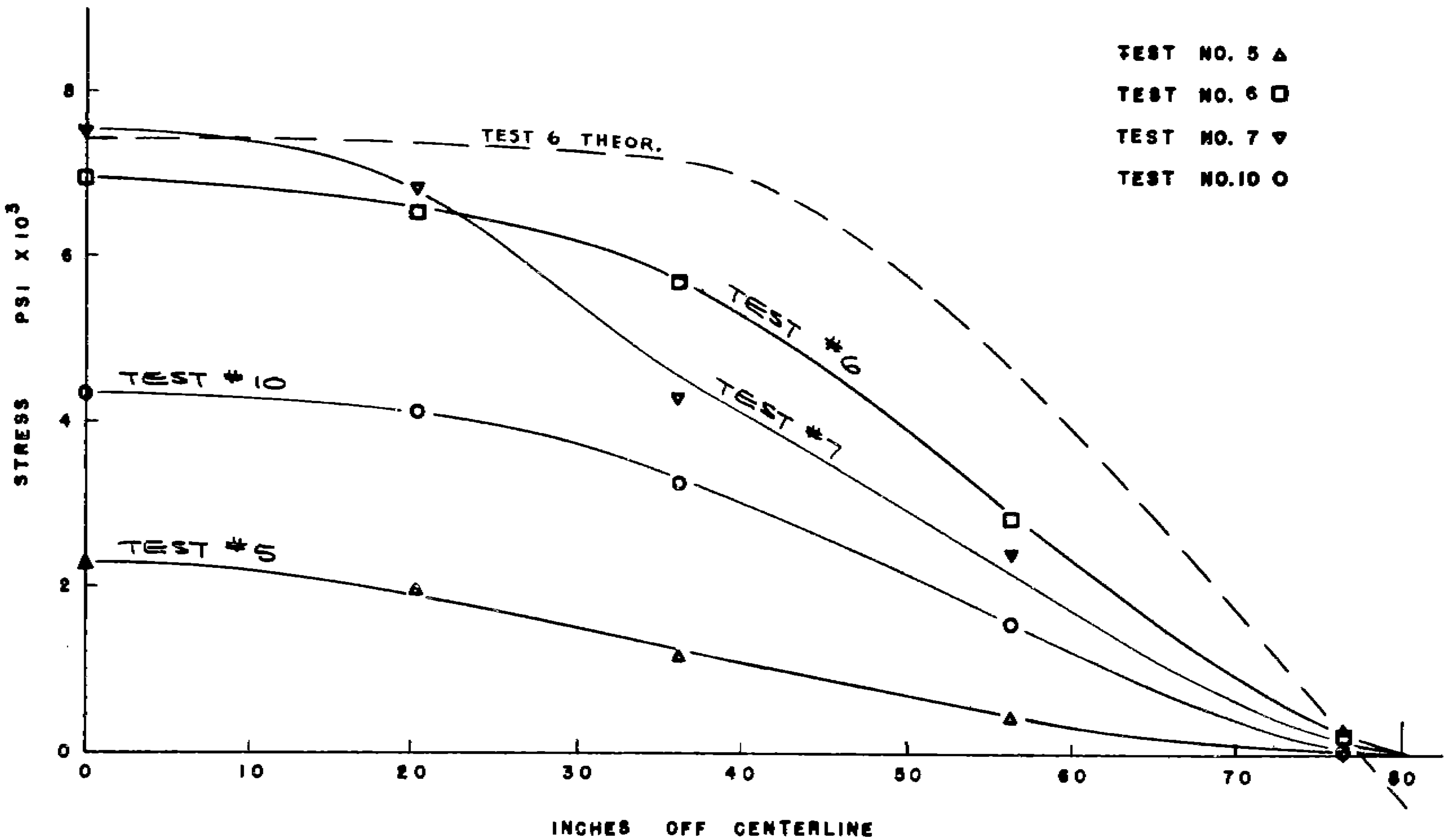


FIG. 38
LONGITUDINAL STRESSES
HOUSE TOP
SHORT HOUSE

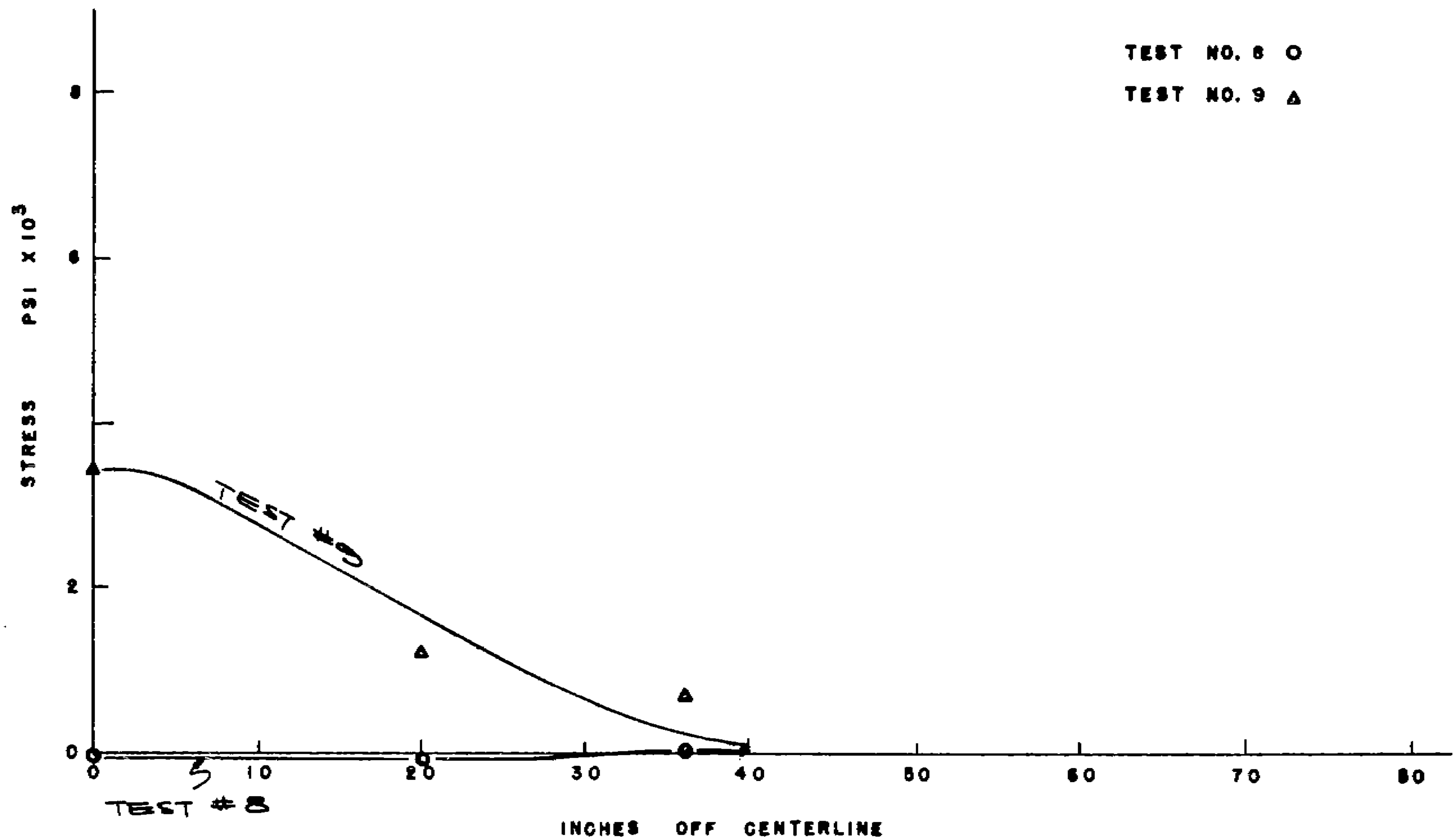


Fig. 39-STRESS CONTOURS-MULTI STATION

TEST NO. 3

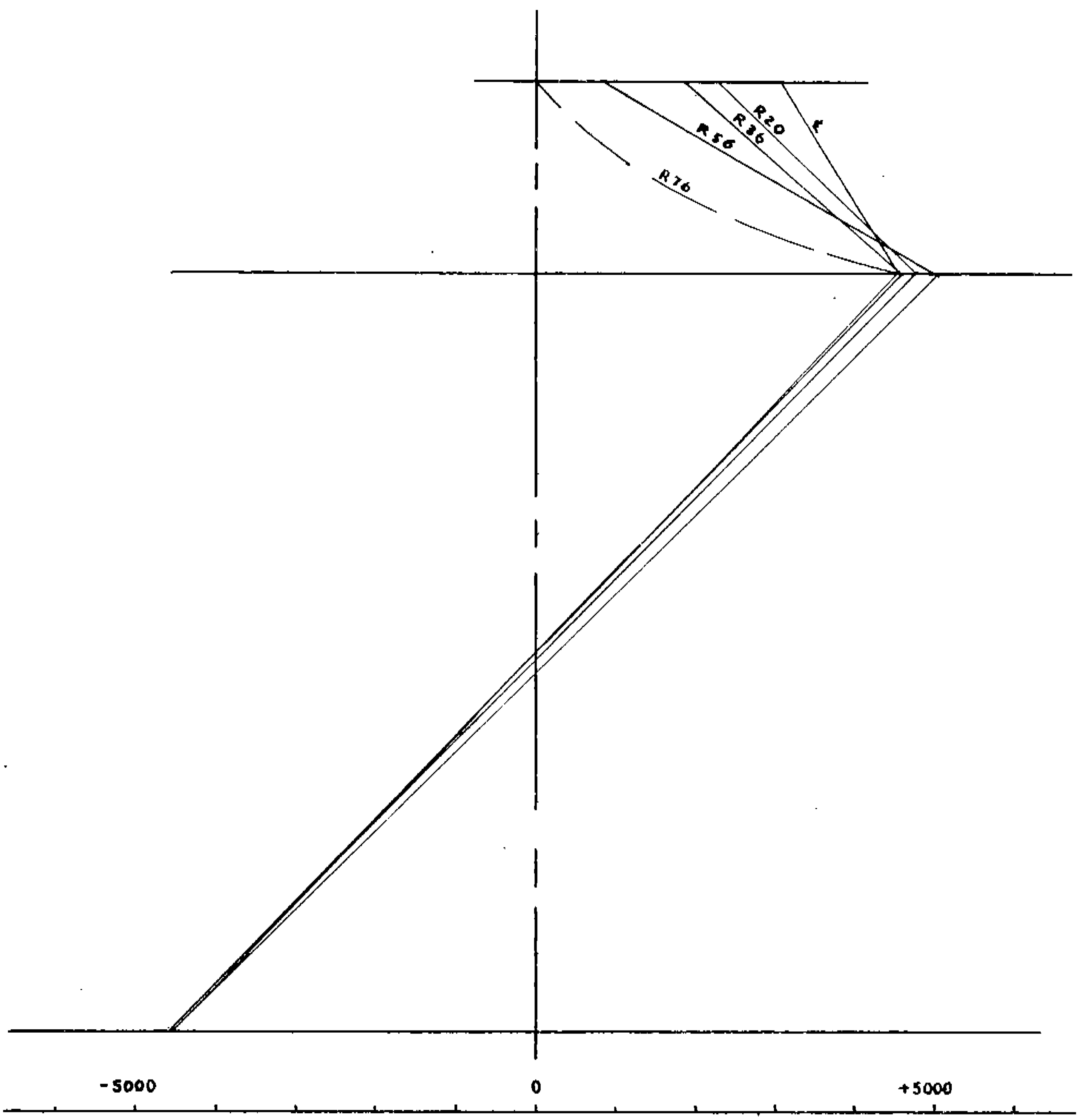


FIG. 40 – LONGITUDINAL SHEAR STRESS

$1\frac{1}{4}$ IN. ABOVE MAIN DECK

LONG, LOW HOUSE

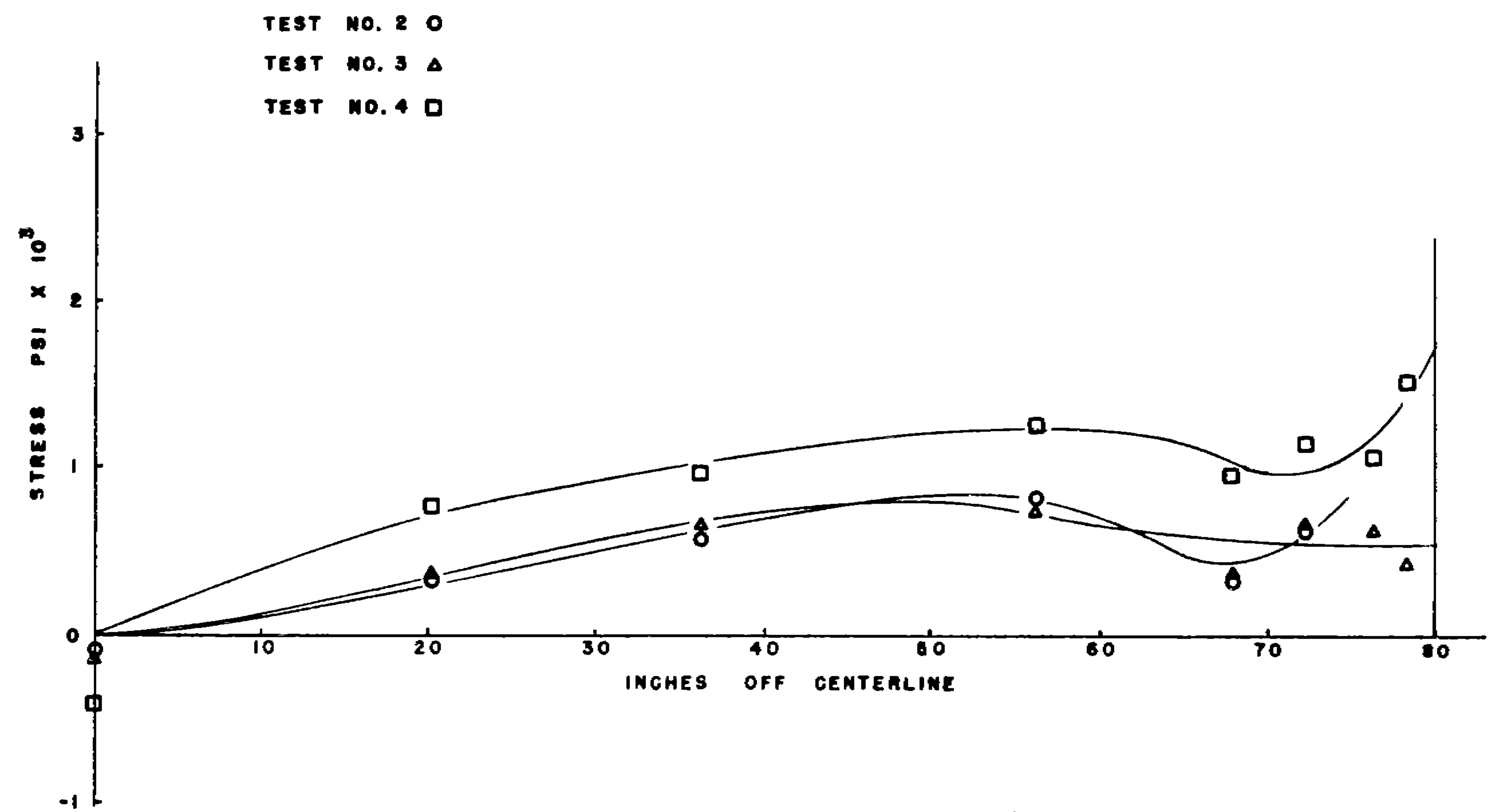


FIG. 41 - LONGITUDINAL SHEAR STRESS
$1\frac{1}{4}$ IN. ABOVE MAIN DECK
LONG, HIGH HOUSE

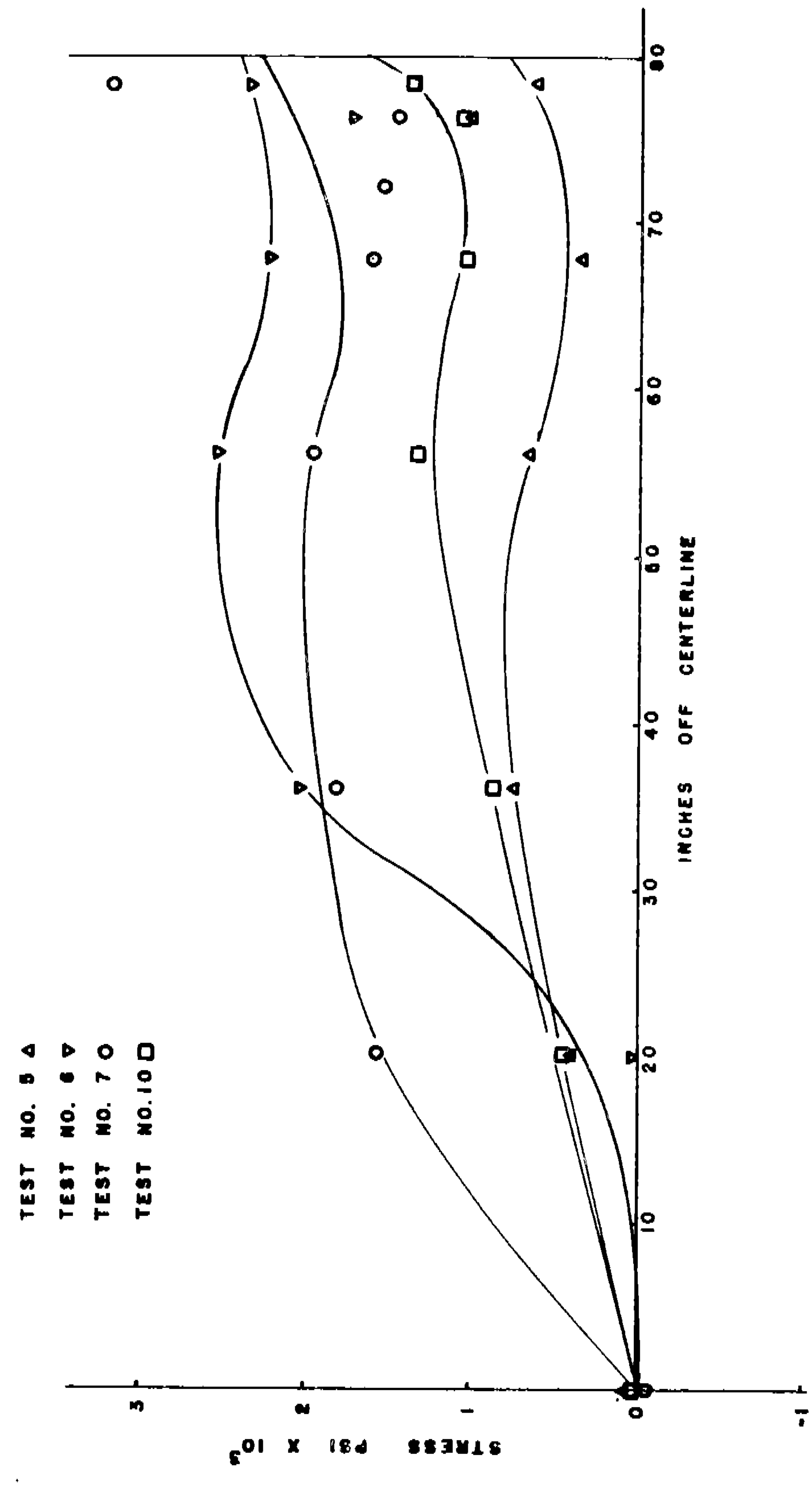


FIG. 42 - LONGITUDINAL SHEAR STRESS
$1\frac{1}{4}$ IN. ABOVE MAIN DECK
SHORT HOUSE

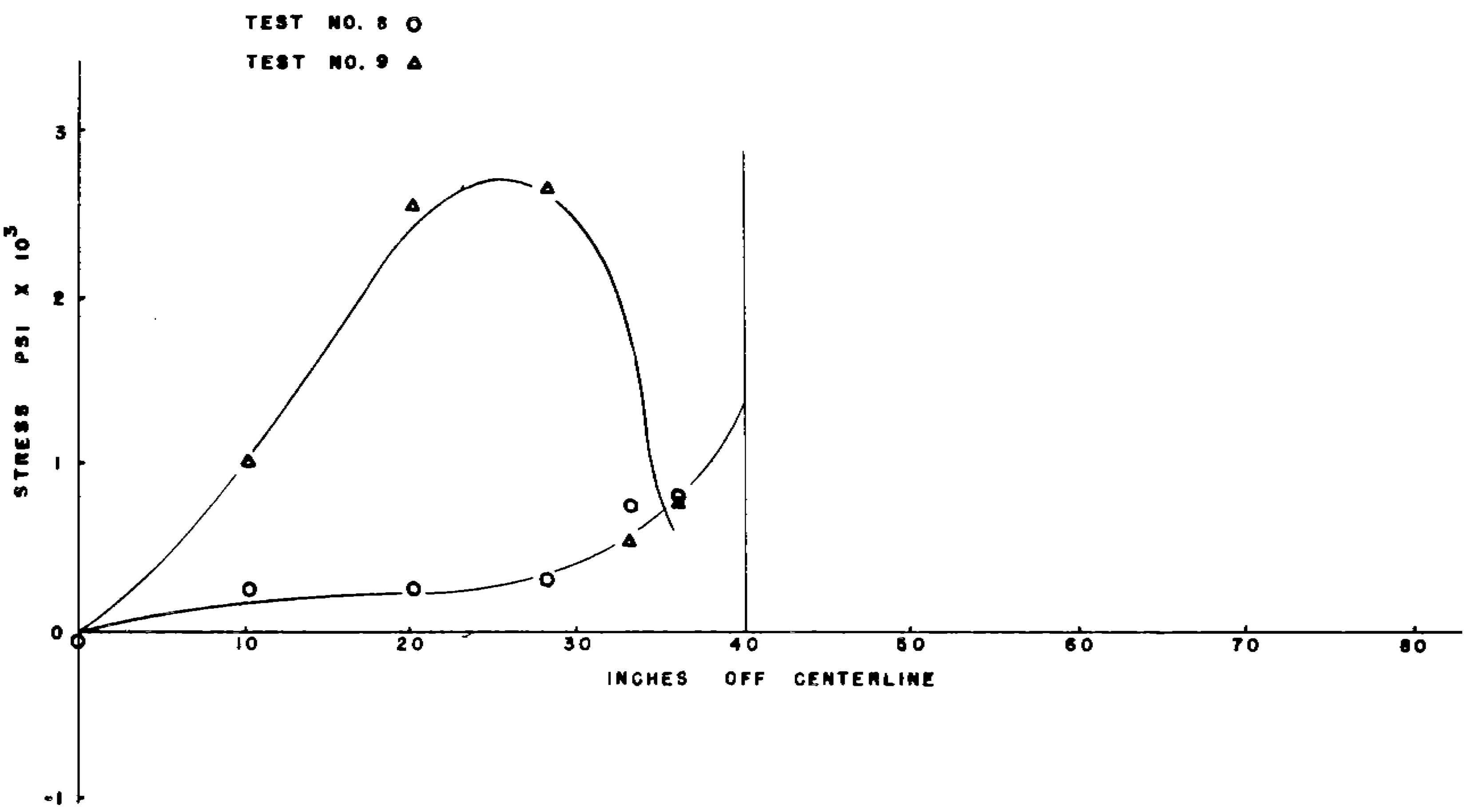
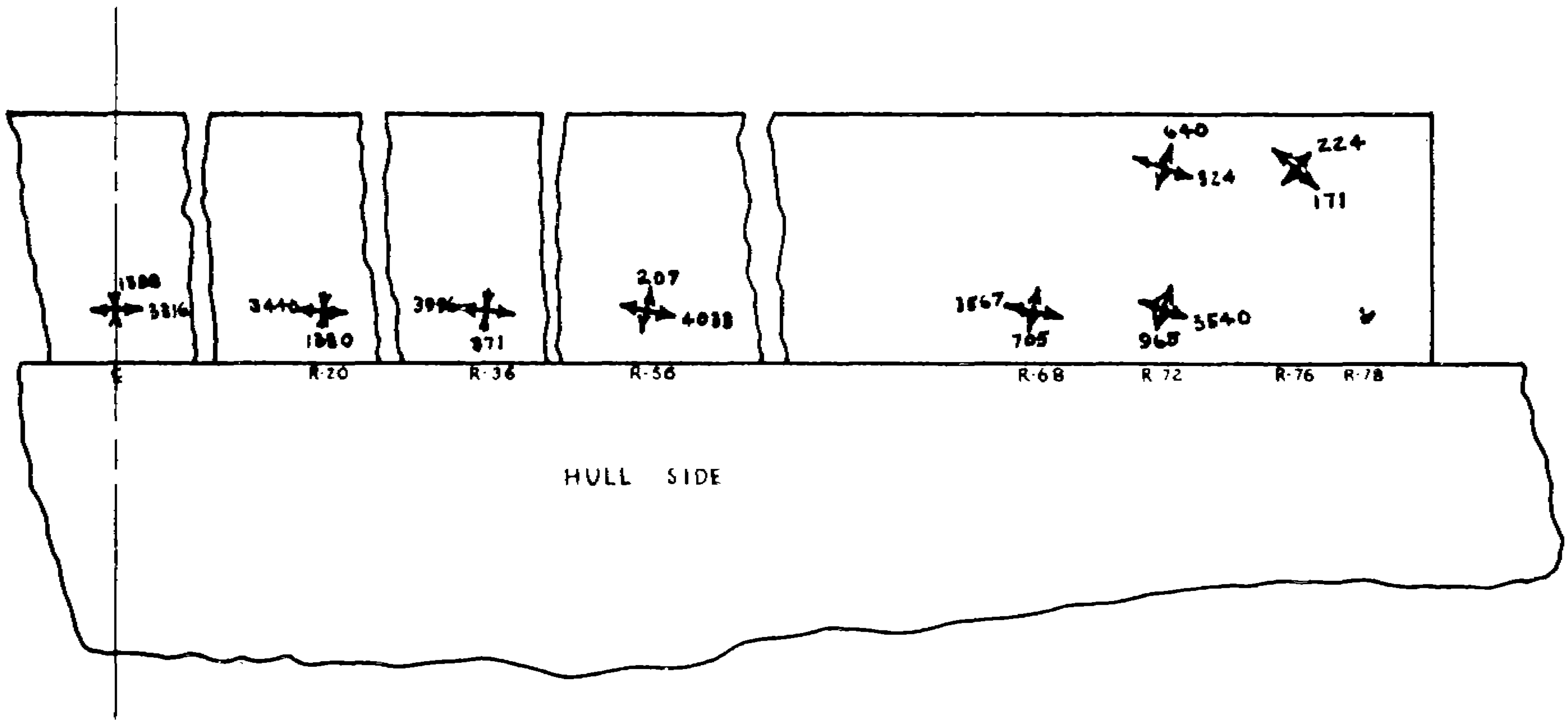
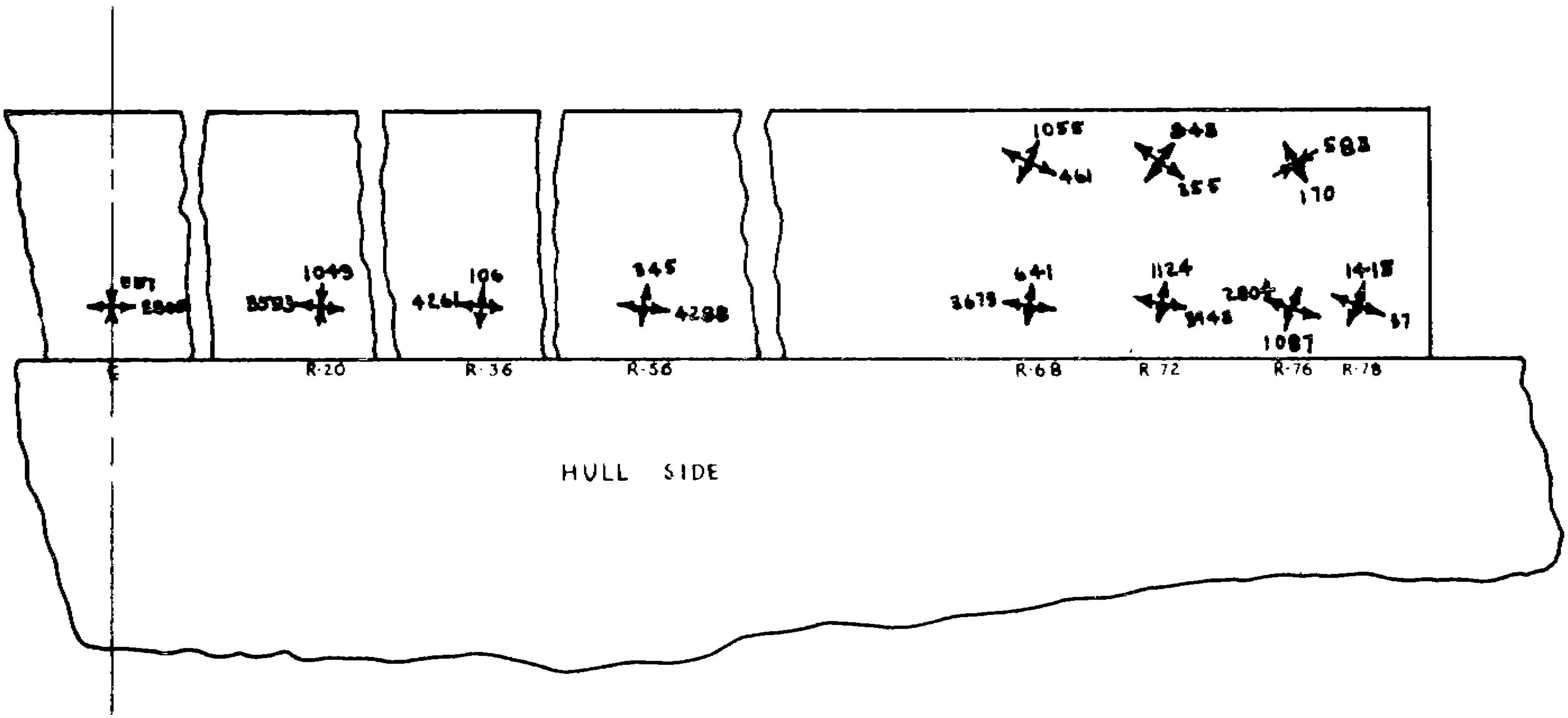


FIG. 43 - PRINCIPAL STRESSES - HOUSE



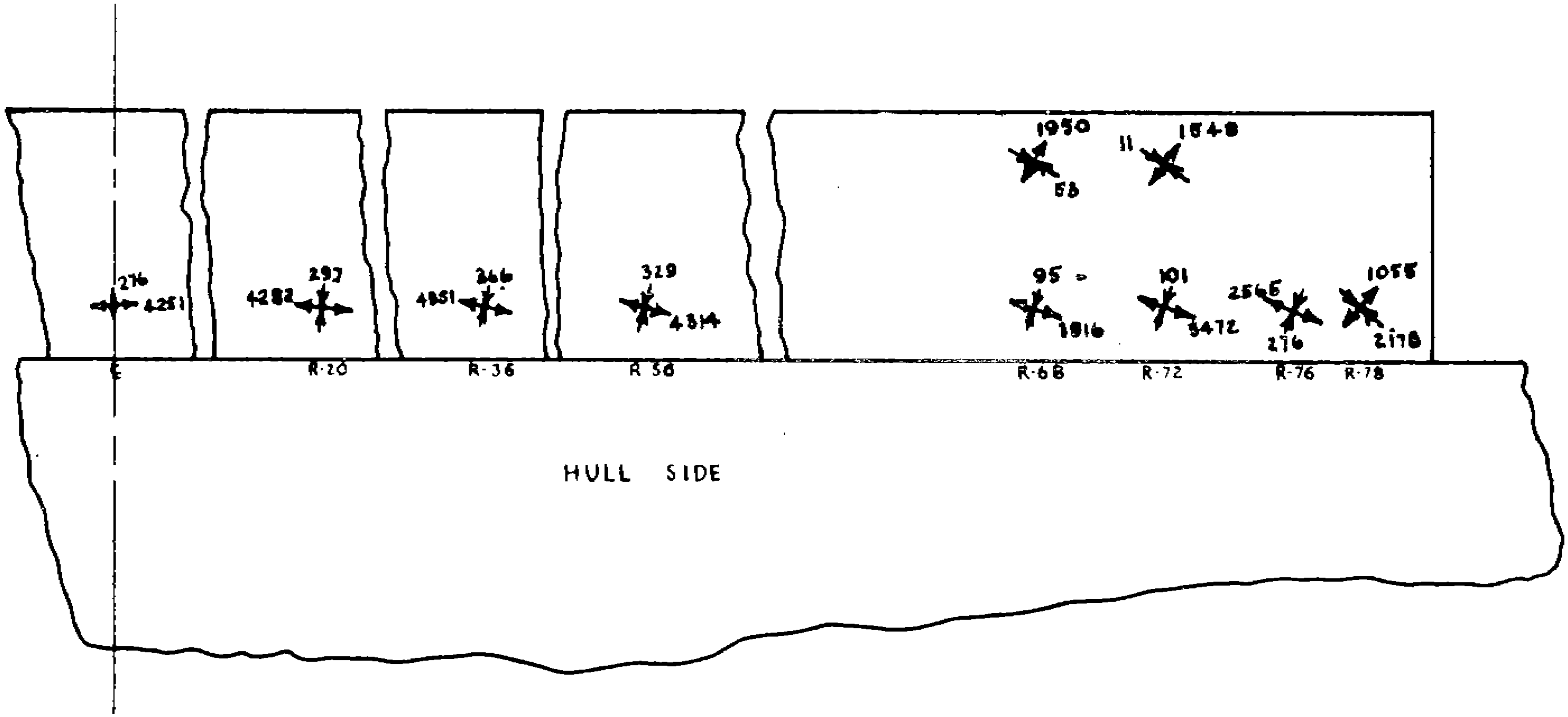
TEST NO. 2

FIG. 44 - PRINCIPAL STRESSES - HOUSE



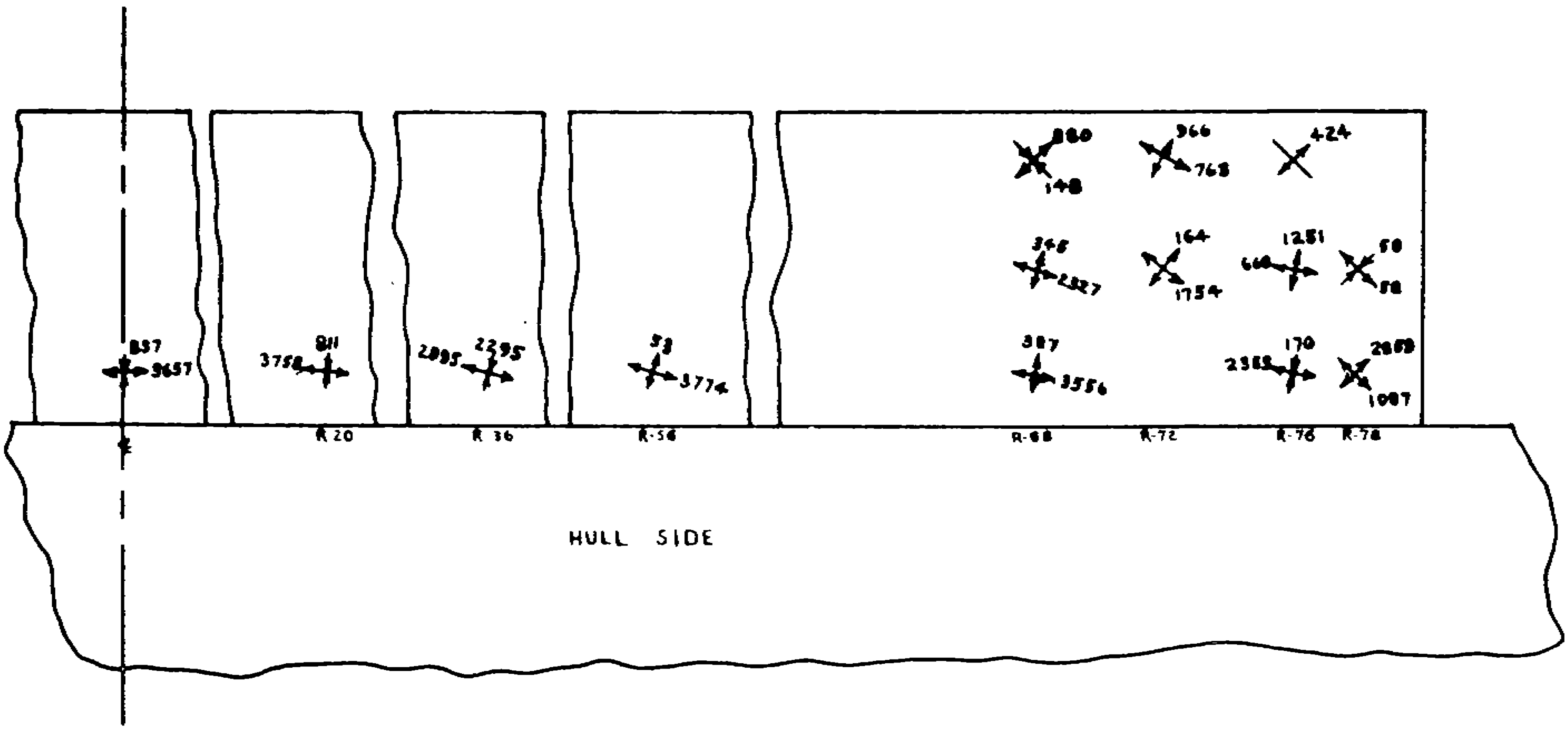
TEST NO. 3

FIG. 45 — PRINCIPAL STRESSES — HOUSE



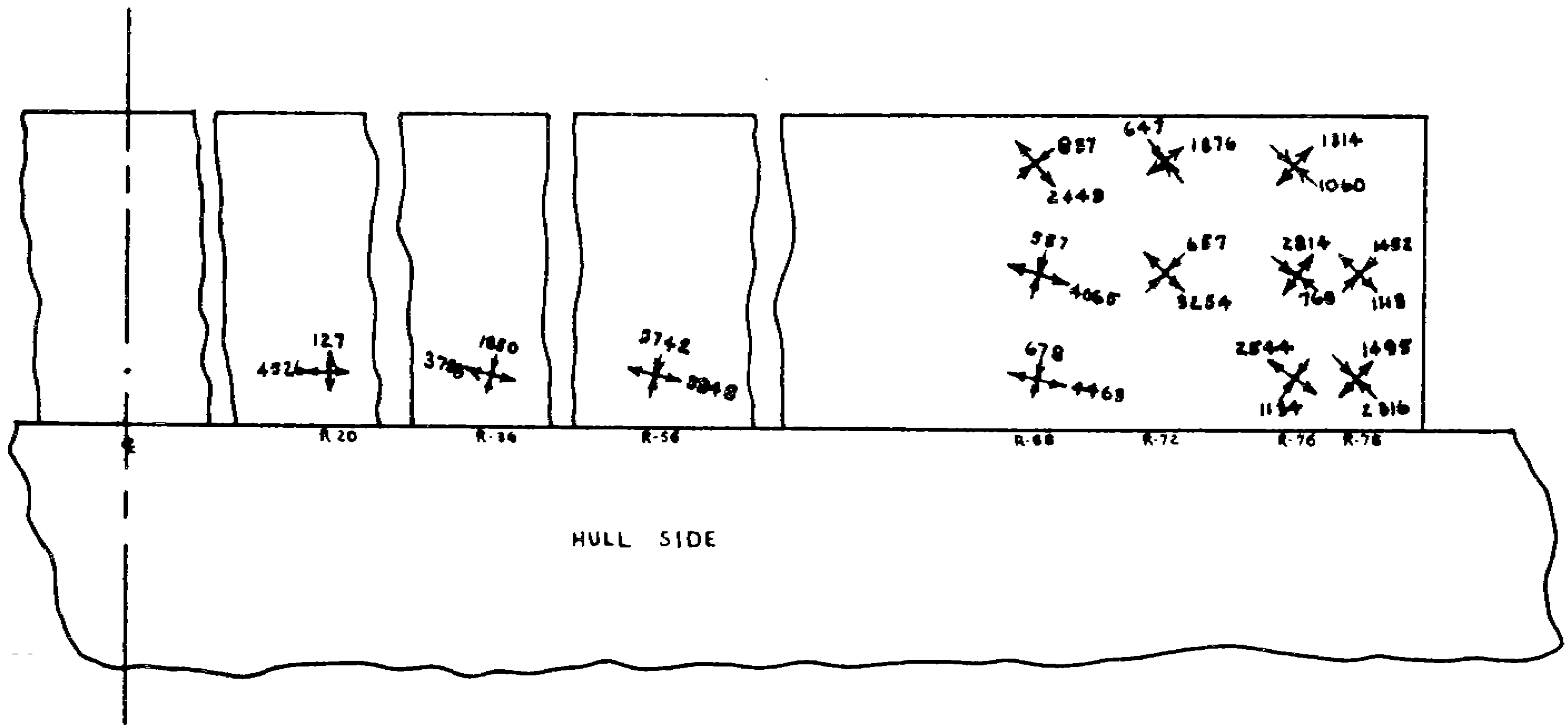
TEST NO. 4

FIG. 46-PRINCIPAL STRESSES - HOUSE



TEST NO. 5

FIG. 47 - PRINCIPAL STRESSES - HOUSE



TEST NO. 6

FIG. 48 - PRINCIPAL STRESSES — HOUSE

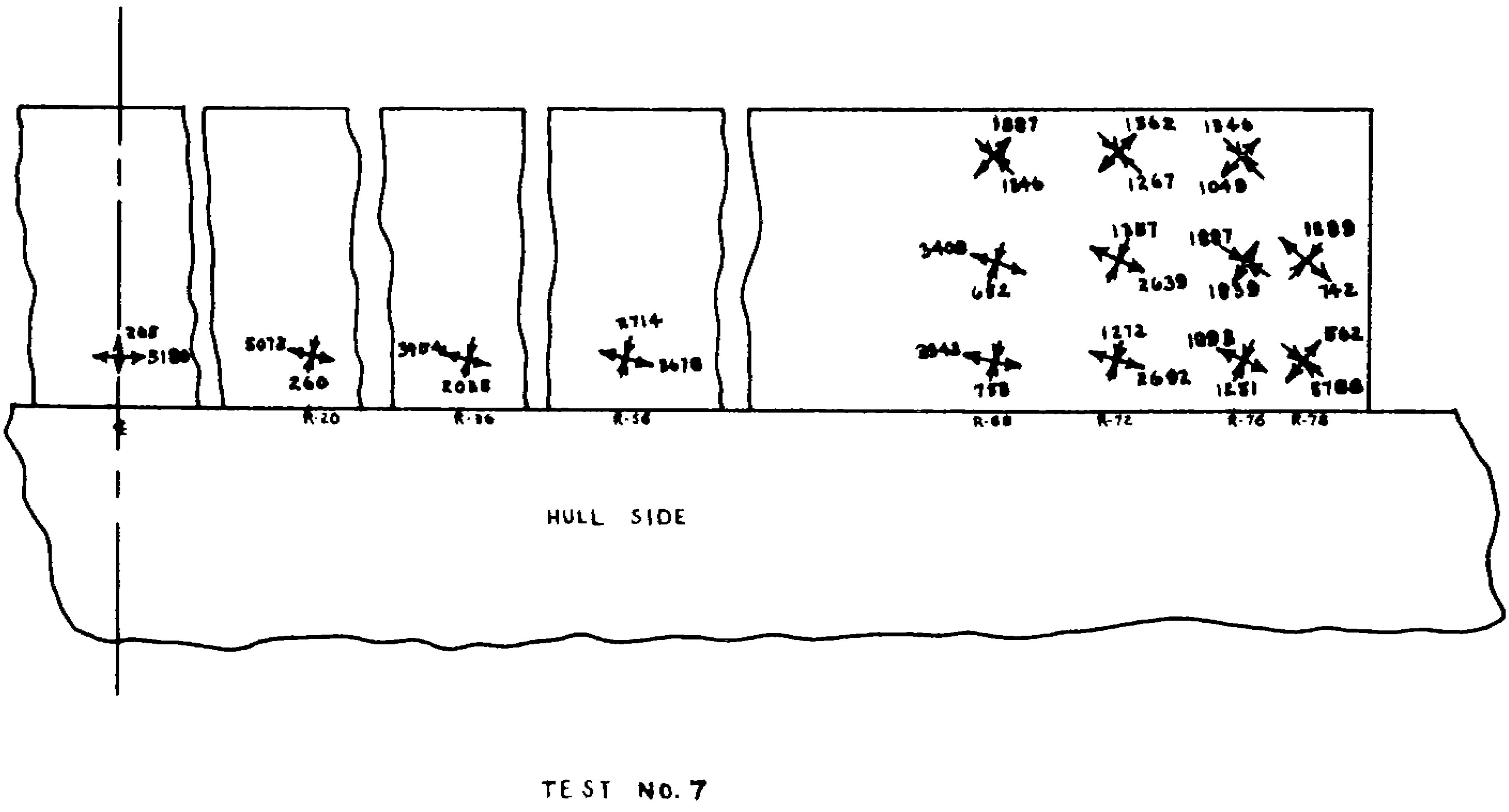
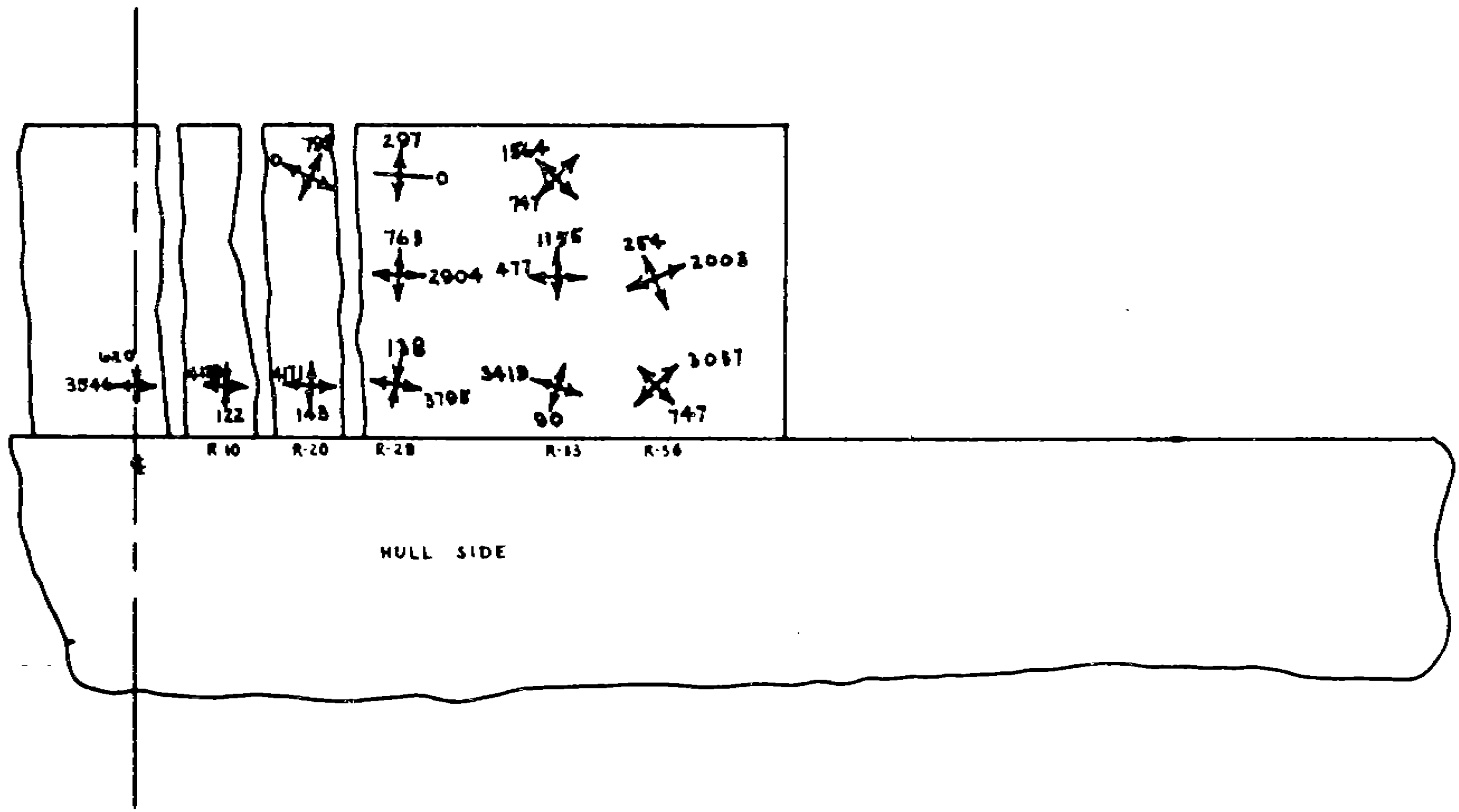
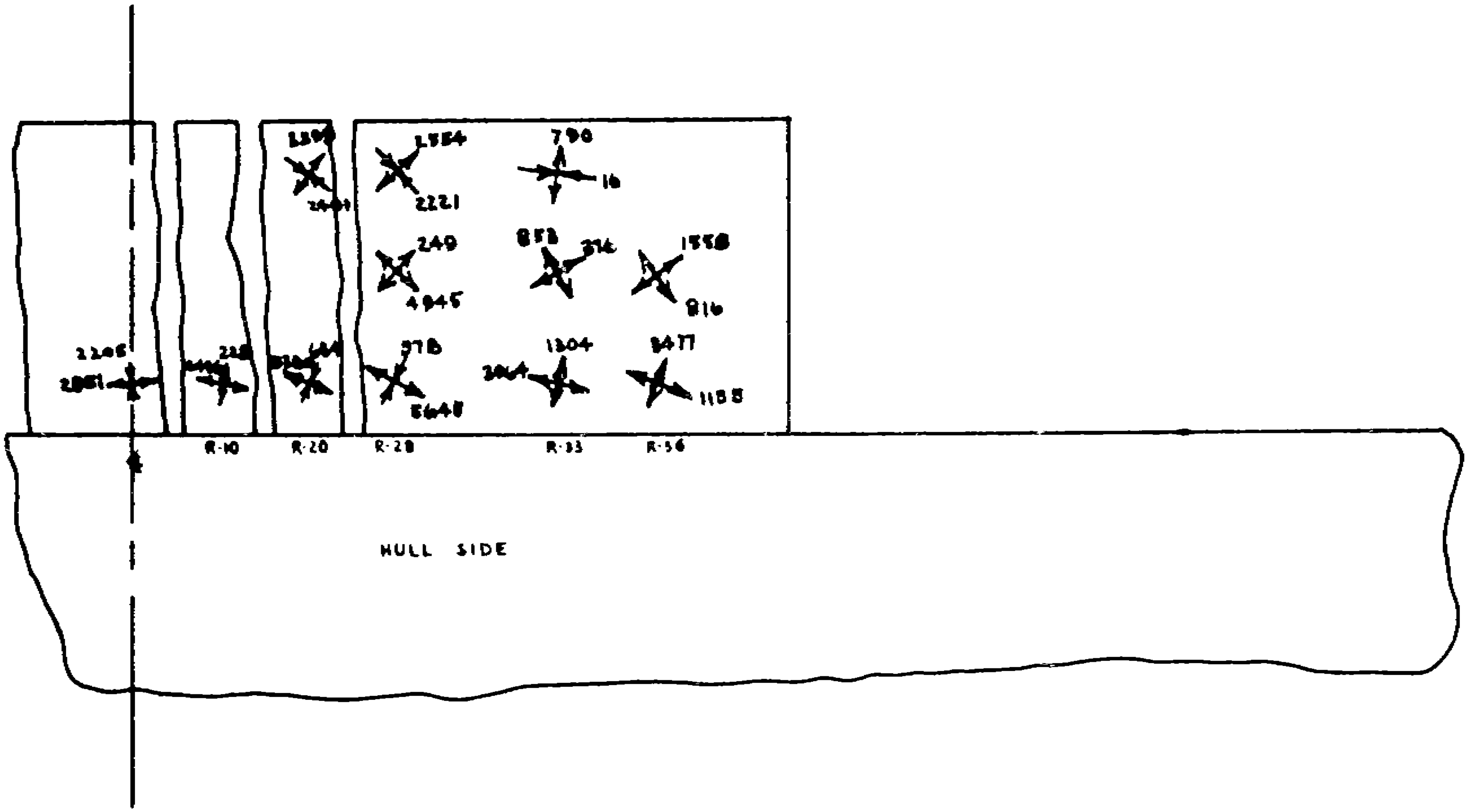


FIG. 49 - PRINCIPAL STRESSES — HOUSE



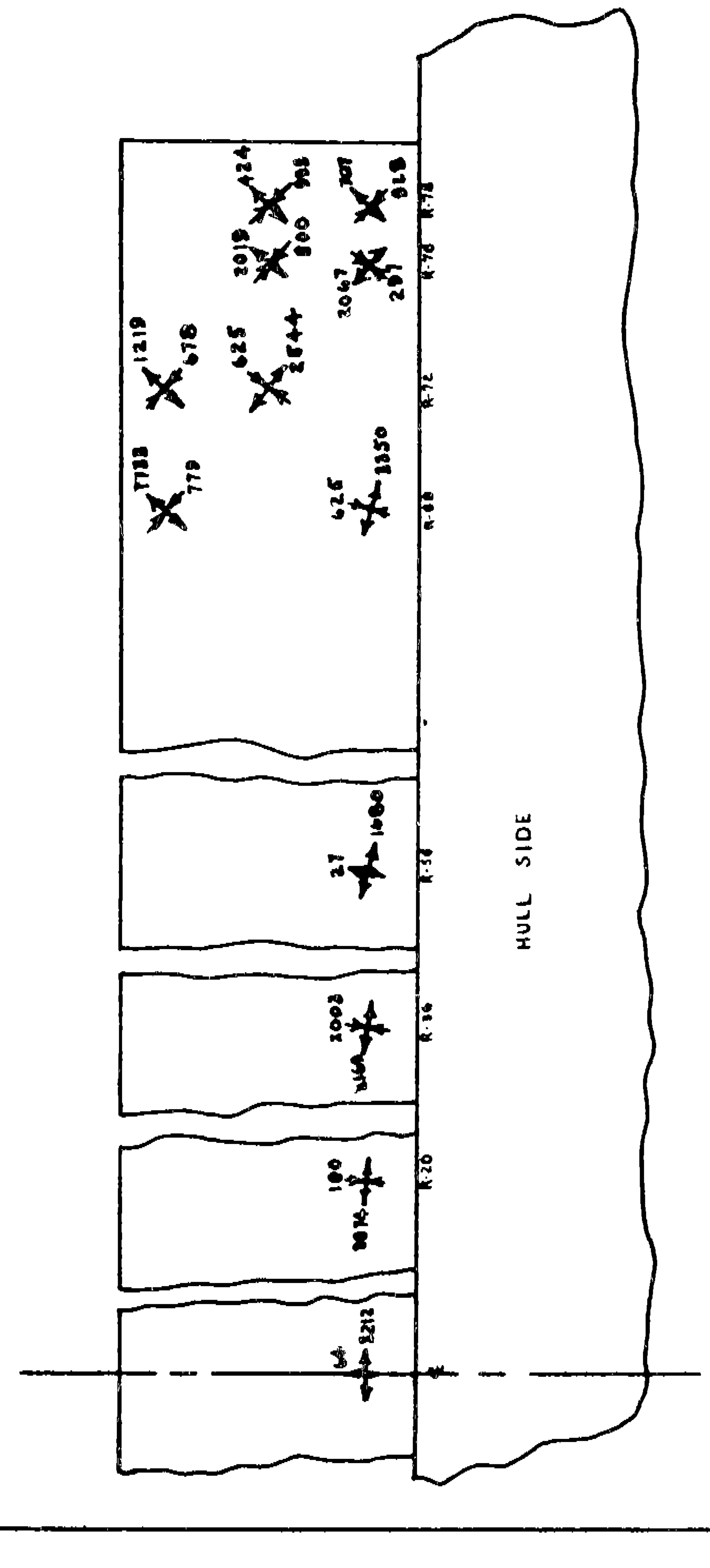
TEST NO.

FIG. 50 – PRINCIPAL STRESSES—HOUSE



TEST NO. 9

FIG. 51 - PRINCIPAL STRESSES - HOUSE



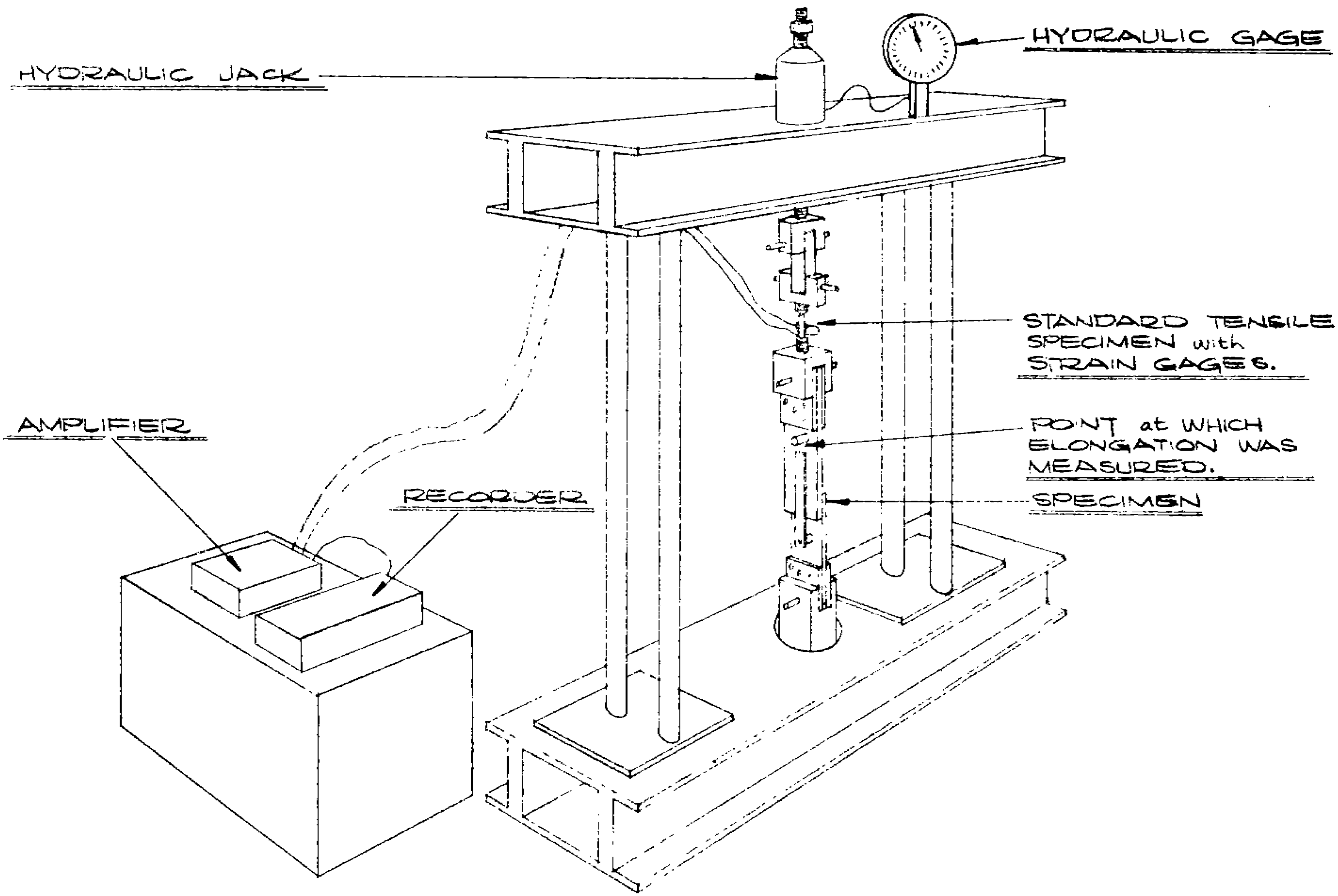


Fig. 52

SLIPPAGE TEST APPARATUS

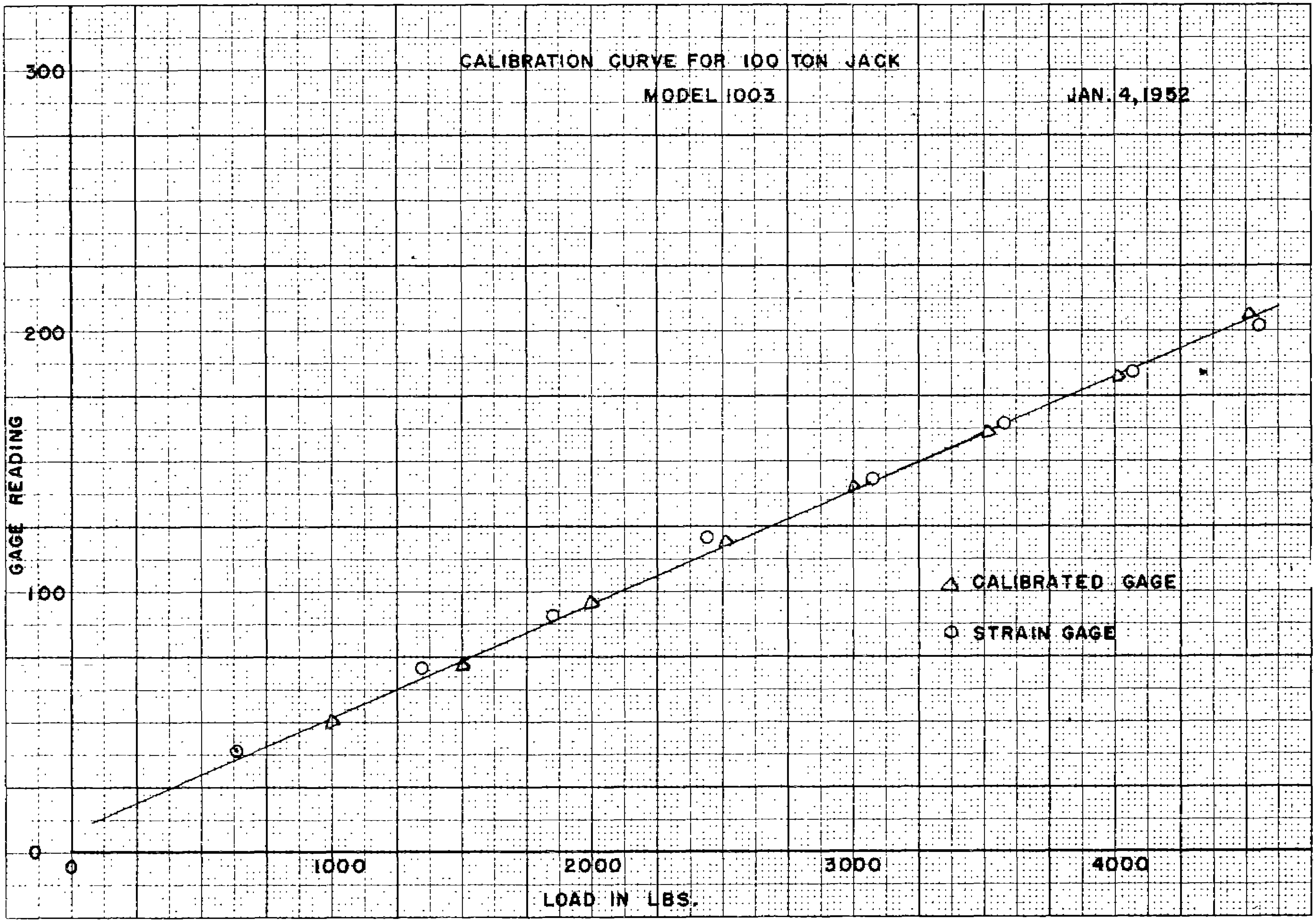

CALIBRATION CURVE FOR 100 TON JACK
MODEL 1003
JAN. 4, 1952
300
200
100
0
GAGE READING
0
1000
2000
3000
4000
LOAD IN LBS.
△ CALIBRATED GAGE
○ STRAIN GAGE

FIG. 53

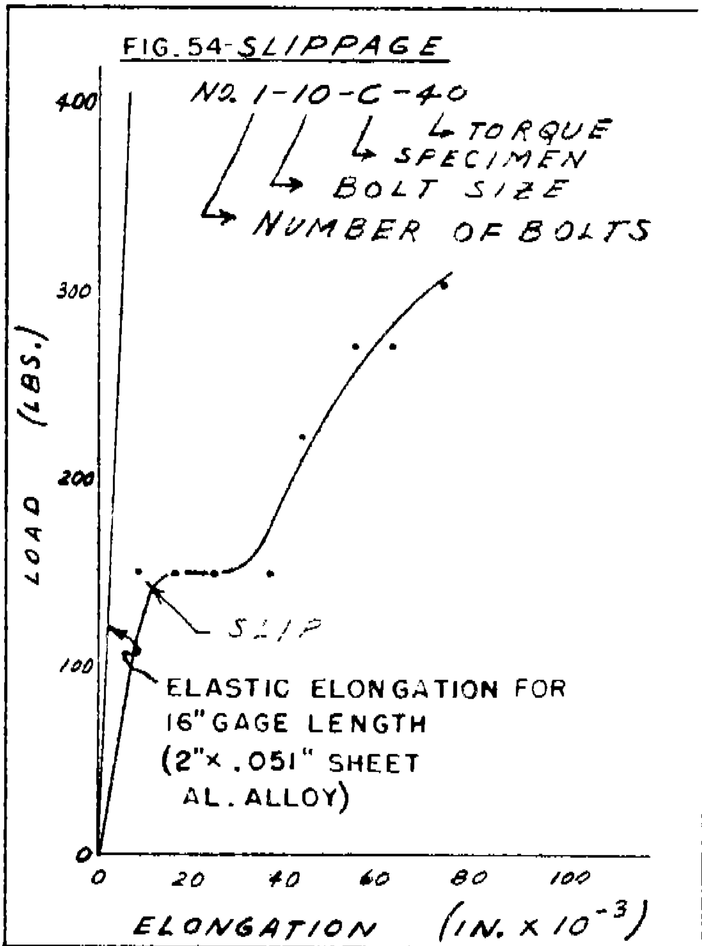


FIG. 54-SLIPPAGE
NO. 1-10-C-40
TORQUE
SPECIMEN
BOLT SIZE
NUMBER OF BOLTS
SLIP
ELASTIC ELONGATION FOR 16" GAGE LENGTH (2" × .051" SHEET AL. ALLOY)
LOAD (LBS.)
ELONGATION (IN. × 10^-3)
0
100
200
300
400
20
40
60
80
100

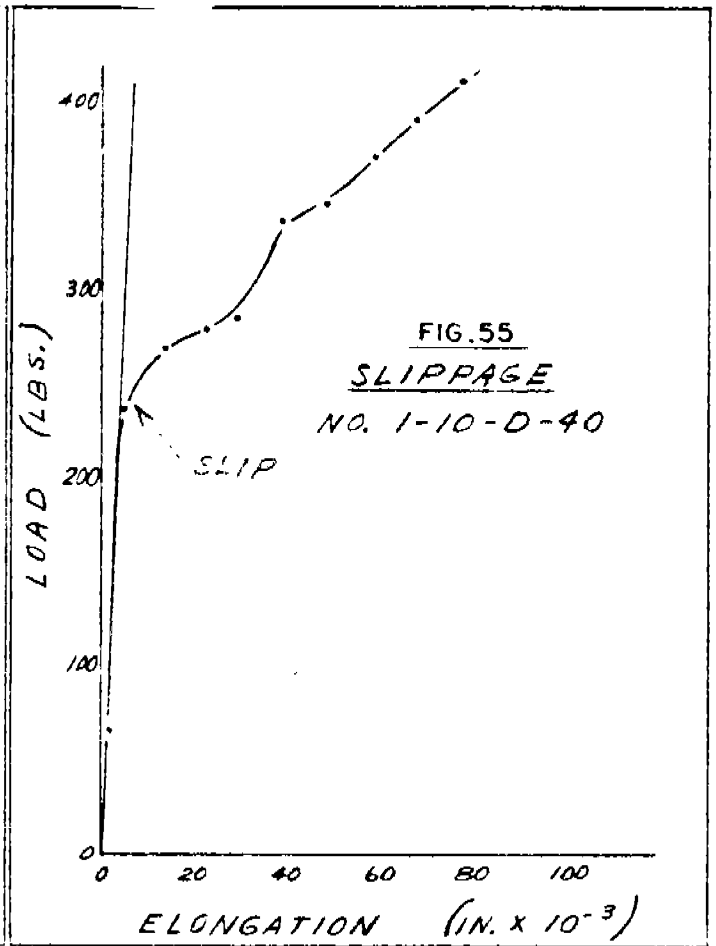


FIG. 55
SLIPPAGE
NO. 1-10-D-40
SLIP
LOAD (LBS.)
ELONGATION (IN. × 10^-3)
0
100
200
300
400
20
40
60
80
100

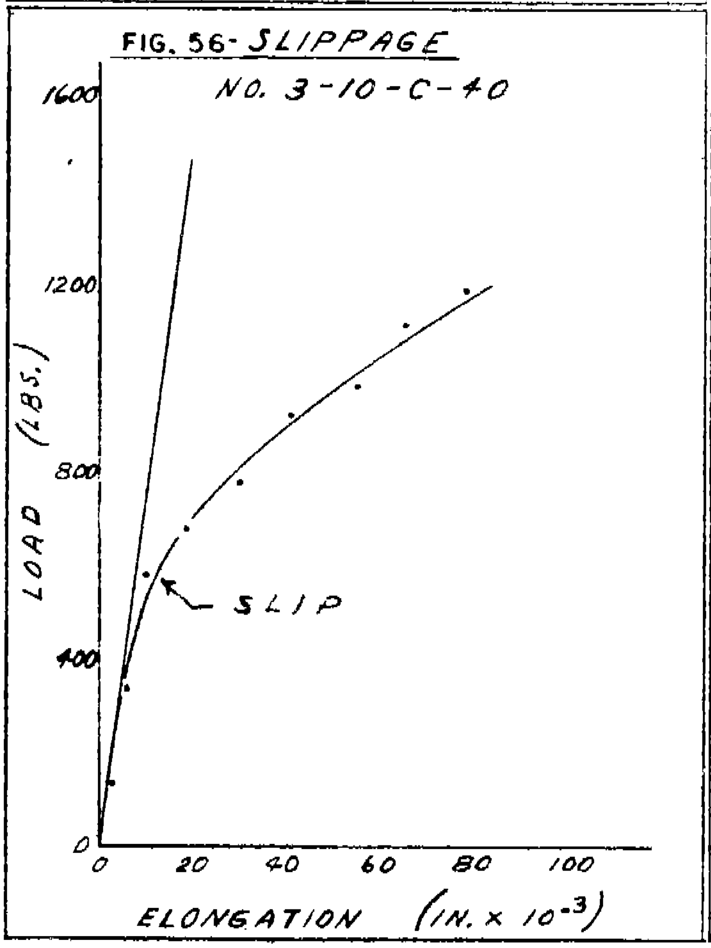


FIG. 56-SLIPPAGE
NO. 3-10-C-40
SLIP
LOAD (LBS.)
ELONGATION (IN. × 10^-3)
0
400
800
1200
1600
20
40
60
80
100

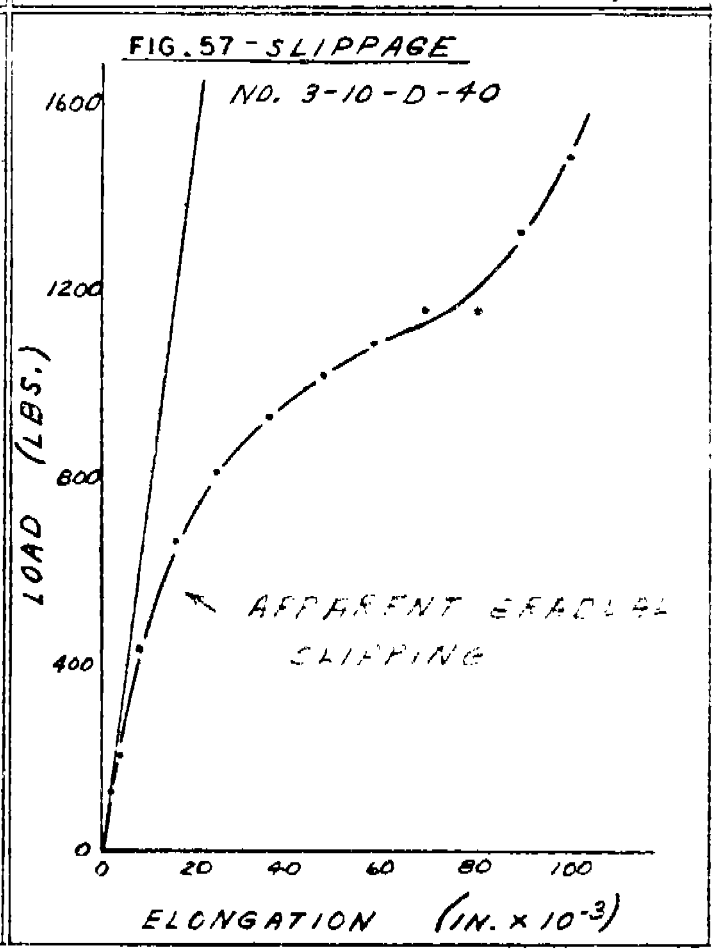


FIG. 57-SLIPPAGE
NO. 3-10-D-40
LOAD (LBS.)
ELONGATION (IN. × 10^-3)
0
400
800
1200
1600
20
40
60
80
100

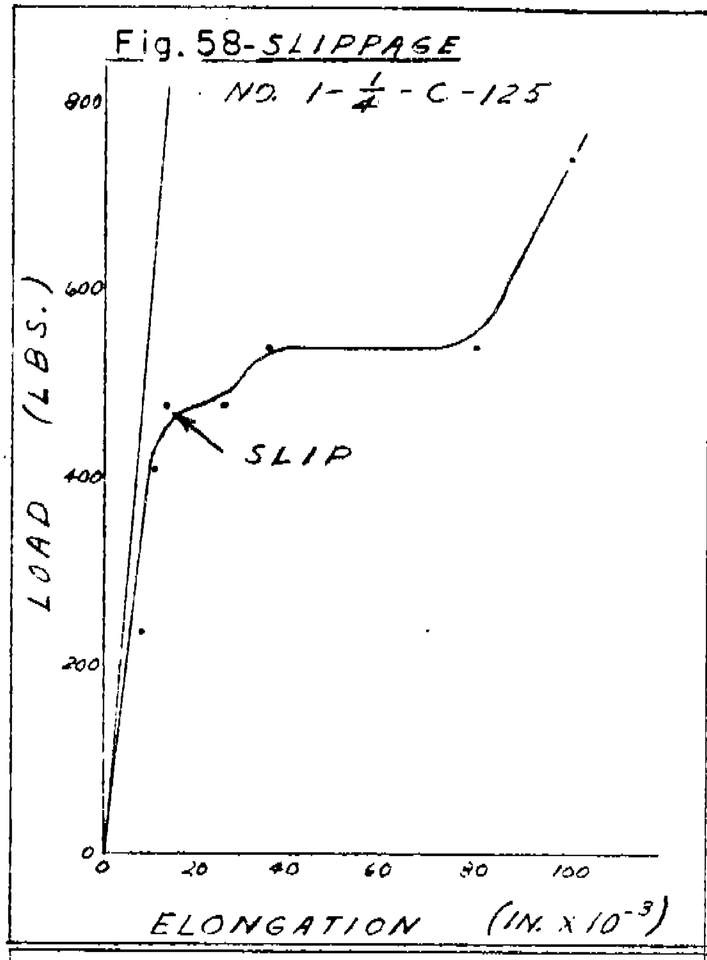


Fig. 58-SLIPPAGE
NO. 1-$\frac{1}{4}$-C-125

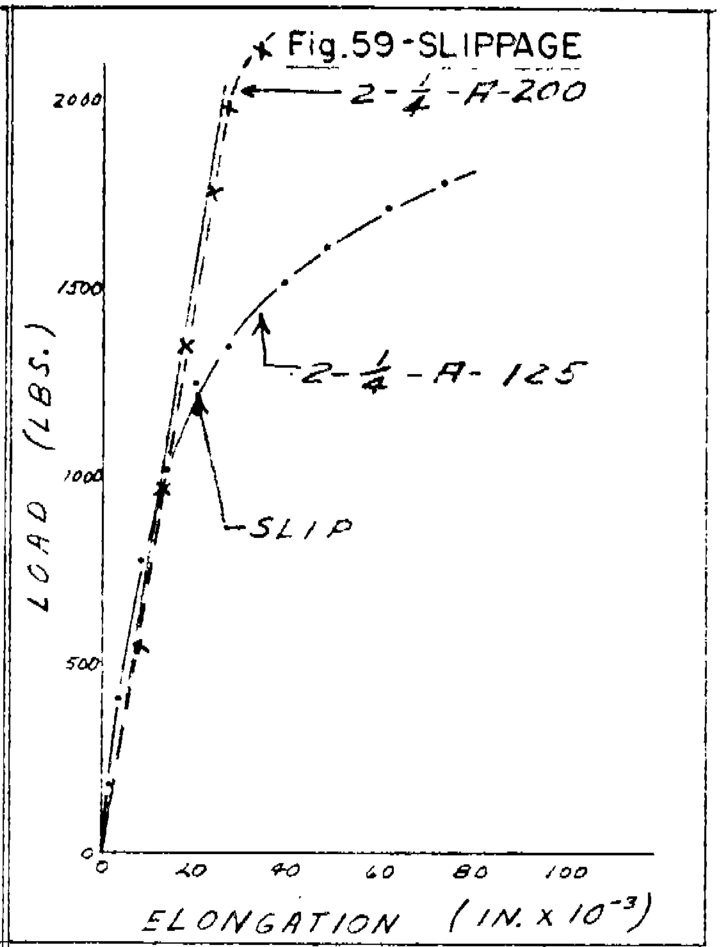


Fig. 59-SLIPPAGE

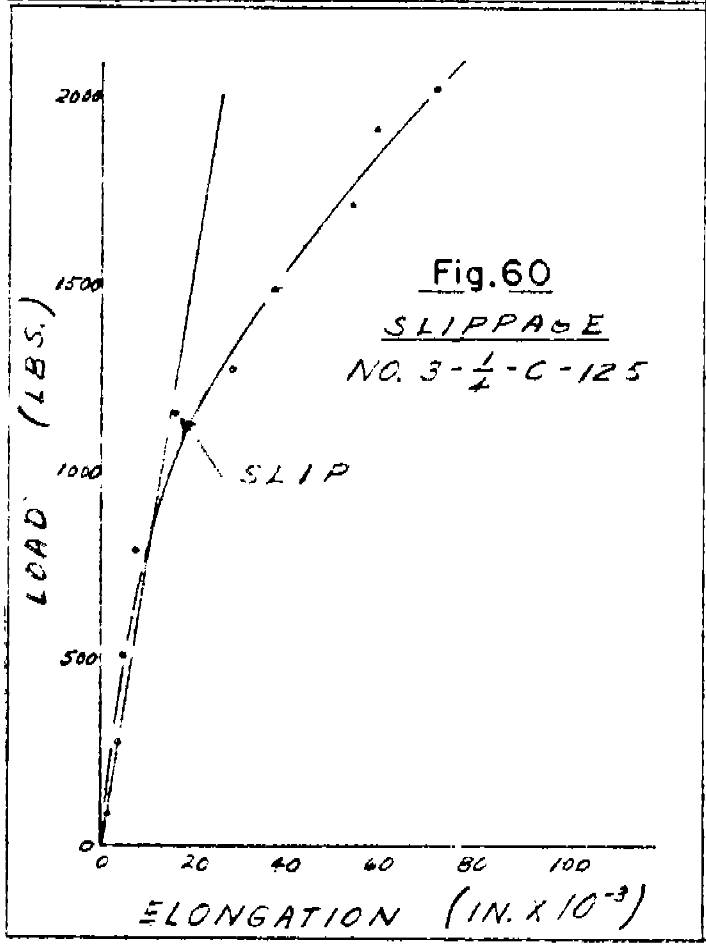


Fig. 60
SLIPPAGE
NO. 3-$\frac{1}{4}$-C-125

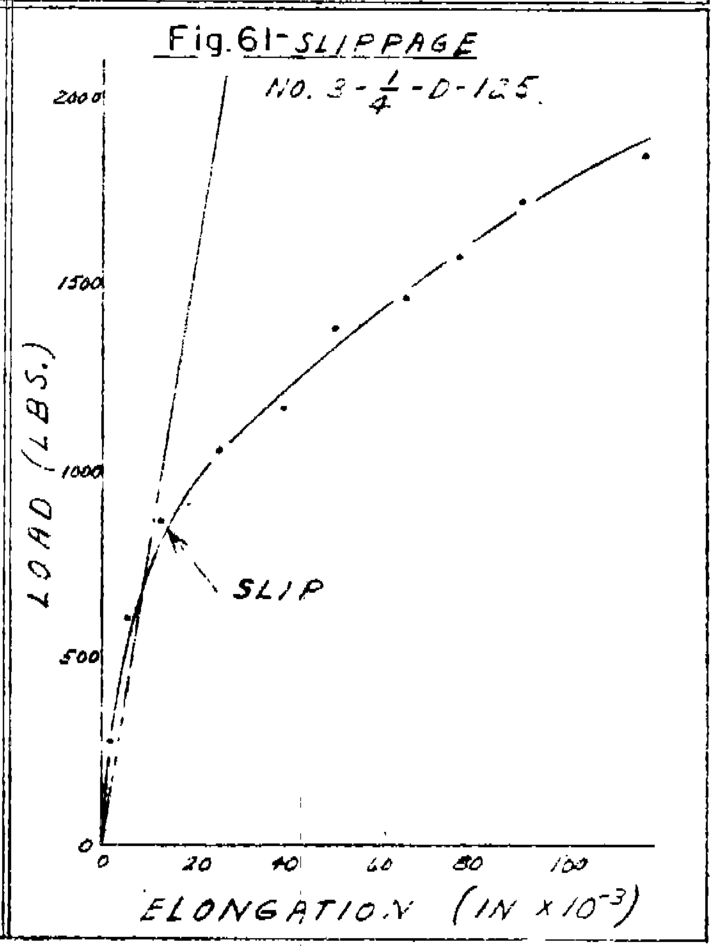


Fig. 61-SLIPPAGE
NO. 3-$\frac{1}{4}$-D-125

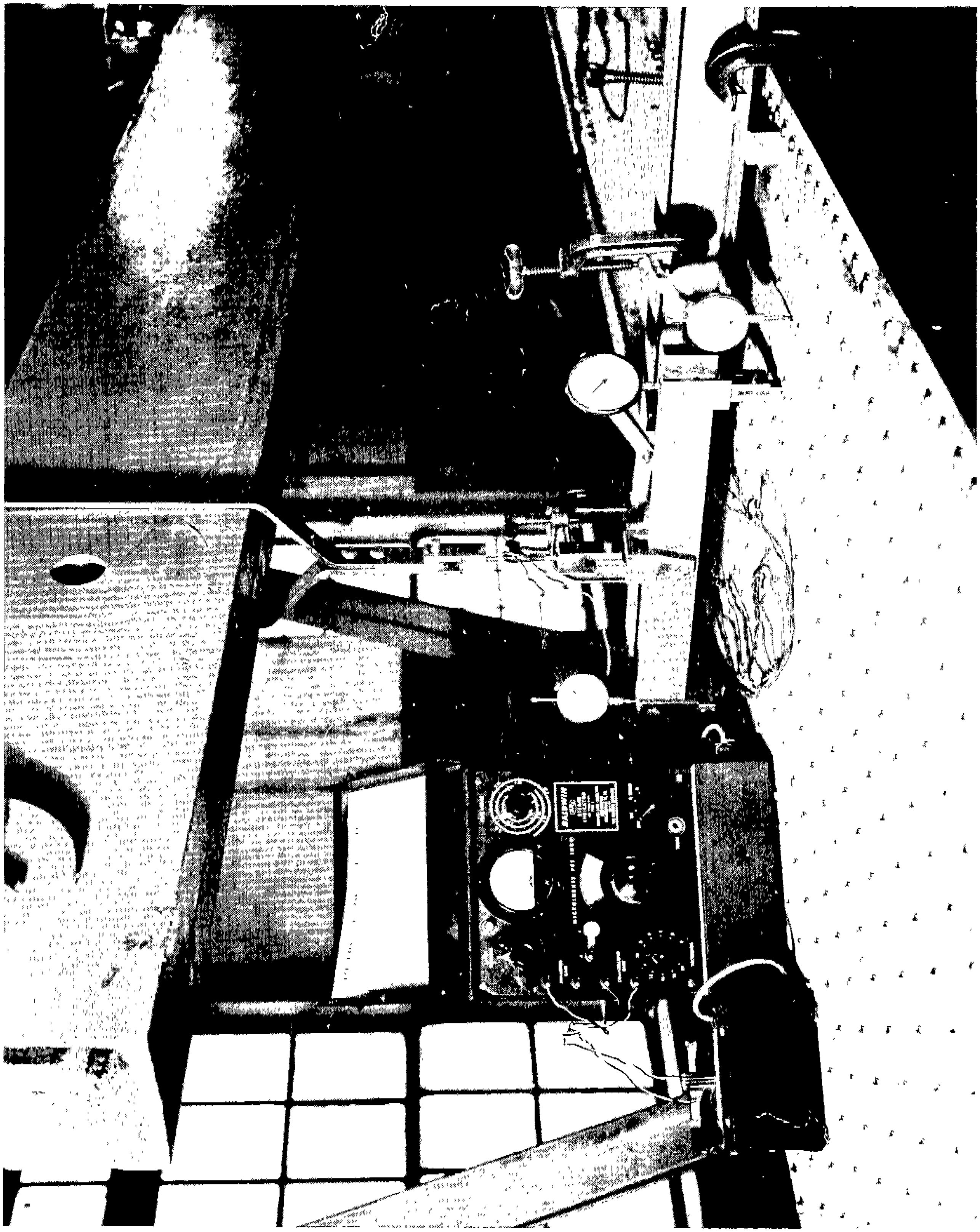


FIG. 62 - STIFFNESS TESTS

FIG. 63
STIFFNESS TEST
STANDARD DECK BEAMS

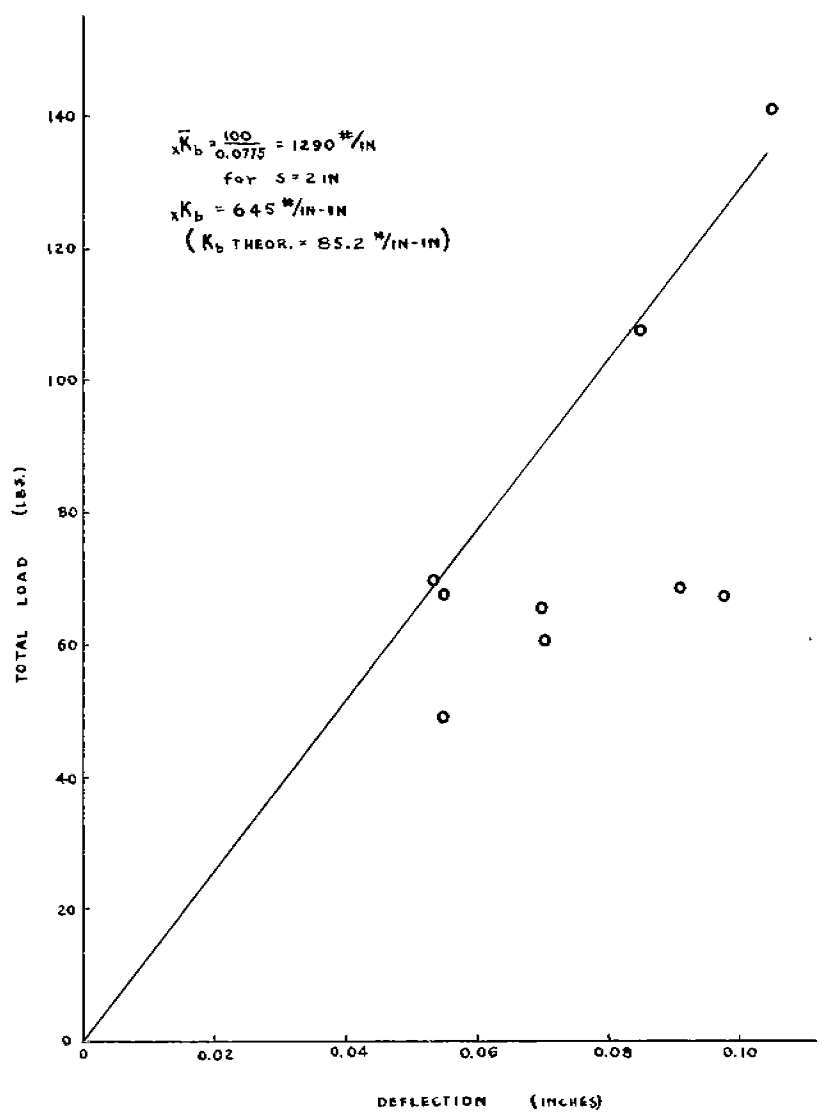


Fig. 64
STIFFNESS TEST
OUTSIZE DECK BEAMS

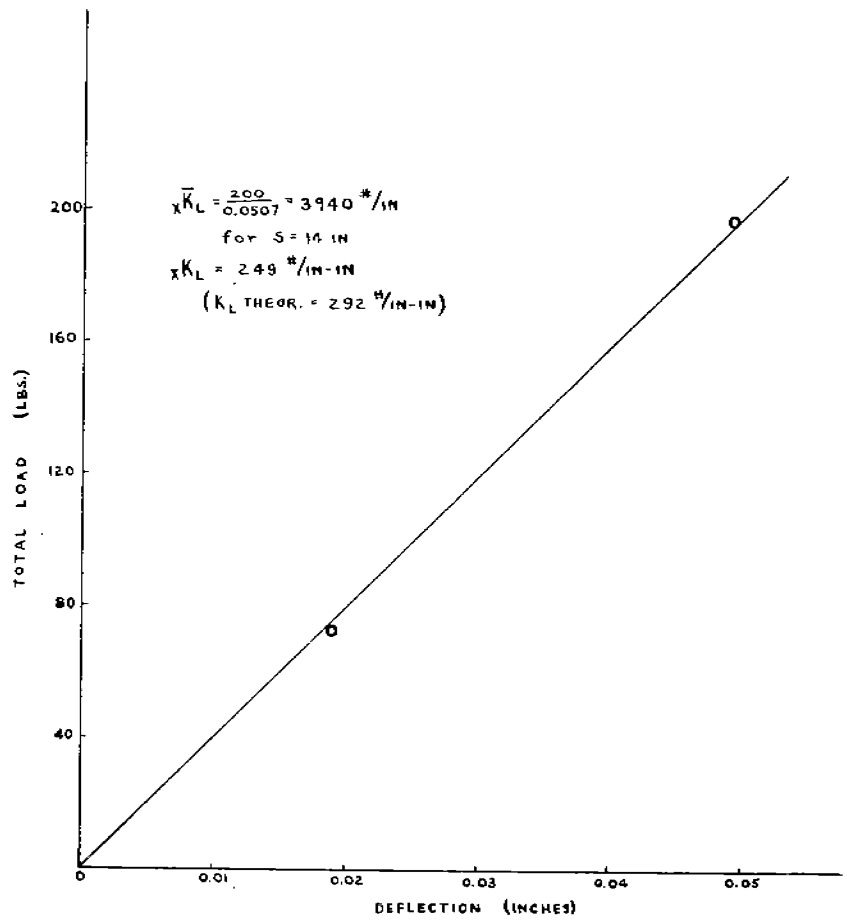


Fig. 65
STIFFNESS TESTS
PARTIAL BULKHEADS

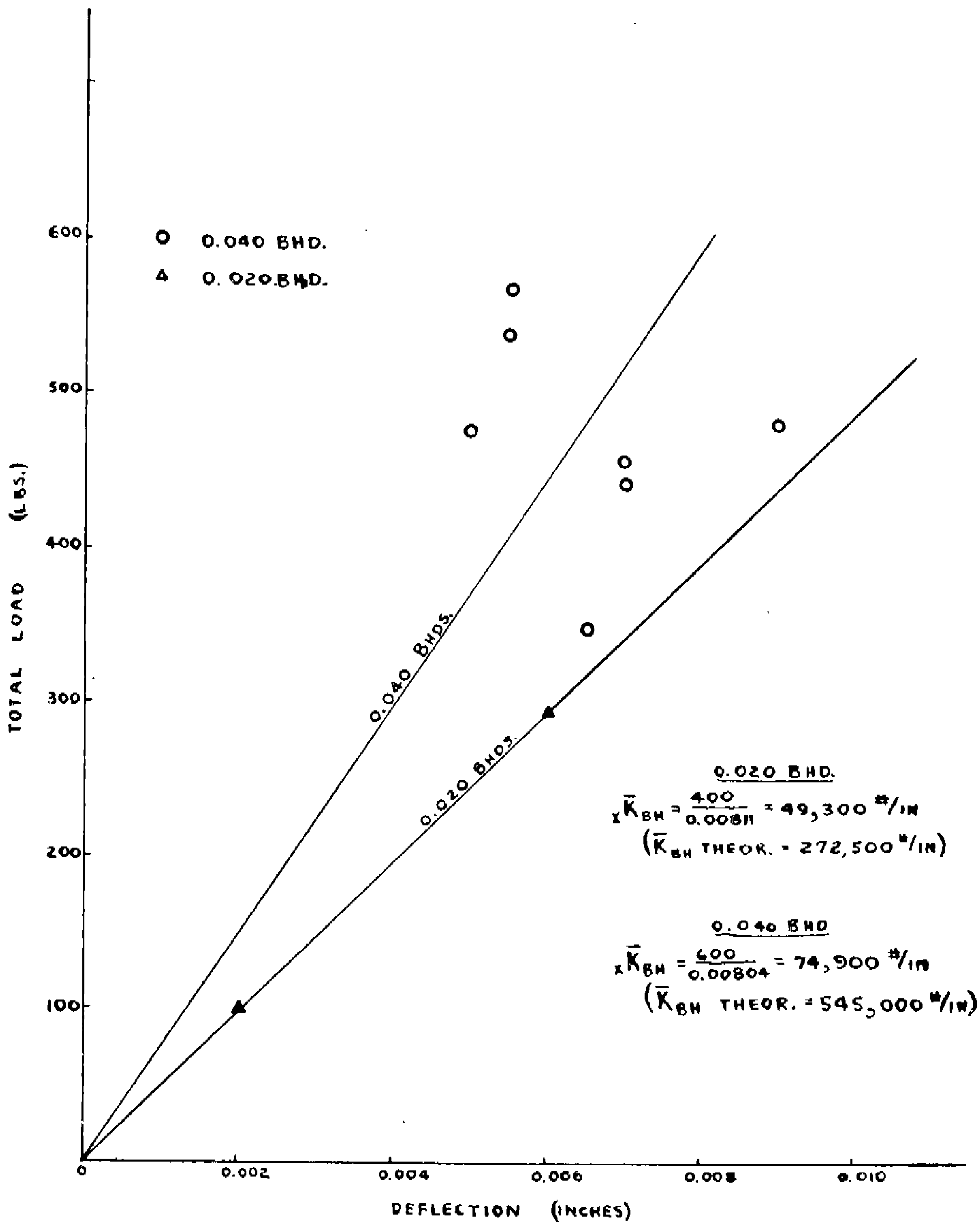


FIG. 66 – MIDSHIP STATION

LONGITUDINAL STRESSES
BARE-HULL TESTS

LEGEND:

———— STRESS from MEASURED STRAINS

— — CALCULATED STRESS

TEST NO. 1

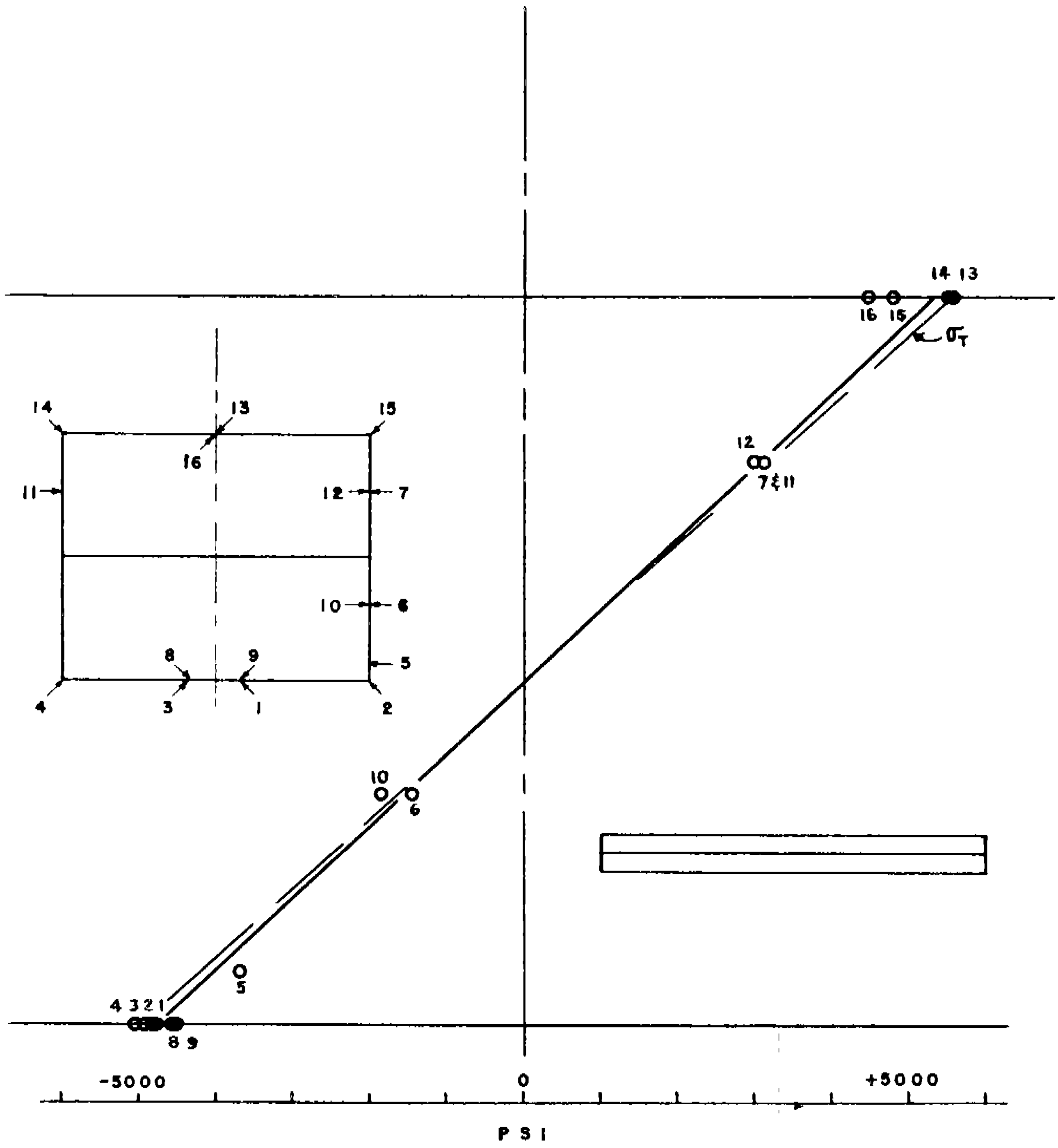


FIG. 67 - MIDSHIP STATION

LONGITUDINAL STRESSES
BARE-HULL TESTS

TEST NO. 11

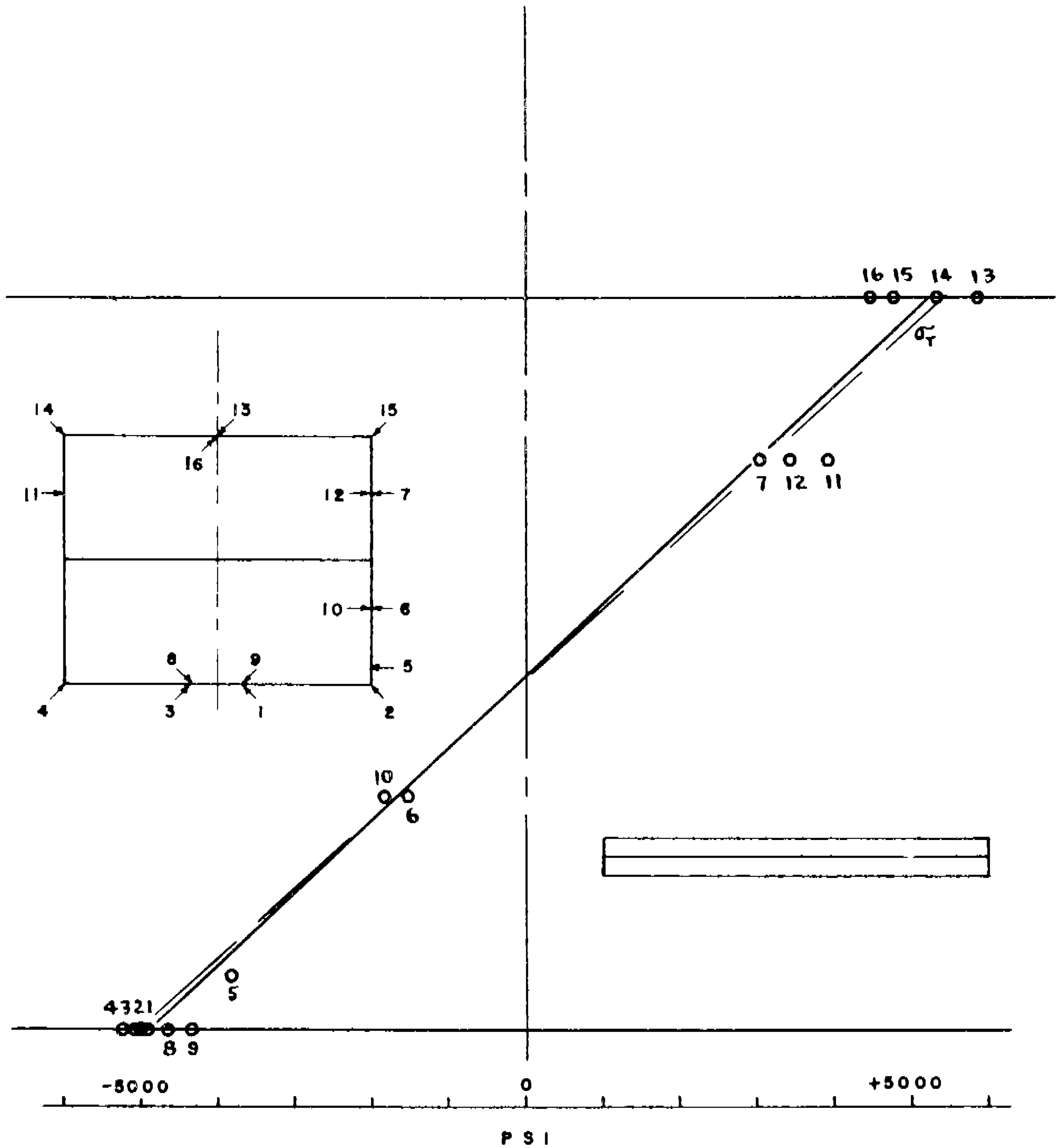


FIG 68 DEFLECTIONS
BARE-HULL TESTS

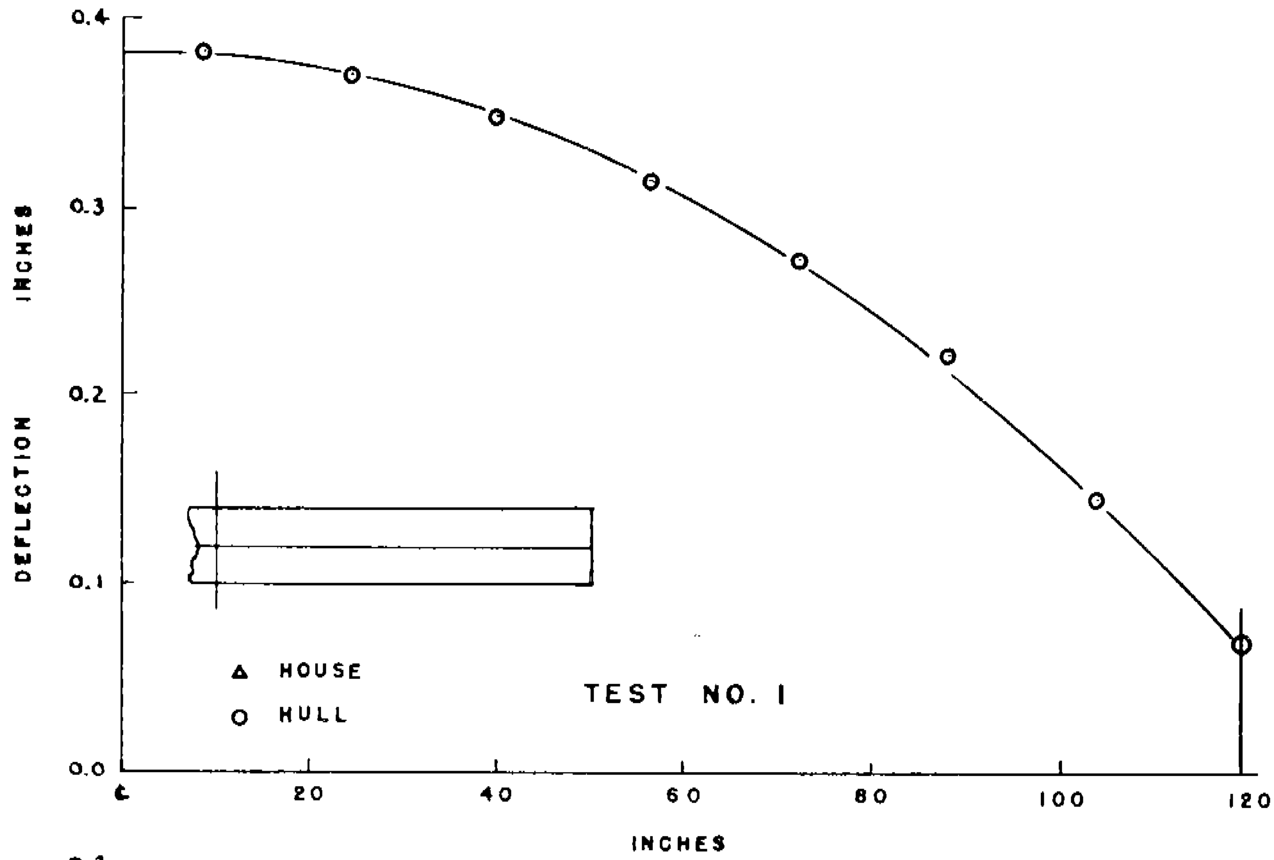
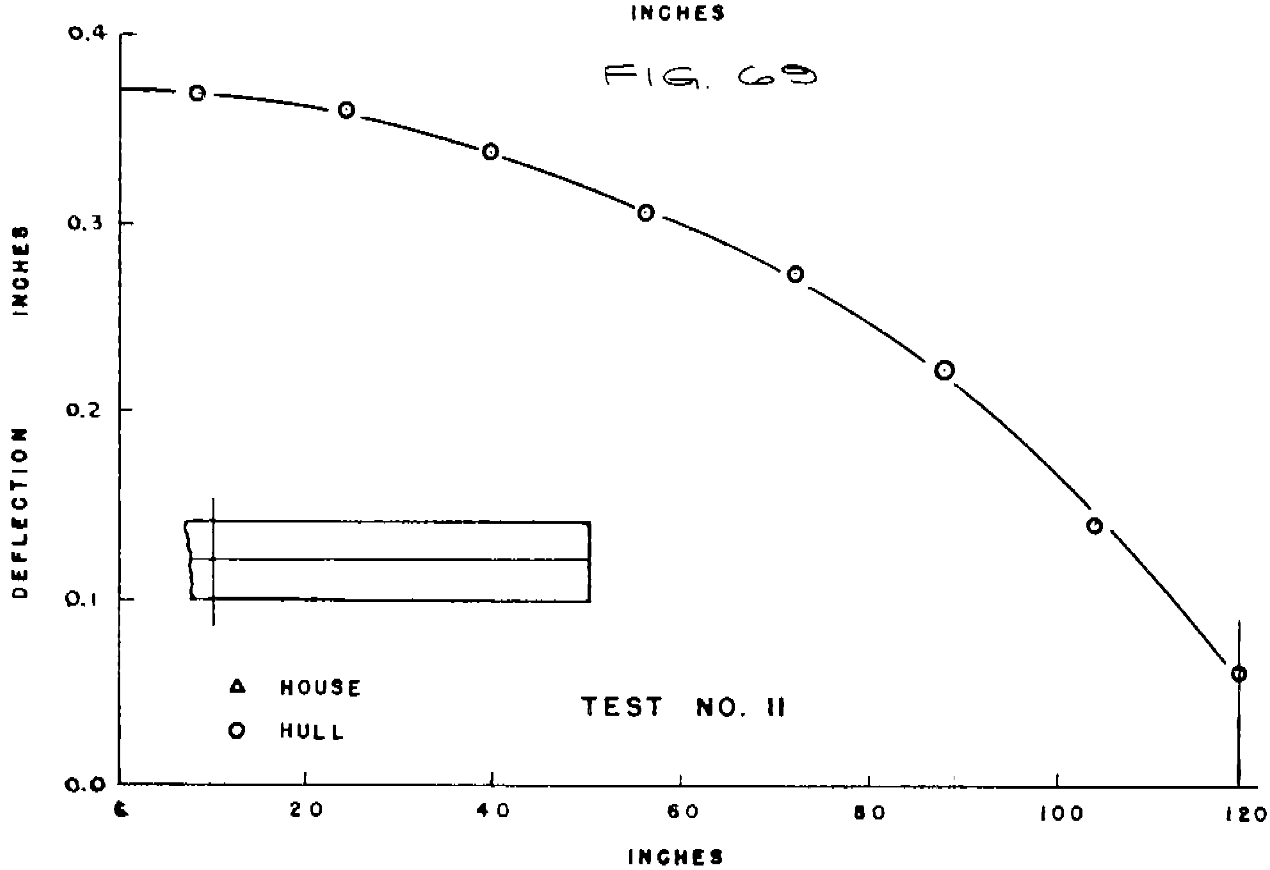


FIG. 69



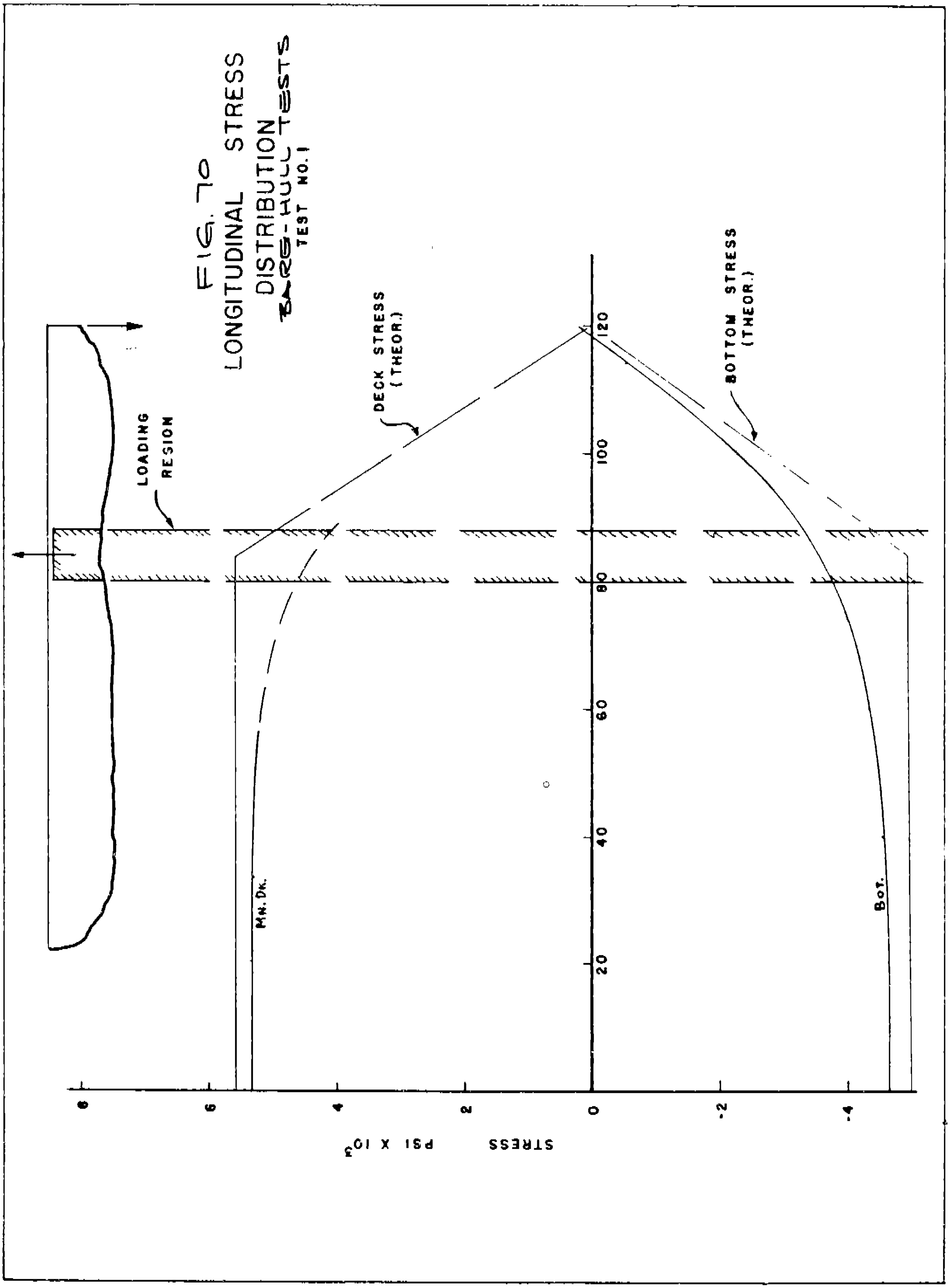


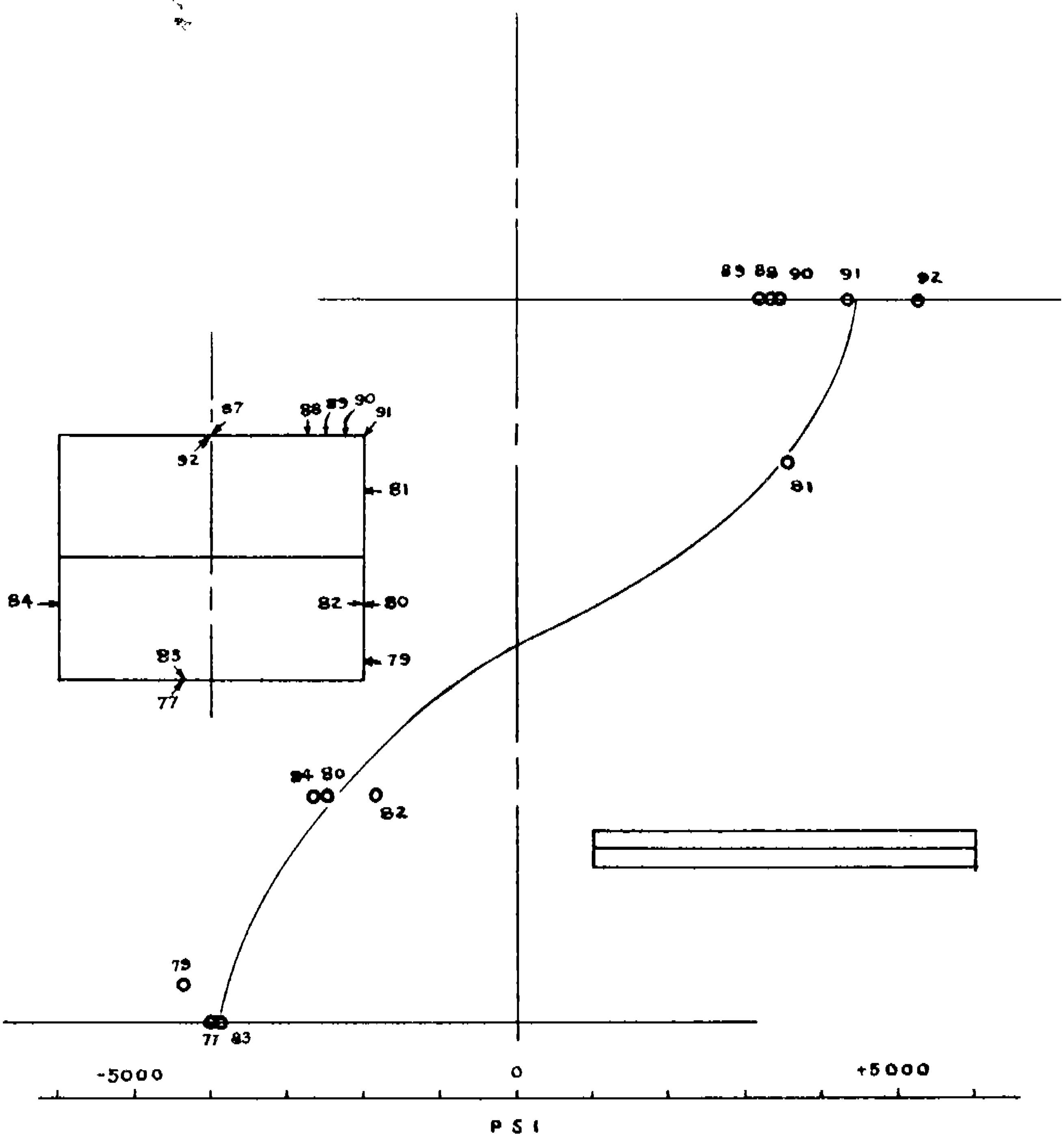
FIG. 70
LONGITUDINAL STRESS DISTRIBUTION
BARG-HULL TESTS
TEST NO.1

FIG. 71 - STATION 76

LONGITUDINAL STRESSES

BARE-HULL TESTS

TEST NO. I



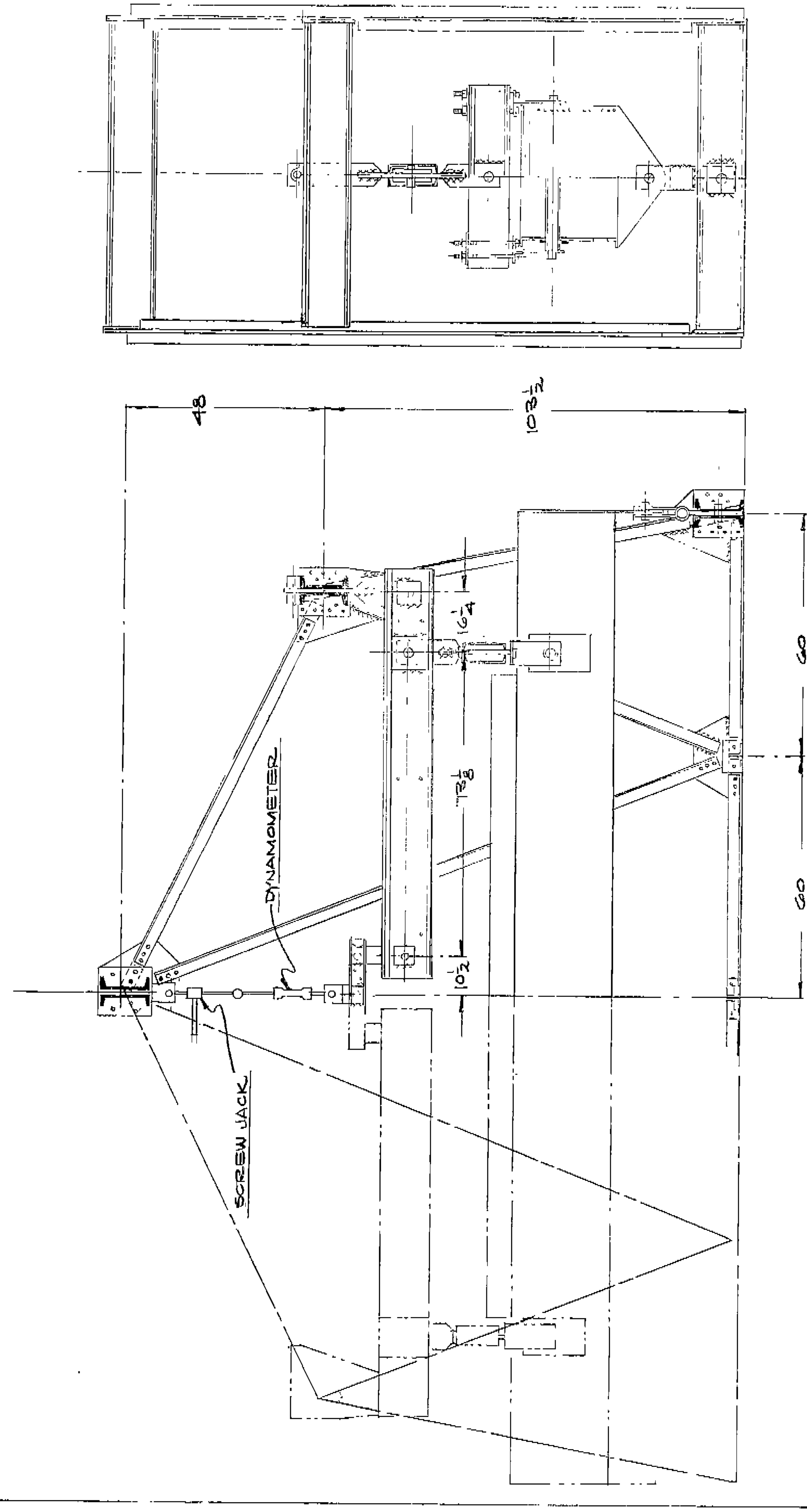


FIG. 72- TEST RIG LOADING ARRANGEMENT

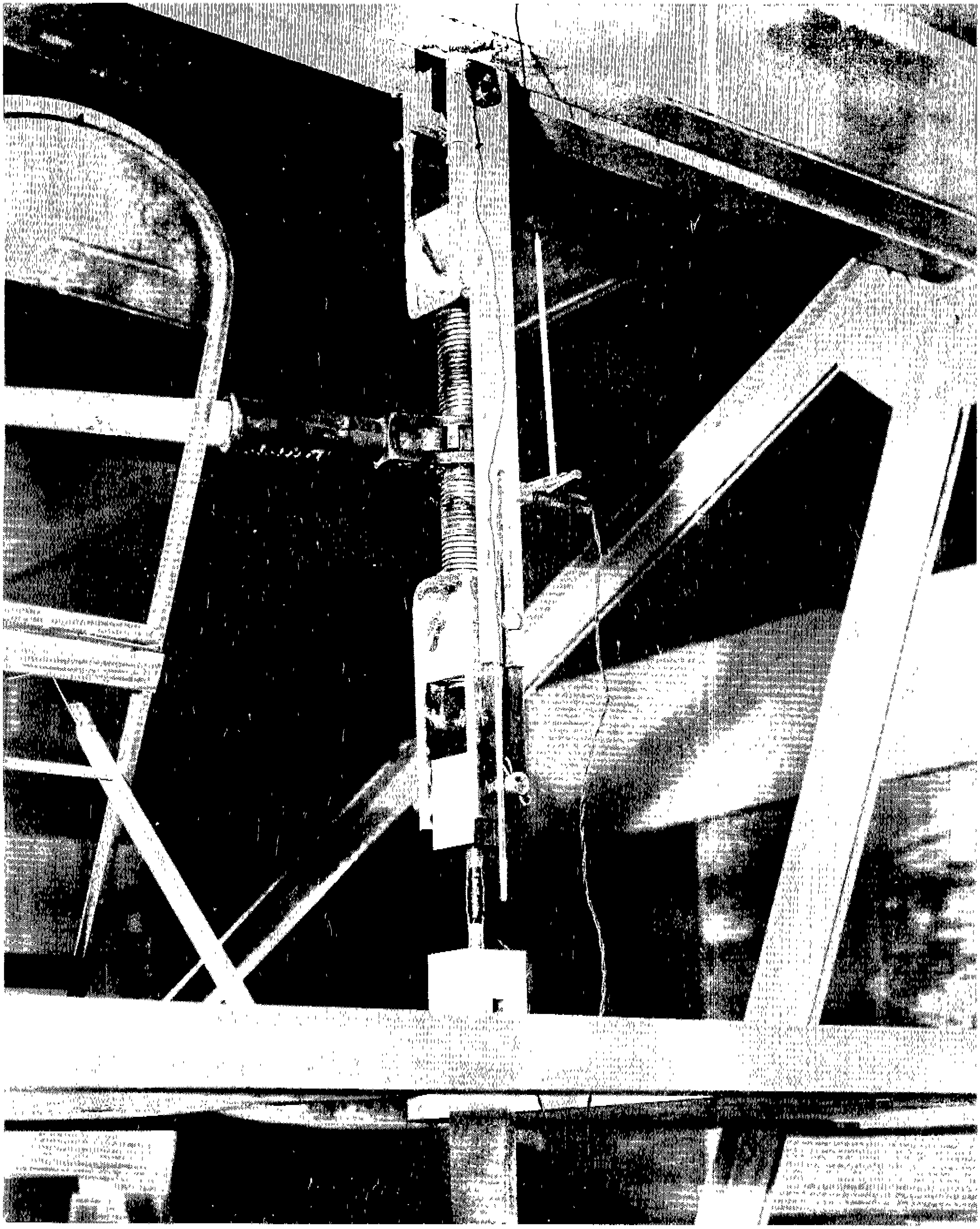
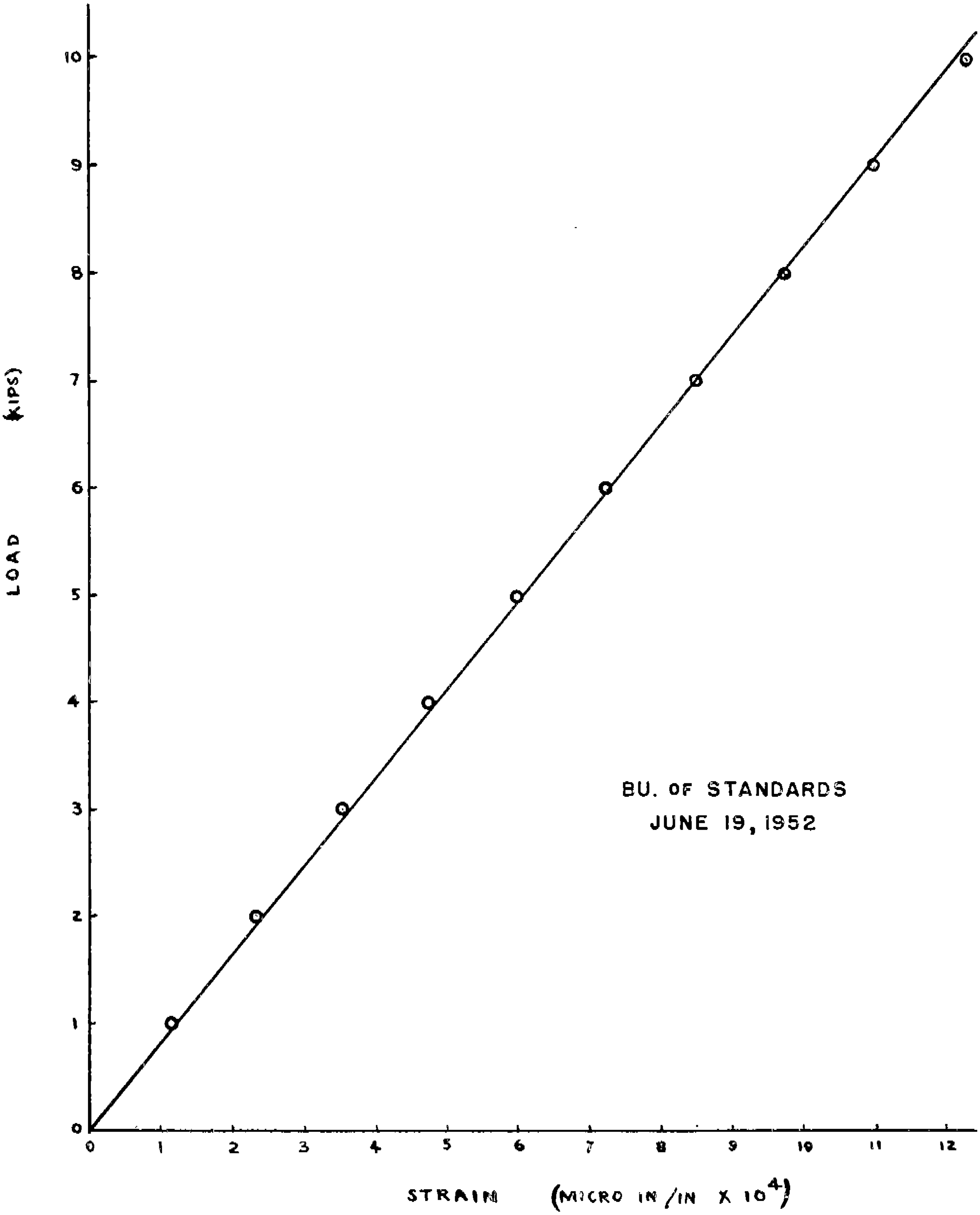


FIG. 73 - MAIN DYNAMOMETER AND JACK

Fig.74 MAIN DYNAMOMETER CALIBRATION



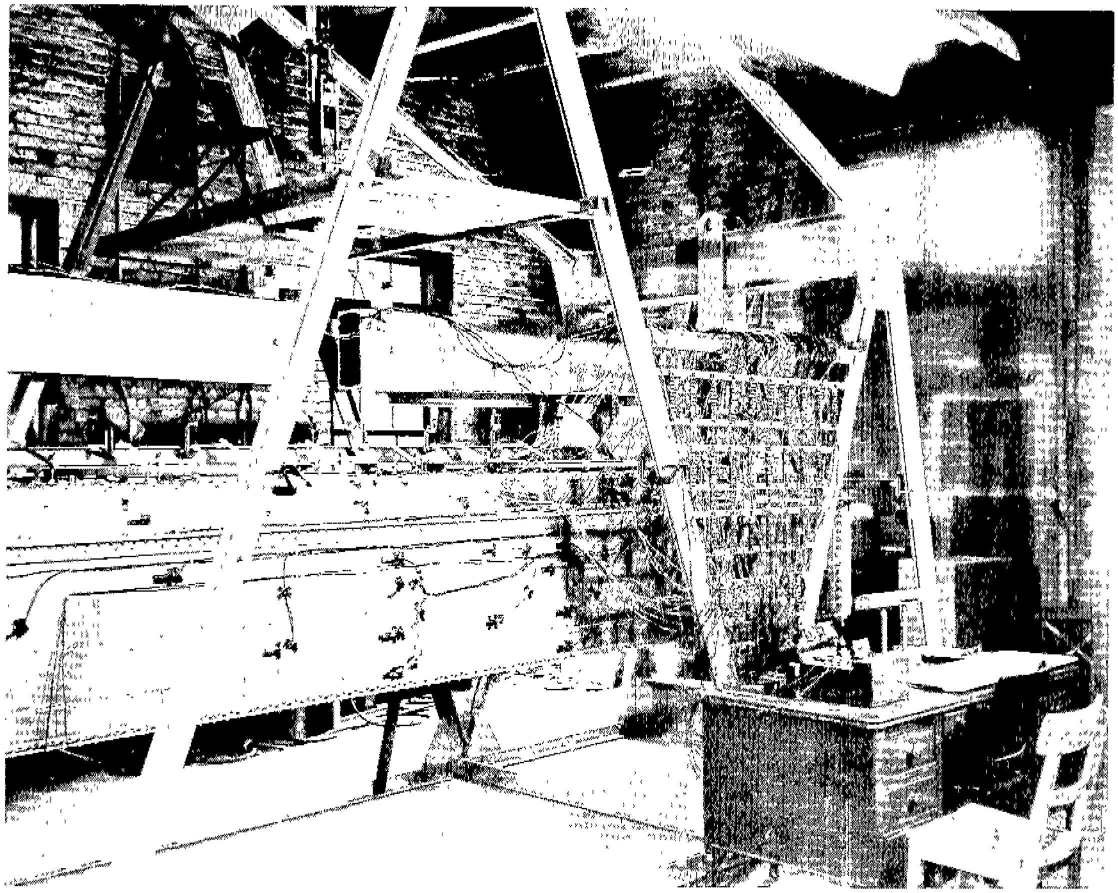


FIG. 75 - GENERAL VIEW - INSTRUMENTATION

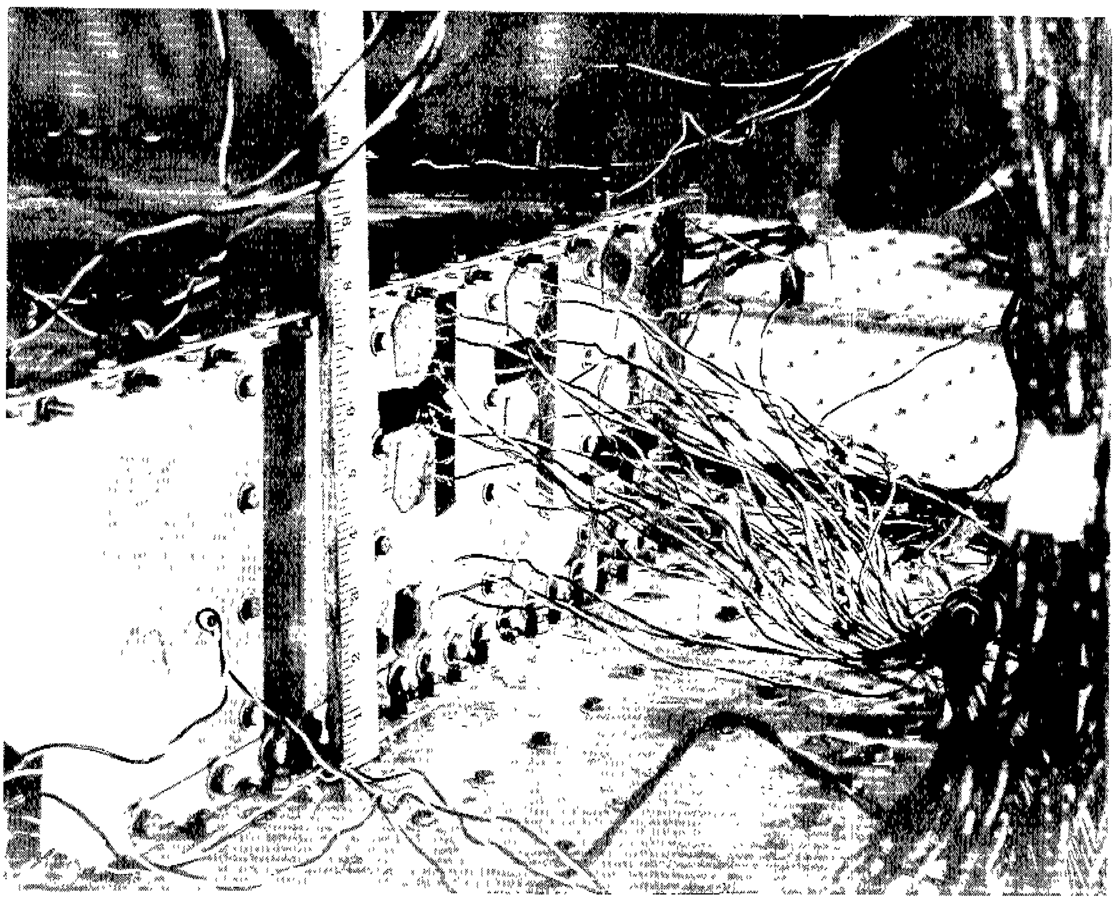


FIG. 76 - HOUSE END INSTRUMENTATION

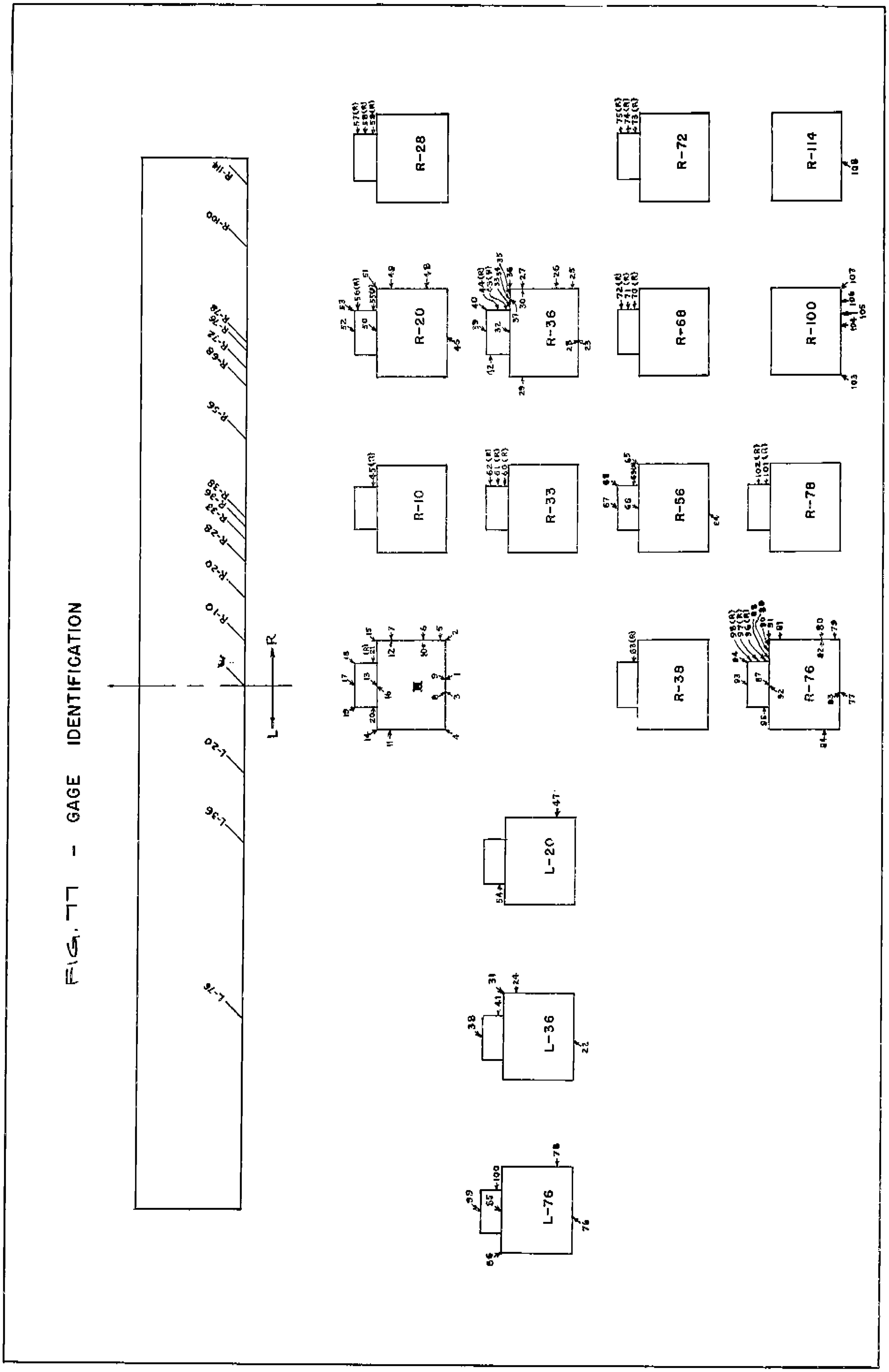


FIG. 77 - GAGE IDENTIFICATION

Fig. 78-SAMPLE STRESS-MOMENT PLOTS
TESTS 1,2,3,&4

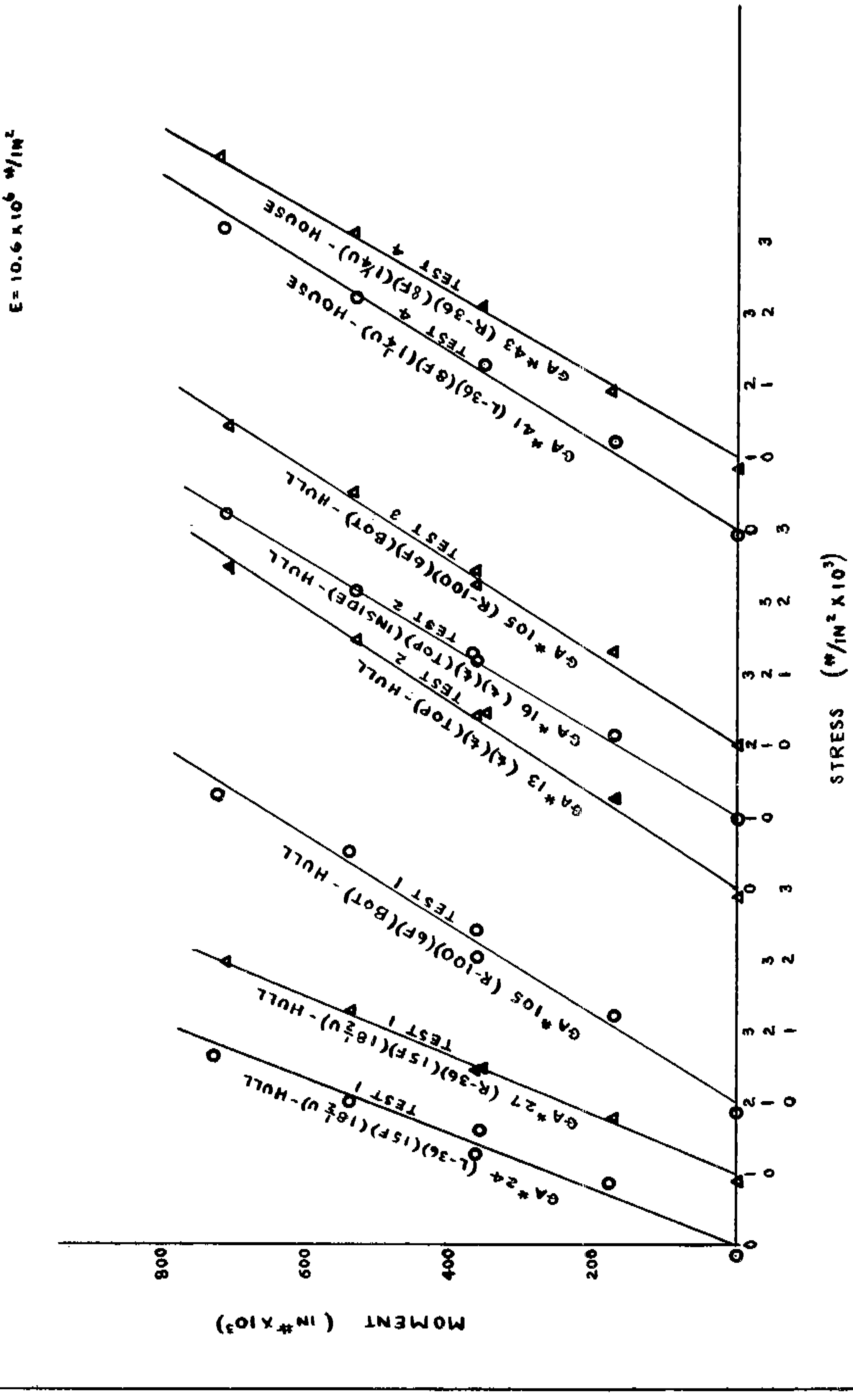
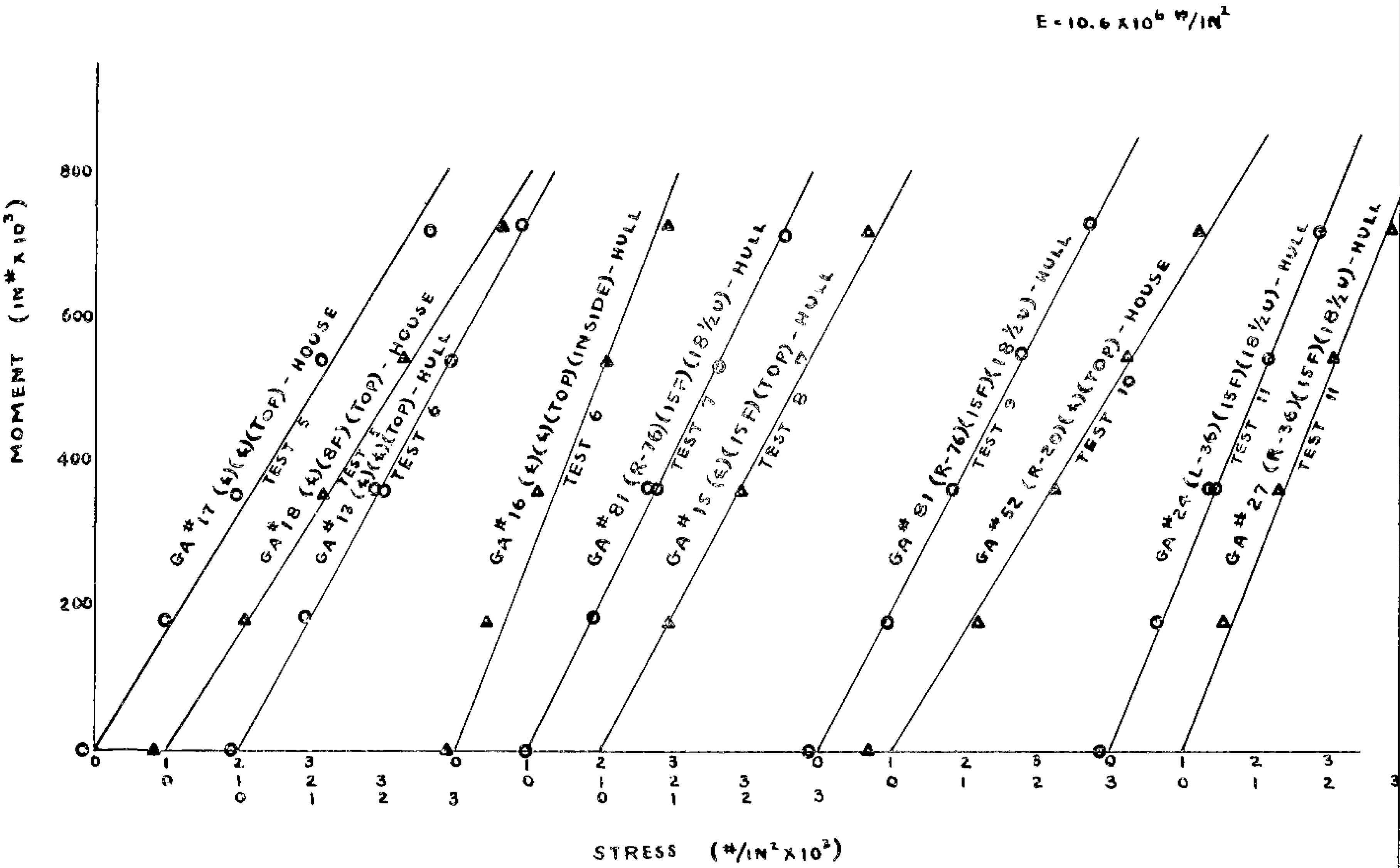


Fig. 79-SAMPLE STRESS-MOMENT PLOTS

TESTS 5,6,7,8,9,10,& 11



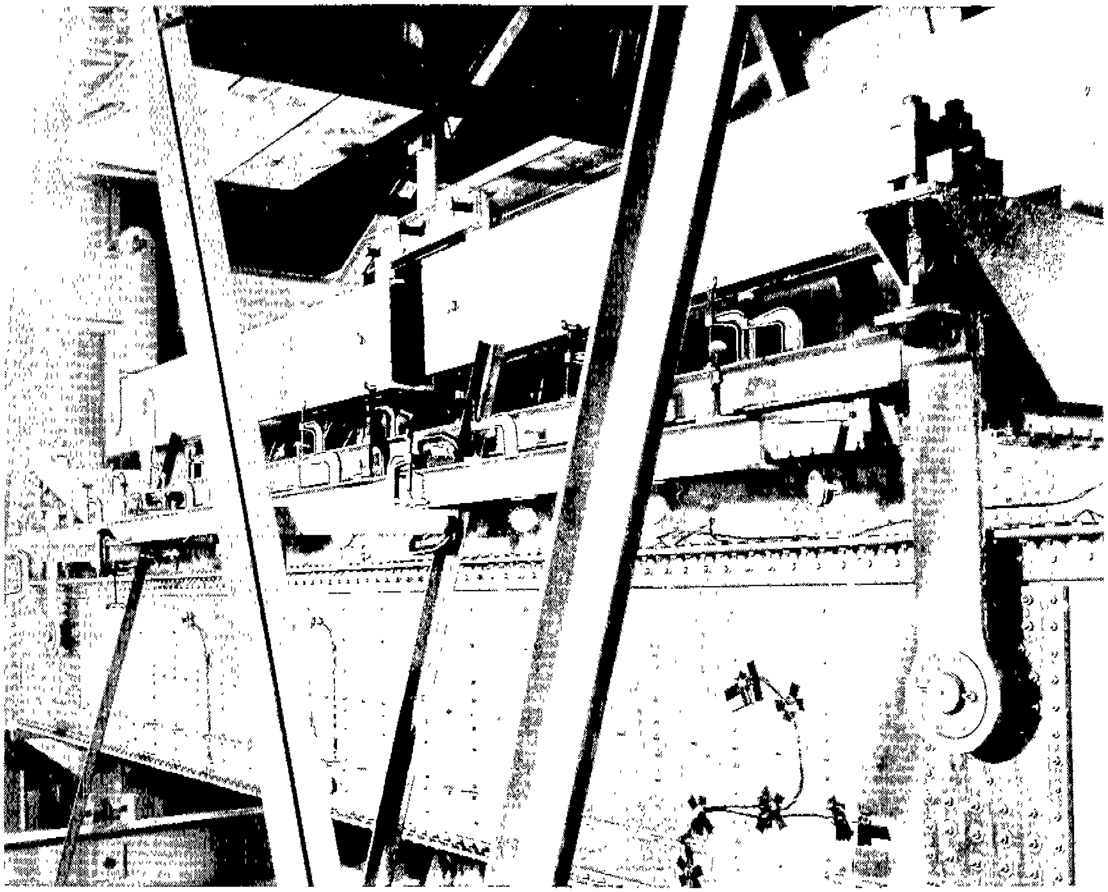


FIG. 80 - DIAL GAGES - HULL

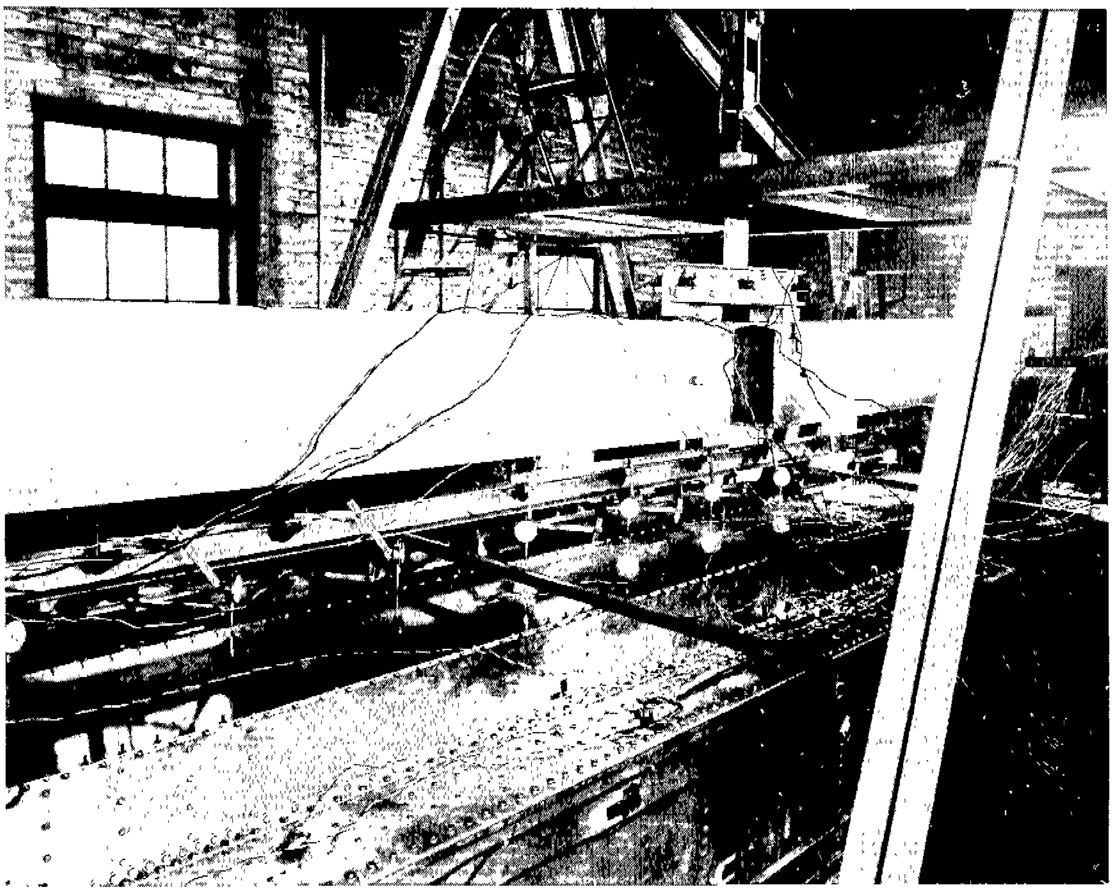


FIG. 81 - DIAL GAGES - HOUSE TOP

TABLE I - SHIP and MODEL DATA

Designation.	President Wilson.	America	Normandie	Conte di Savoia	Liberte (Europa.)	Alcoa Model No. 2. (See Ref. 5)	Bleich's Model Example. (See Ref. 4)	Reed Research[1] 5' Model. (See Ref. 5)	Reed Research[1] 12' Model.	Model for Test Program
Hull Length - L	608'-11"	723'-0"	1029'-4"	814'-8"	938'-6"	10'-0"	10'-0"	5'-0"	12'-0"	20'-0"
Hull Depth - H	61'-6" (To Prom. Deck)	73'-5" (Strength Deck)	91'-10"	79'-10½"	79'-4¾"	10"	10"	6."144	15."03	24"
Beam - B	75'-6"	93'-3"	117'-9"	95'-9"	101'-8½"	15."18	15."18	9."0	18."42	30"
H/L	0.101	0.1017	0.089	0.098	0.085	0.0833	0.0833	0.1022	0.1044	0.10
B/L	0.124	0.129	0.114	0.118	0.108	0.126	0.126	0.15	0.128	0.125
Main Deck Plate Thickness.-t	0.344"	0.66" (St)	0.83" (H.T)	0.63" (H T)	0.945"	0.135" (St)	0.157" (St)	0.072" (St)	0.032" (al)	0.032" (al)
Maximum Moment - M_{max}	2,600,000 ft-tons (Test)	682,000 ft-tons	1,825,000 ft-tons	986,000 ft-tons.	2,067,000 ft-tons	375,000 in-lb.	375,000 in-lb.	—	—	2,460,000 in-lb
Maximum Stress - σ_{max}.	5880 lb/in² (Test)	8.45 Tons/in²	7.79 Tons/in²	8.24 Tons/in²	15.12 Tons/in²	7.85 K/in²	11.02 K/in²	—	—	18,000 lb/in²
Hull Moment of Inertia - I	2,407,000 in²-ft² (To Prom. Deck)	2,960,000 in²-ft²	10,780,000 in²-ft²	4,800,000 in²-ft²	5,470,000 in²-ft²	155 in⁴	160.9 in⁴	14.11 in⁴	289 in⁴	2020.13 in⁴

1/ THESE ARE HYPOTHETICAL MODELS, CONSIDERED for ILLUSTRATION.

	Symbol	Unit	Full Size Vessels: PRESIDENT WILSON	Full Size Vessels: AMERICA	Model for Test Program, Rel. to Pres. Wilson: Houses #1 & #3	Model for Test Program, Rel. to Pres. Wilson: House #2	Model for Test Program, Rel. to America: Houses #1 & #3	Model for Test Program, Rel. to America: House #2
Length	L	in	7307	8676	240	240	240	240
House Moment of Inertia	I_H	in^4	3.47×10^8	5.78×10^8	1653	1653	1653	1653
House Moment of Inertia	I_S	in^4	1.81×10^6	2.08×10^6	8.79	6.66	8.79	6.66
Main Deck Thickness	t_M	in	.625 (Eq.)	.665	.032	.032	.032	.032
Average Hull Side Thickness	t_S	in	.83	.87	.125	.125	.125	.125
Deck Beam Moment of Inertia	I_B	in^4	23.70	26.4	$*1.14 \times 10^{-4}$	$*1.14 \times 10^{-4}$	$*1.14 \times 10^{-4}$	$*1.14 \times 10^{-4}$
Length Ratio	λ				32.8×10^{-3}	32.8×10^{-3}	27.6×10^{-3}	27.6×10^{-3}
	λ^3				35.38×10^{-6}	35.38×10^{-6}	21.2×10^{-6}	21.2×10^{-6}
Multi-cell Factor	$\eta = \lambda T_H$				4.94×10^{-2}	4.94×10^{-2}	3.98×10^{-2}	3.98×10^{-2}
Side Thickness Ratio	T_H				.1506	.1506	.144	.144
Deck Thickness Ratio	T_M				.0512	.0512	.0481	.0481
	T_M^3				1.342×10^{-4}	1.342×10^{-4}	1.111×10^{-4}	1.111×10^{-4}
Hull Inertia Ratio	Φ_H	EQUIVALENT GROUPS			4.76×10^{-6}	4.76×10^{-6}	2.86×10^{-6}	2.86×10^{-6}
	$\lambda^3 T_H$				5.32×10^{-6}	5.32×10^{-6}	3.05×10^{-6}	3.05×10^{-6}
Beam Inertia Ratio	Φ_B				4.81×10^{-6}	4.81×10^{-6}	4.32×10^{-6}	4.32×10^{-6}
House Inertia Ratio	Φ_S				4.85×10^{-6}	3.68×10^{-6}	4.27×10^{-6}	3.26×10^{-6}
	λT_M^3				4.41×10^{-6}	4.41×10^{-6}	3.062×10^{-6}	3.062×10^{-6}

TABLE II

HULL SUPERSTRUCTURE MODELS
APPLICATION of PROPORTIONALITY RULES

* NOTE:
Model Deck Beam "I_B" has been pro-rated for simple supports, single span and revised spacing on model.

TABLE III SECTION CHARACTERISTICS:— HULL — SUPERSTRUCTURE MODEL.

$I_2 = 1653$ in^4
$A_2 = 17.81$ in^2
$M_s = 720{,}000$ in-lb

$M_sI_2 = -72\times10^4 \times 1653 = -1190\times10^6$
$E = 10.5\times10^6$. $4E = 42\times10^6$.

Note:– Subscript Pts. 'S', Refer to Standardized Bending Moment (720,000 in-lb)

Line	h \ House No.	1. (7.5)	2. (6.0)	3. (7.5)
1	ℓ	80.	160.	160.
2	A_1	.94	1.19	.94
3	a	17.60	16.59	17.60
4	a^2	310	275	310
5	$A_1 + A_2$	18.75	19.00	18.75
6	$A_1 \times A_2$	16.75	21.2	16.75
7	$A_1A_2/(A_1+A_2) = (6)/(5)$	.893	1.116	.893
8	$I_A = a^2 \frac{A_1A_2}{A_1+A_2} = (4).(7)$	276.8	306.5	276.8
9	α_1	.2779	.2341	.2779
10	α_2	.7221	.7659	.7221
11	$\alpha_1 I_A$	77.0	71.9	77.0
12	$\alpha_2 I_A$	199.8	234.6	199.8
13	I_1	8.79	6.66	8.79
14	$I_1 + \alpha_1 I_A$	85.8	78.6	85.8
15	$I_2 + \alpha_2 I_A$	1853	1888	1853
16	$\mu = (I_1+\alpha_1 I_A)/(I_2+\alpha_2 I_A) = (14)/(15)$	.0462	.0417	.0462
17	$\alpha_2 I_1$	6.35	5.11	6.35
18	$\alpha_1 I_2$	459	388	459
19	$\mu\alpha_1 I_2 = (16).(18)$	21.19	16.18	21.19
20	$\alpha_2 I_1 + \mu\alpha_1 I_2 = (17)+(19)$	27.54	21.19	27.54
21	$(1+\mu)/(\alpha_2 I_1 + \mu\alpha_1 I_2)$	.0380	.0490	.0380
22	$(21).\frac{1}{4E} = (21)/42\times10^6$	905×10^{-12}	1167×10^{-12}	905×10^{-12}
23	$\sqrt{(22)}$	5.48×10^{-3}	5.85×10^{-3}	5.48×10^{-3}
24	$C = u/\sqrt{K} = \frac{\ell}{2}(23)$	.219	.468	.438
25	$(1+\mu)(\alpha_2 I_1 + \mu\alpha_1 I_2)$	28.78	22.20	28.78
26	$\mu/[(1+\mu)(\alpha_2 I_1+\mu\alpha_1 I_2)] = -\Delta M_1/M_sI_1$	1.607×10^{-3}	1.878×10^{-3}	1.607×10^{-3}
27	$\mu\alpha_2 = (16)(10)$	.03359	.03195	.03359
28	$\alpha_1 - \mu\alpha_2$	.2443	.2021	.2443
29	$(28)(26) = \Delta N_1/(M_sI_A/a)$	$.393\times10^{-3}$	$.380\times10^{-3}$	$.393\times10^{-3}$
30	$(16).(26) = \Delta M_2/(M_sI_2)$	74.3×10^{-6}	78.3×10^{-6}	74.3×10^{-6}

Line	h \ House No.	1. (7.5)	2. (6.0)	3. (7.5)
31	$I_A/a = (8)/(3)$	15.75	18.51	15.71
32	$M_sI_A/a = 720\times10^3.(31)$	-11.33×10^6	-13.32×10^6	-11.33×10^6
33	$M_sI_1 = 720\times10^3.(13)$	-6.32×10^6	-4.79×10^6	-6.32×10^6
34	M_sI_2	-1190×10^6	-1190×10^6	-1190×10^6
35	$\Delta N_1 = -\Delta N_2 = (29)(32)$	−4460	−5070	−4460
36	$\Delta M_1 = -(26)(33)$	+10,140	+8990	+10,140
37	$\Delta M_2 = (30)(34)$	−88,500	−93,200	−88,500
38	$I = I_1 + I_2 + I_A$	1939	1967	1939
39	M_s/I	−371.9	−366.0	−371.9
	House Top			
40	x_1	2.61	2.12	2.61
41	C	19.37	17.68	19.37
42	$\Delta N_1/A_1 = (35)/(2)$	−4750	−4260	−4750
43	$\Delta M_1/I_1 = (36)/(13)$	1155	1348	1155
44	$\Delta M_1x_1/I_1 = (43).(40)$	3020	2858	3020
45	$\Delta\sigma_{1s} = (42)-(44)$	−7770	−7118	−7770
46	$\sigma_{NS} = -M_sC/I = -(39).(41)$	+7190	+6440	+7190
	Main Deck (Hull Top)			
47	x_2	12.71	12.71	12.71
48	C	11.87	11.68	11.87
49	$\Delta N_2/A_2 = -(35)/17.81$	+250	+284	+250
50	$\Delta M_2/I_2 = (37)/1653$	−53.5	−56.4	−53.5
51	$\Delta M_{2s}x_2/I_2 = (50).(47)$	−682	−717	−682
52	$\Delta\sigma_{2s} = (49)-(51)$	+932	+1001	+932
53	$\sigma_{NS} = -(39).(48)$	+4410	+4270	+4410
	Hull Bottom			
54	x_2	−11.29	−11.29	−11.29
55	C	−12.13	−12.32	−12.13
56	$\Delta M_{2s}x_2/I = (50).(54)$	+604	+636	+604
57	$\Delta\sigma_{2s} = (49)-(56)$	−354	−352	−354
58	$\sigma_{Ns} = (39)-(55)$	−4510	−4550	−4510

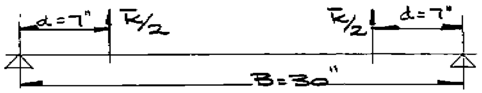
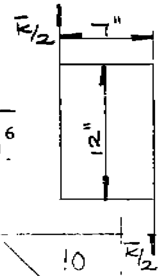


TABLE IV FOUNDATION STIFFNESS — K, u AND Φ ——— THEORETICAL & EXPERIMENTAL VALUES.



for BEAMS: $K = R_1 I$, where $R_1 = \frac{12E}{d^2(3B-4d)} = \frac{12 \times 10.6 \times 10^6}{49(62)} = 4.19 \times 10^4.$

for BULKHEADS: $K = R_2 t_B$, where $R_2 = \frac{2Gh}{a} = \frac{2 \times 3.98 \times 10^6 \times 12}{7} = 13.62 \times 10^6.$

		Line	TEST / HOUSE	2 / 2	3 / 2	4 / 2	5 / 3	6 / 3	7 / 3	8 / 1	9 / 1	10 / 3
Theoretical	Std. Dk. Beams.	1	Moment of Inertia, I_s	.00391								
		2	$\bar{K}_{ST} = R_1 I_s$	164								
		3	Spacing, S_s	2								
		4	$K_{ST} = \bar{K}_{ST}/S_s = (2)/(3)$	82	82	82	82	82	82	82	82	82
	Outsize Dk. Beams	5	I_o		.0976							
		6	$R_1 I_o$		4090							
		7	S_o		14							
		8	$K_{OT} = (6)/(7)$		292							
	Bulkheads.	9	Thickness, t_B			.020		.040	.040		.040	.040
		10	$\bar{K}_{BT} = R_2 t_B$			272,000		544,000	544,000		544,000	544,000
		11	Average Spacing, S_B			80.0		40.0	40.0		16.6	160
		12	$K_{BT} = (10)/(11)$			3,400		13,600	13,600		34,000	3,400
	Total.	13	$K_T = (4) + (8) + (12)$	82	374	3,480	82	13,700	13,700	82	34,100	3480
		14	$\sqrt[4]{K_T}$	3.01	4.40	7.68	3.01	10.8	10.8	3.01	13.6	7.68
		15	$C = u/\sqrt[4]{K_T}$ – from TABLE III	.468	.468	.468	.438	.438	.438	.219	.219	.438
		16	$u_T = (14) \cdot (15)$	1.41	2.06	3.59	1.32	4.73	4.73	0.66	2.98	3.36
		17	Φ_T – from Ref. 4	.565	.117	−.073	.636	−.018	−.018	.966	−.083	−.080
Experimental.	Std. Dk. Beams	18	Total Load, P_s	100								
		19	Observed Deflection, δ_s	.0775								
		20	$\bar{K}_{SX} = P_s/\delta_s = (18)/(19)$	1,290								
		21	S_s	2								
		22	$K_{SX} = (20)/(21)$	645	645	645	645	645	645	645	645	645
	Outsize Dk Beams.	23	P_o		200							
		24	δ_o		.0507							
		25	$\bar{K}_{OX} = (23)/(24)$		3,940							
		26	S_o		14							
		27	$K_{OX} = (25)/(26)$		281							
	Bulkheads.	28	P_B			400		600	600		600	600
		29	δ_B			.00811		.00804	.00804		.00804	.00804
		30	$\bar{K}_{BX} = (28)/(29)$			49,300		74,600	74,600		74,600	74,600
		31	S_B			80		40	40		16.0	160
		32	$K_{BX} = (30)/(31)$			616		1865	1865		4660	466
	Total.	33	$K_X = (22) + (27) + (32)$	645	926	1261	645	2510	2510	645	5310	1111
		34	$\sqrt[4]{K_X}$	5.04	5.52	5.96	5.04	7.08	7.08	5.04	8.54	5.77
		35	$u_X = (34) \cdot (15)$	2.36	2.58	2.79	2.21	3.10	3.10	1.10	1.87	2.53
		36	Φ_X – from Ref. 4	.004	−.046	−.072	.052	−.082	−.082	.788	.222	−.037

Note: Combining theoretical stiffness of beams and experimental stiffness of blds., for test #9, $u_{TX} = .219 \sqrt[4]{82+4670} = 1.82$

TABLE V - PREDICTED STRESSES ON MODEL.

Subscripts:— 'S' refers to standardized condition of 720,000 in-lb bending moment.
'a' refers to condition under actual test bending moment.

'T' refers to predicted deck stiffness.
'x' refers to predictions using deck stiffness tests.

$\sigma_T = \sigma_{Na} + \Phi_T \Delta\sigma_a$ (Theoretical Stress – theoretical 'K'.)

$\sigma_x = \sigma_{Na} + \Phi_x \Delta\sigma_a$ (Theoretical Stress – experimental 'K'.)

Test.	House.	Location.	(1) $M_a \times 10^{-3}$	(2) M_a/M_s (f)	(3) σ_{NS} ($M = 720\times10^3$)	(4) σ_{Na}	(5) $\Delta\sigma_s$	(6) $\Delta\sigma_a$	(7) U_T	(8) Φ_T (Theoretical)	(9) u_x	(10) Φ_x	(11) $\Phi_T\Delta\sigma_a$	(12) $\Phi_x\Delta\sigma_a$	(13) σ_T	σ_x
2	2	House Top.	720.0	1.00	6440	6440	-7118	-7118	1.416	0.565	2.36	0.004	-4030	-28	2410	6412
		Main Deck	720.0	1.00	4270	4270	1001	1001	1.416	0.565	2.36	0.004	566	4	4736	4274
		Bottom.	720.0	1.00	-4550	-4550	-352	-352	1.416	0.565	2.36	0.004	-199	-1	-4749	-4551
3	2	H.T.	715.0	0.994	6440	6390	-7118	-7070	2.059	0.117	2.56	-0.046	-827	+326	5563	6716
		M.D.	715.0	0.994	4270	4240	1001	995	2.059	0.117	2.56	-0.046	116	-46	4356	4194
		B.	715.0	0.994	-4550	-4520	-352	-350	2.059	0.117	2.56	-0.046	-41	+16	-4561	-4504
4	2	H.T.	721.0	1.002	6440	6450	-7118	-7140	3.60	-0.073	2.78	-0.072	+520	+513	6970	6963
		M.D.	721.0	1.002	4270	4280	1001	1003	3.60	-0.073	2.78	-0.072	-73.2	-72	4207	4208
		B.	721.0	1.002	-4550	-4560	-352	-352	3.60	-0.073	2.78	-0.072	+26	+25	4534	4535
5	3	H.T.	721.0	1.002	7190	7200	-7770	-7800	1.318	0.636	2.205	0.052	-4950	-405	2250	6795
		M.D.	721.0	1.002	4410	4420	932	935	1.318	0.636	2.205	0.052	+594	+48.5	5014	4469
		B.	721.0	1.002	-4510	-4520	-354	-355	1.318	0.636	2.205	0.052	-226	-18	-4746	-4538
6	3	H.T.	730.0	1.014	7190	7290	-7770	-7880	4.75	-0.018	3.10	-0.082	+142	+645	7432	7935
		M.D.	730.0	1.014	4410	4470	932	945	4.75	-0.018	3.10	-0.082	-17	-77	4453	4393
		B.	730.0	1.014	-4510	-4570	-354	-359	4.75	-0.018	3.10	-0.082	+6	+29	-4576	-4541
7	3	H.T.	720.0	1.00	7190	7190	-7770	-7770	4.75	-0.018	3.10	-0.082	+140	+636	7330	7826
		M.D.	720.0	1.00	4410	4410	932	932	4.75	-0.018	3.10	-0.082	-17	-76	4393	4334
		B.	720.0	1.00	-4510	-4510	-354	-354	4.75	-0.018	3.10	-0.082	+6	+29	-4504	-4481
8	1	H.T.	728.5	1.012	7190	7270	-7770	-7850	0.660	0.966	1.103	0.788	-7590	-6180	-320	90
		M.D.	728.5	1.012	4410	4460	932	944	0.660	0.966	1.103	0.788	+910	+744	5376	5204
		B.	728.5	1.012	-4510	-4560	-354	-358	0.660	0.966	1.103	0.788	-346	-282	-4906	-4842
9	1	H.T.	737.0	1.023	7190	7350	-7770	-7950	2.978	-0.083	1.870	0.222	+660	-1765	8010	5585
		M.D.	737.0	1.023	4410	4520	932	955	2.978	-0.083	1.870	0.222	-79	+212	4441	4832
		B.	737.0	1.023	-4510	-4610	-354	-362	2.978	-0.083	1.870	0.222	+30	-80	-4580	-4690
10	3	H.T.	723.0	1.003	7190	7210	-7770	-7800	3.352	-0.080	2.535	-0.037	+624	+298	7834	7508
		M.D.	723.0	1.003	4410	4510	932	936	3.352	-0.080	2.535	-0.037	-75	-35	4435	4475
		B.	723.0	1.003	-4510	-4530	-354	-356	3.352	-0.080	2.535	-0.037	+28	+13	-4502	-4517

TABLE VI -(SH. 1)

MAXIMUM STRESSES - HULL

E = 10.6 x 10^6 lbs/in^2

Moment x 10^3 in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
Load Bar		876	866	860	867	867	878	866	876	886	[illegible]	875
(L-76)(2-1/2B)(bott)	76	+ 965	+ 806	+ 901	+ 842	+ 961	+ 953	+ 901	+1018	+ 922	+1049	+ 965
(L-36)(2-1/2B)(bott)	22	+4653	+4375	+4452	+4304	+4452	+4388	+4367	+4611	+4547	+4473	+4643
(℄)(2-1/2F)(bott)	1	-4791	-4632	-4675	-4457	-4579	-4558	-4505	-4738	-4791	-4441	-4918
(℄)(15F)(bott)	2	-4855	-4632	-4683	-4367	-4643	-4547	-4420	-4738	-4696	-4346	-4971
(℄)(2-1/2B)(bott)	3	-4918	-4717	-4823	-4463	-4706	-4622	-4537	-4759	-4844	-4356	-5066
(℄)(15B)(bott)	4	-5056	-4802	-4791	-4558	-4812	-4664	-4611	-4844	-4855	-4537	-5205
(R-20)(2-1/2B)(bott)	46	-4600	-4404	-4494	-4176	-4410	-4378	-4346	-4494	-4558	-4219	-4812
(R-36)(2-1/B)(bott)	23	-4494	-4441	-4335	-4229	-4346	-4346	-4282	-4367	-4537	-4081	-4622
(R-56)(2-1/2B)(bott)	64	-4505	-5385	-4547	-4272	-4367	-4359	-4367	-4431	-4590	-4187	-4622
(R-76)(2-1/2B)(bott)	77	-3964	-3933	-3986	-3880	-3858	-3890	-3901	-3880	-4028	-3667	-4070
(R-100)(15B)(bott)	103	-2385	-3519	-2608	-2480	-2396	-2555	-2364	-2330	-2523	-2311	-2544
(R-100)(2F)(bott)	104	—	—	—	-3010	—	—	-2099	-2025	-2226	-1972	-2258
(R-100)(6F)(bott)	105	-2247	-2321	-2226	-2056	-2167	-2268	-2173	-2194	-2343	-2152	-2396
(R-100)(10F)(bott)	106	-2459	-2512	-2438	-2396	-2480	-2639	-2343	-2332	-2491	-2332	-2544
(R-100)(15F)(bott)	107	-2470	-2703	-2523	-2581	-2703	-2788	-2555	-2470	-2608	-2396	-2692
(R-114)(2-1/2B)(bott)	108	- 488	- 541	- 371	- 329	- 456	- 413	- 392	- 382	- 424	- 329	- 509
(℄)(Front)(1-3/4 U)	5	-3700	-3582	-3646	-3339	-3546	-3498	-3434	-3615	-3625	-3371	-3827
(℄)(Front)(7-1/2 U)	6	-1442	-1526	-1452	-1442	-1399	-1484	-1463	-1463	-1442	-1399	-1537
(℄)(Front)(18-1/2 U)	7	+3106	+2555	+2608	+2342	+2841	+2470	+2523	+2957	+2873	+2629	+3021
(L-76)(Front)(7-1/2 U)	78	-2300	-2459	-2290	-2352	-1611	-2371	-2332	-2258	-2332	-2671	-2406
(L-36)(Front)(18-1/2 U)	24	+3074	+2597	+2235	+2512	+2979	+ 2576	+2629	+3032	+3032	+2756	+3032
(L-20)(Front)(7-1/2 U)	47	-1452	-1632	-1495	-1526	-1357	-1569	-1399	-1431	-1516	-1378	-1558
(R-20)(Front)(7-1/2 U)	48	-1495	-1748	-1590	-1537	-1505	-1590	-1548	-1484	-1558	-1304	-1548
(R-36)(Front)(1-3/4 U)	25	-3816	-3816	-3242	-3540	-3658	-3570	-3625	-3731	-3922	-3509	-3890
(R-36)(Front)(7-1/2 U)	26	-1533	-1680	-1607	-1607	-1575	-1586	-1643	-1526	-1717	-1452	-1632
(R-36)(Front)(18-1/2 U)	27	+2961	+2449	+2608	+2343	+2682	+2459	+2396	+2968	+2936	+2639	+3000
(R-76)(Front)(1-3/4 U)	79	-4398	-4346	-4314	-4240	-4282	-4346	-4388	-4229	-4357	-4251	-4452
(R-76)(Front)(7-1/2 U)	80	-2449	-2438	-2459	-2449	-2400	-2449	-2544	-2438	-2385	-2406	-2542
(R-76)(Front)(18-1/2 U)	81	+3572	—	+3466	+3254	+3403	+3392	+3540	+3625	+3657	+3381	+3540
(R-76)(Front I)(7-1/2 U)	82	-1813	-1919	-1855	-1887	-1870	-1843	-1802	-1685	-1749	-1685	-1760
(℄)(2-1/2B)(bott I)	8	-4558	-4410	-4378	-4176	-4410	-4304	-4261	-4399	-4367	-4282	-4643
(℄)(2-1/2F)(bott I)	9	-4526	-4452	-4505	-4335	-4346	-4494	-4293	-4600	-4611	-4590	-4346
(R-20)(Front)(18-1/2 U)	49	+3063	+2491	+2629	+2458	+2756	+2343	+2491	+2947	+2830	+2756	+3021

TABLE VI (SH.2)

MAXIMUM STRESSES - HULL

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
Load Bar		876	866	860	867	867	878	866	876	886	870	875
(℄)(Front I)(7-1/2 U)	10	-1866	-1876	-1791	-1813	-1749	-1834	-2915	-1675	-1707	-1632	-1876
(R-36)(2-1/2B)(bott I)	28	-4569	-4431	-4388	-4282	-4484	—	-4325	-4463	-4675	-4304	-4653
(R-76)(2-1/2B)(bott I)	83	-3858	-3943	-3901	-3827	-3615	-3858	-3848	-3827	-4092	-3689	-4007
(℄)(Back((18-1/2 U)	11	+3106	+2523	+2586	+2268	+3000	+2332	+2194	+2947	+2904	+2724	+3964
(R-36)(Back)(18-1/2 U)	29	+3000	+2618	+2639	+2364	+3032	+2438	+2374	+2926	+3010	+2830	+3434
(L-76)(Back)7-1/2 U)	84	-2650	-2650	-2608	-2639	-6561	-2777	-2661	-2512	-2608	-2480	-2692
(℄)(Front I)(13-1/2 U)	12	+2989	+2544	+2544	+2067	+3191	+2078	+2184	+2947	+2629	+2533	+3434
(R-36)(Front I)(13-1/2 U)	30	+3021	+2682	+2586	+ 2438	+2820	+2406	+2459	+3074	+3042	+2735	+3010
(L-76)(℄)(top)	85	—	+3519	+3519	+3509	+3530	+3657	+3721	+3954	+4219	+3498	—
(L-76)(15 B)(top)	86	+5289	+4166	+4070	+5003	+3848	+5014	+5395	+5470	+5682	+5173	+5459
(L-36)(15F)(top)	31	+4940	+4346	+4208	+4039	+4028	+4198	+4251	+5014	+5162	+4675	+4834
(R-20)(℄)(top)	50	+5035	+4441	+5056	+3593	+4908	+3933	+3752	+5183	+4738	+4653	+5523
(R-36)(℄)(top)	32	+5650	+3456	+4357	—	+3954	+2989	+3328	+4410	+4293	—	+4579
(℄)(15B)(top)	14	+5491	+5300	+4516	+3625	+5205	+3540	+3837	+5311	+3986	+4993	+5364
(℄)(15F)(top)	15	+4770	+3657	+3392	+3456	+3530	+4155	+3880	+3710	+4494	+4537	+4802
(R-20)(15F)(top)	51	+5321	+3752	+3774	+3911	+2851	+4017	+4155	+5056	+5236	+3530	+5141
(R-36)(9-1/2F)(top)	33	+4876	+4378	+4187	+4166	+4579	+3668	+4123	+5109	+5576	+4516	+4918
(R-36)(11-1/2F)(top)	34	+4516	+3805	+3222	+3456	+4145	+3275	+3562	+3890	+4049	+e7wl	+4494
(R-36)(13-1/2F)(top)	35	+4579	+4219	+4802	+4028	+4463	+3795	+3954	+4664	+4685	+4304	+4770
(R-36)(15F)(top)	36	+4918	+5014	+5077	+4749	+5247	+4219	+4547	+5024	+4494	+5077	+5141
(R-56)(15F)(top)	65	+5194	+4431	+4441	+3339	—	+4537	+4187	+5067	+5268	+3933	+4643
(R-56)(℄)(top)	106	+4887	+4272	+4526	+4049	+4123	—	+4876	+5660	+6042	+4791	+5289
(R-76)(℄)(top)	87	—	+4622	+4516	+4696	—	+4876	+5067	+4505	+4590	+4611	+4346
(R-76)(11-1/2F)(top)	89	+3233	+4420	+5067	+5173	+4749	+5205	+5586	+3922	+3933	+4791	+3954
(R-76)(13-1/2F)(top)	90	+3434	+5236	+6699	+4961	+5554	+5077	+5311	+4219	+4346	+4770	+4304
(R-76)(15F)(top)	91	+4357	+3975	+4187	+5109	+3424	+4940	+5501	+4823	+5205	+5215	+4950
(℄)(℄)(Top I)	16	+4452	+4155	+4176	+2809	+3986	+3000	+3297	+4558	+3911	+3954	+4473
(R-36)(11-1/2F)(Top I)	37	+6243	+5523	+5660	+4929	+5109	+4420	+5067	+5745	+6360	+5289	+5724
(R-76)(℄)(Top I)	92	+4770	+3911	+4145	+4102	+3360	+5300	+4081	+4664	+4865	+3890	+3880
(℄)(℄)(Top)	13	+5576	+4473	+5014	+3339	+4908	+3943	+3689	+5406	+3445	+4770	+5362
(R-76)(9-1/2F)(top)	88	+3318	+3307	+3752	+3954	+3795	+4346	+4611	+4261	+4314	+4081	+4251

TABLE VII

MAXIMUM STRESSES - HOUSE

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		720.0	715.0	721.0	721.0	730.0	720.0	723.0	728.5	723.0
IDENTIFICATION	Gage No.	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Load Bar		866	860	867	867	878	866	876	886	870
(L-76)(℄)(top)	99	+ 32	- 53	- 21	- 413	+ 413	+1314			+ 763
(L-76)(Front)(1-1/4 U)	100	+2109	+2162	+2131	+1961	+ 954	+1622			+1685
(L-36)(℄)(top)	38	+1272	+1632	+3890	+1378	+6233	+4791	+ 42	+ 233	+3063
(L-36)(Front)(1-1/4 U)	41	+3710	+3890	+4070	+4092	+3890	+4134	+2268	+2427	+3933
(L-20)(Back)(1-1/4 U)	54							+3572	+3774	
(℄)(℄)(top)	17	+2343	+3127	+6922	+2290	+6954	+7526	- 11	+3445	+4388
(℄)(8F)(top)	18		+3010	+7897	+2290	+6593	+7335	- 201	+2351	+4505
(℄)(8B)(top)	19	+2088	+3074	+8014	+2279	+7590	+7526	- 106	+4240	+4378
(℄)(Back)(1-1/4 U)	20	+3848	+4049	+4039	+4092	+4102	+4092	+3816	+3890	+3858
(R-20)(℄)(top)	52		+2311	+5088	+1982	+6551	+6805	- 74	+1251	+4145
(R-20)(8F)(top)	53							- 254	+1590	
(R-36)(℄)(top)	39	+1473	+2025	+4145	+1198	+5756	+4823	+ 21	+ 738	+3275
(R-36)(8F)(top)	40	+1442	+1876	+4113	+1177	+6116	+4971	- 106	–––	+3095
(R-36)(Back)(5-1/4 U)	42							+ 922	+1028	
(R-56)(℄)(top)	67	+ 392	+ 816	+1940	+ 456	+2841	+2406			+1558
(R-56)(8F)(top)	68	+ 382	+ 488	+1855	+ 339	+2639	+2300			+2661
(R-76)(℄)(top)	93	- 64	+ 53	+ 74	+ 318	+ 244	+ 21			+ 64
(R-76)(8F)(top)	94	- 138	- 85	- 159	–––	+ 371	+ 201			+ 42
(R-76)(Back)(1-1/4 U)	95	+ 106	+ 95	+ 360	0	+ 212	+ 127			+ 85

TABLE XIII. MAXIMUM DEFLECTIONS — HULL.

Moment (in-lb × [illegible])	728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5	
Location	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11	
L - 80												
L - 72	0.287	0.302	0.310	0.250	0.301	0.255	0.256	0.261	0.263	0.248	0.268	
L - 64												
L - 56	0.330	0.298	0.309	0.281	0.300	0.290	0.288	0.303	0.303	0.282	0.309	
L - 48												
L - 40	0.356	0.313	0.317	0.305	0.321	0.310	0.314	0.341	0.350	0.301	0.341	
L - 32												
L - 24	0.374	0.325	0.329	0.319	0.328	0.338	0.334	0.350	0.355	0.324	0.360	
L - 16												
L - 8	0.384	0.337	0.340	0.331	0.342	0.345	0.341	0.359	0.360	0.337	0.370	
℄												
R - 8	0.381	0.335	0.340	0.330	0.345	0.341	0.334	0.354	0.362	0.337	0.369	
R - 16												
R - 24	0.370	0.325	0.326	0.321	0.337	0.332	0.330	0.348	0.348	0.329	0.360	
R - 32												
R - 40	0.343	0.300	0.306	0.296	0.313	0.311	0.309	0.339	0.333	0.302	0.338	
R - 48												
R - 56	0.316	0.282	0.293	0.276	0.294	0.286	0.284	0.297	0.297	0.282	0.307	
R - 64												
R - 72	0.274	0.280	0.297	0.244	0.295	0.256	0.251	0.258	0.257	0.242	0.274	
R - 80												
R - 88	0.222	0.221	0.241	0.206	0.232	0.225	0.222	0.208	0.204	0.210	0.223	
R - 104	0.147	0.124	0.129	0.127	0.131	0.138	0.135	0.134	0.131	0.129	0.141	
R - 120	0.069	0.045	0.052	0.055	0.051	0.064	0.063	0.058	0.055	0.053	0.062	

TABLE IX. MAXIMUM DEFLECTIONS — HOUSE

Moment (in-lb x 10³)		720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0		
Location.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11	
L - 80												
L - 72		0.348	0.358	0.246	0.346	0.255	0.256			0.238		
L - 64												
L - 56		0.303	0.317	0.256	0.304	0.281	0.273			0.226		
L - 48												
L - 40		0.272	0.292	0.279	0.278	0.314	0.300			0.223		
L - 32								0.337	0.365			
L - 24		0.255	0.282	0.302	0.263	0.338	0.327	0.323	0.361	0.223		
L - 16								0.314	0.362			
L - 8		0.245	0.276	0.318	0.255	0.344	0.344	0.308	0.363	0.221		
℄								0.304	0.366			
R - 8		0.243	0.275	0.318	0.254	0.341	0.343	0.308	0.354	0.223		
R - 16								0.317	0.358			
R - 24		0.249	0.277	0.298	0.264	0.326	0.324	0.326	0.354	0.219		
R - 32								0.338	0.356			
R - 40		0.266	0.290	0.272	0.276	0.301	0.299	0.361	0.359	0.217		
R - 48												
R - 56		0.292	0.312	0.248	0.303	0.270	0.265			0.219		
R - 64												
R - 72		0.337	0.349	0.233	0.343	0.249	0.243			0.231		

TABLE XI - (SH. 1)
ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(℄)(Front)(1-1/4 U)	21											
σ_x			+3307	+3807	+4580	+3652	—	+3188	+3545	+2712	+3212	
γ_{xy}			- 92	- 112	- 400	+ 88	—	- 40	- 42	—	+ 44	
ϕ			+1°7'	+1°28'	+4°53'	- 107	—	+0°47'	+0°43'	+9°42'	-0°48'	
σ_{max}			+3316	+3805	+4251	+3657	—	+38180	+3546	+2851	+3212	
σ_{min}			-1398	- 551	+ 276	- 837	—	+ 265	- 620	-2205	+ 64	
(R-10)(Front)(1-1/4 U)	45											
σ_x												
γ_{xy}									+ 268	+1036		
ϕ									-3°37'	-14°40'		
$\sigma_{max.}$									+4129	+4436		
$\sigma_{min.}$									- 122	+ 228		
(R-20)(Front)(1-1/4 U)	55											
σ_x									+4163	+3961		
γ_{xy}			+ 324	+ 340	+ 776	+ 408	+ 32	+1592	+ 212	+2580	+ 436	
ϕ			-3°54'	-4°11'	-9°53'	-5°8'	-0°25'	-18°15'	-3°1'	- 29°	-5°10'	
σ_{max}			+3440	+3593	+4282	+3758	+4526	+5072	+4171	+5380	+3874	
σ_{min}			-133 0	-1049	- 297	- 811	+ 127	- 260	+ 143	- 684	- 180	
(R-20)(Front)(5-1/4 U)	56											
σ_x												
γ_{xy}												
ϕ									+63°26'	+57°24'		
σ_{max}									+ 795	+3599		
σ_{min}									0	-2401		
(R-28)(Front)(1-1/4 U)	59											
σ_x												
γ_{xy}									+ 308	+2664		
ϕ									-4°30'	-29°15'		
σ_{max}									+3795	+5645		
σ_{min}									- 138	- 578		

TABLE I (SH. 2)
ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(R-28)(Front)3-7/8 U)	58											
σ_x												
γ_{xy}												
ϕ									-3°26'	-33°12'		
$\sigma_{max.}$									+2904	+4945		
$\sigma_{min.}$									+ 763	+ 249		
(R-28)(Front)(5-1/4 U)	57											
σ_x												
γ_{xy}												
ϕ									+87°9'	+ 47°		
$\sigma_{max.}$									+ 297	+2454		
$\sigma_{min.}$									0	-2221		
(R-33)(Front)(1-1/4 U)	60											
σ_x												
γ_{xy}									+ 752	+ 548		
ϕ									-11°52'	-12°6'		
$\sigma_{max.}$									+3419	+3964		
$\sigma_{min.}$									+ 90	+1304		
(R-33)(Front)(3-7/8 U)	61											
σ_x												
γ_{xy}												
ϕ									+92°21'	+124°17'		
$\sigma_{max.}$									+1155	+ 853		
$\sigma_{min.}$									+ 477	+ 376		
(R-33)(Front)(5-1/4 U)	62											
σ_x												
γ_{xy}												
ϕ									+128°15'	+79°53'		
$\sigma_{max.}$									+1564	+ 790		
$\sigma_{min.}$									+ 747	- 16		

TABLE X-(SH. 3)
ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(R-36)(Front)(1-1/4 U)	43											
σ_x			+3914	+4151	+4140	+2879	+2938	+3343	+4163	+3961	+3021	
γ_{xy}			+ 596	+ 672	+ 992	+ 760	+2048	+1820	+ 812	+ 796	+ 864	
ϕ			-7°54'	-9°24'	-12°23'	-8°19'	-23°4'	-18°37	+ 45°	+68°28'	-9°47'	
$\sigma_{max.}$			+3996	+4261	+4351	+2995	+3758	+3954	+3037	+3477	+3169	
$\sigma_{min.}$			- 371	+ 106	- 366	-2295	-1850	-2035	+ 747	+1155	-2003	
(R-36)(Front)(3-7/8 U)	44											
σ_x												
γ_{xy}												
ϕ									+24°50'	+38°8'		
$\sigma_{max.}$									+2003	+1558		
$\sigma_{min.}$									+ 254	+ 815		
(R-38)(Front)(1-1/4 U)	63											
σ_x									---	---		
γ_{xy}									---	---		
ϕ									---	---		
$\sigma_{max.}$									---	---		
$\sigma_{min.}$									---	---		
(R-56)(Front)(1-1/4 U)	69											
σ_x			+3854	+4140	+3949	+3676	+2902	+2998			+3128	
γ_{xy}			+ 824	+ 764	+1264	+ 688	+2524	+1980			+1320	
ϕ			-12°42'	-11°20'	-15°25'	-9°29'	-20°45'	-19°3'			-15°28'	
$\sigma_{max.}$			+4033	+4288	+4314	+3774	+3848	+3678			+1680	
$\sigma_{min.}$			+ 207	+ 345	- 329	+ 53	-3742	-2714			+ 27	
(R-68)(Front)(1-1/4 U)	70											
σ_x												
γ_{xy}			+ 340	+ 380	+ 972	+ 372	+2252	+1608			+1064	
ϕ			-6°51'	-7°13'	-14°49'	-6°46'	-22°56'	-21°32'			-16°23'	
$\sigma_{max.}$			+3567	+3673	+3816	+3556	+4463	+3943			+33 50	
$\sigma_{min.}$			+ 705	+ 641	- 95	+ 387	- 678	- 753			- 625	

TABLE X - (SH. 4)

ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(R-68)(Front)(3-7/8 U)	71											
σ_x											---	
γ_{xy}											---	
ϕ						-16°57'	-27°46'	-27°8'			---	
σ_{max}						+2327	+4065	+3408			---	
σ_{min}						+ 345	- 557	- 652			---	
(R-68)(Front)(4-3/4 U)	71		---									
σ_x			---									
γ_{xy}			---									
ϕ			---	+62°3'	+62°9'							
σ_{max}			---	+1055	+1950							
σ_{min}			---	+ 461	- 53							
(R-68)(Front)(6-1/2 U)	72											
σ_x												
γ_{xy}												
ϕ						+53°6'	+125°13'	+55°34'			+56°24'	
σ_{max}						+ 880	+2449	+1887			+1733	
σ_{min}						- 148	- 837	-1346			- 779	
(R-72)(Front)(1-1/4 U)	73											
σ_x						---	---				---	
γ_{xy}			+ 612	+ 672	+1172	---	---	+1552			---	
ϕ			-14°7'	-14°9'	-20°25'	---	---	-25°36'			---	
σ_{max}			+3540	+3943	+3472	---	---	+2692			---	
σ_{min}			+ 965	+1124	- 101	---	---	-1272			---	
(R-72)(Front)(3-7/8 U)	74											
σ_x												
γ_{xy}												
ϕ						-26°22'	-33°52'	-33°20'			-30°8'	
σ_{max}						+1754	+3254	+2639			+2544	
σ_{min}						+ 164	- 657	-1357			- 625	

TABLE X (SH. 5)
ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ in#		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(R-72)(Front)(4-3/4 U)	74											
σ_x												
γ_{xy}												
ϕ			+68°31'	+66°50'	+60°59'							
σ_{max}			+ 640	+ 843	+1548							
σ_{min}			+ 324	+ 355	- 11							
(R-72)(Front)(6-1/2 U)	75											
σ_x												
γ_{xy}												
ϕ						+64°46'	+51°35'	+52°44'			+55°35	
σ_{max}						+ 996	+1876	+1362			+1219	
σ_{min}						+ 763	- 647	-1267			- 678	
(R-76)(Front)(1-1/4 U)	96											
σ_x			—	+2558	+2070	+1844	+1261	+1035			+1368	
γ_{xy}			—	+ 608	+1084	+1016	+1764	+1484			+1080	
ϕ			—	-22°19'	-24°39'	-26°45	-36°15'	-32°53'			-32°51'	
σ_{max}			—	+2804	+2565	+2353	+2544	+1993			+2067	
σ_{min}			—	+1087	- 276	- 170	-1134	-1251				
(R-76)(Front)(3-7/8 U)	97											
σ_x												
γ_{xy}												
ϕ						+82°31'	+57°10	+59°8'			+60°12'	
σ_{max}						+1251	+2814	+1839			+2019	
σ_{min}						+ 668	- 769	- 1887			- 800	
(R-76)(Front)(4-3/4 U)	97											
σ_x					---							
γ_{xy}					---							
ϕ			+ 49°	-67°56'	---							
σ_{max}			+ 224	+ 170	---							
σ_{min}			+ 171	- 583	—							

TABLE X (SH. 6)
ANGLES AND MAGNITUDE OF PRINCIPAL STRESSES

$E = 10.6 \times 10^6$ lbs/in^2

Moment $\times 10^3$ inE		728.5	720.0	715.0	721.0	721.0	730.0	720.0	728.5	737.0	723.0	727.5
IDENTIFICATION	Gage No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
(R-76)(Front)(6-1/2 U)	98											
σ_x											—	
γ_{xy}											—	
ϕ						+47°42'	+45°46'	+47°58'			—	
$\sigma_{max.}$						+ 424	+1314	+1049			—	
$\sigma_{min.}$						0	-1060	-1346			—	
(R-78)(Front)(1-1/4 U)	101											
σ_x												
γ_{xy}				+ 416	+1532	+ 624	+2352	+3184			+2344	
ϕ				+71°30'	+54°26'	+51°30'	+45°36'	+46°31'			+45°35'	
$\sigma_{max.}$				+1415	+1055	+2359	+1495	+ 562			+ 928	
$\sigma_{min.}$				+ 37	-2178	+1087	-2316	-5788			-3747	
(R-78)(Front)(3-7/8 U)	102											
σ_x												
γ_{xy}												
ϕ							-40°56'	-42°44'	-39°3'		+43°19'	
$\sigma_{max.}$							+ 58	+1113	+ 742		+ 424	
$\sigma_{min.}$							- 58	-1452	-1389		- 933	

TABLE XI LOADING SYMMETRY - SAMPLE - Test #6, 3/4 Load

Main Dynamometer Dia. - 0.619 in. A = 0.300 in.^{2} Loading Bolts - 2 per trunnion point

E = 28.0 × 10^6 (from N.B.S. Calibration) Dia = 1 in E = 29.5 × 10^6

Equalizer Lever Factor = 5.5/2 = 2.75 (to be applied to Dynamometer Load)

	(1) Zero Reading	(2) Load Reading	(3) Strain	(4) Strain	(5) Trunnion Load (lb) $\frac{\pi}{4} \times 29.5 \times (4)$	(6) Transverse Symmetry (%)	(7) Load Per End (lb)	(8) Longtdl. Symmetry (%)	(9) Main Dyn. Load 28 × .3 × 10^6	(10) Load Precision (%)
LEFT 4	10,470	10,640	170	334	7,750	1.0	15,350	1.1		1.0
LEFT 3	15,019	15,183	164							
LEFT 2	12,603	12,760	157	327	7,600					
LEFT 1	13,408	13,578	170							
RIGHT 4	8,662	8,829	167	335	7,780	0.9	15,700			3.3
RIGHT 3	9,520	9,688	168							
RIGHT 2	10,640	10,821	181	341	7,920					
RIGHT 1	10,000	10,160	160							
Main Dynamometer			659(tot)				15,200		5,540	