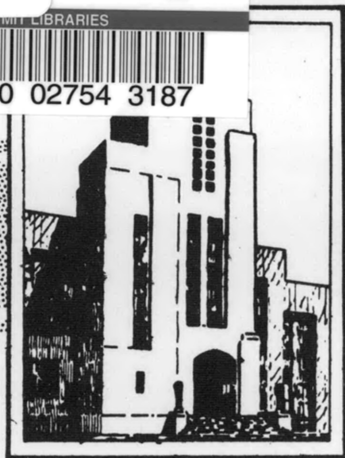

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HYDROMECHANICS

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APPLIED MATHEMATICS

TRANSFER OF LOCAL AXIAL LOAD INTO BULKHEAD PLATING

by

Joseph S. Brock

STRUCTURAL MECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

March 1959 Report 1300

PRNC-TMB-648 (Rev. 3-58)

DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

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Ser 7-75
15 Apr 1959

From: Commanding Officer and Director
To: Chief, Bureau of Ships (312) (in duplicate)

Subj: NS731-037, Subtask 1/4, Stress fields in bulkheads; forwarding of report on

Ref: (a) BUSHIPS ltr S11-5 (442-440-330) of 25 May 1948

Encl: (1) DTMB Report 1300 entitled "Transfer of Local Axial Load into Bulkhead Plating" 13 copies

1. By reference (a) the Bureau of Ships authorized a comprehensive investigation to determine the distribution of load into bulkhead plating. As a first step two photoelastic models were built and tested. It developed that this exploratory test would provide the information necessary to satisfy the primary objective of determining how a vertical concentrated load on a stiffener is transferred to and distributed into bulkhead plating.

2. Enclosure (1) describes the photoelastic tests of models with tapered and uniform stiffeners. The loads on the stiffeners were resisted by shear at the side shell and by compression at the bottom. It is concluded that, for practical purposes, the entire load is absorbed into the plating within one deck height for both uniform and tapered stiffeners and for both types of support.

3. Since the primary objective of Subtask 1/4 of Project NS731-037 has been achieved, it is recommended that this subtask be considered completed.

E. E. Johnson

E.E. JOHNSON
By direction

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TRANSFER OF LOCAL AXIAL LOAD INTO BULKHEAD PLATING

by

Joseph S. Brock

March 1959

Report 1300

NS731-037

ABSTRACT

The distribution of a vertical load on a bulkhead stiffener into the bulkhead plating was studied photoelastically. Both tapered and uniform stiffeners were investigated. The loads on the stiffener were resisted by two types of reaction, namely, by shear at the side shell and by compression at the bottom. It is concluded that, for practical purposes, the entire load is absorbed into the plating within one deck height for both uniform and tapered stiffeners and for both types of support.

INTRODUCTION

In addition to its well-understood function of preventing the spread of water after damage, a bulkhead on a surface ship is frequently required to support vertical concentrated loads imposed by stanchions, deck girders, or foundations. These loads are usually transmitted to the bulkhead stiffeners by the aforementioned structural members which frame into them.

Just how these columnar loads on the stiffeners get absorbed into the bulkhead plating has never been definitely known. Normal design practice has been to size the upper section of the loaded stiffener to absorb the total imposed load and then to taper the stiffener to that size required by the hydrostatic load of flooding. The extent of taper has been a matter of individual preference or prejudice. In an effort to determine the distribution of load into the bulkhead plating the Bureau of Ships authorized a comprehensive investigation.*

As originally envisioned, the test program would have included a systematic variation of:

a. Deck height (One, three, and five deck heights were contemplated.)

b. Plating thickness (Two thicknesses were planned.)

c. Variation of taper (A uniform stiffener and one with a single deck-height taper were planned.)

d. Location of load (Four different locations were considered.)

e. Type of support (Both shear at the shell and compression at the bottom plus combinations of the two types of action were considered necessary.)

f. Type of bulkhead (The original scheme called for specimens representative of a typical bulkhead continuous between load and bottom shell and of the type that does not extend to the bottom.)

As a first step it was considered that a photoelastic analysis would provide more guidance for less cost than any other experimental method. Although this first step was undertaken merely as guidance for the more extensive investigation, it soon developed that this exploratory test

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* Bureau of Ships letter S11-5 (442-440-330) of 25 May 1948.

would provide the information necessary for the primary objective: To determine how a vertical concentrated load on a stiffener is transferred to and distributed into bulkhead plating.

DESCRIPTION OF MODELS

Two models were constructed of cellulose nitrate. One, Figure 1, simulated a bulkhead three decks in height with a uniform stiffener; the other, Figure 2, simulated a similar bulkhead with a tapered stiffener. In both models the stiffeners were built up from strips of the basic plastic material and joined by cement.

An interesting feature of both models was that the stiffener to be examined was purposely located on the opposite side of the plating from the typical stiffeners. This was done to facilitate the photoelastic analysis.

Although these models were not deliberately planned as scaled representations of existing bulkheads, the deck height of 16 in. is a convenient 1/6-scale of the typical 8-ft deck height. If this scale factor (1/6) had been used for thickness, the model plating would have been only 1/16 in. to represent a 3/8-in. thick bulkhead. Since it is not feasible to work with such thin plastic plates, all thicknesses were made to 1/2 scale.

TEST PROCEDURE

A loading frame was designed which permitted support either by shear at the sides or by compression at the bottom. The loading frame also provided rigid support of the model at the top two decks to prevent motion normal to the plane of the plating--simulating the role of the decks in a ship. The model was loaded by applying a force of 860 lb through a dynamometer to the stiffener at its center of gravity.* Figure 3 shows the model with the tapered stiffener supported by shear at the sides in the loading frame.

Both models were tested with both types of support, shear at the sides and compression at the bottom. Normal photoelastic procedure for cellulose nitrate was used to obtain optical data. The fringe pattern in the loaded specimen was measured by means of a quartz compensator in a dark field polariscope. A fringe is the locus of points of constant difference between principal stresses. Conversely, isoclinic parameters were obtained by viewing the loaded specimen in the field of a plane polariscope. An isoclinic is the locus of points along which the directions of principal stresses are parallel. By proper orientation of the plane polariscope, the parameter of the isoclinics was adjusted to give the angle θ between a principal stress and

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* This point is the center of gravity of the stiffener alone and does not include the associated plating, normally taken as 30 to 60 thicknesses.

the line of attachment of the stiffener to the bulkhead plating.

In addition to the photoelastic data, strains in the axial direction were measured at various locations along the flanges of the stiffener and along the bulkhead plating at the line of attachment of the stiffener but on the side opposite. Whittemore strain gages of 2-in. gage length were used for these measurements.

TEST RESULTS

The photoelastic data were combined by the well-known relation:

$$\tau_{xy} = \frac{1}{2}(\sigma_1 - \sigma_2)\sin 2\theta \qquad [1]$$

where τ_{xy} is the shear stress along the xy-face (here taken as the line of attachment of the stiffener to the plating),

$\sigma_1 - \sigma_2$ is the difference between principal stresses (here derived from the fringe pattern), and

θ is the angle between one principal stress and the line of attachment of the stiffener to the plating.

The resulting distributions of shear stress as a function of vertical distance from the load are shown in Figures 4 and 5. Figure 4 includes information for the uniform stiffener for both the compressive and shear reactions; Figure 5 includes similar information for the tapered stiffener.

The distributions of axial stress in flange and plating as a function of vertical distance from load are shown in Figures 6 and 7. Figure 6 incorporates information for both types of stiffener for the compressive reaction; Figure 7 incorporates similar information for the shear reaction.

It will be noted that Figures 4 and 5 have a different basis from that for Figures 6 and 7. In the former case, the type of stiffener is the different parameter; in the latter case, it is the type of support reaction. The reason for change is clarity. Had the type of stiffener been the basis for the latter case rather than type of support reaction, the data points would have been essentially coincident.

DISCUSSION OF RESULTS

Both the curves and the associated experimental points of Figures 4 and 5 clearly show that, for all practical purposes, the externally imposed vertical load is transferred in entirety to the bulkhead plating within the first deck height. This is true regardless of whether the stiffener is tapered or uniform or whether the bulkhead is supported by shear at the sides or compression at the bottom. An additional factor enhancing credence is that the areas under the empirical curves shown in Figures 4 and 5 when multiplied by the thicknesses of the stiffener web agree within 6 percent with the applied vertical load. The results shown in these figures have been approximated by the nondimensional form of Figure 8.

Essentially the same trend is shown in Figures 6 and 7. For practical purposes, the axial compressive stress in the stiffener disappears after the first deck height although some slight bending stress persists in the second deck height. What Figures 6 and 7 do show is that the fiber stress in the tapered stiffener is somewhat greater than that in the uniform stiffener. The difference in magnitude may be attributed to the difference in eccentricity of loading and to the change in section.

Consider the well-known relation for the fiber stress in an eccentrically loaded strut:*

$$\sigma = \frac{P}{A} \pm \frac{Pe}{S} \qquad [2]$$

where A is area of cross section,

e is eccentricity,

P is load acting,

S is section modulus, and

σ is fiber stress.

Superposition of Figures 4 and 5 shows that the portion of the applied load not yet transferred into the bulkhead plating is about the same for both the tapered and uniform stiffeners. The load was applied at the center of gravity of

*A strut here means a column with sufficiently small slenderness ratio to be free from buckling.

the stiffener section alone (without including the associated plating). Since both the uniform and the tapered stiffener have identical sections at the point of load applications, the eccentricities then are also identical. As distance down the tapered stiffener increases, the center of gravity of the combined section shifts closer to the plating with a resulting increase in eccentricity whereas the eccentricity for the uniform stiffener remains constant. Similarly, as distance down the tapered stiffener increases, the area and section modulus of the combined section decrease, whereas, for the uniform stiffener, these properties remain constant.

Thus, at any distance down from the load, the portion of load not yet absorbed by the bulkhead plating is about the same for both types of stiffeners, the eccentricity is greater for the tapered stiffener, and the area and section modulus are less for the tapered stiffener. This combination results in greater magnitude of each term of Equation [2] for the tapered stiffener and hence, in the extreme, greatest compression in the flange of the tapered stiffener.

Equation [2] may be used to obtain an approximation for the axial stress in the stiffener-plate combination. In this calculation the strut is taken as the stiffener combined with a width of plating equal to the stiffener spacing. The load is taken as the load not yet transferred from the stiffener to the plate. The magnitude of the load at any height could be derived from Figure 8. Since the transfer of load is rapid at first, the maximum effect will be at the first deck and only the initial calculation need be made. From the given geometry, the axial stress in the stiffener flange at the first deck is 2400 psi compression, and the axial stress in the plate is 30 psi, also compression. The maximum measured axial stress in the stiffener flange was approximately 1800 psi. This difference may be due to the relatively long gage length used to measure the axial strains and to the fact that just under the load the structure does not immediately behave as an idealized strut. However, the calculation appears to be conservative.

A free-body sketch of the model with a uniform stiffener and a compressive reaction is shown in Figure 9. The reaction at the second deck due to an applied load P of 860 lb is

$$R = \frac{860 \times 1.45}{16} = 78 \text{ lb}$$

Dividing this reaction by the area of the web gives an approximation to the shear to be expected. The magnitude of the stress is

$$\frac{78}{0.131 \times 1.807} = 330 \text{ psi}$$

This compares favorably with the measured shear stresses of 330 psi and 385 psi for the flat portions of Figures 4 and 5, respectively.

It would be expected that these stresses would be in agreement since the deck reaction scheme shown in Figure 9 will not allow any significant shear stress below the second deck.

CONCLUSIONS

It must be remembered that hydrostatic loading has not been considered and that adequate margin against instability was provided. Subject to these limitations, it is concluded that:

1. Regardless of type of support or taper of stiffener, for practical purposes, the externally imposed vertical load is transferred in entirety to the bulkhead plating within the first deck height.

2. The transfer of shear stress between stiffener and bulkhead plating as a function of vertical distance from load can be approximated by a uniform distribution over one deck height with a triangular spike for the upper 1/8 of the deck height superposed. This is shown in Figure 8 which is a nondimensional approximation of Figures 4 and 5.

3. The area under the curve of shear stress distribution is proportional to the fraction of the applied load transferred into the bulkhead plating. The integral curve of the approximate distribution is also shown in Figure 8.

4. The tapered stiffener is stressed slightly more highly than the uniform one because of diminution of section properties and increased eccentricity of load.

RECOMMENDATIONS

1. Bulkhead stiffeners subjected to axial or columnar loads should have a taper of not more than one deck height to save weight.

2. The cross section in the tapered section should be sized in accordance with the usual relation

$$\sigma = \frac{P}{A} \pm \frac{Pe}{S}$$

for eccentrically loaded short columns. The minimum section should be governed by consideration of the hydrostatic load for which the bulkhead is designed.

3. Adequate intermediate lateral support should be provided to prevent instability of the stiffener.

4. No further work in this area should be prosecuted.

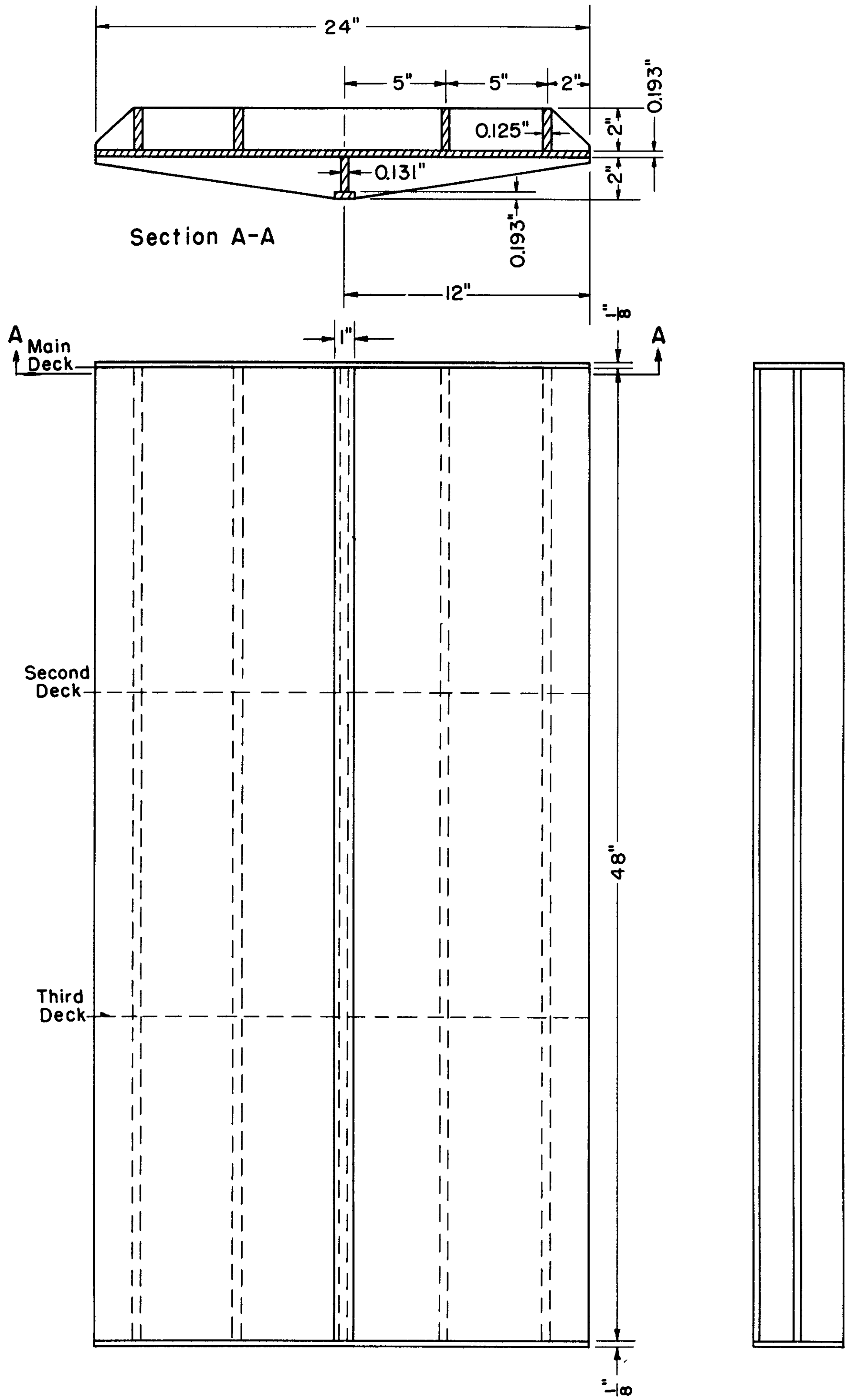

Figure 1 - Bulkhead Model with Uniform Stiffener

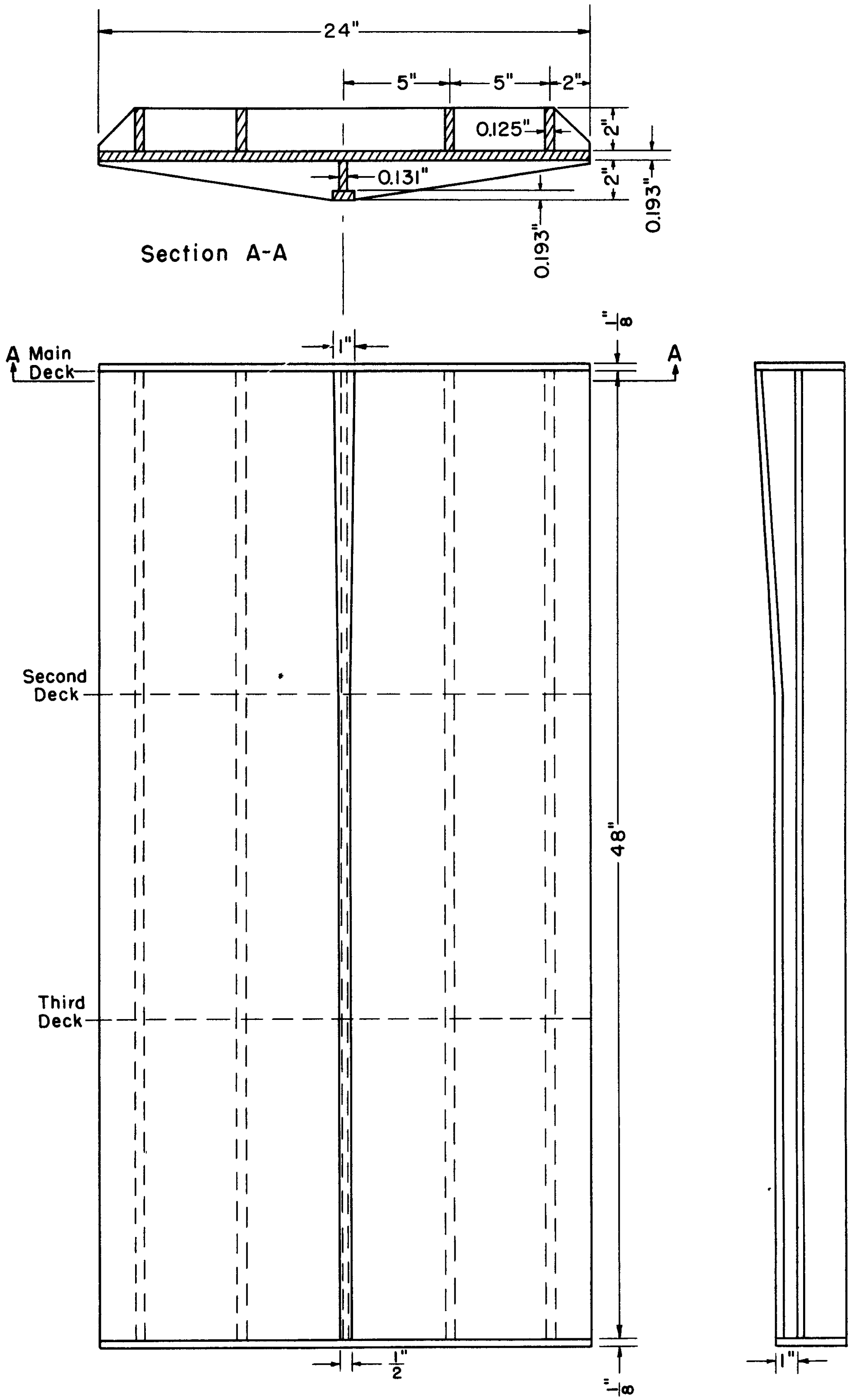

Figure 2 - Bulkhead Model with Tapered Stiffener

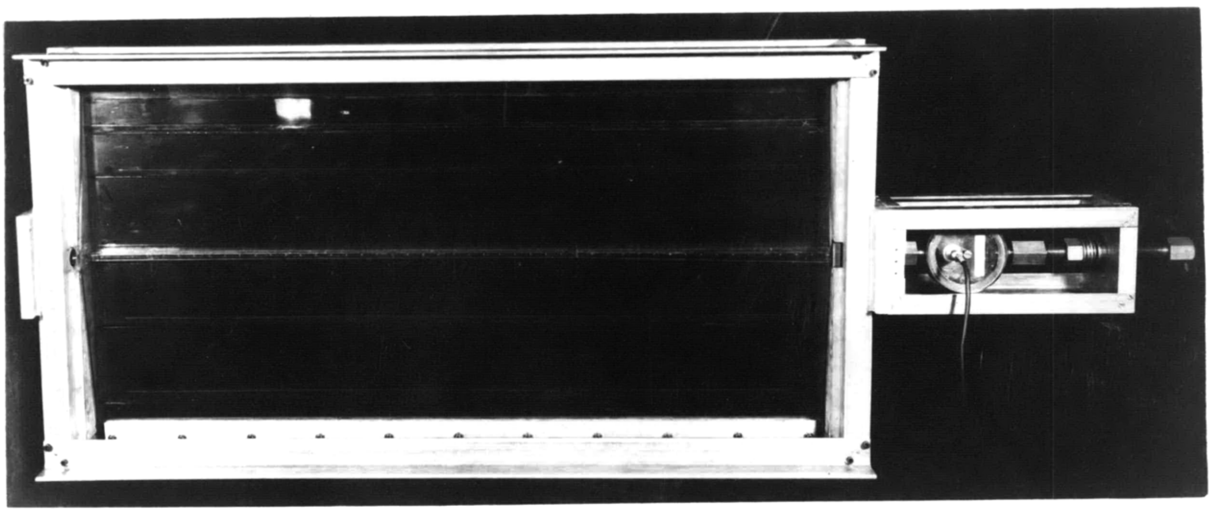

Figure 3 - Loading Frame Showing Model with Tapered Stiffener Supported by Shear at Sides

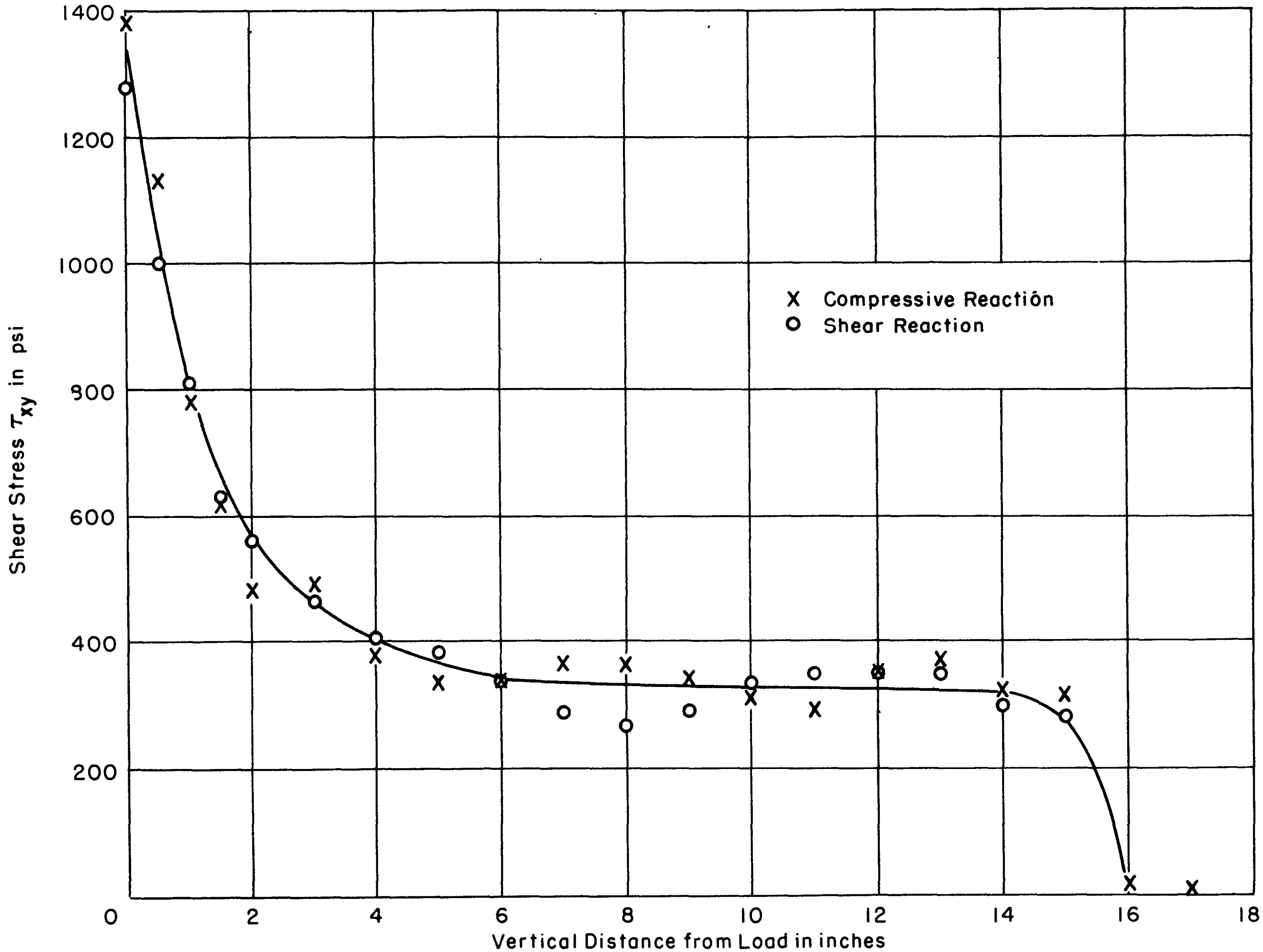

Figure 4 - Shear Stress Distribution for Uniform Stiffener as a Function of Vertical Distance from Load (860 Pounds)

The area under the curve is equivalent to a load of 858 pounds.

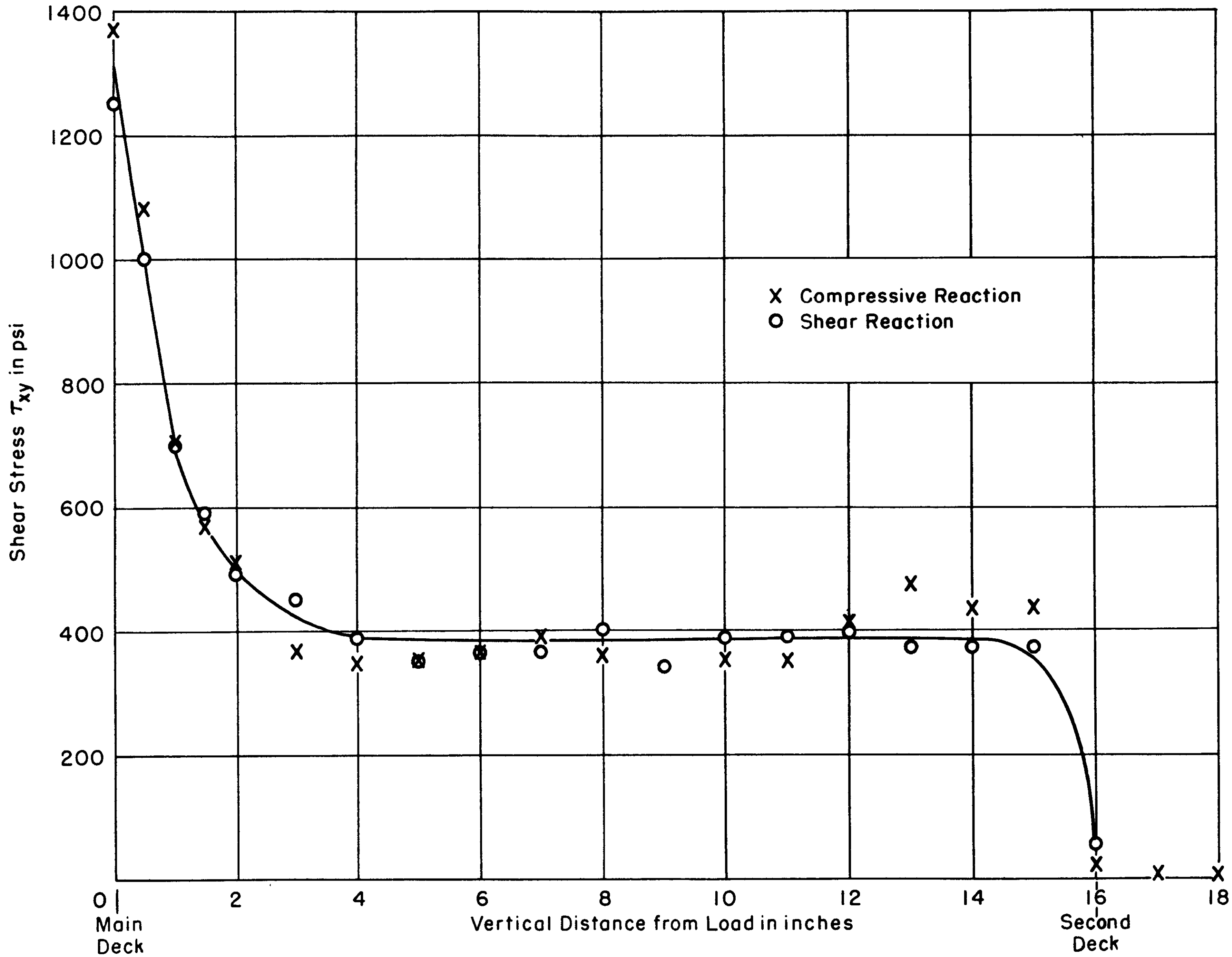

Figure 5 - Shear Stress Distribution for Tapered Stiffener as a Function of Vertical Distance from Load (860 Pounds)

The area under the curve is equivalent to a load of 913 pounds.

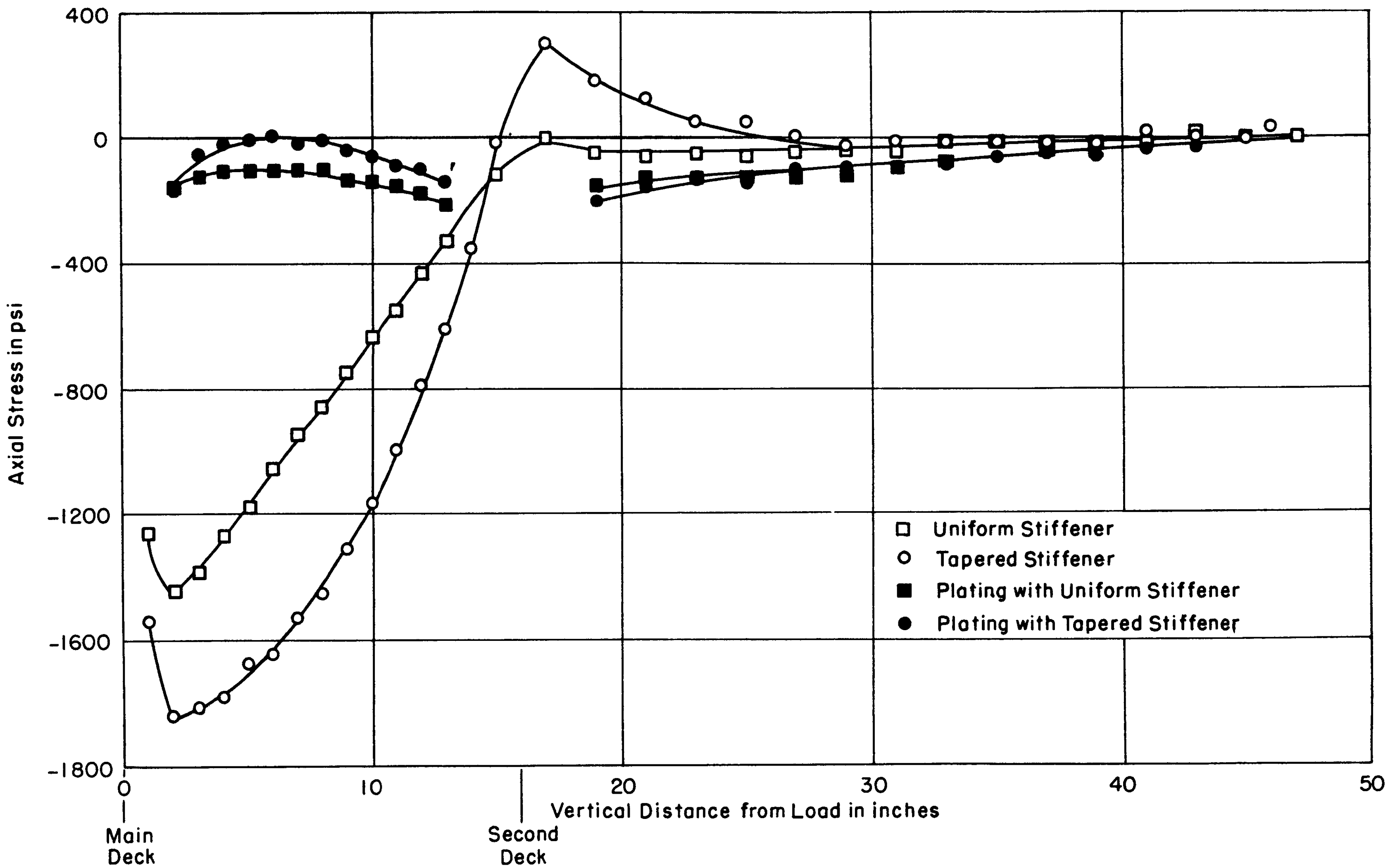

Figure 6 - Axial Stress from Strain Data for Compressive Reaction as a Function of Vertical Distance from Load

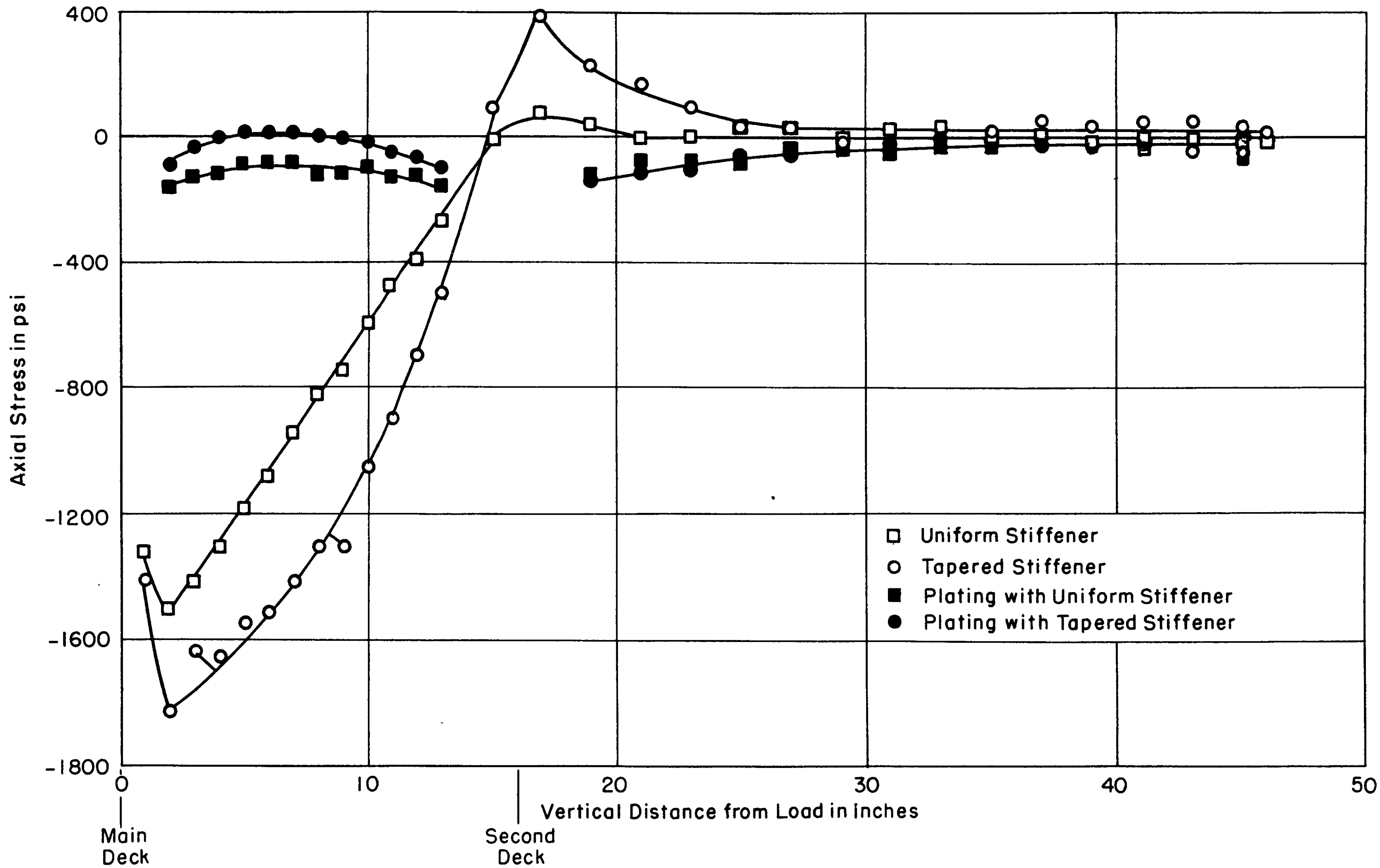

Figure 7 - Axial Stress from Strain Data for Shear Reaction as a Function of Vertical Distance from Load

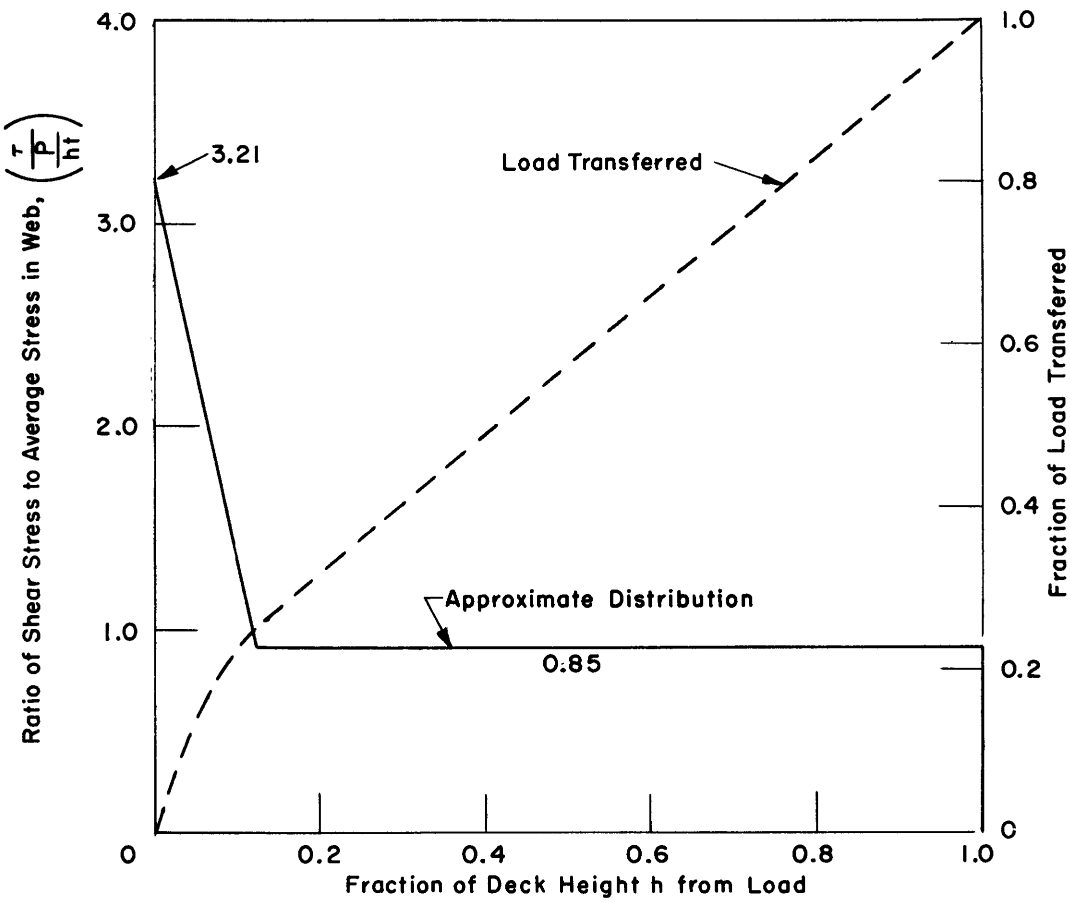

Figure 8 - Approximate Distribution of Shear Stress and Rate of Load Transfer for First Deck Height

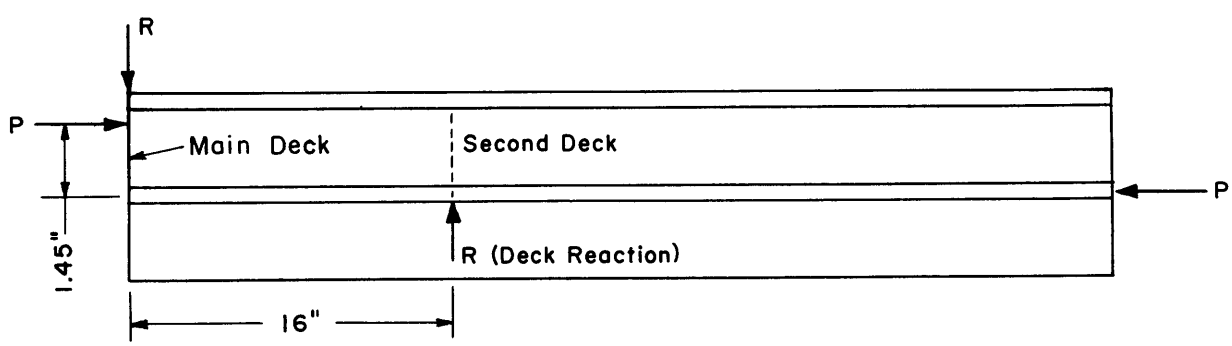

Figure 9 - Free-body Sketch of Bulkhead Model with Uniform Stiffener and Compressive Reaction

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