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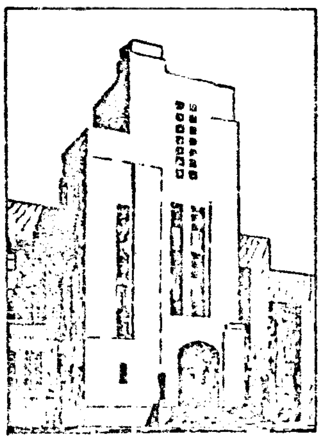
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

INVESTIGATION OF PRESSURES ON KEEL BLOCKS DURING DRYDOCKING OF USS MIDWAY (CVA 41), USS VALLEY FORGE (CVS 45), AND USS INTREPID (CVA 11)

by

Peter M. Palermo and Joseph S. Brock



RESEARCH AND DEVELOPMENT REPORT

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TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	1
HISTORY OF MEASUREMENT OF DOCKING LOADS	2
DESCRIPTION OF PRESSURE WAFER	2
THEORIES OF COMPUTING KEEL-BLOCK LOADS	4
Previous Methods	
TMB Approximate Method	6
TEST PROCEDURES AND RESULTS	9
USS MIDWAY (CVA 41)	9
USS VALLEY FORGE (CVS 45)	11
USS INTREPID (CVA 11)	12
DISCUSSION OF RESULTS AND COMPARISON WITH THEORY	18
USS MIDWAY (CVA 41)	18
USS VALLEY FORGE (CVS 45)	19
USS INTREPID (CVA 11)	21
SUMMARY AND CONCLUSIONS	26
RECOMMENDATIONS	26
ACKNOWLEDGMENTS	26
APPENDIX A - PRESSURE WAFER CALIBRATIONS	27
APPENDIX B - KEEL BLOCK CALIBRATION	29
APPENDIX C - SAMPLE CALCULATIONS BY TMB APPROXIMATE METHOD	30
REFERENCES	32

LIST OF ILLUSTRATIONS

Page

Figure 1 - Typical Keel Block ... 3

Figure 2 - Pressure Wafer for Measuring Keel-Block Loads 4

Figure 3 - Pressure Wafer Under Keel Block ... 5

Figure 4 - Parameters Involved in the Solution of a Beam on an Elastic Foundation 6

Figure 5 - Drydock Setup Prior to Docking of USS MIDWAY..... 9

Figure 6 - View of Stern Blocks Used Under USS MIDWAY .. 10

Figure 7 - Locations of Pressure Wafers Under Keel Blocks During Drydocking of USS MIDWAY.......... 10

Figure 8 - Locations of Pressure Wafers Under Keel Blocks During Drydocking of USS VALLEY FORGE.......... 13

Figure 9 - Drydock Setup Prior to Docking of the USS INTREPID 14

Figure 10 - Stern Blocking Arrangement for USS INTREPID 14

Figure 11 - Instrumented Blocks Under INTREPID 14

Figure 12 - Method of Measuring Initial Block Height. 15

Figure 13 - Apparatus for Water-Level Survey of Keel Profile...... 15

Figure 14 - Contour of Main Deck of USS INTREPID from Transit Survey.... 18

Figure 15 - Comparison of Experimental and Theoretical Keel-Block Loads Under USS MIDWAY 19

Figure 16 - Moment of Inertia and Foundation Modulus Curves Used for Theoretical Computation on USS INTREPID 22

Figure 17 - Comparison of Experimental Data with Theoretical Curves for USS INTREPID 23

Figure 18 - Effect of Addition of 150-Ton Load at Frame 207 on USS INTREPID 25

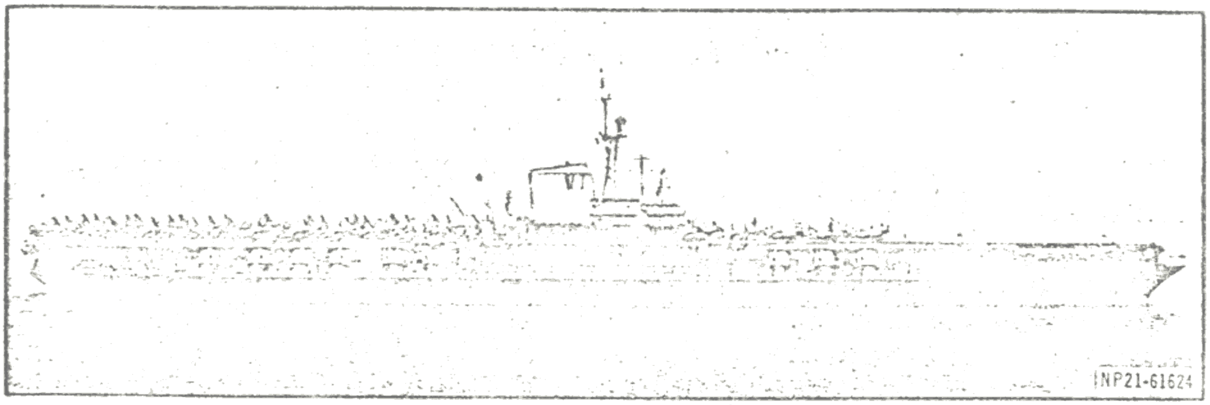
Figure 19 - Comparison Between Yeh-Ruby Method and TMB Approximate Method for Computing Keel-Block Load for USS INTREPID 25

Figure 20 - Calibration Curves for Pressure Wafers .... 2?

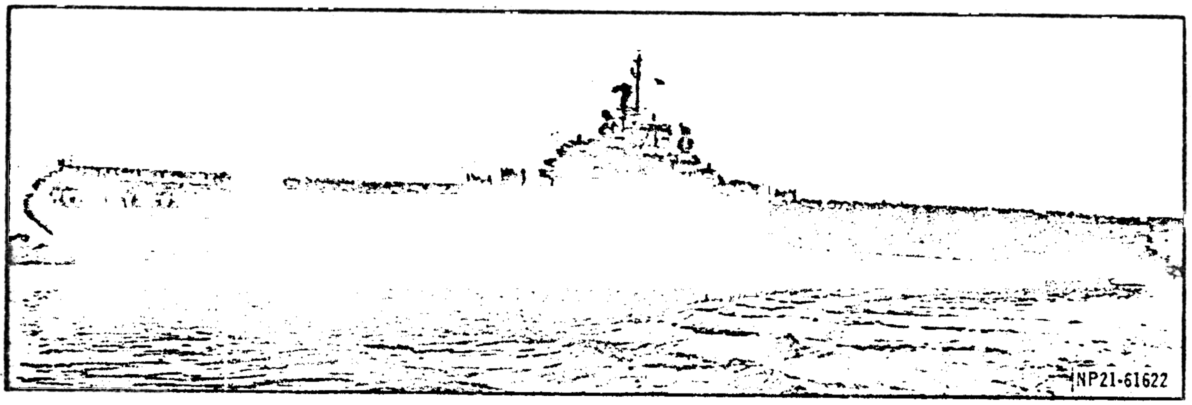
Figure 21 - Keel Block Deflection Plotted Against Load.

LIST OF TABLES

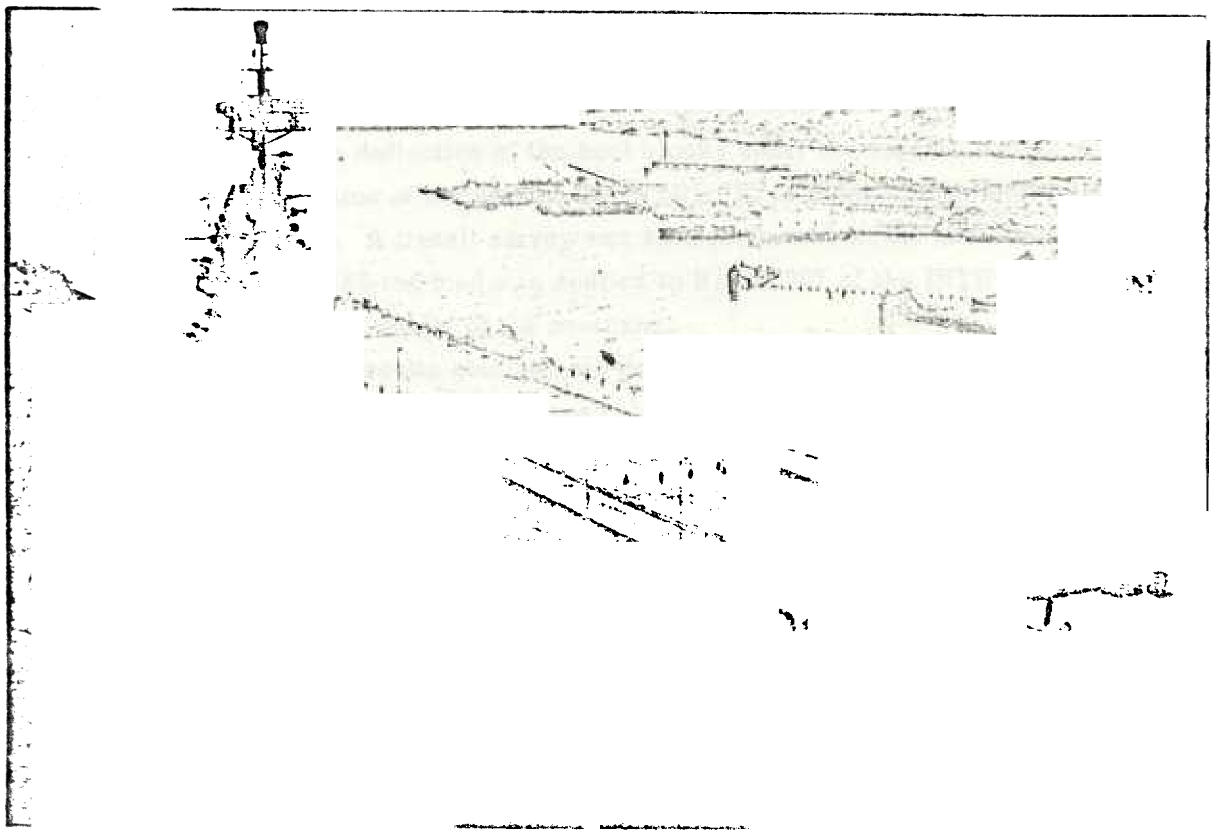
	Page
Table 1 - Loads on Instrumented Blocks Under USS MIDWAY (CVA 41)	11
Table 2 - Loads on Instrumented Blocks Under USS VALLEY FORGE (CVS 45)	13
Table 3 - Loads on Instrumented Blocks Under USS INTREPID (CVA11)	16
Table 4 - Change in Block Pressure Under USS INTREPID Due to Addition of 150-Ton Load	17
Table 5 - Comparison of Loads on Comparable Blocks Under USS VALLEY FORGE and USS INTREPID	20
Table 6 - Comparison of Experimental and Theoretical Loads on the Sternmost Block	24
Table 7 - Calculated Effect of 150-Ton Load on Overhang of USS INTREPID	31



USS MIDWAY (CVA 41)



USS VALLEY FORGE (CVS45)



USS INTREPID (CVA11)

ABSTRACT

Loads on the keel blocks during drydocking of three aircraft carriers were determined by means of pressure wafers placed under the docking piers. The purpose was to study the loads on the keel blocks, especially in the area of the stern overhang as these loads are sometimes the controlling factor in the design of the stern. For the three ships tested the maximum load was at least twice as great as the nominal load and did not occur at the aftermost block as expected but at a distance of 40 to 70 ft forward of this block.

Several theories of computing keel-block loads are discussed. A new TMB approximate method is presented which assumes the ship to be a simple beam on an elastic foundation. This method proved to be rapid and adequate to determine the loads on the after blocks.

INTRODUCTION

The David Taylor Model Basin, at the request of the Bureau of Ships,[1] has investigated the pressures developed on the keel blocks* under the aircraft carriers USS MIDWAY (CVA41), USS VALLEY FORGE (CVS45), and USS INTREPID (CVA11) in drydock. The main purpose of these tests was to measure the loads on the keel blocks especially in the area of the stern overhang since these loads are sometimes the controlling factor in determining the configuration of the skeg and the amount of overhang. The MIDWAY was chosen because of its twin skeg aft and its large weight. The VALLEY FORGE and INTREPID, although of medium weight were chosen because of their single skeg aft and large lengths of stern overhang.

A new type of pressure wafer was developed to measure the pressures on the keel blocks during drydocking of all three carriers. Additional tests were also performed on the INTREPID to determine the deflection of the keel blocks under the applied loads. A survey was made on the stern section of the keel of the INTREPID to determine its deflection profile in the "in-dock" condition. A transit survey was also performed on the main deck before and after docking. Finally, a 150-ton load was applied to Frame 207 of the INTREPID in order to study the effect of increased weight of the overhang.

Test procedures and results obtained are described in this report. The experimental loads and deflections are compared with those calculated by existing theory and also by a new TMB approximate method; conclusions are drawn from these comparisons.

---

[1] References are listed on page 32.

*The term "keel block" actually refers to the individual wooden blocks which comprise the top surface of the docking pier; however, since it is common usage to refer to the docking pier itself as a keel block, this nomenclature is used in this report.

HISTORY OF MEASUREMENT OF DOCKING LOADS

Before a ship is drydocked, it is necessary to compute the distribution and magnitude of the loads that will be distributed to the keel blocks. These calculations should also include the effect of a difference between the forward and after drafts on the knuckle or pivot block, i.e., the block that the ship first touches and pivots about. These calculations are necessary to insure that the blocks are capable of withstanding the crushing force of the ship and also the tipping force introduced by the ship pivoting about one block.

The approximations in the methods used in computing the loads on the blocks are compensated for by the large factor of safety applied in the design of the block. Prior to World War II, there were numerous drydock accidents[2] which were attributed mostly to keel-block instability. Consequently, attempts were made to measure the magnitude of the loads on the blocks. Most of these measurements were made by inserting into the block a steel plate that would deform under the load and, upon removal, would reveal the maximum load attained in the block. The instability problem is not a major factor today since the height, width, and length of the blocks are now approximately the same; see Figure 1. The problem of crushing still exists, however, because of the greater weight of present-day vessels and the large overhang of the stern.

As a ship settles in the drydock, it has a certain longitudinal inclination. Due to this trim the aftermost part of the ship usually touches the keel blocks first. In this condition, the aftermost keel block is the only supporting block. Then, as the ship settles down over the other keel blocks, the heavy load on the aftermost block is distributed to the adjoining blocks. However, theoretical calculations have shown that the maximum load is attained in the aftermost block not at the time the ship first touches the block but at the time when the original trim of the ship is decreased by one-half.

It was because of this high initial loading that a crusher-type device was not considered suitable for the recording of keel-block loads. The loads recorded would be the maximum loads supported by the blocks and would not give a true picture of the simultaneous load distribution. A strain-gage dynamometer such as was used on the USS WARE[3] will give continuous indication of load, thus overcoming the objections which were found with the crusher-type device. However, it too was considered impractical since its installation required additions to the standard keel blocks, and the data recording was more time consuming. A comparatively inexpensive hydraulic-pressure wafer (Patent Pending) that could be inserted under the keel block on the floor of the drydock was designed at the Model Basin.

DESCRIPTION OF PRESSURE WAFER

Before a pressure wafer could be designed, the conditions under which it had to operate and the results it was expected to produce were considered. It was decided that any suitable wafer should have the following characteristics:

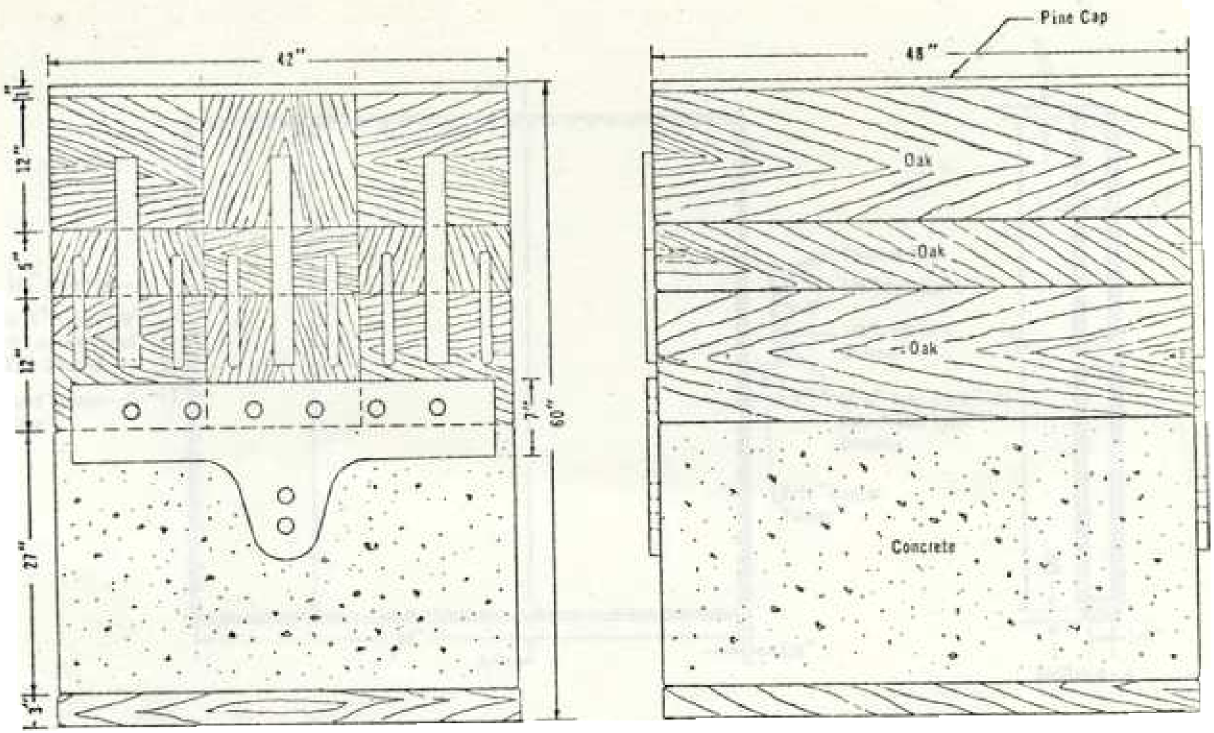


Figure 1 - Typical Keel Block

1. It must not affect the elastic properties of the keel block itself.

2. It should be simple to fabricate and install.

3. It should be easy to operate and, if necessary, be operable from a remote station

4. It should give not only the maximum load but also the load at any time during the drydocking.

5. It should be accurate to within 2 percent.

6. It should be insensitive to temperature variations.

After all these features had been considered, the pressure wafer shown in Figure 2 wa constructed. The wafer is made of medium steel and is the same length and width as a keel block. It is equipped with a capped bleeder tube on one edge and a 1/4-in. gate valve on the opposite edge. The wafer is filled with water (approximately 8½ quarts) and operates on the principle of a pressure capsule, developing pressure in the contained fluid due to elastic deformations of the wafer under load. As the wafer is loaded, the change in water pressure is measured. This water pressure can be obtained by means of an elastic tube pressure gage wl the dock is filled with water, or a Bourdon tube pressure gage when the dock is dry.

Before the wafers were used, each one was calibrated up to a load of 600,000 lb. The calibration plots are shown in Appendix A; by means of these calibration curves, the recorde pressure in pounds per square inch can be resolved into load per block. A deflection curve o a typical keel block is shown in Appendix B.

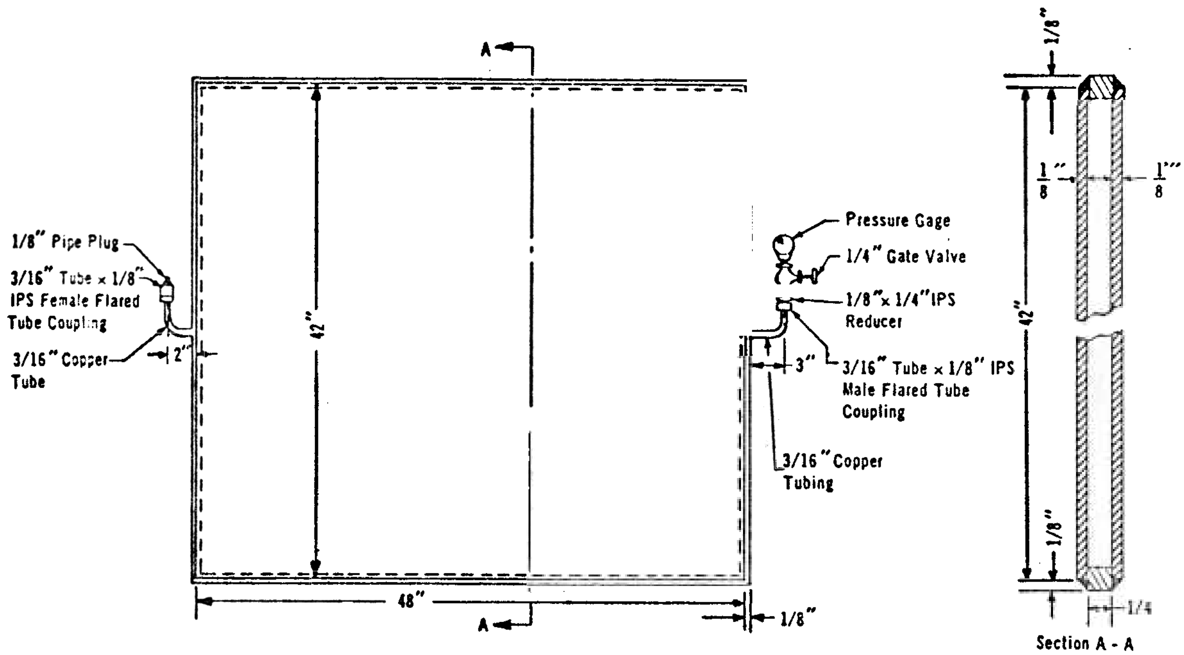


Figure 2 - Pressure Wafer for Measuring Keel-Block Loads

The wafers were installed under the keel blocks as shown in Figure 3. To avoid puncturing the wafer, the bottom of the keel block must be clear of foreign matter and the block must be centered over the wafer.

THEORIES OF COMPUTING KEEL-BLOCK LOADS

PREVIOUS METHODS

The most recent method of computing keel-block loads is that derived by Yeh and Ruby, described in References 4 and 5. The theory is a combined application of Ritz's energy method and a normal-mode approximation to the solution of a beam on an elastic foundation. In order to apply the method, certain simplifying assumptions must be made. These are listed in Reference 5 as:

"1. The vessel is a monolithic beam (homogeneous, isotropic, and elastic).

2. The underlying soil, rock, and the dock floor are infinitely rigid.

3. The reaction forces of keel blocks are proportional at every point to the deflection of the vessel at that point."

Assumption 1 is logical, but it does not account for local indentations and hard spots in the vessel. Assumption 2 is not quite accurate since the dock floor is not infinitely rigid. Assumption 3 may seem logical at first glance; however, when the blocks are set to a certain elevation, it is necessary to shim the top of the blocks with a soft cap (usually pine). This soft cap may be as much as 3 in. in thickness, depending upon the amount of shim needed.

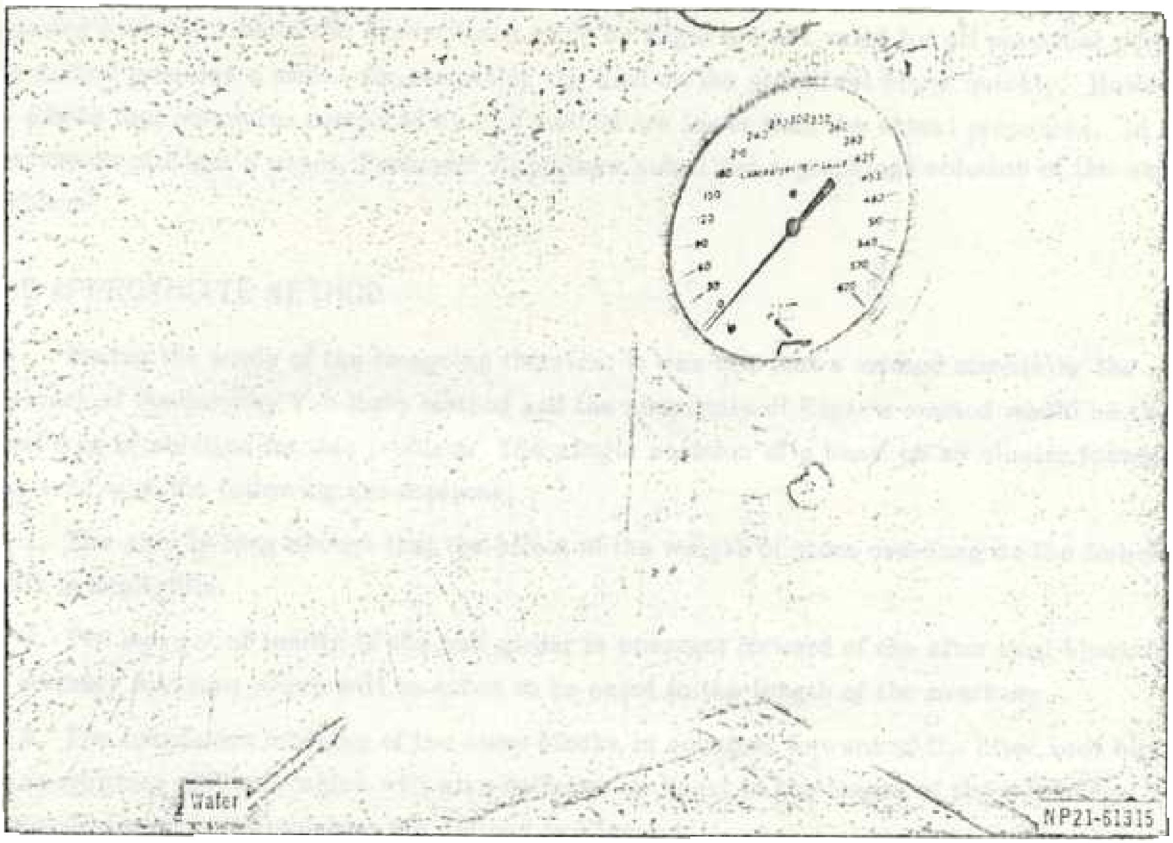


Figure 3 - Pressure Wafer Under Keel Block

Therefore, when the ship settles on the blocks, the keel usually cuts through the soft cap slightly until the cap is compressed to the point where its modulus approximates that of the hard cap. Consequently, if all the blocks do not have the same amount of shim material, ce tain blocks will deflect less than others under the loads and form hard spots, and the keel, in turn, will follow the contour of the blocks. In addition, the bulkheads and stiffeners pres in the hull structure also form hard spots in the ship girder. Due to these effects, the third assumption is questionable. However, these assumptions are the best that can be made to make this solution at all.practical.

In 1899, Francis Elgar presented a method[6] of computing the load on the sternmost o foremost block of a ship in drydock assuming a perfectly rigid ship and a perfectly elastic blocking system. Elgar states that the load distribution for a ship that is blocked from bow to stern is

$$p = \frac{w}{n+1}$$

where w is the weight of the ship and $n+1$ is the number of keel blocks. He further that, if there is an overhang, a couple is introduced due to the misalignment of the center gravity of the ship and the blocking system. He then resolves this couple into a load on t sternmost or foremost blocks, assuming the ship to rotate about the center of gravity of the blocking systems. While the assumptions made by Elgar are not valid for all practical purposes, his method provides a means for computing the load on the sternmost block quickly. However, he admits that pressures computed by this method are lower than the actual pressures. In a discussion of Elgar's paper, Professor Hele-Shaw submitted a graphical solution of the same problem.[6]

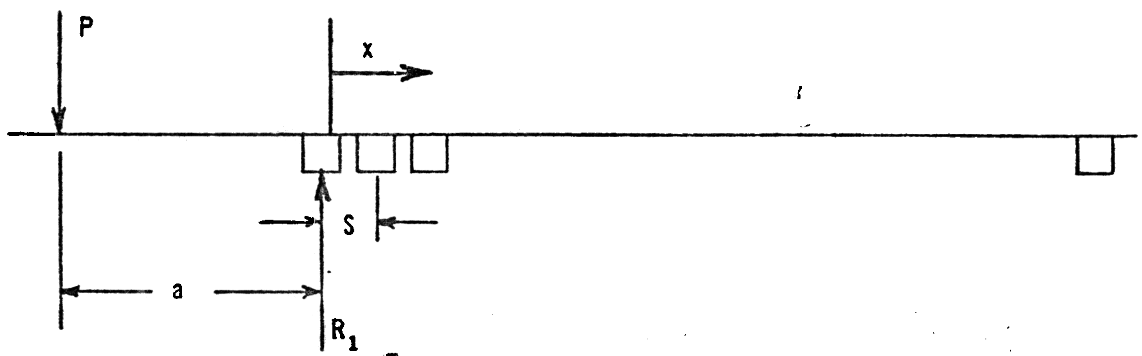
TMB APPROXIMATE METHOD

During the study of the foregoing theories, it was felt that a method combining the accuracy of the lengthy Yeh-Ruby method and the simplicity of Elgar's method would be the ideal type of solution for this problem. The simple solution of a beam on an elastic foundation[7] was used with the following assumptions:

1. The ship is long enough that the effect of the weight of stern overhang on the foremost block is negligible.

2. The moment of inertia of the hull girder is constant forward of the after keel block for an arbitrary distance which will be taken to be equal to the length of the overhang.

3. The foundation modulus of the stern blocks is constant forward of the after keel block for an arbitrary distance which will also be taken as equal to the length of the overhang. The parameters used in the solution are defined in Figure 4.



Here P is the weight of the overhang,

a is the distance from the aftermost keel block to the center of gravity of the overhang,

S is the center-to-center distance between blocks,

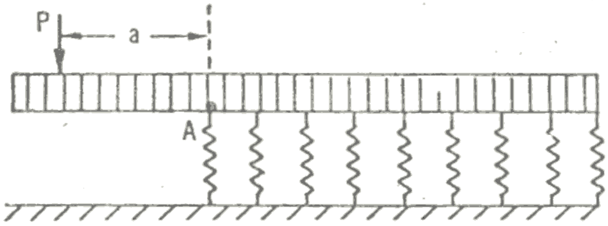
R_1 is the load on the aftermost block,

K is the foundation modulus, i.e., load per inch deflection per foot of length of block, and

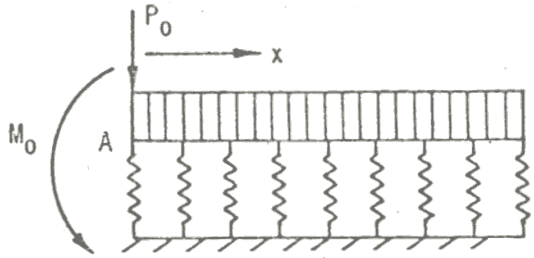
x is the distance measured from the center of the aftermost block.

Figure 4 - Parameters Involved in the Solution of a Beam on an Elastic Foundation

By applying the foregoing assumptions to a ship and using the solution of a beam on an elastic foundation, we have the following configuration



which by the method of superposition can be resolved into



The deflection of the ship due to overhang is then

$$y = e^{-\beta x} (C \cos \beta x + D \sin \beta x)$$

where $\beta = \sqrt[4]{\frac{K}{4EI}}$ and C and D are constants of integration,

M_0 is the moment at A due to the overhang,

P_0 is the weight of the overhang,

a is the distance from the center of the aftermost block to the center of gravity of the overhang,

K is the foundation modulus of the blocks, i.e., load per inch of deflection per foot of length of ship, and

I is the average moment of inertia of the ship from the stern block to the start of the side blocks.

The boundary conditions at the origin $x = 0$ are

$$EI\frac{d^2y}{dx^2} = M_0 = P_0 a \quad [1]$$

$$EI\frac{d^3y}{dx^2} = -V = P_0 \quad [2]$$

where

$$\frac{dy}{dx} = \beta e^{-\beta x} [(D - C) \cos \beta x - (C + D) \sin \beta x] \qquad [3]$$

$$\frac{d^2y}{dx^2} = 2\beta^2 e^{-\beta x} (C \sin \beta x - D \cos \beta x)$$

$$\frac{d^3y}{dx^3} = 2\beta^3 e^{-\beta x} [(C + D) \cos \beta x + (D - C) \sin \beta x]$$

Therefore, substituting Equations [4] and [5] into Equations [1] and [2], respectively, we obtain

$$EI\, 2\beta^2 e^{-\beta x} (C \sin \beta x - D \cos \beta x) = P_0 a$$

$$EI\, 2\beta^3 e^{-\beta x} [(C + D) \cos \beta x + (D - C) \sin \beta x] = P_0 \qquad [7]$$

At $x = 0$

$$D = -\frac{P_0 a}{2EI\beta^2}$$

$$C = \frac{P_0 (1 + a\beta)}{}$$

$$\longrightarrow Y_0 = C = \frac{P_0 (1 + a\beta)}{2EI\beta^3} = \text{deflection due to } M_0 \text{ and } P_0$$

and

$$R_1 = Y_0 KS + q_0 S$$

where R_1 is the reaction at the aftermost block including not only the effect of the weight of the overhang but also the effect of the weight of the ship itself,

S is the center-to-center distance between the blocks, and

q_0 is the weight per foot of the ship in the area being studied.

From Table 6 it can be seen that this method gives loads for the aftermost block that compare favorably with the loads calculated by the more complex Yeh-Ruby method. It can also be seen from Figure 19 that results from this simplified calculation compare favorably with measured loads for a distance forward of the aftermost keel block up to the point where there is an abrupt change of the foundation modulus.

TEST PROCEDURES AND RESULTS

USS MIDWAY (CVA 41)

The USS MIDWAY (CVA 41) was drydocked on 356 keel blocks in Graving Dock 8 at the Norfolk Naval Shipyard on 3 July 1953. The primary reasons for conducting tests on this vessel were its large weight, its twin skeg aft, and the fact that the keel-block loads for this ship had already been investigated theoretically.[4]

Figure 5 is a view of the dock setup prior to receiving the ship, looking forward from the stern blocks. The port and starboard sternmost blocks were scotched as shown in Figure 6, and it may be seen from Figure 7 that six blocks were crowded into the space normally occupied by four blocks. All other blocks were located 6 ft apart on centers.

At the time of docking, the ship and the dock setup had the following characteristics:

Displacement of Ship	48,053 tons
Length of Ship	968 ft
Length of Overhang of Ship	120 ft, 3 in.
Trim by Stern	Approximately 5½ ft
Docking Position	3
Total Bearing Area of Blocks	4,928 ft^2
Nominal Block Pressure	9.75 $tons/ft^2$
Nominal Block Load	136.5 tons

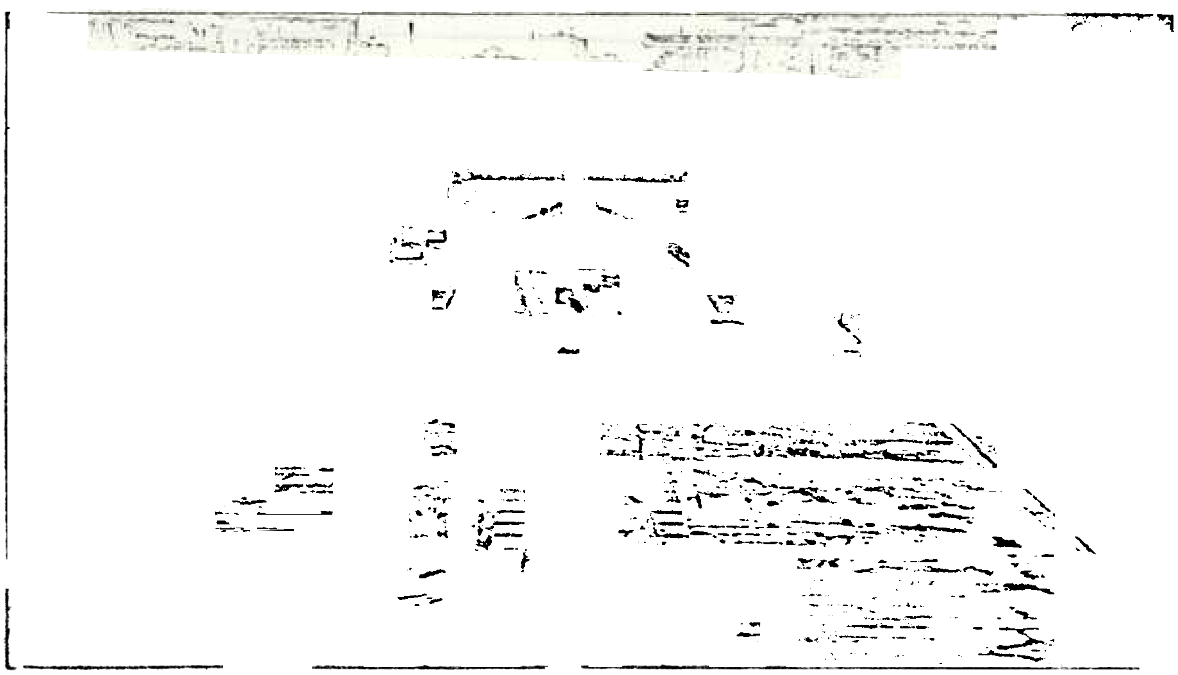


Figure 5 - Drydock Setup Prior to Docking of USS MIDWAY

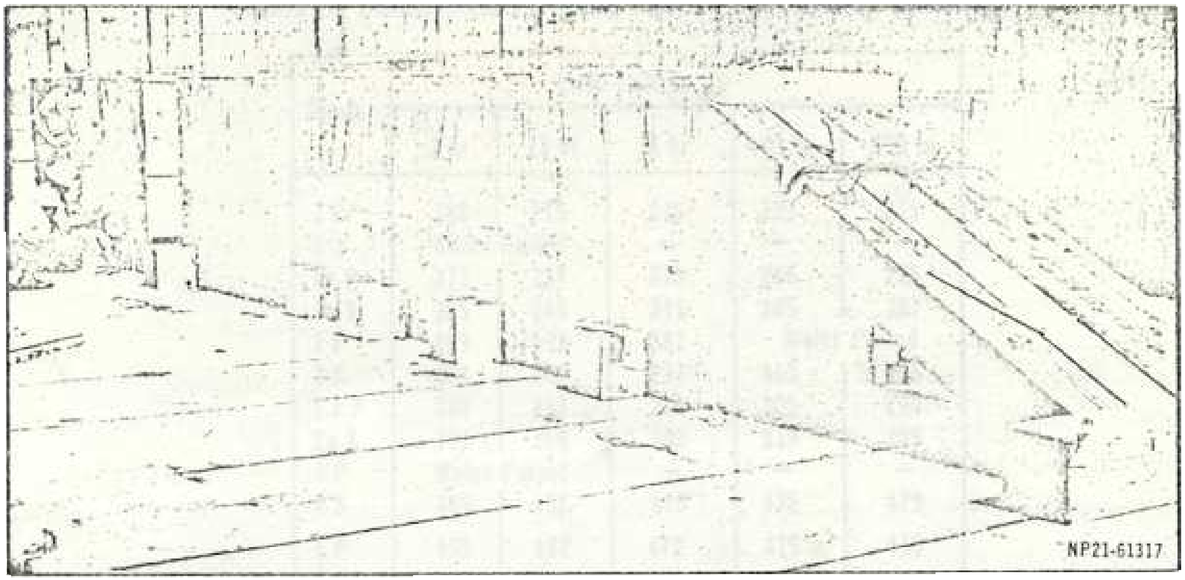


Figure 6 - View of Stern Blocks Used Under USS MIDWAY

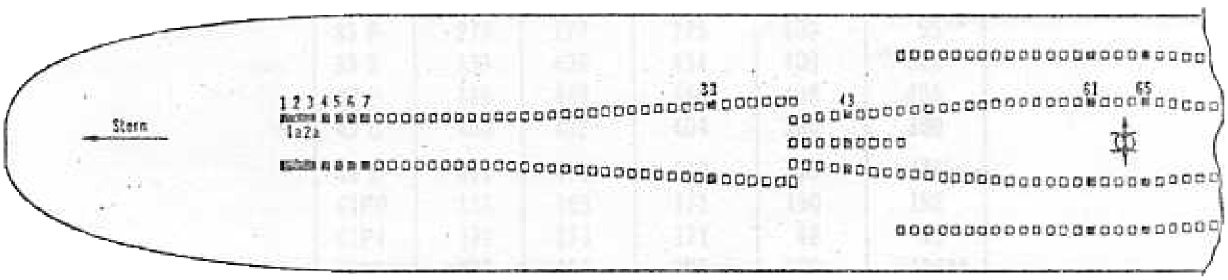


Figure 7 - Locations of Pressure Wafers Under Keel Blocks During Drydocking of USS MIDWAY

Instrumented blocks are marked with solid squares.

Pressure wafer readings taken 2 hr, 11 hr, 16 hr, and 40 days after the initial docking are tabulated in Table 1. The maximum recorded load was 604 kips on the starboard block at Position 7. The highest average load, 445 kips per block, also occurred at Position 7. These two blocks remained the most highly stressed stern blocks during the entire docking.*

However, at the start of the triple skeg, Position 43, the average load was 387 kips per block after 40 days, while the average load across Position 7 decreased to 363 kips per block after 40 days. The loads on the port block at Position 33 and on the starboard outboard block at Position 61 decreased by 182 tons and 215 tons, respectively, after 40 days. Examination of the data in Table 1 indicates that the wafers at Positions 33 P and 61SO had apparently developed slow leaks, thereby rendering their results erroneous.

---

*Where only one wafer functioned at a station, the station was disregarded in the averages.

TABLE 1

Loads on Instrumented Blocks Under USS MIDWAY (CVA 41)

Block	Load in kips				
	2 hr	11 hr	16 hr	480 hr	490 hr
1 P*	188	215	215	235	215
1 S	Wafer Failed		—	—	—
1a P	271	284	273	286	275
1a S	225	243	245	305	287
2 P	389	397	382	Wafer Failed	
2 S	285	299	297	340	325
2 a P	260	293	284	305	290
2a S	297	306	300	319	305
4 P	Wafer Failed		—	—	—
4 S	406	412	410	436	429
5 P	459	462	449	415	410
5 S	Wafer Failed		—	—	—
6 P	201	206	199	Wafer Failed	
6 S	420	391	406	348	341
7 P	287	287	278	230	230
7 S	604	587	583	505	505
33 P	277	277	275	100	95**
33 S	430	436	434	400	388
43 P	480	468	468	408	405
43 C	400	402	404	380	380
43 S	481	471	465	380	376
61PO	153	165	171	190	192
61PI	173	171	171	48	45
61SO	413	397	395	200	198**
61SI	146	164	169	Wafer Failed	
65PO	Wafer Failed		—	—	—
65PI	360	346	357	342	329
65SO	322	312	313	230	228
65SI	120	147	152	287	290

*The letter designations have the following meanings

P, Port — PI, Port Inboard
S, Starboard — SO, Starboard Outboard
C, Center — SI, Starboard Inboard
PO, Port Outboard

**Wafer apparently had slow leak.

USS VALLEY FORGE (CVS 45)*

The USS VALLEY FORGE (CVS 45) was drydocked at the Norfolk Naval Shipyard on 25 September 1953. This vessel was chosen because of its single skeg aft and its large ov hang. At the time of docking, the ship and the dock setup had the following characteristics

*Formerly CVA 45.

Displacement of Ship	32,798 tons
Length of Ship	888 ft
Length of Overhang of Ship	151 ft
Trim by Stern	8 5/16 in.
Docking Position	3
Total Bearing Area of Blocks	2,519 ft^2
Nominal Block Pressure	13.02 $tons/ft^2$
Nominal Block Load	182.5 tons

Figure 8 shows the location of the keel blocks under the ship, with the instrumented blocks marked with solid blocks. The sternmost blocks were arranged similarly to those under the MIDWAY, where six blocks were crowded into the space normally occupied by four blocks.

Pressure wafer readings taken 2 hr, 14 hr, and 40 days after the docking are tabulated in Table 2. The highest initial load, 819 kips, occurred at Position 12, but the load continuously decreased and it is probable that the wafer developed a slow leak. The largest load on any of the stern blocks was at Position 6. After 2 hr the load was 761 kips; it decreased slightly to 715 kips after 40 days. Position 20 had the largest load after 40 days, 725 kips. However, it seems likely that the measured load at Position 12 would have been slightly higher if the wafer had not developed a slow leak.

USS INTREPID (CVA11)

The USS INTREPID (CVA 11) was drydocked on 210 blocks at the Norfolk Naval Shipyard on 23 June 1954. The INTREPID was selected because of its single skeg aft and its large stern overhang. As the INTREPID is a sister ship of the VALLEY FORGE, an opportunity was provided to determine the reproducibility of the data. At the time of docking, the ship and the dock setup had the following characteristics:

Displacement of Ship	33,362 tons
Length of Ship	898 ft
Length of Overhang of Ship	157 ft, 3 in.
Trim by Stern	Approximately 3 ft, 4 in.
Docking Position	3
Total Bearing Area of Blocks	2,397.5 ft^2
Nominal Block Pressure	13.87 $tons/ft^2$
Nominal Block Load	194 tons

Figure 9 is a view, looking forward, of the dock setup prior to receiving the ship. Figure 10 shows the stern blocking arrangement. All other blocks were located 6 ft apart on centers; see Figure 11. It will be noted that, unlike the VALLEY FORGE and the MIDWAY where six blocks were crowded into the space normally occupied by four, six blocks were crowded into the space normally occupied by five blocks in the stern section of the INTREPID. Under the

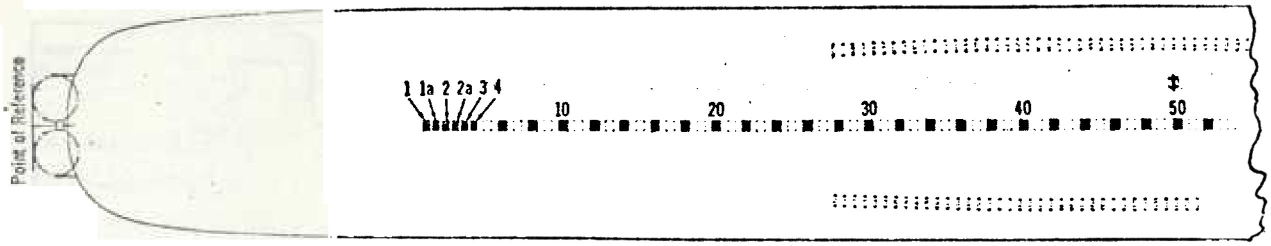


Figure 8 - Locations of Pressure Wafers Under Keel Blocks During Drydocking of USS VALLEY FORGE

Instrumented blocks are marked with squares. Note the small side blocks,

Table 2 - Loads on Instrumented Blocks Under USS VALLEY FORGE (CVS 45)

Block	Load in kips		
	2 hr	14 hr	480 hr
1	450	444	380
1A	632	660	584
2	601	621	598
2A	540	550	540
3	516	557	519
4	491	482	473
6	761	747	715
8	601	400	556
10	695	675	594
12	819	770	345*
14	721	600	65*
16	Wafer Failed		—
18	632	604	600
20	782	754	725
22	600	560	525
24	563	572	542
26	Wafer Failed		
28	748	713	561
30	547	518	543
32	305	332	353
34	Wafer Failed		—
36	386	430	515
38	466	457	Wafer Failed
40	452	444	480
42	579	583	575
44	659	650	685
46	522	510	476
48	418	430	431
50	516	497	Wafer Failed
52	407	400	365

*Wafer apparently had slow leak.

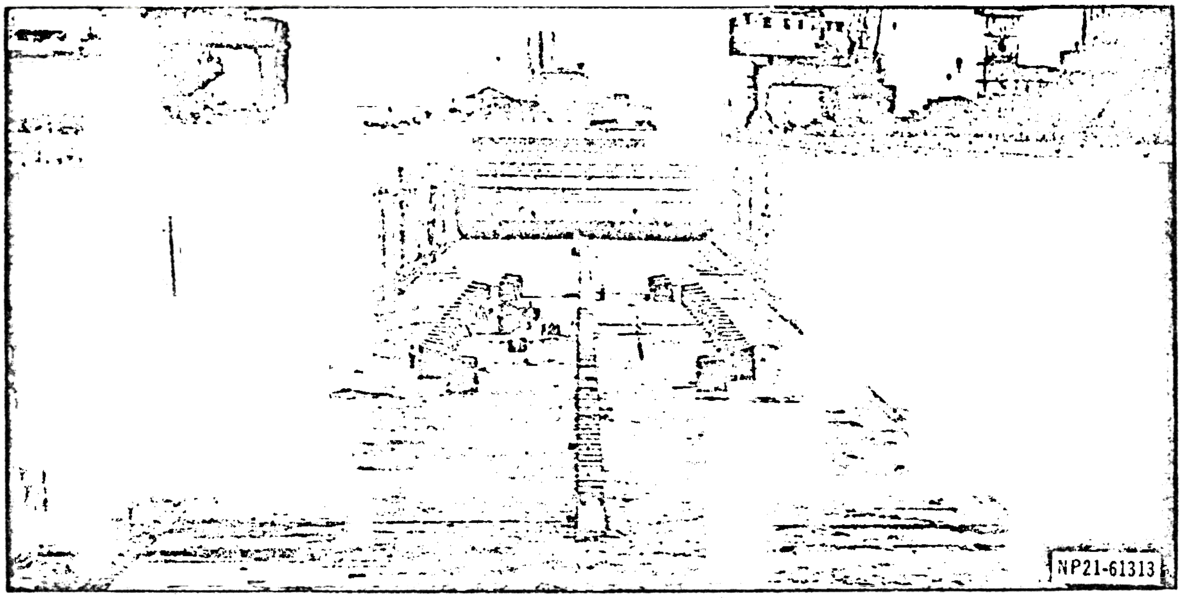


Figure 9 - Drydock Setup Prior to Docking of the USS INTREPID

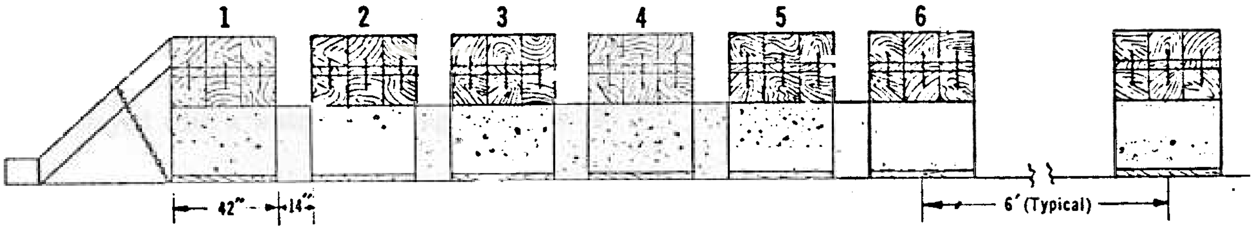


Figure 10 - Stern Blocking Arrangement for USS INTREPID

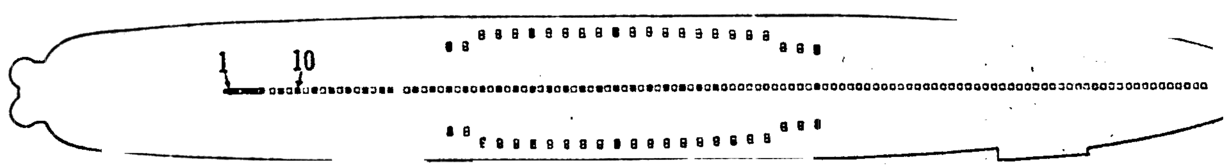


Figure 11 - Instrumented Blocks Under USS INTREPID

INTREPID, however, 14-in. spacer blocks were used between each of the stern blocks while under the other two ships the stern blocks were touching; see Figure 10.

It was desired to use the pressure readings from the INTREPID and VALLEY FORGE to compare the effectiveness of the two different blocking setups. The INTREPID, like the VALLEY FORGE, had a single skeg aft, and the weights of the two ships were approximately the same. However, as mentioned previously, the blocking arrangement in the stern section a the sizes of the side blocks were different, as can be seen in Figures 8 and 16.

Before the vessel was docked, the heights of the keel blocks were measured by means of a 2-in. Ames dial indicator mounted on a 5-ft rod. A 60-lb I-beam planed across the bottom face was laid on the keel block to give a smooth surface to which to read the elevation (Figure 12). To straighten any warped sections of shim material, a 200-lb weight was placed on the I-beam. After the ship was docked, heights were measured to the keel of the ship to determine the deflections of the blocks.

Keel-block pressures taken 2 hr, 26 hr, and 194 hr after the ship was docked are tabulated in Table 3. Block 6 had the highest initial loading, 1050 kips, and, though the load decreased to 807 kips after 194 hr, it remained the most highly stressed block.

The stern section of the keel was surveyed with a water-level gage, Figure 13.

Figure 12 - Method of Measuring Initial Block Height

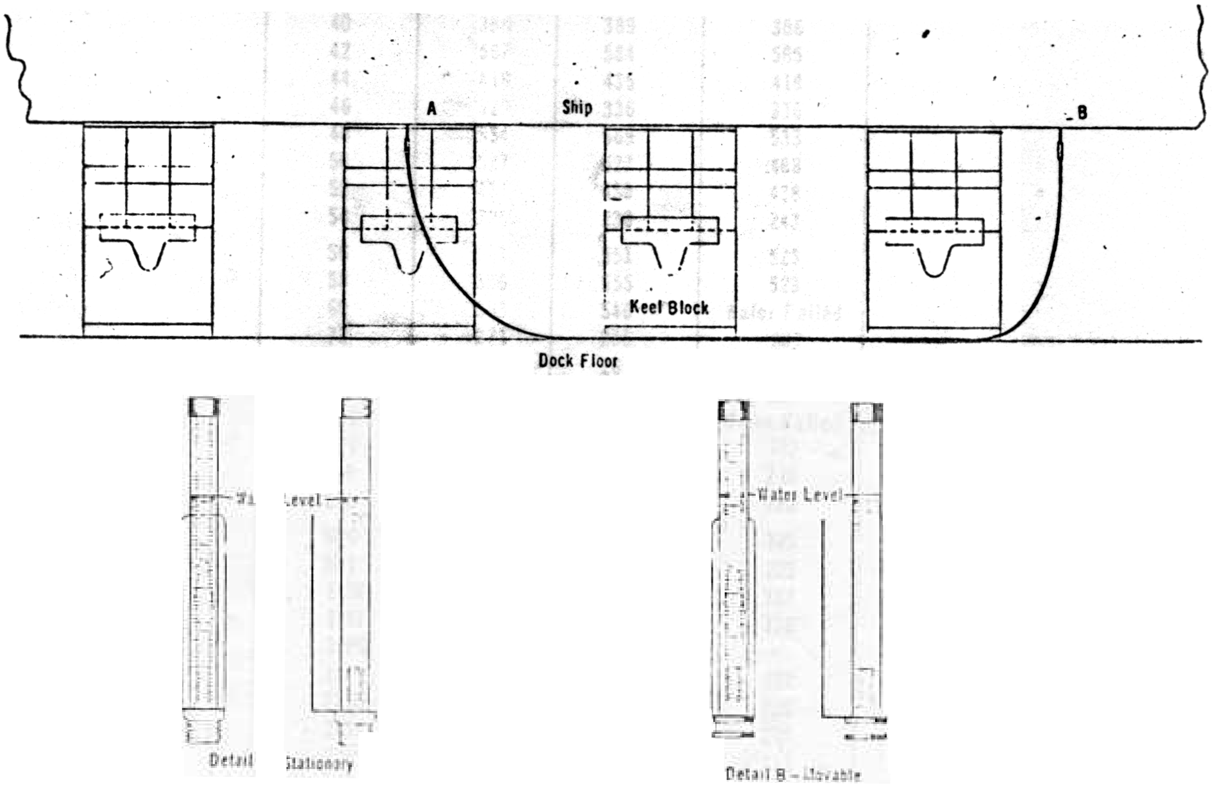


Figure 13 - Apparatus for Water-Level Survey of Keel Profile

TABLE 3

Loads on Instrumented Blocks Under USS INTREPID (CVA 11)

Block	Load in kips		
	2 hr	26 hr	194 hr
1	743	658	653
2	Wafer Failed		–
3	882	751	Wafer Failed
4	Wafer Failed		–
5	815	751	718
6	1050	910	807
8	810	750	716
10	454	472	251
12	660	660	740
14	590	590	599
16	707	687	638
18	629	618	596
20	405	397	376
21	798	768	716
24	695	675	470
26	655	655	635
28	553	565	488
30	344	361	400
32	510	517	Wafer Failed
34	324	348	382
36	342	370	404
38	573	582	564
40	386	389	386
42	567	584	565
44	418	435	418
46	329	336	336
48	554	569	533
50	527	527	488
52	451	450	438
54	225	230	243
56	553	551	525
58	536	555	528
60	583	546	Wafer Failed
72	271	285	307
1SO	255	267	267
1SI	178	194	227
1PO	225	238	Wafer Failed
1PI	98	113	192
6SO	205	215	210
6SI	183	201	222
6PO	185	200	225
6PI	149	170	203
11SO	121	139	337
11SI	161	162	176
11PO	Wafer Failed		–
11PI	195	198	192
23SO	220	222	220
23SI	225	224	210
23PO	103	104	112
23PI	174	180	178

TABLE 4

Change in Block Pressure Under USS INTREPID Due to Addition of 150-Ton Load

Block	Change in Load kips	Block	Change in Load kips
1	74	48	– 9
3	81	50	–26
5	58	52	–13
6	49	54	5
8	23	56	0
10	26	58	0
12	30	60	–26
14	24	72	Wafer Failed
16	4	1S0	– 7
18	– 5	1SI	– 2
20	0	1P0	– 5
21	– 9	1PI	– 3
24	–19	6S0	– 3
26	– 7	6SI	– 3
28	–13	6P0	– 2
30	0	6PI	0
32	–22	11S0	5
34	– 7	11SI	10
36	– 4	11P0	Wafer Failed
38	– 2	11PI	0
40	– 2	23S0	– 3
42	0	23SI	– 5
44	4	23P0	0
46	– 2	23PI	– 2

Water-level readings were taken along the stern section of the keel, not only as a check of the profile obtained from the deflection readings but also to investigate the possibility of using a water level rather than a transit in future tests. Two graduated plastic tubes were mounted at each end of a 100-ft garden hose; one end was made stationary, and the other end was lined up with the bottom face of the keel at different locations. The results of this survey are included on the deflection curve of Figure 17. Figure 14 shows the results of a transit survey of the main deck before and after docking. In order to obtain the deflection curve, it was assumed that Frames 42 and 176 remained stationary and that all other stations moved in relation to these two. The maximum relative deflection of 1.02 in. was observed at Frame 100.

Three 50-ton pieces of armor plate were placed on the flight deck at Frame 207 in order to study the effect of increased weight of the overhang. Table 4 presents the change in block loads resulting from this 150-ton load. While the change in block pressure as the armor plate was applied in increments is not shown, it was linear as expected.

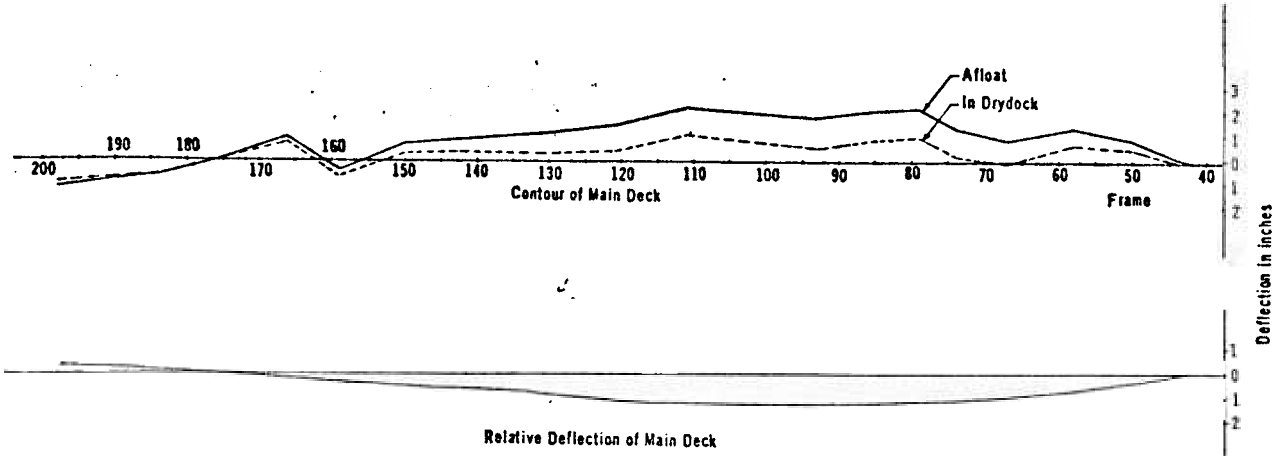


Figure 14 - Contour of Main Deck of USS INTREPID from Transit Survey

The relative deflection was obtained by plotting the difference between the afloat and in drydock conditions.

DISCUSSION OF RESULTS AND COMPARISON WITH THEORY

USS MIDWAY (CVA 41)

From Table 1, it can be seen that the ship settles over a period of time. When the ship docks with trim by the stern, the aftermost blocks are loaded first. As the ship settles on the other blocks, the loads on the stern blocks decrease. In fact, the loads continue to be redistributed for days after the initial docking. However, the average load in each area remains approximately the same after the first day, barring any weight change in the ship itself.

The rise of average load for the stern blocks after 11 hr can be attributed to the expansion effect of the hot sun on the ship's hull. These 11th hour readings were taken at mid-morning, when the sun was heating the upper portion of the hull and the lower portion was still in shadows.

It can also be seen from Table 1 that Block 7 starboard received an initial load of 604 kips which, after 40 days, decreased to 505 kips. This block received the highest load of any of the blocks in the blocking system. While it was expected that the sternmost block would receive the highest load, it was found that the foremost block in the cribbed area was the most highly stressed. This is apparently due to the fact that:

1. The sternmost blocks were deflected a large amount when the ship first landed on them. The blocks when loaded act plastically rather than elastically, i.e., a certain amount of creep of the material is present during loading. When the load is reduced, the blocks exhibit an apparent permanent set. Because of this permanent set, these blocks do not carry their theoretical full share of the load. Hence the blocks further forward received part of the load that would normally be transmitted to the sternmost block.

2. The keel is not straight in this area and actually appears to rise slightly, thereby removing load from the sternmost block and transmitting it to the ones further forward.

3. A hard spot may exist in the ship-block combination at this position.

It is interesting to note that the highest average pressure recorded throughout the entire docking is not in the stern section but amidships at Position 43. The weight curve for the ship showed a large concentration of weight in that area, thereby causing a local hard spot in the weight distribution to the blocks.

The experimental data are compared with a theoretical curve (Figure 15) obtained by means of the method described in References 4 and 5. The theoretical curve is higher than the experimental data except in the area of the triple skeg.

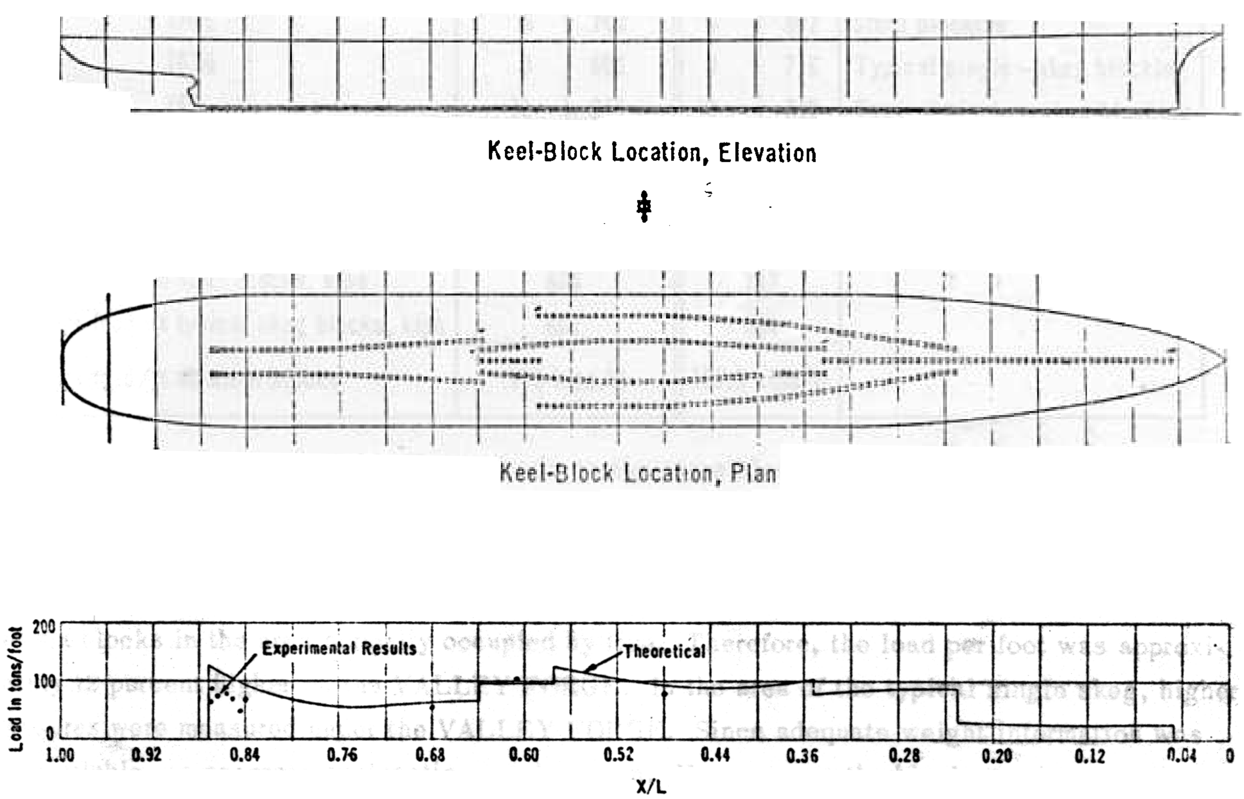


Figure 15 - Comparison of Experimental and Theoretical Keel-Block Loads Under USS MIDWAY

USS VALLEY FORGE (CVS 45)

No attempt was made to compare the results of the VALLEY FORGE test with theory because of the lack of weight-distribution data. However, since the ship was approximately the same weight as the USS INTREPID, wafer readings on comparable blocks are compared in Table 5.

TABLE 5

Comparison of Loads on Comparable Blocks Under USS VALLEY FORGE and USS INTREPID

Frame	VALLEY FORGE		INTREPID		Blocking Arrangement
	Block	Load kips	Block	Load kips	
176	1	450	1	653	Stern blocking
174½	2	601	3	751	Stern blocking
170½	6	761	6	807	Stern blocking
167½	8	601	8	716	Typical single – skeg blocking
161	12	819	12	740	Typical single – skeg blocking
158	14	721	14	599	Typical single – skeg blocking
152	18	632	18	596	Typical single – skeg blocking
143	24	563	24	470	Typical single – skeg blocking
Average load on stern blocks, kips	604		737		
Average load on typical skeg blocks, kips	667		624		
Average load/ft on stern blocks	173 kips/ft		157.8 kips/ft		

It can be seen from Table 5 that loads on the stern blocks of the INTREPID were approximately 20 percent higher than those in similar locations on the VALLEY FORGE. However, as explained previously, the VALLEY FORGE had a stern blocking arrangement where six blocks were crowded into the area normally occupied by four blocks while the INTREPID had six blocks in the area normally occupied by five. Therefore, the load per foot was approximately 12 percent higher on the VALLEY FORGE. In the area of the typical single skeg, higher pressures were measured under the VALLEY FORGE. Since adequate weight information was not available, no concrete explanation can be given. However, as the block spacing was the same for both ships in this vicinity, it can be assumed that the smaller side blocks used under the VALLEY FORGE affected the loads in the single skeg area. These smaller blocks were not capable of taking large loads and, therefore, the blocks along the centerline keel and the blocks in the single skeg area had to carry more of the load.

From the comparison of the results of the INTREPID and the VALLEY FORGE, it appears that the INTREPID had a more efficient blocking arrang ment. The blocks under the INTREPID were more uniformly loaded, thereby reducing the possibility of any one block being over-loaded. However, where large loads were recorded under the VALLEY FORGE, it was noted that the keel profile, as shown in the docking plans, showed a general depression.

USS INTREPID (CVA 11)

Table 3 shows the variance of pressure wafer readings over the eight days. The highest recorded load was 1050 kips on Block 6. This block remained the most highly stressed block during the entire docking, although the load dropped to 807 kips in eight days. It is interesting to note that this same situation existed on the MIDWAY. While it was expected that the sternmost block would be the most highly stressed, the foremost block of the stern blocking received the highest load on both ships. On the VALLEY FORGE the largest load on the sternmost blocking was in approximately the same location. As was noted on the MIDWAY, the stern blocks under the INTREPID had a high initial load that decreased during the first day and continued to decrease over the next few days. The load on the blocks of the typical skeg increased slightly the first day and decreased slightly during the next few days. Unlike the MIDWAY, however, the loads on both the typical skeg blocks and the stern blocks decreased over the next seven days. The rates of drop of load over the last seven days are approximately the same in both areas. It is possible that some of the movable weight (stores, fuel, etc.) were removed from the ship while it was in dock.

Figure 16 shows the moment of inertia curve of the INTREPID and the foundation modulus curve of the blocks. As much more complete data were available on the INTREPID, a much more complete comparison with theory was possible. In Figure 17, the experimental loads are compared with theoretical loads computed by the method of References 4 and 5. It can be seen that the maximum theoretical load in the stern area was not exceeded by the experimental loads. However, the experimental loads did exceed the theoretical loads in the area of the last side block and the foremost of the scotched stern blocks (X/L from 0.66 to 0.80). However, the mean of the observed values in this area does correspond closely with the theory. Loads in way of the side blocks were also higher, but there were large concentrations of weight in this area that could not be adequately considered in the theoretical calculations, since these calculations do not take into account the effect of hard spots or bulkheads in the ship-girder combination.

The stresses in the blocks were also slightly higher than the theoretical stresses, but this was expected since the recorded loads per foot were higher than the theoretical loads. The experimental deflection curve (block contraction) of Figure 17 is displaced by approximately 1/4 in. from the theoretical curve in the way of the side blocks and approximately 1 1/4 in. in way of the sternmost blocks. However, the data from the water-level survey of the keel of the ship coincide almost exactly with the experimental deflections as obtained by recording a deflection on each block. The discrepancies between the experimental and theoretical deflections are due to the fact that the deflection of the dock floor, the crushing of the wood, and the effect of creep in the wood are not considered in the theory.

The change in keel-block loads due to the addition of 150 tons to the overhang was appreciable; see Figure 18 and Table 4. The theoretical curve was obtained by means of the TMB approximate method of a beam on an elastic foundation, which was discussed earlier and which can be found in Appendix C. The correlation between experiment and theory appears to

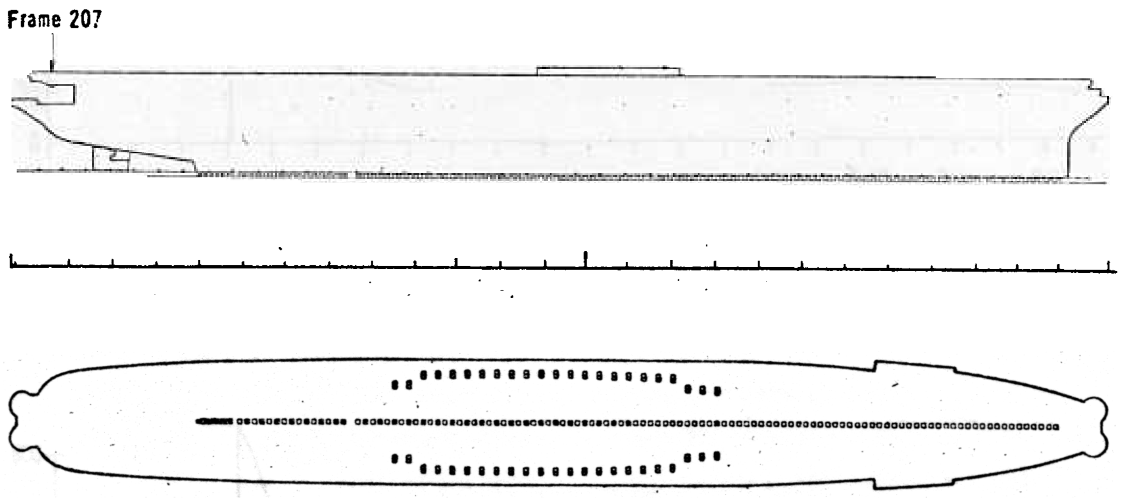


Figure 16a - Blocking Plan

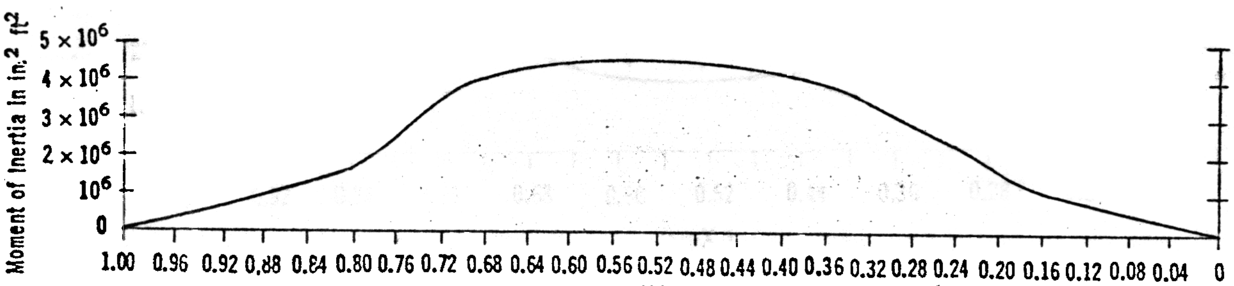


Figure 16b - Moment of Inertia of Ship

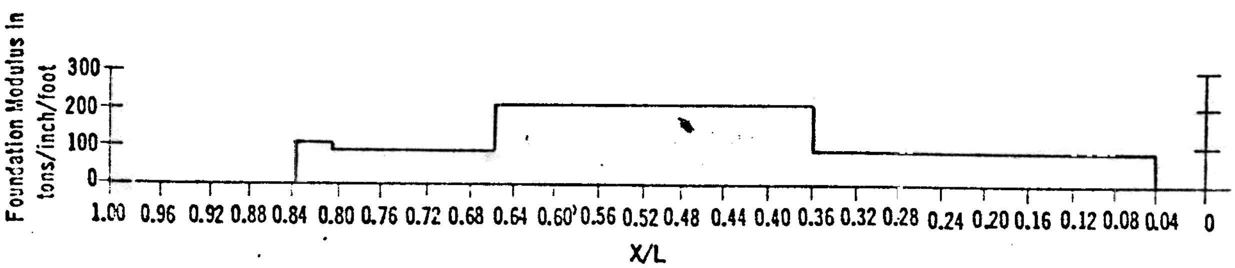


Figure 16c - Foundation Modulus of Blocks

Figure 16 - Moment of Inertia and Foundation Modulus Curves Used for Theoretical Computation on USS INTREPID

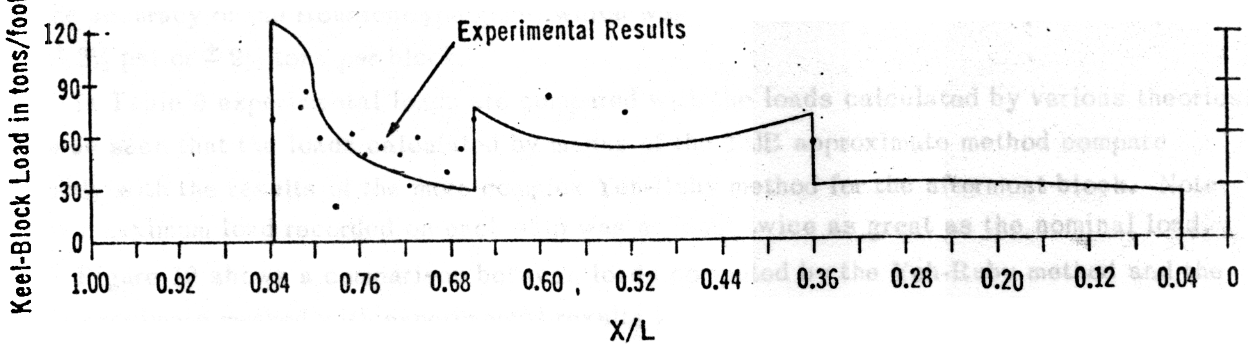


Figure 17a - Loads per Foot on Keel Blocks

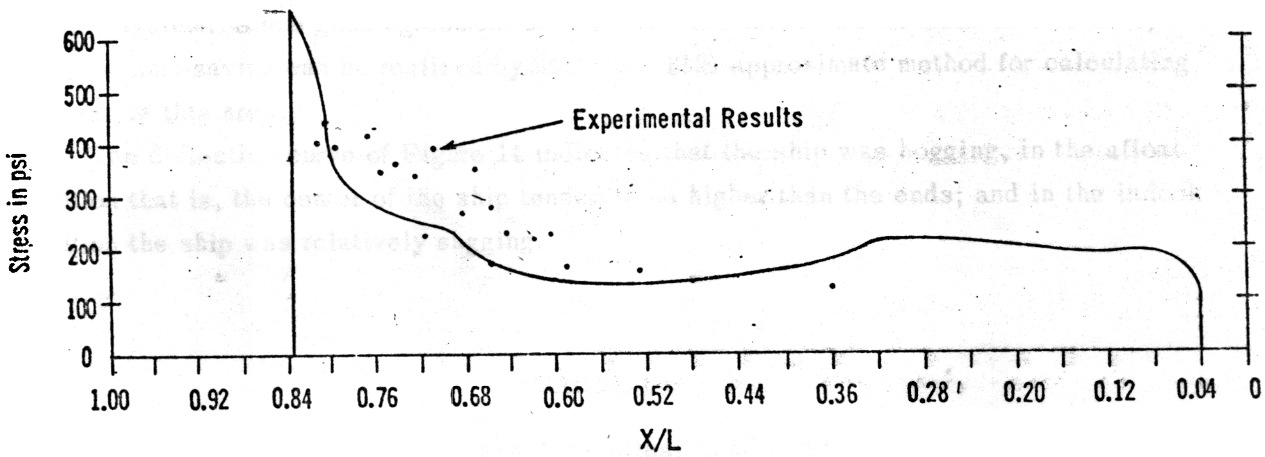


Figure 17b - Stress in Keel Blocks

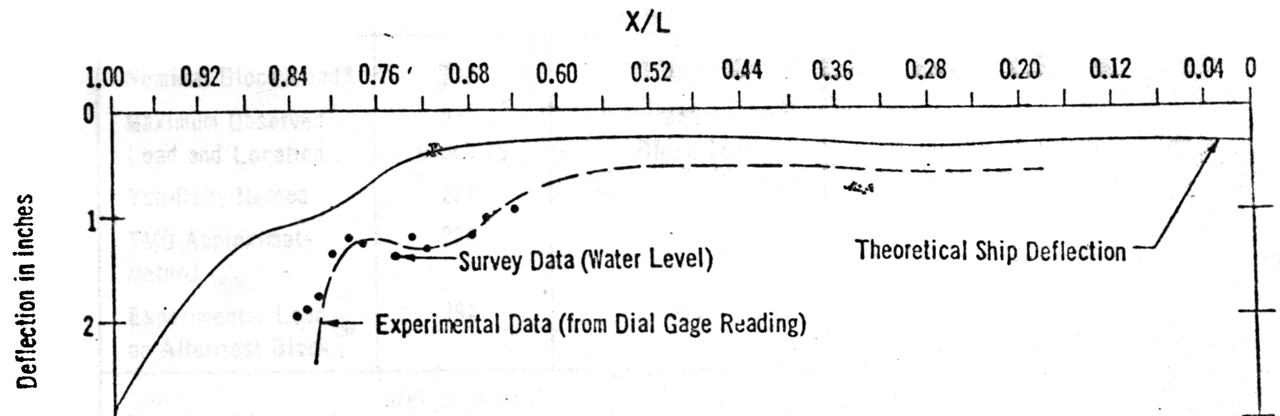


Figure 17c - Deflection

Figure 17 - Comparison of Experimental Data with Theoretical Curves for USS INTREPID

The theoretical curves were obtained by the method of References 4 and 5.

be very good, especially in view of the fact that some of the pressure changes were very small and the accuracy of the Bourdon-type gage, which was used to record the wafer pressures, was only ± 2½ psi or ± 2½ tons per block.

In Table 6 experimental loads are compared with the loads calculated by various theories. It can be seen that the loads calculated by means of the TMB approximate method compare favorably with the results of the more complex Yeh-Ruby method for the aftermost block. Note that the maximum load recorded on each ship was at least twice as great as the nominal load.

Figure 19 shows a comparison between loads computed by the Yeh-Ruby method and the TMB approximate method with experimental results at the aft end of the blocking system of the INTREPID. It can be noted that the two methods give comparable results near the sternmost block; further forward, however, appreciably higher loads were computed by the TMB approximate method than were computed by the Yeh-Ruby method.

The most important loads to be considered are those at the extreme after end of the blocking system. Since good agreement existed between these two methods in this area, considerable time-saving can be realized by using the TMB approximate method for calculating the loads in this area.

The deflection curve of Figure 14 indicates that the ship was hogging, in the afloat condition that is, the center of the ship tended to be higher than the ends; and in the indock condition the ship was relatively sagging.

TABLE 6

Comparison of Experimental and Theoretical Loads on the Sternmost Block

Method	Load in tons		
	USS MIDWAY (CVA 41)	USS VALLEY FORGE (CVS 45)	USS INTREPID (CVA 11)
Nominal Block Load*	137	182	194
Maximum Observed Load and Location	270 Block 7S	366 Block 12	469 Block 6
Yeh-Ruby Method	224		441
TMB Approximate Method	228		459
Experimental Load on Aftermost Block	194	201	332

$$\text{*Nominal Block Load} = \frac{\text{Weight of ship}}{\text{Total block area}} \times \text{Area of Typical Block}$$

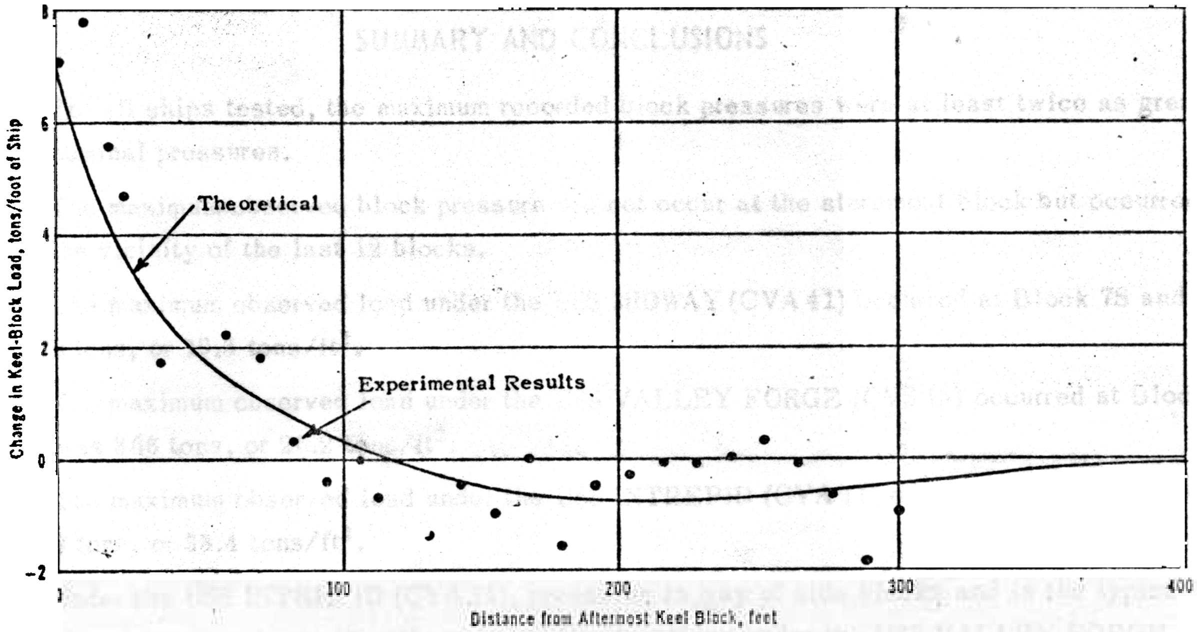


Figure 18 - Effect of Addition of 150-Ton Load at Frame 207 on USS INTREPID

The points are experimental; the theoretical curve was obtained by the method described in Appendix C.

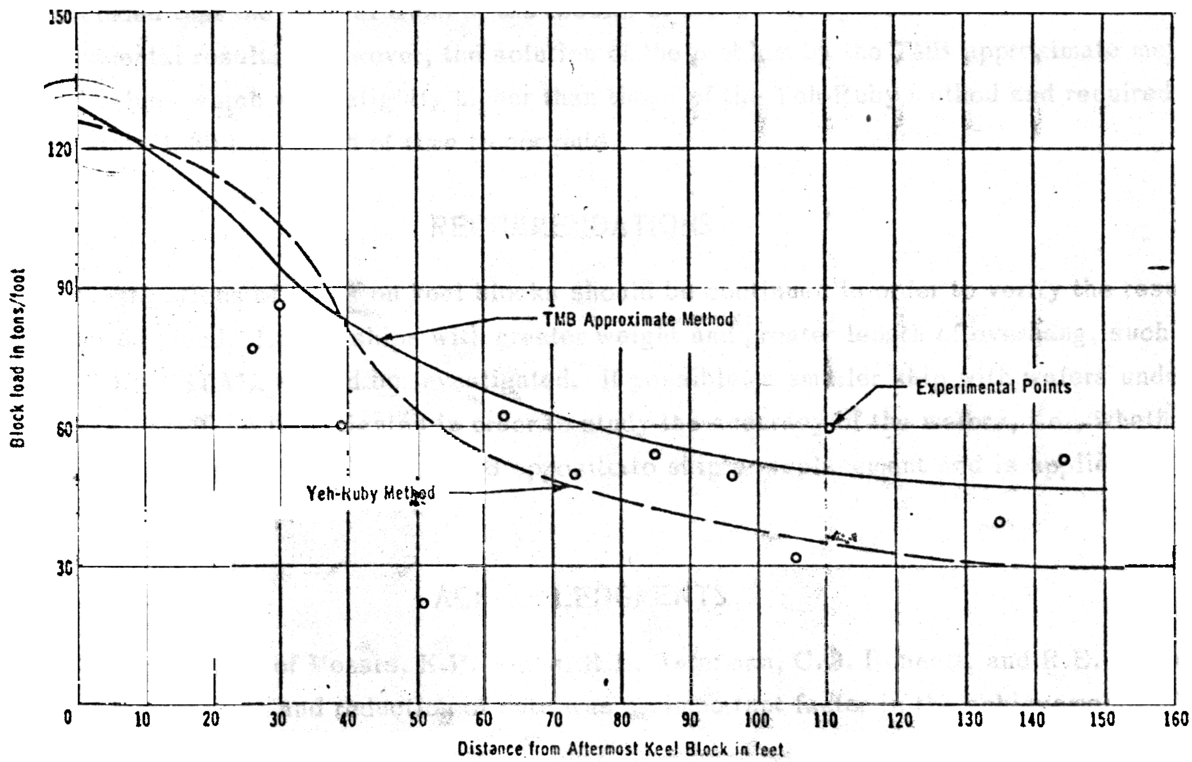


Figure 19 - Comparison Between Yeh-Ruby Method and TMB Approximate Method for Computing Keel-Block Load for USS INTREPID

SUMMARY AND CONCLUSIONS

1. For all ships tested, the maximum recorded block pressures were at least twice as great as the nominal pressures.

2. The maximum observed block pressure did not occur at the sternmost block but occurred within the vicinity of the last 12 blocks.

3. The maximum observed load under the USS MIDWAY (CVA 41) occurred at Block 7S and was 270 tons, or 19.3 tons/ft^2.

4. The maximum observed load under the USS VALLEY FORGE (CVS 45) occurred at Block 12 and was 366 tons, or 26.2 tons/ft^2.

5. The maximum observed load under the USS INTREPID (CVA 11) occurred at Block 6 and was 469 tons, or 33.4 tons/ft^2.

6. Under the USS INTREPID (CVA 11), pressures in way of side blocks and in the typical single skeg area were lower than those in similar locations under the USS VALLEY FORGE (CVS 45). This seemed to indicate that the larger side blocks used under the INTREPID were more efficient than the smaller side blocks used under the VALLEY FORGE.

From the comparison of the experimental and theoretical results on the USS INTREPID, it is concluded that the general trend of the results of the Yeh-Ruby method followed that of the experimental results. However, the solution of the problem by the TMB approximate method produced values which were slightly higher than those of the Yeh-Ruby method and required approximately 1/80 the length of time to compute.

RECOMMENDATIONS

Investigations of loads on keel blocks should be continued in order to verify the results previously obtained. Larger ships with greater weight and greater length of overhang, such as the USS FORRESTAL, should be investigated. If possible, a smaller ship with wafers under every block should be investigated in order to study the accuracy of the wafers, i.e., whether resultant of wafer reactions is equal and opposite to ship's displacement and is applied at center of gravity of ship.

ACKNOWLEDGMENTS

The assistance of Messrs. K.P. Arges, R.L. Waterman, C.O. Bennett, and R.E. Stuckey in the conduct of tests and reduction of data was an important factor in the achievements of the test objectives.

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The authors also wish to thank the personnel of the Norfolk Naval Shipyard and the officers and men of the ships tested, for their whole-hearted cooperation during these tests.

APPENDIX A

PRESSURE WAFER CALIBRATIONS

Each pressure wafer was calibrated before and after each field trial, by placing them under a keel block, loading the keel block to 600 kips, and recording wafer pressures at load intervals of 50 kips. The load was applied by means of a Southwark-Emery 600,000-lb testing machine.

The curves were extrapolated to obtain loads for pressures exceeding the calibration pressures. The calibration plots are shown in Figure 20.

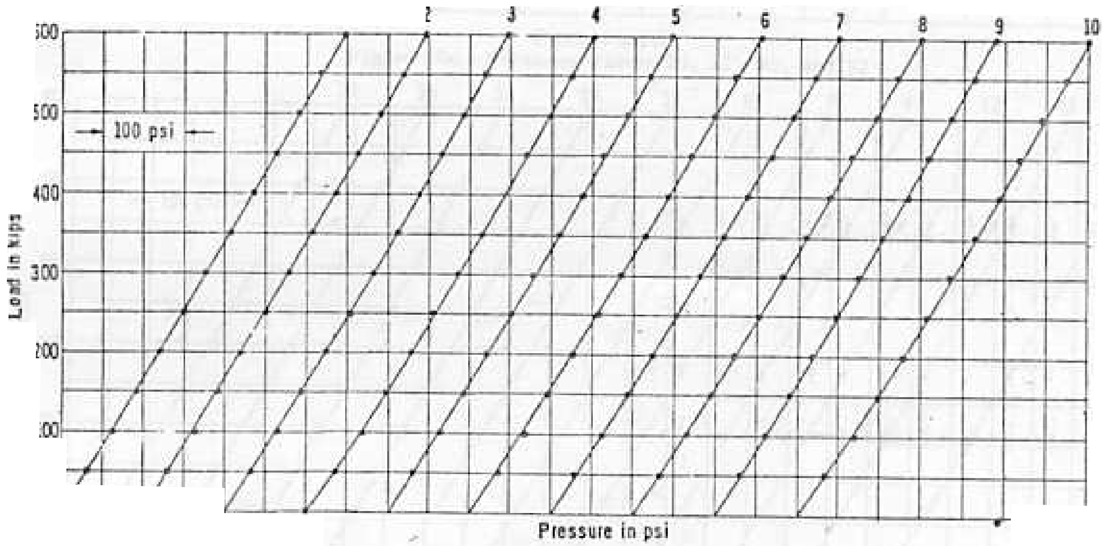
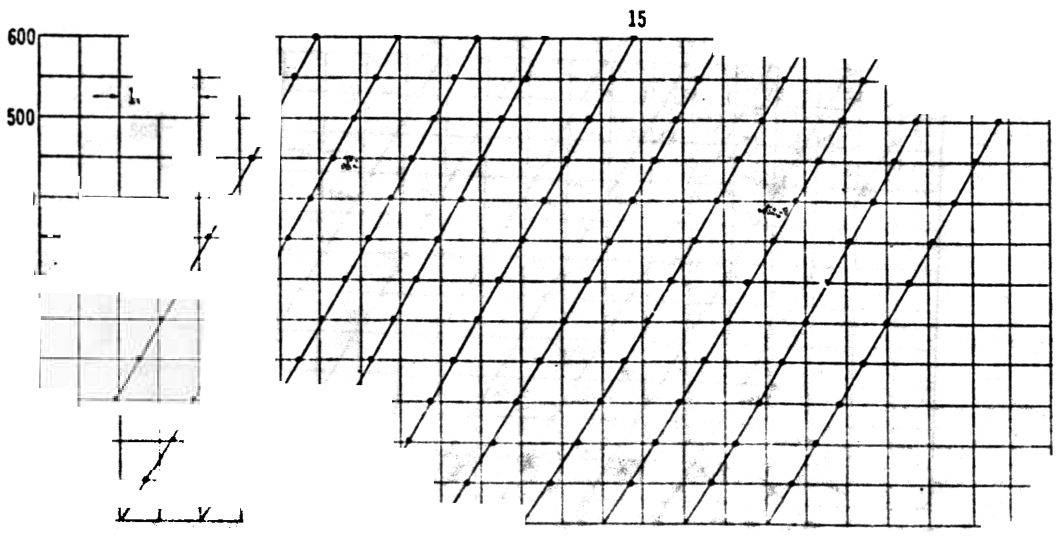


Figure 20a - Pressure Wafers 1 - 10



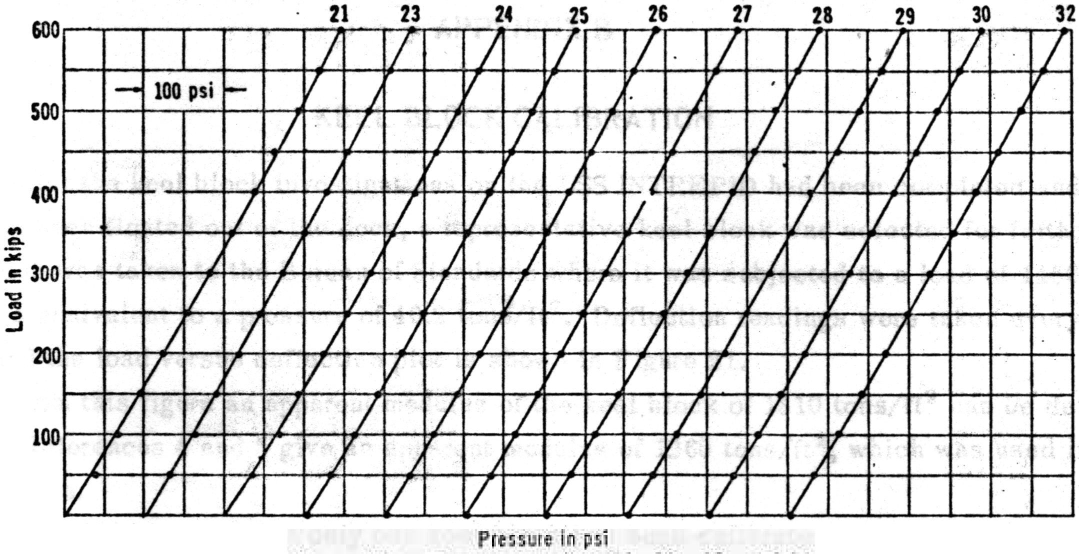


Figure 20c - Pressure Wafers 21, 23 - 30, and 32

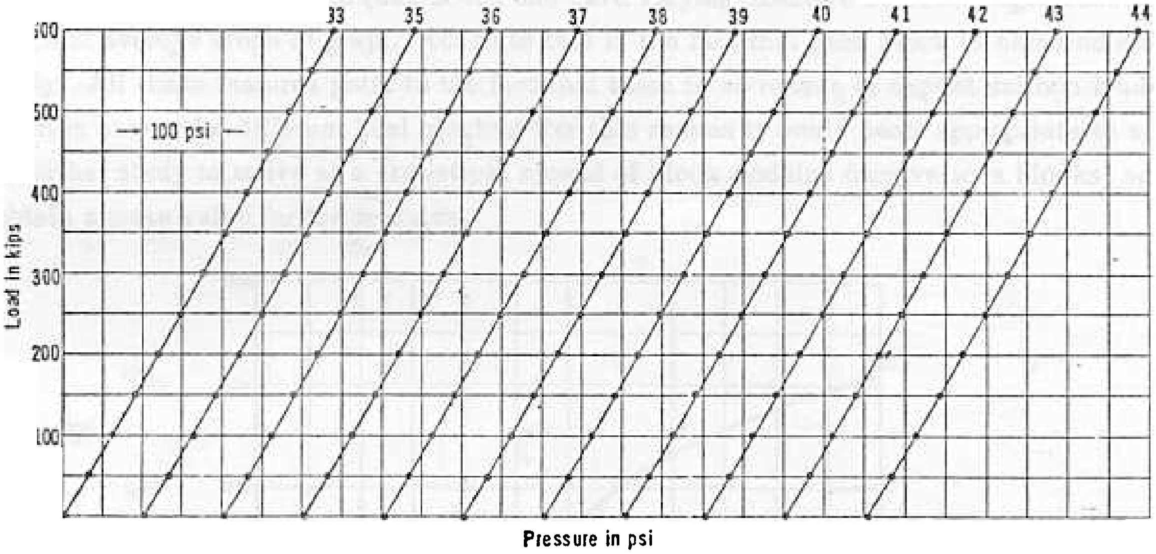


Figure 20d - Pressure Wafers 33 and 35 - 44

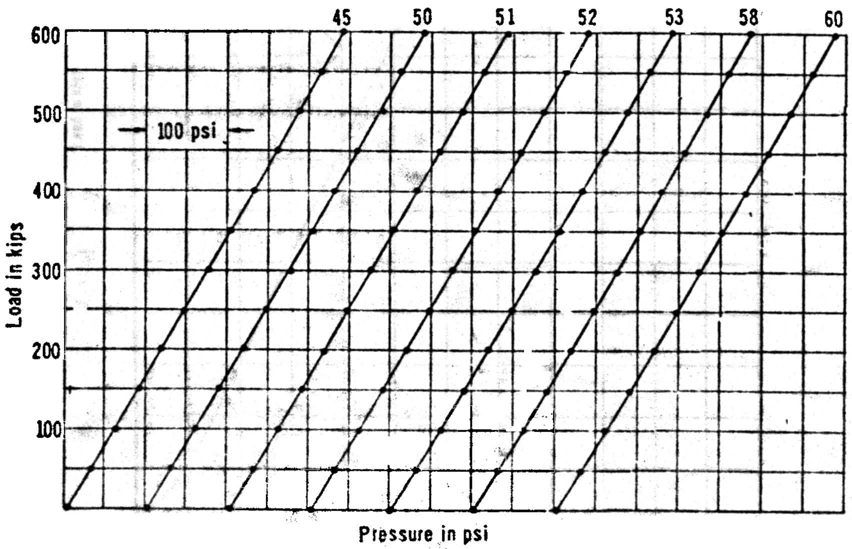


Figure 20e - Pressure Wafers 45, 50 - 53, 58, and 60

Figure 20 - Calibration Curves for Pressure Wafers

APPENDIX B

KEEL BLOCK CALIBRATION

After the keel block investigations on the USS INTREPID had been completed and the ship had been floated out of the dock, a representative keel block was selected for further tests. The block was taken to the Bureau of Standards where it was subjected to a load of 1450 kips, which is equivalent to a pressure of 46.2 tons/ft^2. Deflection readings were taken every 100 kips, and the load versus deflection plot is shown in Figure 21.

From this figure an apparent modulus of the keel block of 1310 tons/ft^2 can be determined. References 4 and 5 give an apparent modulus of 1260 tons/ft^2, which was used in the calculations.

It should be noted that only one keel block has been calibrated. Keel blocks are made of different types of hard wood (oak or fir) and have varying moisture contents, age, consistency, and average slope of grain. Added to this is the fact that each block is shimmed differently. All these features point to the fact that there is no reason to expect uniform load-deflection curves for different keel blocks. For this reason it would seem appropriate to suggest further study to arrive at a statistical spread of block modulus from various blocks, so as to obtain a mean value for the modulus.

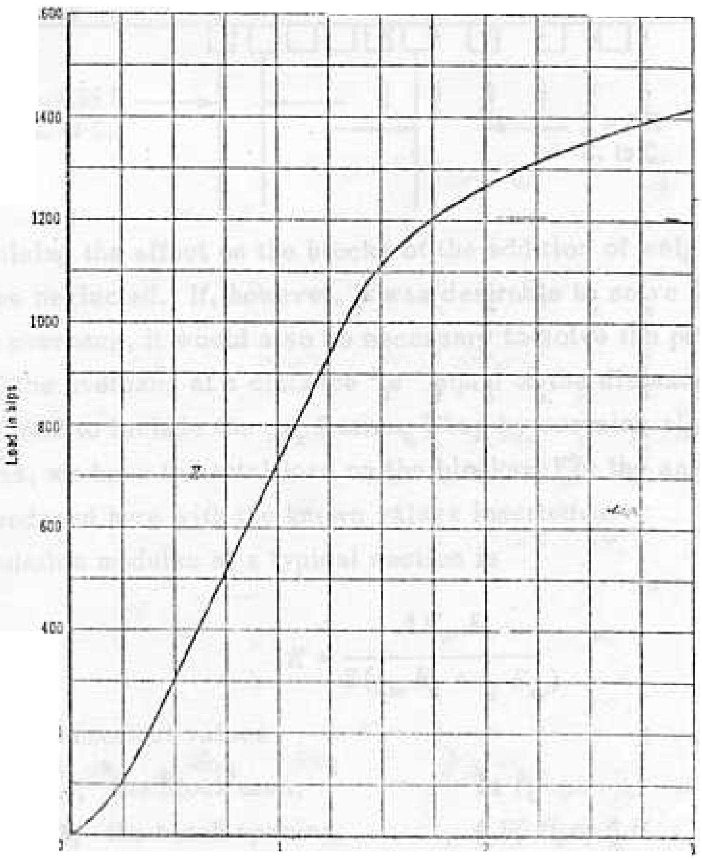


Figure 21 - Keel Block Deflection Plotted Against Load

APPENDIX C

SAMPLE CALCULATIONS BY TMB APPROXIMATE METHOD

The method of obtaining the theoretical curve of Figure 18 is illustrated. The formula for the load at any point x is

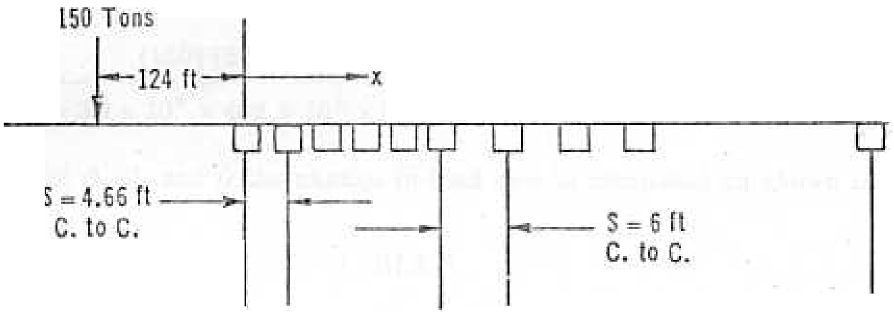
$$R_x = (Y_x)(K_x S_x) + q_{0x} S_x$$

where

$$Y_x = e^{-\beta x} (C \cos \beta x + D \sin \beta x)$$

Here Y_x is the deflection at any distance x,
K_x is the foundation modulus of the blocks,
S is the center-to-center spacing of the blocks,
q_0 is the weight per foot of the ship, and

the subscript x indicates that the quantities are those which exist at a distance x from the center of the aftermost block.



In determining the effect on the blocks of the addition of weight to the overhang the $q_{0x} S$ term can be neglected. If, however, it was desirable to solve for the block load with the 150 tons on the overhang, it would also be necessary to solve the problem with a load P equal to the weight of the overhang at a distance "a" equal to the distance to the center of gravity of the overhang, and to include the $q_{0x} S$ term. Then by summing algebraically the results of the two solutions, we have the total load on the blocks. For the sake of convenience, Figure 4 is reproduced here with the known values inserted.

The foundation modulus at a typical section is

$$K = \frac{A E_w E_c}{S(h_w E_c + h_c E_w)}$$

With the following numerical values

A,	the block area,	14 ft^2
S,	the block spacing	4.66 ft or 6 ft
h_w,	the height of wood,	33 in.

h_c, the height of concrete, 27 in.
E_w, the modulus of wood, 1260 tons/ft^2
E_c, the modulus of concrete, 196,360 tons/ft^2

$$K = \frac{(14)\,(1260)\,(196{,}360)}{6\,(6{,}490{,}000 + 34{,}000)} = 90 \text{ tons/in./ft}$$

The average moment of inertia in the stern area, 432×10^6 in.^{4} , was taken from the moment of inertia curve. A foundation modulus of 90 tons/in./ft was used. In the area of the aftermost blocks, this value was corrected to account for the crowding of five blocks into the space normally occupied by four, as can be noted in Table 7.

Then

$$\beta = \sqrt[4]{\frac{K}{4EI}} = \left[\frac{90 \times 2240}{12 \times 4 \times 30 \times 10^6 \times 432 \times 10^6}\right]^{1/4} = 0.000754/\text{in.}$$

$$C = \frac{P_o(1+a\beta)}{2EI\beta^3} = \frac{(150)\,(2240)\,[1 + (124)\,(12)\,(0.000754)]}{2 \times 30 \times 10^6 \times 432 \times 10^6 \times (0.000754)^3} = 0.0641 \text{ in.}$$

$$D = -\frac{P_o a}{2EI\beta^2} = -\frac{(150)\,(2240)\,(124)\,(12)}{2 \times 30 \times 10^6 \times 432 \times 10^6 \times (0.000754)^2} = -0.0339 \text{ in.}$$

From these values of β, C, and D the change in load can be computed as shown in Table 7.

TABLE 7

Calculated Effect of 150-Ton Load on Overhang of USS INTREPID

As solved previously: $\beta = 0.000754$/in. $C = 0.0641$ in. $D = -0.0339$ in.

x in.	βx	$e^{-\beta x}\cos\beta x$	$Ce^{-\beta x}\cos\beta x$	$e^{-\beta x}\sin\beta x$	$De^{-\beta x}\sin\beta x$	$Ce^{-\beta x}\cos\beta x + De^{-\beta x}\sin\beta x = Y$	Ky	Corrected Change in Load tons/ft
0	0	1.0000	0.0641	0	0	0.0641	5.77	6.92
600	0.45	0.5742	0.0368	0.2774	−0.0094	0.0274	2.47	2.47
1200	0.90	0.2527	0.0162	0.3185	−0.0108	0.0054	0.49	0.49
1800	1.36	0.0537	0.0034	0.2510	−0.0085	−0.0051	−0.46	−0.46
2400	1.81	−0.03[illegible]8	−0.0025	0.1590	−0.0054	−0.0079	−0.71	−0.71
3000	2.26	−0.0664	−0.0043	0.0805	−0.0027	−0.0070	−0.63	−0.63
3600	2.71	−0.0605	−0.0039	0.0279	−0.0009	−0.0048	−0.43	−0.43
4200	3.17	−0.0420	−0.0027	−0.0012	0.0000	−0.0027	−0.24	−0.24
4800	3.52	−0.0238	−0.0015	−0.0123	0.0004	−0.0011	−0.01	−0.01
5400	4.07	−0.0103	−0.0007	−0.0137	0.0005	−0.0002	−0.002	−0.002
6000	4.52	−0.0021	−0.0001	−0.0105	0.0004	0.0003	0.003	0.003

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