Report 1591

DEPARTMENT OF THE NAVY

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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INVESTIGATION OF LOADS ON KEEL BLOCKS DURING DRYDOCKING OF USS VALLEY FORGE (CVS 45), USS FORRESTAL (CVA 59), AND USS BENNINGTON (CVS 20)

by

Joseph S. Brock

[redacted]

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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30 March 1962

From: Commanding Officer and Director, David Taylor Model Basin
To: Chief, Bureau of Ships (442) (in duplicate)

Subj: S-F013 0301 Task 1972 Keel-block loading; forwarding of report on

Ref: (a) BUSHIPS ltr N16-8(442) Ser 442-10 of 15 May 1953
(b) BUSHIPS ltr CVA/S29(442) over A11/NS731-037 Ser 442-22 of 22 Mar 1957

Encl: (1) DATMOBAS Report 1591 entitled "Investigation of Loads on Keel Blocks during Drydocking of USS VALLEY FORGE (CVS 45), USS FORRESTAL (CVA 59), and USS BENNINGTON (CVS 20)" 2 copies Separate Cover

1. Reference (a) established a research project at the David Taylor Model Basin for the investigation of the loads developed on keel blocks under ships in drydock. This project was expanded by reference (b) to include the investigation of the effect of the elasticity of the drydock on the keel-block loads. The results of tests on two aircraft carriers docked at the Norfolk Naval Shipyard and one carrier docked at the San Francisco Naval Shipyard are reported in enclosure (1).

2. Test results indicate that there is no practical overall difference in docking aircraft carriers in graving docks of different elasticities, and that the transient loads on the knuckle blocks when loading a ship with large trim are not critical. It is further shown that the skeg of the FORRESTAL class could be shortened 12 feet and possibly more without producing unacceptable keel-block loads. Comparison of the experimental results with theory indicated that existing analytical methods are satisfactory for computing keel-block loads.

E.E. Johnson
E.E. JOHNSON
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INVESTIGATION OF LOADS ON KEEL BLOCKS DURING DRYDOCKING OF USS VALLEY FORGE (CVS 45), USS FORRESTAL (CVA 59), AND USS BENNINGTON (CVS 20)

by

Joseph S. Brock

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TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

ABSTRACT

Loads on the keel blocks were measured for two classes of aircraft carriers. The tests were conducted to provide reliable experimental data which could be used as the basis for the rational development of docking plans, and the determination of the allowable extent of the stern overhang.

The results of tests on the ESSEX class show that the measurements of block loads are reproducible for independent drydockings; there is no practical overall difference in docking this class in graving docks of different elasticities; and the transient loads on the knuckle blocks when landing a ship with large trim (4-5 ft) are not critical. The results of tests on the FORRESTAL class indicate that the docking plan is adequate and that the skeg of this class of ship could be shortened by 12 ft and possibly more without producing unacceptable keel-block loads.

Experimental values of keel-block loads for all ships tested when compared with theory confirm the results of previous tests, which showed that existing theoretical methods are satisfactory for computing these loads.

INTRODUCTION

For several years the Bureau of Ships has sponsored a research project on the determination of keel-block loads for naval ships in a drydock.[1,2] One of the main purposes of this work was to provide reliable experimental data on keel-block loads. In addition, it was desired that simplified methods for calculating the loads be developed since the most complete method[3] of calculating these loads is long and time-consuming. These general objectives have been achieved previously for some types of ships.[4,5] Reference 4 contains the results of keel-block loads measured on several aircraft carriers, and Reference 5 reports the measurements of loads for a long-hull DD 692-Class destroyer. These investigations left several problems to be investigated. Thus the original objectives were broadened to cover the more important unanswered questions. These latter objectives may be summarized as follows:

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[1]References are listed on page 45.

1. To determine whether a series of measurements could be repeated to confirm results on separate drydockings of the same ship.

2. To determine keel-block loads on the larger type aircraft carrier, such as the CVA 59 class.

3. To determine the effect of the elasticity of the drydock on the keel-block loads.

4. To determine experimentally the maximum pressures sustained by the blocks at the point of first contact (knuckle) when docking with trim.

To accomplish the first objective, keel-block loads were measured a second time on USS VALLEY FORGE (CVS 45) and were compared with the measured loads of a previous drydocking.[4] USS FORRESTAL (CVA 59) was chosen to carry out the second objective. USS BENNINGTON (CVS 20)* was chosen to pursue the third and fourth objectives.

Pressures wafers originally described in Reference 4 were used to measure the keel-block loads on all three ships.

In addition to measuring keel-block loads, tests were made on FORRESTAL to determine the <u>deflections</u> of keel blocks resulting from the applied loads. A transit survey was made of the keel of FORRESTAL to determine the keel profile of the skeg area as docked. A survey was also made of the drydock before and after drydocking to determine the deflection of the dock floor due to the keel-block loads. Also, strains were measured on the ship's hull at a section near the aftermost block to study the effect of the stern overhang on the stress in the hull due to drydocking.

Keel-block loads were measured for BENNINGTON in the San Francisco Naval Shipyard to study the effect of the dock itself on the block loads. All other tests on aircraft carriers were made in the Norfolk Naval Shipyard in Drydock 8. This dock is a thick, concrete slab, resting on a relatively soft foundation of marl through steel piles and thus should be less rigid than the drydock in San Francisco, which rests on a solid rock foundation.

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*Formerly CVA 20.

Additional tests were also made on BENNINGTON to determine the nature of the creep in the block deflections during the docking period. A survey was made on the keel of BENNINGTON to determine its deflection profile in the "in-dock" condition. A survey was also made on the main deck before and after docking to determine the magnitude of the sag during docking. Finally, transient block loads were measured for BENNINGTON as the ship was being docked to determine the maximum loads in the skeg area as the ship landed with large trim by the stern.

TEST PROCEDURE AND RESULTS

USS VALLEY FORGE (CVS 45)

VALLEY FORGE was drydocked at the Norfolk Naval Shipyard on 119 centerline blocks and 130 side blocks. Keel-block loads were measured on this ship to compare with loads previously measured on the same ship to determine the reproducibility of pressure-wafer readings for a second docking in the same drydock. Also, for this test, it was possible to obtain information (weight data, and foundation modulus) from which the keel-block loads could be calculated by theoretical methods. This affords another opportunity to compare measurements with calculated results.

At the time of docking, 7 Aug 1956, the ship and dock setup had the following characteristics:

Displacement of ship	31,648 tons
Length of ship, B.P.	820 ft
Length of overhang of ship to point of reference	153 ft
Trim by stern	1 ft 6 1/2 in.
Docking position number	1
Bearing area of centerline blocks	1666 sq ft
Bearing area of side blocks	881 sq ft
Nominal block pressure	12.43 tons/sq ft
Nominal block load, centerline blocks	174 tons(390 kips)

Figure 1 shows a typical keel-block with more concrete and less wood than used in earlier dockings. Figure 2 shows the stern-block arrangement wherein the first six blocks were separated by 14-in. spacer blocks which did not touch the hull. All other centerline blocks were located 6 ft apart on centers as shown by the docking plan.[6] The side blocks were 14-in. piers located 4 ft apart on centers.

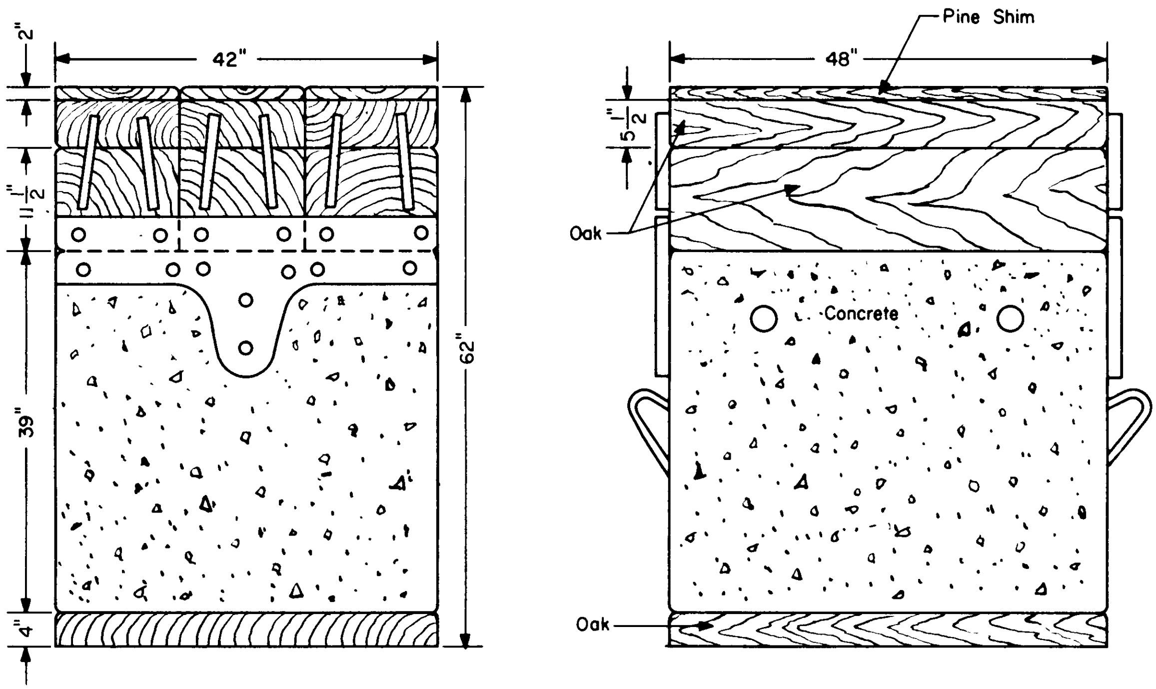

Figure 1 - Typical Keel Block Used in Docking CVS 45 and CVA 59

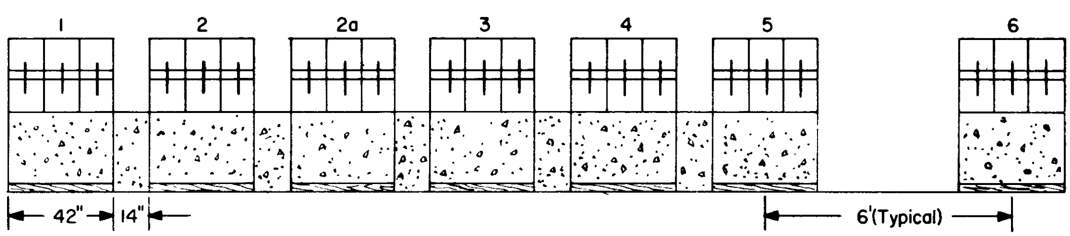

Figure 2 - Stern-Block Arrangement for USS VALLEY FORGE (CVS 45)

Because the side blocks were 6 ft by 14 in. with the long dimension in the athwartship direction, they were placed upon two 3 1/2- by 4-ft blocks so that regular pressure wafers could be used to measure the loads on the side blocks.

Pressure-wafer readings were taken 2 hr, 19 hr, and 34 days after the ship was docked. The loads obtained from these readings are shown in Table 1. The maximum recorded load was 775 kips at Block 11. The aftermost block (Block 1) carried an initial load of 700 kips.

Table 1

Loads on Instrumented Blocks under USS VALLEY FORGE (CVS 45)

Block	Load in kips			Block	Load in kips		
	2 hr	19 hr	34 day		2 hr	19 hr	34 day
1	700	508	515	54	125	160	349
2	650	680	F	56	375	385	435
2a	650	650	F	58	190	225	370
3	373	F	-	60	665	625	570
4	759	733	618	61	675	665	335
5	739	695	595	64	385	400	450
7	650	604	539	66	325	351	435
9	695	675	595	68	445	455	550
11	775	746	660	70	515	510	520
13	764	737	617	72	F	-	-
15	F	-	-	74	706	665	615
16	610	628	610	76	635	635	585
18	583	603	660	78	480	485	480
20	650	650	620	80	420	405	F
22	475	520	635	82	360	370	450
24	415	445	590	84	460	480	540
26	535	545	535	86	370	F	-
28	650	665	670	88	525	425	475
30	569	585	612	93	490	465	435
32	475	503	522	112	0	0	0
34	345	400	465	115	0	0	0
36	435	435	500	Side Blocks			
38	475	490	505	1P	48	55	68
40	500	500	510	1S	210	174	150
42	330	360	435	22P	115	118	118
44	540	510	460	22S	86	94	100
46	415	445	510	42P	236	225	195
48	330	335	380	42S	184	178	161
50	150	170	295	64P	5	5	52
52	560	545	525	64S	53	56	125

P, S - Denote Port and Starboard Respectively

F - Denotes Wafer Failure

USS FORRESTAL (CVA 59)

FORRESTAL was drydocked in Graving Dock 8 at the Norfolk Naval Shipyard on 190 centerline blocks and 408 side blocks. The docking was in general accordance with an auxiliary docking plan[7] designed for the first docking of the class ship at the Norfolk Naval Shipyard. Keel-block load tests were made on this ship because it was the first of its class and little information was available to assist in evaluating the adequacy of design docking plans. In addition, it was desired to obtain information which could be used in designing the skeg and the allowable length of overhang in future designs.

At the time of docking, 10 May 1956, the ship and the dock setup had the following characteristics:

Displacement of ship	66,446 tons
Length of ship, B.P.	990 ft
Length of overhang of ship to point of reference	126 ft
Trim by bow	0.34 ft
Docking position	1
Bearing area of centerline keel blocks*	2454 sq ft
Bearing area of side blocks	4424 sq ft
Nominal block pressure	9.66 tons/sq ft

Figure 3 is a view of the dock setup prior to drydocking. Figure 4 shows the location of the keel blocks; the position of pressure wafers is indicated by x. Note that many side blocks were omitted to assure access to various openings in the hull. The area of the blocks left out was 1120 sq ft. Also, the auxiliary docking plan was designed on the assumption that the centerline blocks in way of the side blocks (Frames 39 - 187) were for local support only and did not contribute to the total bearing area.

*Total area of all blocks on centerline including blocks in way of side blocks (Frames 39 - 187).

Figure 3 - Drydock Setup Prior to Docking USS FORRESTAL (CVA 59)

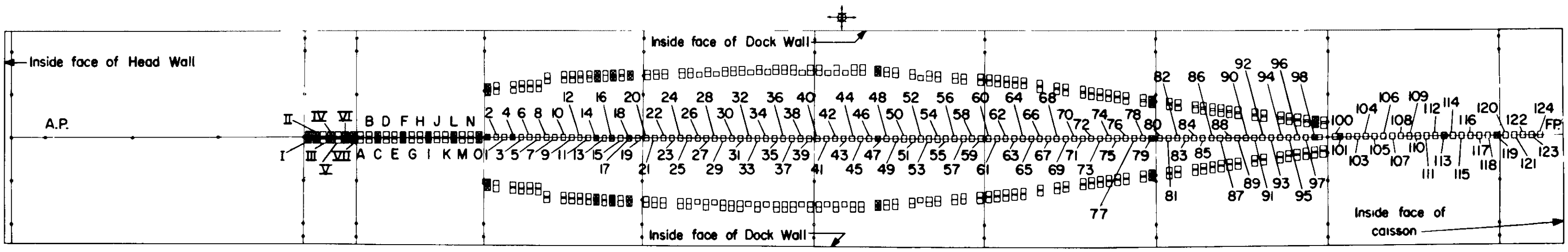

Figure 4 - Locations of Pressure Wafers and Drydock Survey Stations during Drydocking of USS FORRESTAL (CVA 59)

⊠ Denotes position of wafers for small (14" x 48") keel blocks

⊠ Denotes position of wafers for large (42" x 48") keel blocks

○ Denotes position of survey stations

Figure 5 shows the stern-block arrangement; note that seven blocks were crowded into the space normally occupied by six blocks. All other blocks were located 6 ft apart on centers except that centerline Block 99 was placed against Block 98, and Block 100 was placed against Block 101.

Figure 5 - View of Stern Blocks Used under USS FORRFSTAL (CVA 59)

Pressure-wafer readings were taken 15 hr, 111 hr, 144 hr, and 156 hr after the ship was docked. The corresponding loads are tabulated in Table 2. Centerline Block 4 had the highest initial load, 730 kips. The load on this block only decreased to 690 kips after 111 hr. The highest loaded side block was inboard Block 79 on the port side. This block carried 530 kips 15 hr after docking and increased to 545 kips after 111 hr.

TABLE 2

Recorded Keel-Block Loads in KIPS under USS FORRESTAL (CVA 59)

Block	Port Side			Centerline			Starboard Side			Time of Readings After Docking
	Outboard Block	Center Block	Inboard Block	Port Block	Center Block	Stbd Block	Inboard Block	Center Block	Outboard Block	
I				290 215 290 90	53 70 92 29	300 230 345 80				15 hr 111 hr 144 hr 156 hr
II				275 200 280 82		377 280 370 120				
IV				540 435 520 295		530 430 530 288				
VI				555 500 577 385		595 530 585 408				
VII				565 560 590 465	165 170 170 130	615 600 660 175				
C				245 250 273 200	150 145 140 120	520 510 530 445				
F				505 550 535 520	180 180 176 165	595 600 592 546				
I				665 660 662 622	117 135 130 125	595 650 640 605				
L				540 565 560 540	228 225 215 212	360 440 450 448				
O				420 448 444 444	130 125 124 124	405 460 440 450				
1	0 0	0 0	0 0		out		0 0	0 0	0 0	15 hr 111 hr
4					730 690					
14	1 1	7 15	290 355		550 585		240 265	30 65	80 95	
16	120 150	83 92	250 295		435 500		20 65	30 65	230 245	
18	305 315		160 225		455 490		55 90		95 125	
47	360 355		380 320		460 450		305 320		500 470	
79	0 0	0 0	530 545		505 530		395 390	52 70	35 25	
98	10 0	2 0	295 300		430 430					
101					out					
113					210 270 300 0					15 hr 111 hr 144 hr 156 hr
119					320 250 225 0					

The readings taken at 144 hr and 156 hr were used to obtain the diurnal effect of the sun's radiation on the block pressures.

The 144-hr readings were taken at 1600 when the flight deck should be warmest, and the 156-hr readings were taken at 0400 when the flight deck should be coldest. The air temperatures at the time of these readings were 74°F and 53°F, respectively. The deck temperature was not determined. The effect of the sun's radiation on the block loads is shown in Figure 6.

The centerline keel-block deflections were measured in the following manner: Before the ship was docked the relative heights of the keel blocks were measured by a 2-in.-travel Ames dial indicator mounted on a 5-ft rod. An aluminum I-beam was laid across the keel block to give a smooth reference surface for the block elevation. To straighten out any warped sections of the shim material, a 200-lb weight was placed on the I-beam. After the ship was docked, the readings were repeated using the keel of the ship as the reference surface. The difference in readings at corresponding locations gives the block deflections, which are shown in Figure 7.

The stern section of the keel was surveyed with an engineer's level to obtain a keel profile in the "in-dock" condition. The purpose of this survey was to determine any irregularities in the keel profile in the event of irregular pressure readings in the stern area, and to determine if any "turn up" existed in the keel profile. The results of this survey are shown in Figure 8.

The dock floor was surveyed before and after docking to determine the dock deflections and/or settlement. The survey stations are shown in Figure 4. The primary purpose of this survey was to either verify or disprove one of the three basic assumptions (the dock floor is rigid) made in calculating keel-block loads, Reference 3. Figure 9 shows the change in the longitudinal profile of the centerline of the dock, and Figure 10 shows the change in various transverse profiles of the dock floor due to docking the ship.

Strain gages were used to determine the magnitude of the shear in the ship's structure due to the stern overhang. A total of 28 strain-gage rosettes, consisting of 84 SR-4 electrical-resistance strain gages, were applied to the hull and longitudinal bulkheads at Frame 220. The gages were located as shown in Figure 11, and were moisture-proofed with "Ozite B" compound. The gages were connected to switchboxes containing enclosed silver-contact

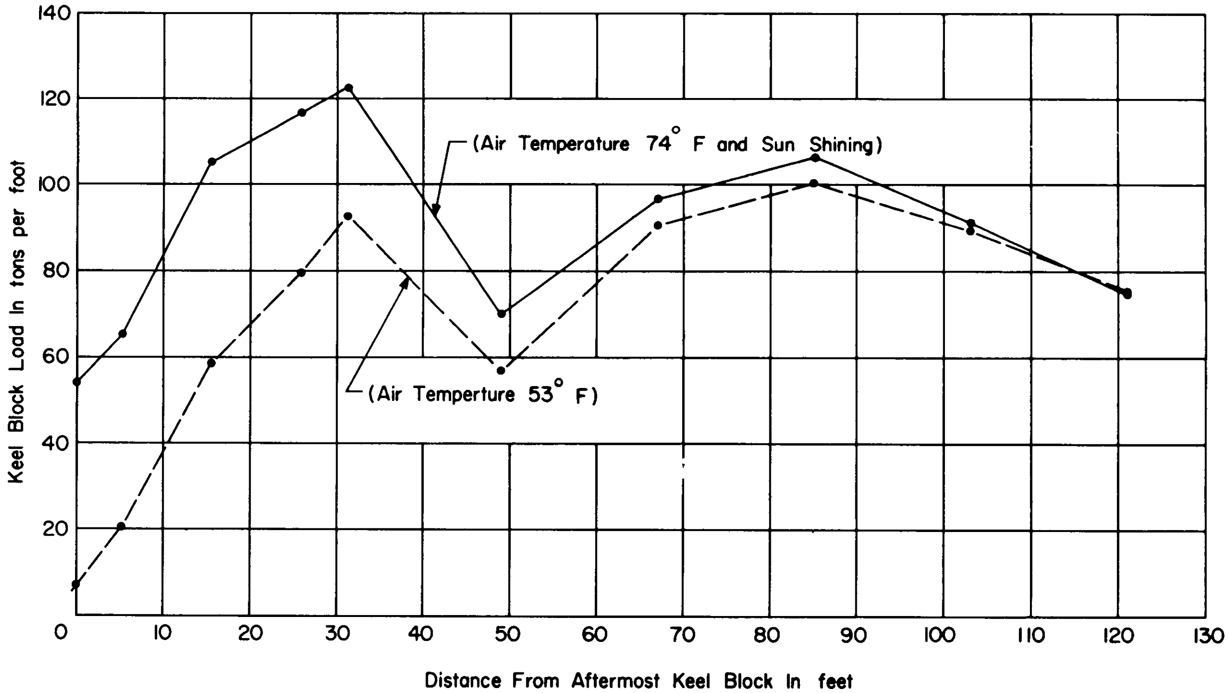

Figure 6 - Diurnal Effect on Keel-Block Loads in Stern Area for USS FORRESTAL (CVA 59)

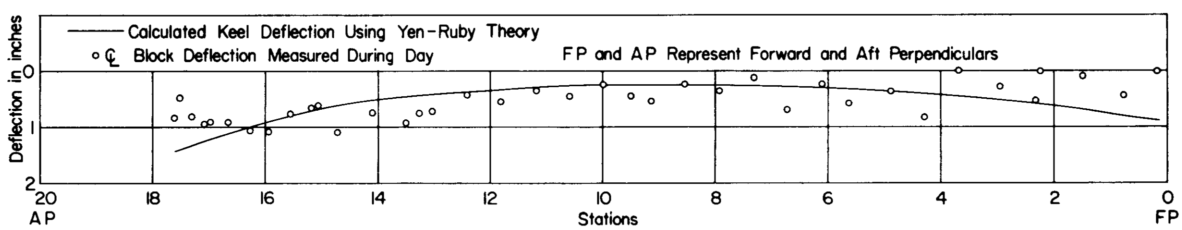

Figure 7 - Keel-Block Deflections, USS FORRESTAL (CVA 59)

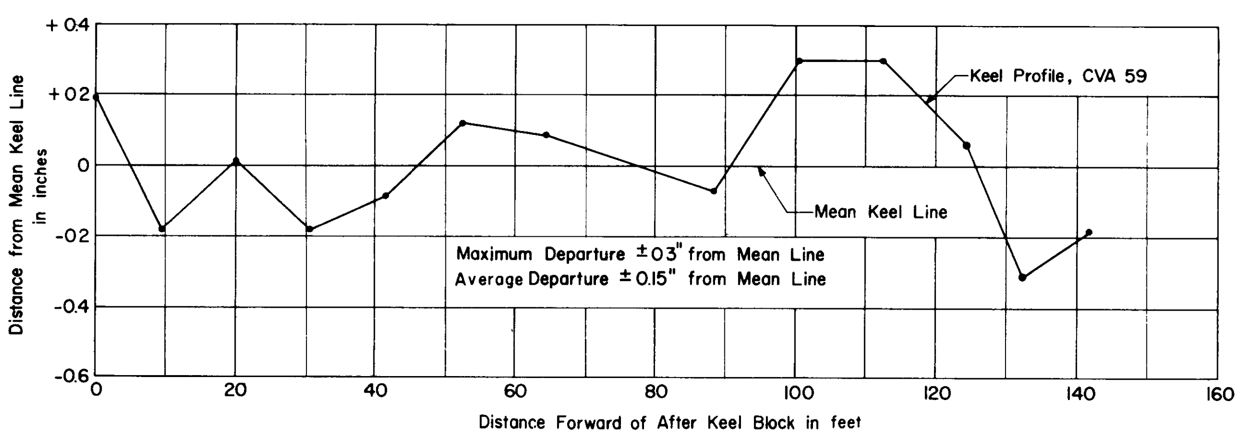

Figure 8 - Keel Profile in Skeg Area, USS FORRESTAL (CVA 59)

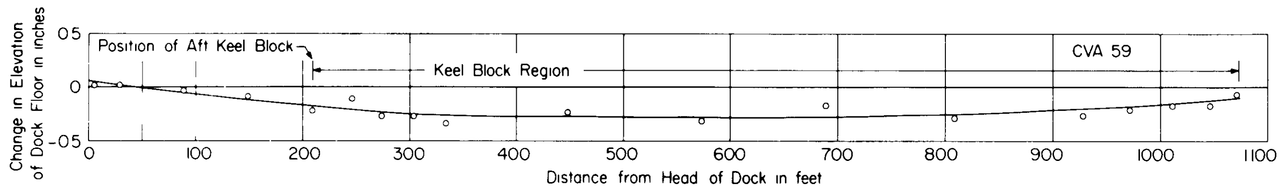

Figure 9 - Deflection of Centerline of Dock Floor Due to Docking
USS FORRESTAL (CVA 59)

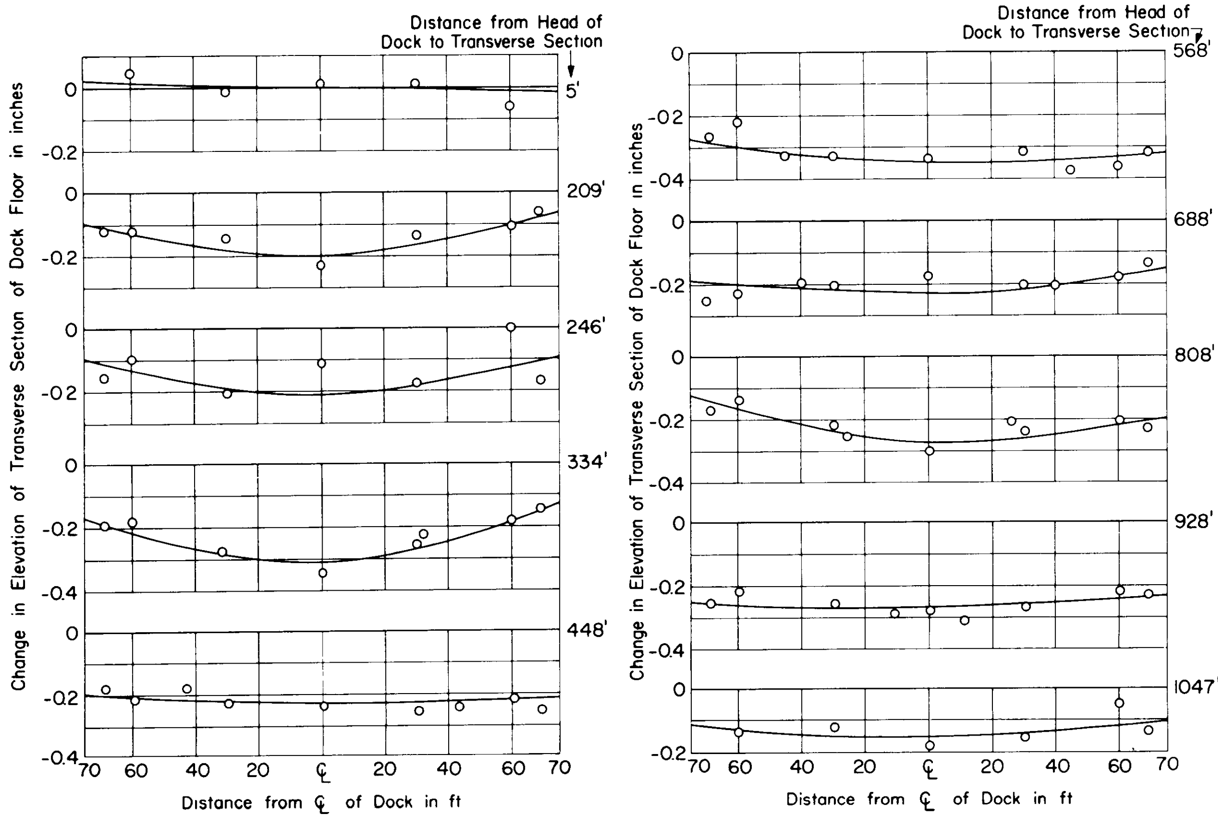

Figure 10 - Deflection of Transverse Sections of Dock Floor Due to Docking
USS FORRESTAL (CVA 59)

rotary switches. Strains were read by Baldwin Type-L strain indicators at three recording stations. Zero readings were taken with the ship afloat at 0700 when the air temperature was 60°F and again at 1230 when the temperature was 75°F. The differences in these readings are shown as the "temperature strains" on the left side of Table 3. Final readings were taken with the ship resting on the keel blocks at 1745 when the temperature was 77°F. The difference in the readings at 1230 and 1745 are the "load strains" on the right side of the

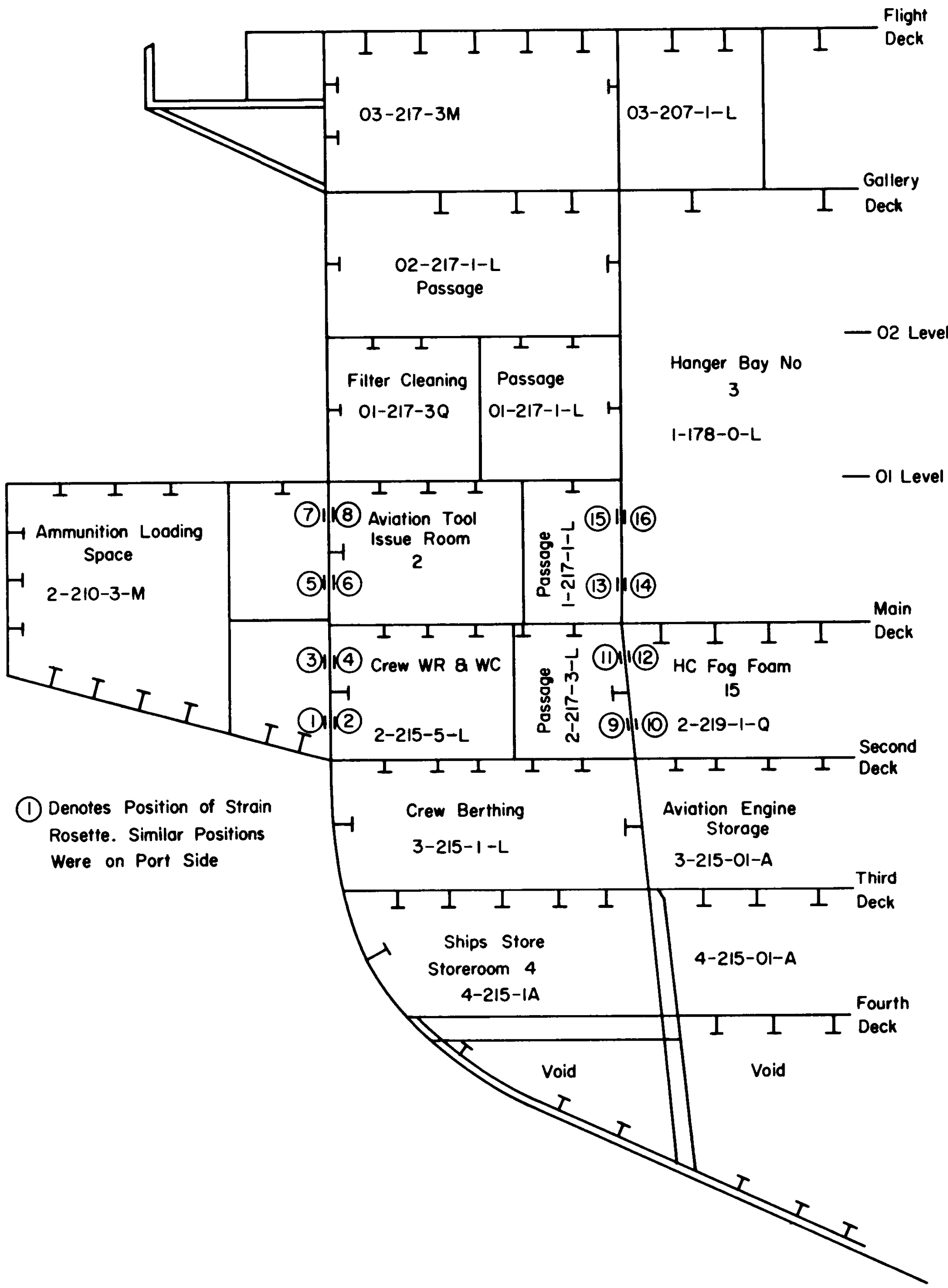

Figure 11 - Location of Strain Rosettes on Hull and Longitudinal Bulkhead of USS FORRESTAL (CVA 59)

Frame 220 facing aft

same table. The table shows that the magnitude of the temperature strains are as large or larger than the load strains.

TABLE 3

Membrane Strains on Hull and Longitudinal Bulkhead near Frame 220 of USS FORRESTAL (CVA 59)

		Temp Strains 0700-1230 60°F-75°F			Load Strains 1230-1745 75°F-77°F		
		Strain Gage Orientation *					
Rosette Numbers		e_H	e_D	e_V	e_H	e_D	e_V
1 and 2	Stbd	-50	10	10	-20	-20	5
3 and 4		-75	-50	40	-20	-25	5
5 and 6		-40	-30	25	5	0	0
7 and 8		-50	+15	35	-20	10	15
9 and 10		5	0	0	-20	-10	10
11 and 12		- 5	-10	20	-25	-20	10
13 and 14		-10	5	10	- 5	10	10
15 and 16	↓	45	50	20	-10	20	10
1 and 2	Port	-40	-30	5	-10	-10	10
3 and 4		-40	-10	40	-10	- 5	20
5 and 6		-50	5	40	5	10	35
7 and 8		-60	0	45	-10	10	20
11 and 12		20	35	40	5	0	40
13 and 14	↓	50	50	40	-10	20	25

*V = Vertical, H = Horizontal, D = Diagonal

USS BENNINGTON (CVS 20)**

BENNINGTON was drydocked at the San Francisco Naval Shipyard on 119 centerline blocks and 46 side blocks. Keel-block loads were measured on this ship to evaluate the effect of the elasticity of the dock on these loads. Previous tests on similar aircraft carriers were made in a concrete dock at the Norfolk Naval Shipyard. This dock rests on piles driven into a soft foundation of marl whereas the dock in the San Francisco Naval Shipyard

**Formerly CVA 20.

rests on solid rock. In addition to evaluating the effect of the elasticity of the dock, the maximum keel-block loads on the stern or knuckle blocks, when docking with large trim by the stern, were determined experimentally.

At the time of docking, 20 Jul 1957, the ship and the dock setup had the following characteristics:

Displacement of ship	32,760 tons
Length of ship, B.P.	820 ft
Length of stern overhang to point of reference	161 ft
Trim by stern, docking	4 ft 6 in.
Trim by stern, undocking	5 ft 4 in.
Docking position	2
Bearing area, centerline blocks	1666 sq ft
Bearing area, side blocks	938 sq ft
Total bearing area	2604 sq ft
Nominal block pressure	12.58 tons/sq ft
Nominal block load, centerline blocks	176 tons (394 kips)

The dock arrangement before the ship was docked is shown in Figure 12. The docking was in general accordance with the docking plan[8] for the ship with the following exceptions:

1. The ship was docked on relatively high blocks(approximately 6 1/2 ft) as a production convenience. The composition of a typical centerline block is shown in Figure 13.

2. The stern-block arrangement, Figure 14, shows that 16 blocks were crowded into the space normally occupied by 10 blocks. All other centerline blocks were 6 ft apart on centers. Keel blocks were placed as shown in Figure 15.

After the ship was docked, an individual pressure gage was installed on each wafer as shown in Figure 16. Centerline Blocks 1 through 64 were instrumented. Protection from mechanical damage was provided by wooden boxes as shown in the figure.

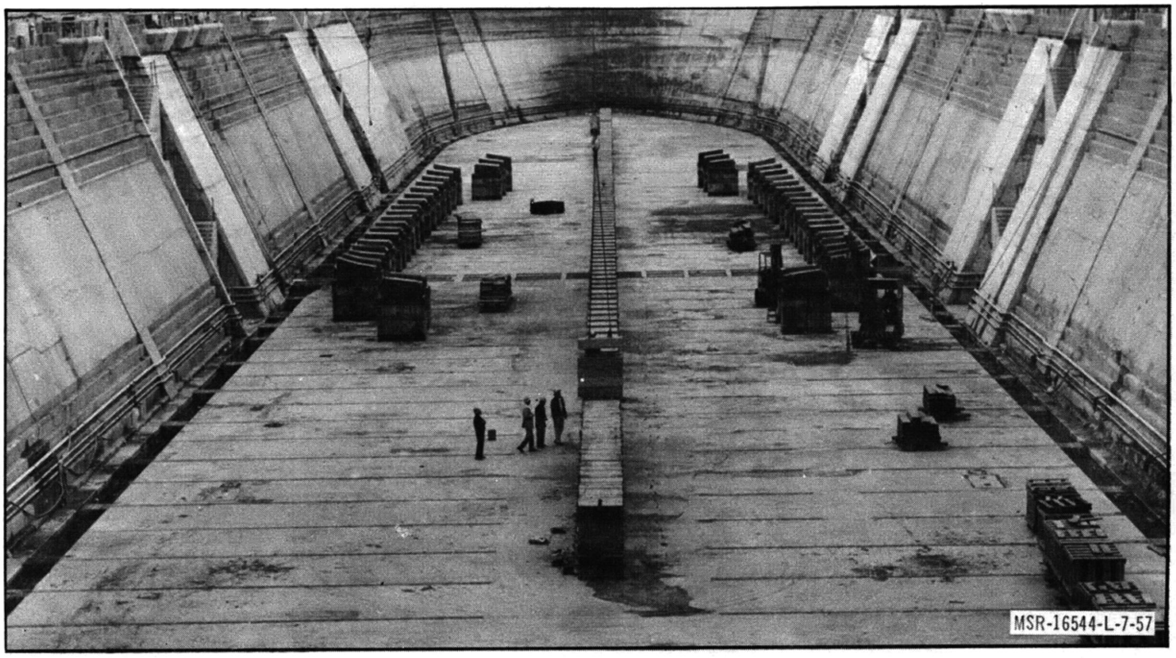

Figure 12 - Drydock Setup Prior to Docking USS BENNINGTON (CVS 20)

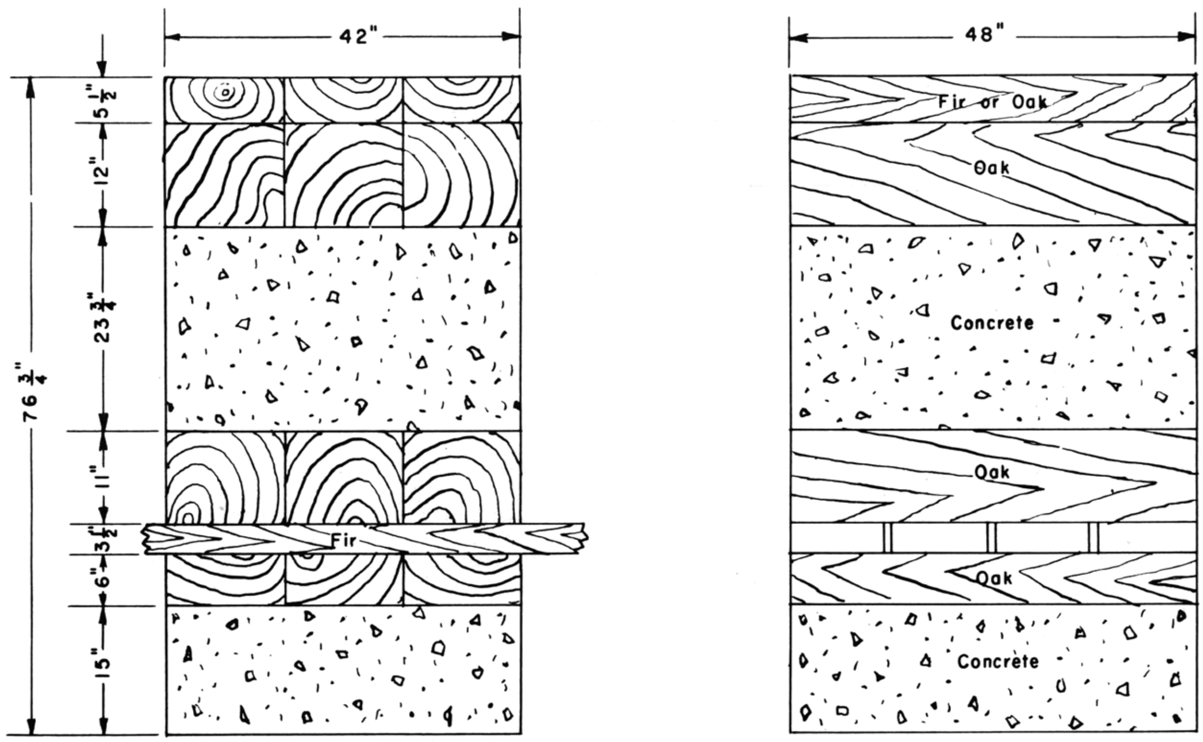

Figure 13 - Typical Centerline Block Used in Docking USS BENNINGTON (CVS 20)

Hard caps (oak) were used on blocks 1 through 16

Soft caps (fir) were used on all other blocks

Figure 14 - View of Stern Blocks Used in Docking USS BENNINGTON (CVS 20)

Pressure readings were taken on all gages periodically throughout the docking period at approximately the same time of day to study the redistribution of load as a function of time. The loads on the individual keel blocks are tabulated in Table 4. The measured loads on the first and last days in drydock are shown in Figure 17. After the loads had become stabilized, pressure readings were taken every 2 hours for a 24-hour period to study the diurnal temperature effect. These loads are listed in Table 5. The loads on the last six blocks are plotted in Figure 18.

Keel-block deflections were determined from the changes in block heights. The block heights were measured just before flooding the dock and at selected times during the docking period. Measurements were made with a Vernier scale reading to 0.01 in. Figure 19 shows the block deflection on the first and last days of the docking period. Figure 20 shows the average block deflection as a function of time while the ship was in dock.

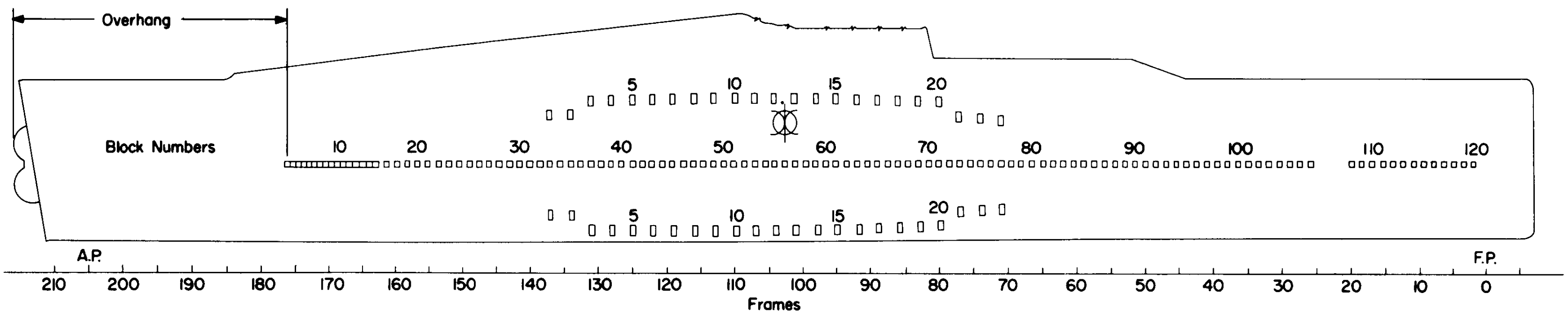

Figure 15 - Locations of Keel Blocks Used in Docking USS BENNINGTON (CVS 20)

Figure 16 - View of Instrumented Keel Blocks under USS BENNINGTON (CVS 20)

The hangar deck was surveyed for hog or sag prior to drydocking and after the ship was in dock with an engineer's transit to determine the overall hull deflection due to drydocking. Stations were taken only in way of transverse bulkheads to preclude the possibility of picking up local effects. The keel was also surveyed after the ship was docked to obtain the keel profile as docked. Both surveys were made at night to minimize temperature effects. The results of these surveys are shown in Figure 21.

Finally, pressures were measured on stern blocks as the ship came down upon the knuckle or point of first contact due to docking with trim. This was accomplished by using remote-reading pressure gages with Baldwin strain indicators while the dock was being pumped out. Because changes were too fast to follow with the manually operated instrument, the experiment was repeated in undocking, and the output from the pressure gages were recorded automatically with an electromagnetic oscillograph. The "knuckling down" loads are shown in Figure 22, and the "knuckling up" loads are shown in Figure 23. The measurements of loads for Block 2 were not available because the pressure transducer failed in the "knuckling up" test.

TABLE 4

Keel-Block Loads under USS BENNINGTON (CVS 20) Throughout Docking Period

		Individual Keel Block Loads in kips													
	Avg Temp deg F	59	60	59	61	60	61	58	60	61	60	61	64	65	65
Block	Wafer Number \ Date	20 Jul	21 Jul	22 Jul	26 Jul	28 Jul to 3 Aug	4 Aug to 10 Aug	14 Aug to 17 Aug	18 Aug to 24 Aug	25 Aug to 31 Aug	1 Sep to 7 Sep	8 Sep to 14 Sep	15 Sep to 21 Sep	23 Sep	25 Sep
1	2	632	632	602	602	595	574	563	576	578	570	547	552	550	585
2	3	600	605	591	600	605	589	585	598	592	589	561	563	567	585
3	13	566	605	577	583	581	569	555	564	560	546	528	533	535	567
4	15	714	715	698	695	678	661	647	644	643	632	620	626	626	652
5	17	815	799	748	725	704	684	670	685	674	667	660	659	657	675
6	19	775	775	762	755	743	727	716	710	708	698	693	693	695	709
7	22	750	739	725	715	708	696	689	686	692	685	677	678	681	696
8	24	820	780	766	735	726	709	705	696	699	692	685	683	681	681
9	25	934	887	867	830	807	809	771	765	762	722	732	744	745	760
10	27	812	783	771	750	730	710	698	692	689	680	676	674	660	691
11	32	825	757	752	745	723	711	687	656	658	655	654	652	660	673
12	39	785	750	735	713	696	675	667	660	661	655	651	648	652	661
13	52	795	750	734	707	688	668	652	644	642	634	627	627	630	640
14	53	767	740	736	705	692	674	662	656	653	647	640	642	644	653
15	54	857	829	820	790	772	752	744	734	733	721	717	717	721	725
16	56	745	713	707	685	671	658	655	649	641	636	637	636	643	645
17	57	255	316	331	365	378	380	396	397	401	400	404	403	415	413
18	59	266	325	336	370	380	377	396	400	406	405	411	416	425	425
19	61	463	475	485	483	476	467	468	469	467	462	462	463	472	470
20	62	515	520	523	518	504	495	493	485	487	481	482	481	485	485
21	63	393	433	497	470	475	471	485	485	487	484	496	491	505	502
22	64	330	372	395	–	–	Broken	Valve	–	–	–	–	–	–	402
23	30	380	407	415	416	420	416	430	438	431	430	436	436	447	444
24	18	345	370	380	360	384	392	410	416	416	419	432	432	440	437
25	20	447	486	499	465	493	499	520	524	519	520	534	534	540	537
26	35	515	520	525	467	441	493	507	513	459	480	508	515	521	519
27	14	572	537	537	520	527	531	540	534	533	531	536	535	541	536
28	8	546	545	553	497	513	520	526	531	521	520	526	523	535	520
29	9	592	590	591	535	537	536	527	529	519	518	520	520	523	518
30	10	550	554	554	537	521	512	510	510	508	509	511	509	512	510
31	11	542	561	566	547	517	497	477	459	433	416	415	399	400	380
32	12	475	285	0	–	–	–	–	–	–	–	–	–	–	Failed
33	7	437	462	480	465	458	455	455	459	456	454	463	464	467	464
34	16	–	–	498	438	450	481	476	483	476	476	484	483	485	483
35	4	443	460	473	473	409	466	462	467	465	467	475	477	480	476
36	5	516	509	513	500	482	485	471	471	469	468	470	470	471	469
37	21	410	427	440	455	458	461	461	467	470	474	482	483	485	485
38	23	486	491	500	499	492	490	485	488	491	495	500	498	498	495
39	26	353	367	380	384	383	385	382	388	389	395	398	395	395	394
40	28	386	400	412	418	416	415	415	422	424	430	431	427	425	421
41	29	392	409	422	425	425	432	428	436	444	457	448	449	442	442
42	6	450	452	455	445	440	439	425	422	430	437	421	420	413	413
43	31	496	500	503	497	486	485	475	478	490	501	473	477	469	467
44	33	605	530	493	377	321	332	329	326	334	333	305	322	322	300
45	34	580	565	563	541	523	520	507	510	505	470	452	469	465	467
46	1	615	593	593	570	547	542	532	530	531	502	498	504	493	496
47	36	636	625	628	608	588	580	574	574	578	583	572	566	550	560
48	37	272	290	297	297	296	298	302	305	312	312	315	316	312	313
49	38	558	545	552	523	505	498	495	492	492	491	488	489	477	480
50	40	533	555	560	542	542	541	538	540	540	540	540	540	522	520
51	41	397	407	412	405	401	403	407	406	413	420	415	419	412	410
52	42	577	552	552	517	507	499	494	485	492	491	479	480	475	472
53	43	638	605	602	558	545	530	521	513	516	511	499	502	500	497
54	44	482	476	478	455	452	445	441	440	441	440	436	437	435	435
55	45	546	524	526	492	484	477	470	459	463	461	459	459	457	445
56	46	517	515	521	502	503	500	493	486	489	487	487	489	488	484
57	47	412	415	425	414	427	428	427	421	425	427	428	432	432	428
58	48	270	295	290	295	207	188	213	205	226	239	248	263	275	278
59	49	422	408	425	405	418	416	414	413	416	414	419	425	425	425
60	50	263	292	305	280	318	330	335	342	339	342	349	356	357	355
61	51	227	243	254	248	256	260	266	266	269	274	279	286	286	286
62	55	306	325	336	327	336	338	342	338	320	316	325	338	340	339
63	58	–	485	455	415	378	355	347	312	292	305	337	335	345	330
64	60	200	222	234	238	249	257	265	265	269	271	279	288	290	285

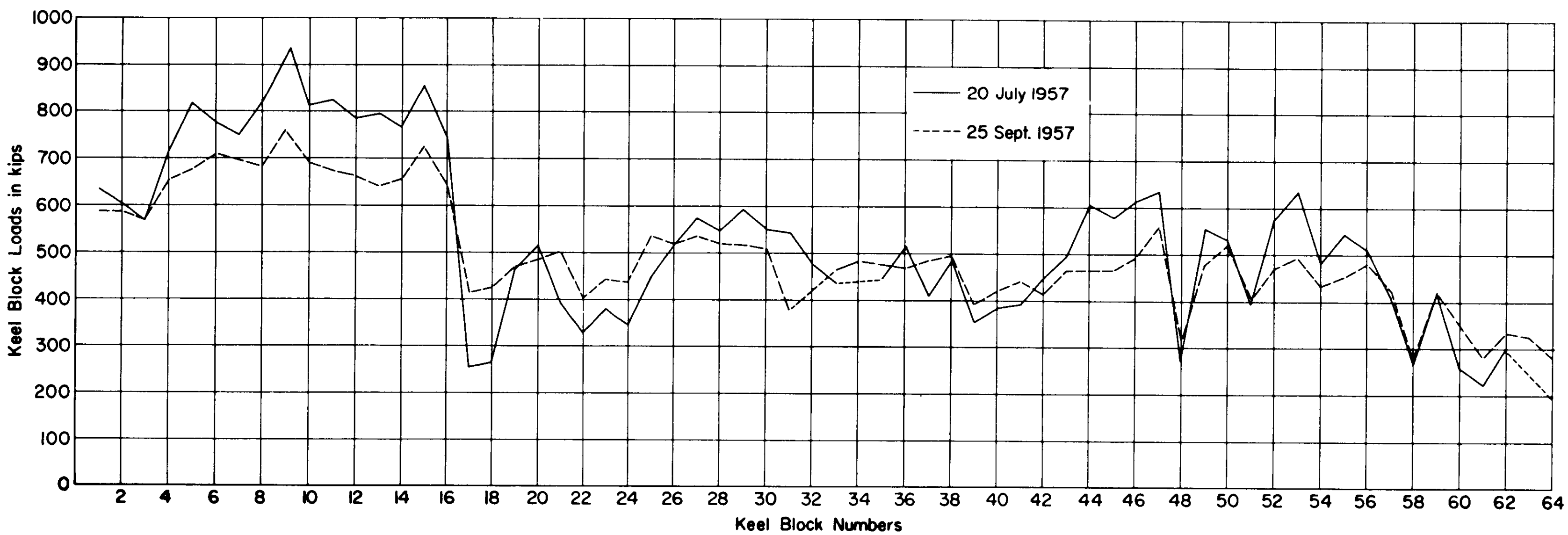

Figure 17 - Measured Block Loads on First and Last Days of Drydock Period of USS BENNINGTON (CVS 20)

TABLE 5

Variation in Keel-Block Loads under USS BENN]

in a 24 Hour Period

Block	Wafer (Temp deg F / Time)	Individual Keel Block Loads in kips										
	Temp deg F	62½	64	63	64	65	62½	62	63	62	64	63
	Time	7 Aug 0755	0955	1209	1354	1605	1810	2005	2205	2400	8 Aug 0200	0400
1	2	575	590	610	625	630	625	622	610	600	595	586
2	3	592	597	617	625	629	620	617	608	604	602	599
3	13	575	567	590	591	611	600	595	592	582	575	573
4	15	661	667	676	682	685	683	681	680	672	670	665
5	17	686	690	700	706	709	706	705	698	690	690	688
6	19	728	731	735	739	742	742	743	742	734	731	730
7	22	698	698	705	710	712	712	712	711	705	703	698
8	24 (new)	711	710	714	717	716	716	715	715	715	713	710
9	25	788	788	793	793	797	797	797	797	797	793	788
10	27	710	707	710	710	715	715	715	715	713	710	709
11	32	716	711	715	715	716	715	715	715	711	710	710
12	39	676	676	679	680	687	685	684	680	679	677	677
13	52	670	668	670	668	672	670	670	670	670	668	668
14	53	677	575	677	675	677	675	675	677	679	677	675
15	54	756	753	753	756	753	753	753	753	756	754	754
16	56	660	654	652	650	650	650	650	651	654	654	654
17	57	386	385	386	386	386	386	386	386	393	393	393
18	59	387	387	387	388	390	388	380	388	390	393	390
19	61	470	468	468	468	470	470	470	470	472	472	472
20	62	499	501	499	499	501	501	501	501	501	503	503
21	63	481	480	480	478	480	478	480	478	481	481	481
22	64	–	–	–	–	–	–	–	–	–	–	–
23	30	423	423	418	420	420	418	416	416	426	426	429
24	18	400	400	398	395	400	400	400	400	401	403	403
25	20	508	512	502	505	504	504	504	500	512	512	513
26	35	500	500	499	500	498	498	498	498	499	499	500
27	14	535	536	536	536	532	532	532	532	532	532	535
28	8	525	525	521	521	519	517	517	517	519	519	521
29	9	532	535	536	532	532	532	532	529	531	531	531
30	10	513	517	517	518	512	512	510	510	512	513	513
31	11	495	492	488	485	482	481	482	482	488	488	488
32	12	Failed	–	–	–	–	–	–	–	–	–	–
33	7	455	455	455	453	450	450	450	452	455	455	455
34	16	80	80	477	477	470	472	472	477	475	475	477
35	4	468	464	464	462	460	458	458	460	462	462	464
36	5	480	481	477	475	472	472	470	472	473	475	475
37	21	575	575	573	570	570	570	566	566	570	572	572
38	23	488	485	488	486	485	485	482	482	482	482	482
39	26	380	378	378	378	373	372	372	372	373	373	375
40	28	417	415	415	414	412	412	412	412	414	414	415
41	29	431	426	426	426	426	424	420	420	426	428	431
42	6	431	430	430	428	428	425	425	425	428	428	431
43	31	485	479	479	477	477	475	475	475	475	479	479
44	33	326	325	325	326	325	325	325	325	326	327	327
45	34	513	513	513	511	513	507	507	507	511	511	511
46	1	540	538	538	532	532	531	532	534	534	534	534
47	36	579	580	575	575	575	575	575	575	575	576	580
48	37	297	297	297	295	297	297	297	297	299	301	301
49	38	498	496	492	492	496	498	496	496	498	498	498
50	40	542	538	541	542	538	538	538	538	538	538	538
51	41	404	398	396	396	399	399	399	398	404	404	405
52	42	494	494	490	508	494	494	494	494	494	496	498
53	43	529	529	527	527	527	527	529	525	524	527	525
54	44	444	442	442	444	441	441	441	439	442	442	442
55	45	476	475	475	475	475	472	472	472	475	475	475
56	46	498	498	495	496	498	496	498	498	498	498	500
57	47	428	425	419	421	424	424	424	428	429	429	430
58	48	206	200	196	196	193	191	191	191	201	201	201
59	49	417	412	412	412	409	410	410	411	414	414	417
60	50	330	329	319	324	319	319	324	327	328	328	330
61	51	263	263	258	258	258	258	260	260	261	261	263
62	55	338	338	335	333	333	333	333	335	337	337	338
63	58	355	350	350	363	355	350	350	355	355	355	363
64	60	260	258	256	256	254	254	254	256	258	260	260

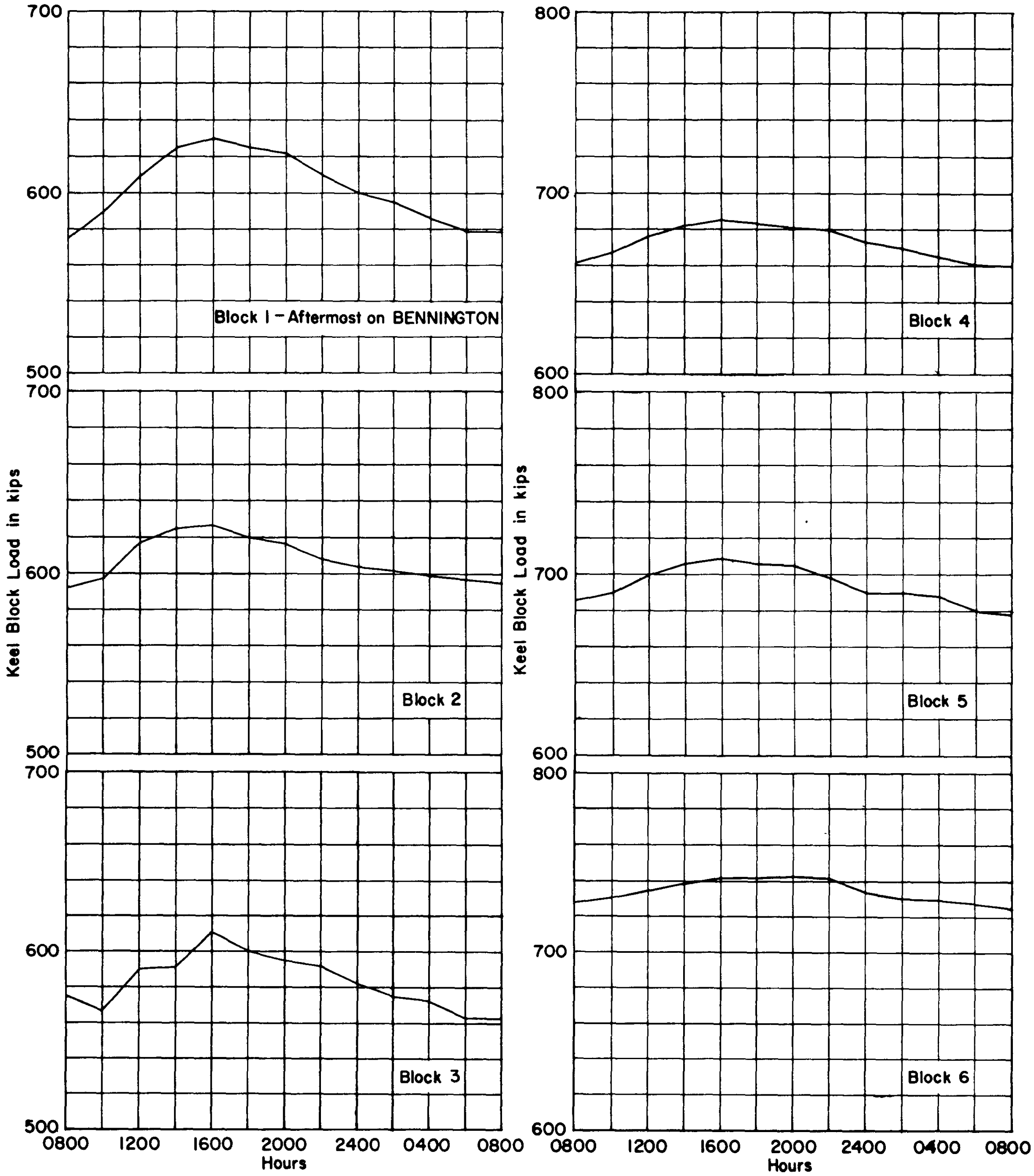

Figure 18 - Diurnal Effect on Loads on Six Aftermost Blocks under USS BENNINGTON (CVS 20)

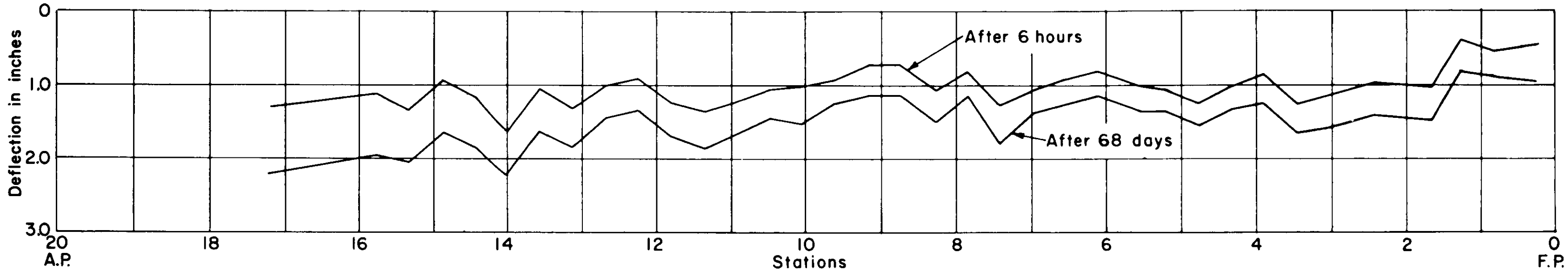

Figure 19 - Centerline Keel-Block Deflections for USS BENNINGTON (CVS 20)

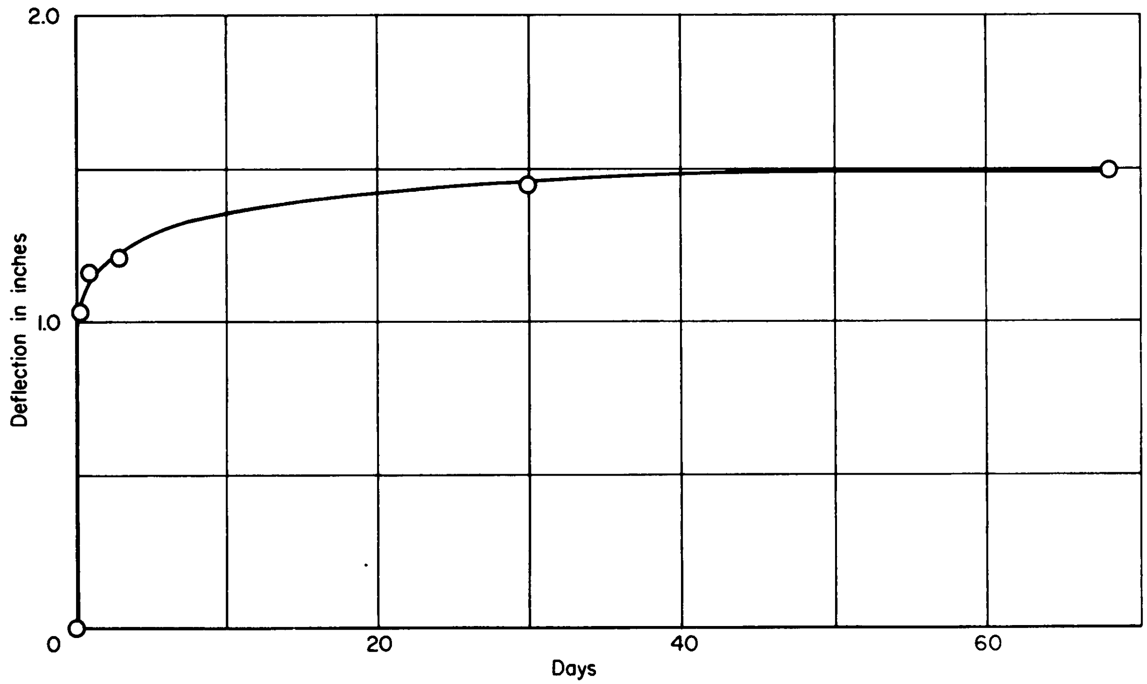

Figure 20 - Average Keel-Block Deflection for USS BENNINGTON (CVS 20)
as a Function of Time

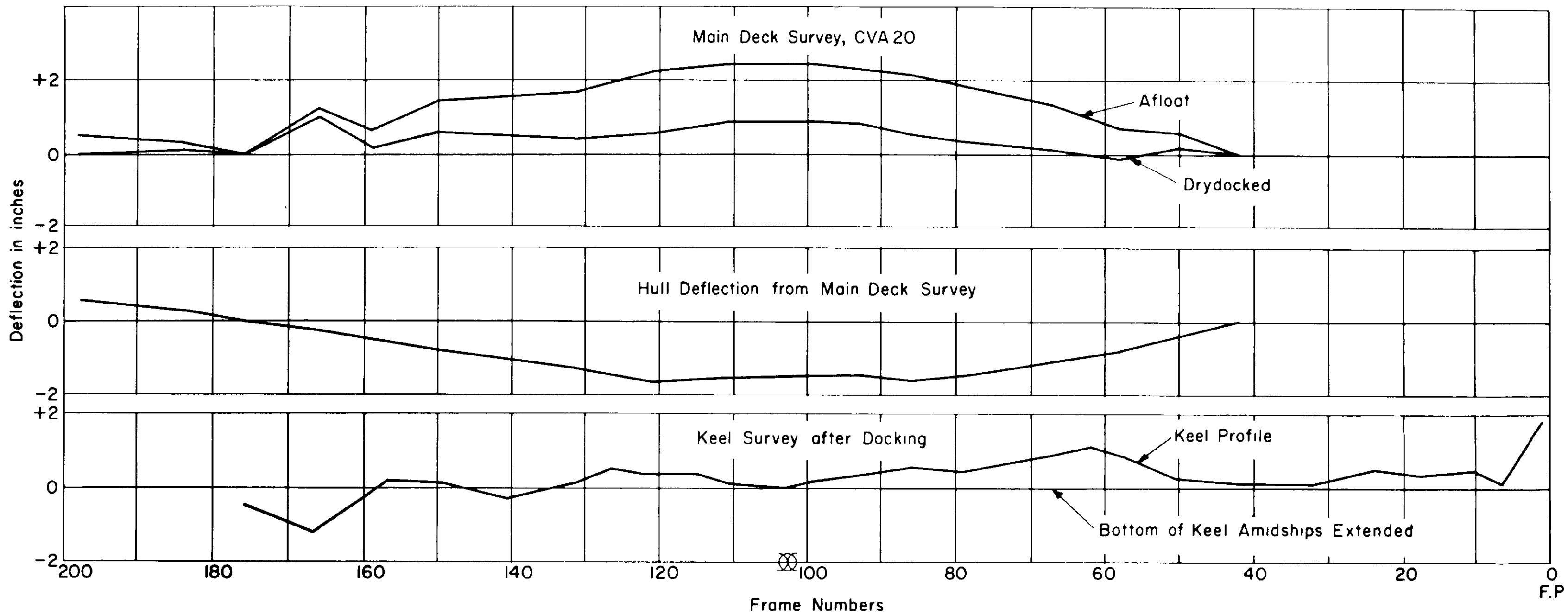

Figure 21 - Profile of Main Deck and Keel of USS BENNINGTON (CVS 20) from Transit Survey

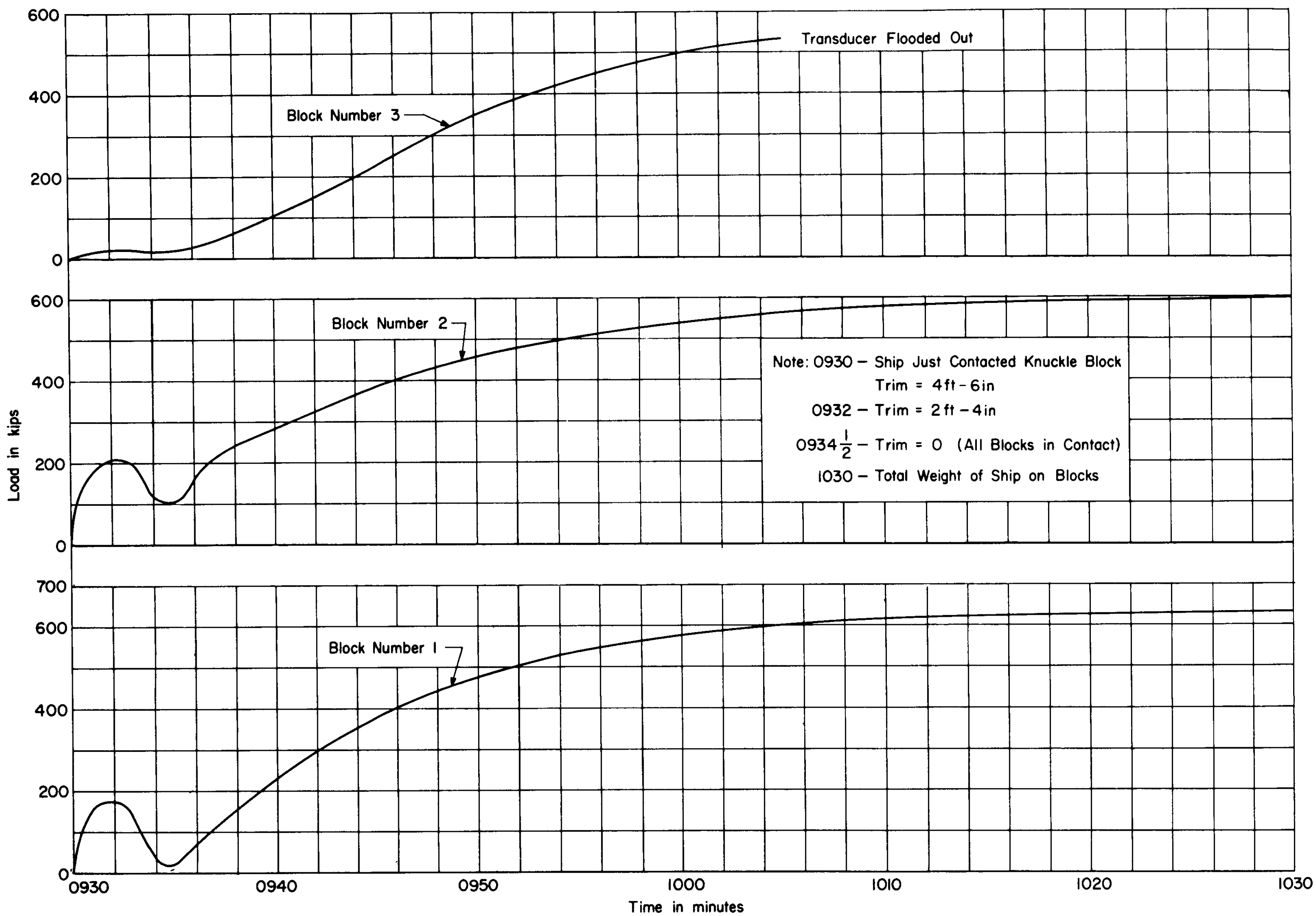

Figure 22 - Loads on Stern Blocks while Pumping out Dock for USS BENNINGTON (CVS 20)

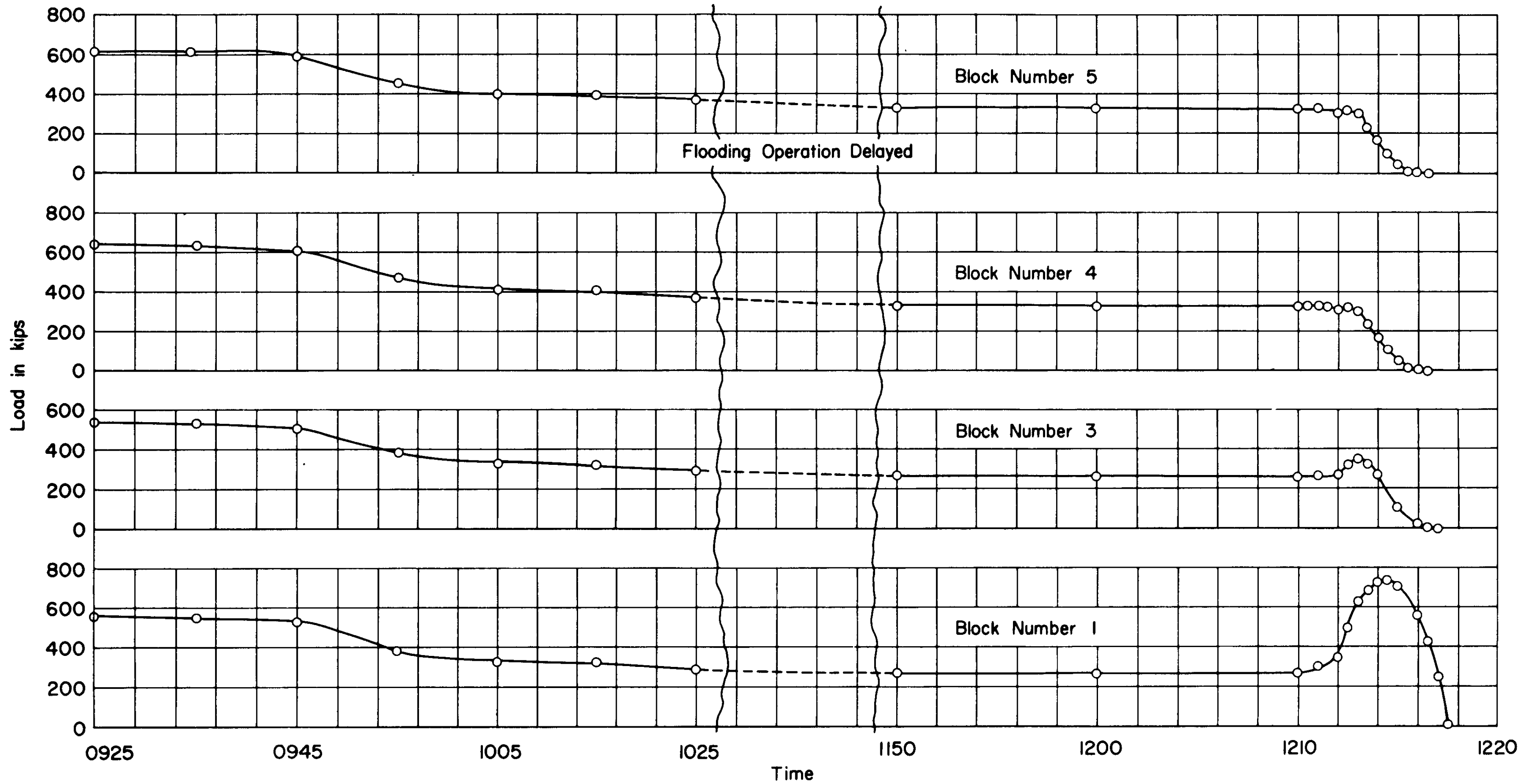

Figure 23 - Loads on Stern Blocks while Flooding Dock for USS BENNINGTON (CVS 20)

Transducer on Block No. 2 Failed

0925 – started flooding dock

0945 – ship gaining bouyancy rapidly

1005 – flooding rate slowed down

1030 – flooding operation delayed

1145 – flooding operation resumed

1210 3/4 – trim = 0 and starting to develop

1214 1/2 – trim = 2′3″

1217 3/4 – trim = 5′4″ (ship afloat)

DISCUSSION OF RESULTS AND COMPARISON WITH THEORY

USS VALLEY FORGE (CVS 45)

Table 1 shows the variation in the block loads during the docking period. Although considerable redistribution of load occurs during this time, the total load, excluding the loads on those blocks for which the pressure wafers failed, remained essentially constant. This would be expected if we assume no significant change in weight of the ship during the docking period. The maximum measured load on Block 11 of 775 kips is approximately 2 times the nominal block load of 390 kips.

Figure 24 shows a comparison of the loads on the centerline blocks with those of a previous drydocking. The general shape of the two curves are similar. The maximum measured load for the previous test was 819 kips (366 tons) on Block 12, whereas the maximum measured load for this test was 775 kips (346 tons) on Block 11. Table 6 shows the differences in the setup for the two tests. In addition, the sets of keel blocks were completely different. However, the two sets of data show remarkable agreement. Figures 25, 26, and 27 show the foundation modulus of the keel blocks, the moment of inertia of the hull, and the weight curve for the ship, respectively, at the time of docking. These data were used to calculate the keel-block loads by the method of Yeh and Ruby[3] as modified by the Model Basin.[5] A comparison of the calculated and measured loads is shown in Figure 28. The general shape of the curves are similar although the experimental data show the characteristic "saw tooth" variation. This variation may be attributed to:

1. local variation in block heights and block modulus,
2. departures from a straight line built into the keel plate, and
3. local "hard spots" in the hull structure such as would be caused by bulkheads.

The maximum calculated load is at the aftermost keel block and is approximately 81 tons/ft, whereas the maximum point on the experimental curve is slightly forward of amidships and is 75 tons/ft. This is in a region of fairly high foundation modulus (side blocks present), high on the weight curve and near a transverse bulkhead.

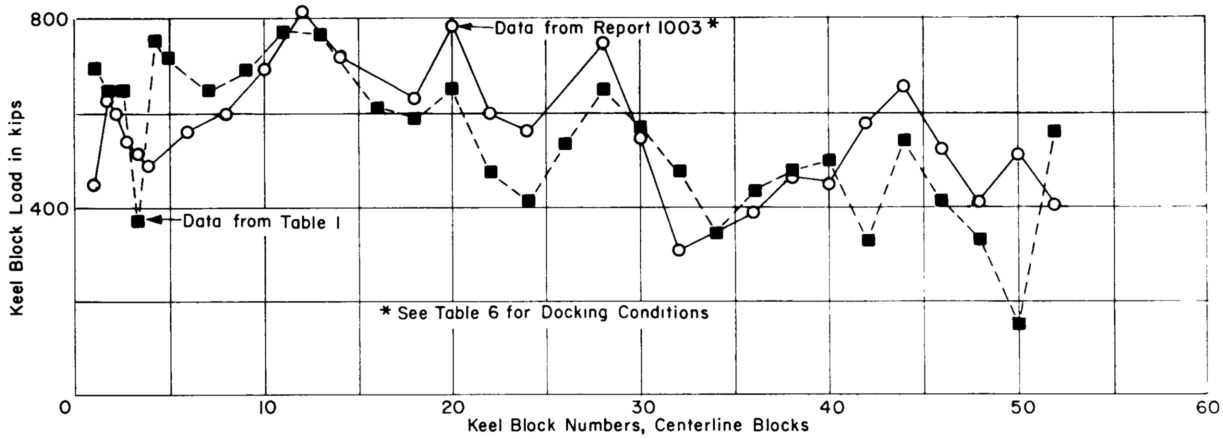

Figure 24 - Comparison of Measured Keel-Block Loads for Independent Drydockings of USS VALLEY FORGE (CVS 45)

TABLE 6

Differences in Condition of Ship (USS VALLEY FORGE (CVS 45) and Dock Setup for Independent Keel-Block Load Tests

	Test 1 (TMB Report 1003)	Test 2
Ship's Displacement	32,798 tons	31,648 tons
Docking Position	3	1
Stern-Blocking Arrangement	6 Blocks in space for 4	6 Blocks in space for 5
Composition of ℄ Keel-Blocks	27 in. Concrete 32 in. Oak 1-in. Pine Cap	39 in. Concrete 21 in. Oak 2-in. Pine Cap

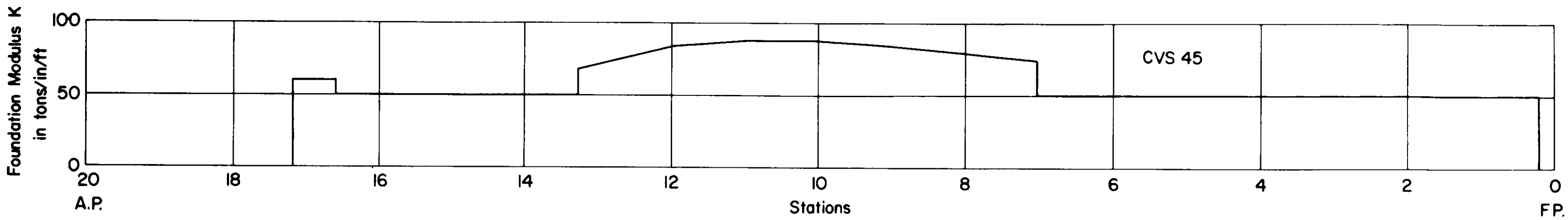

Figure 25 - Foundation Modulus of Keel Blocks under USS VALLEY FORGE (CVS 45)

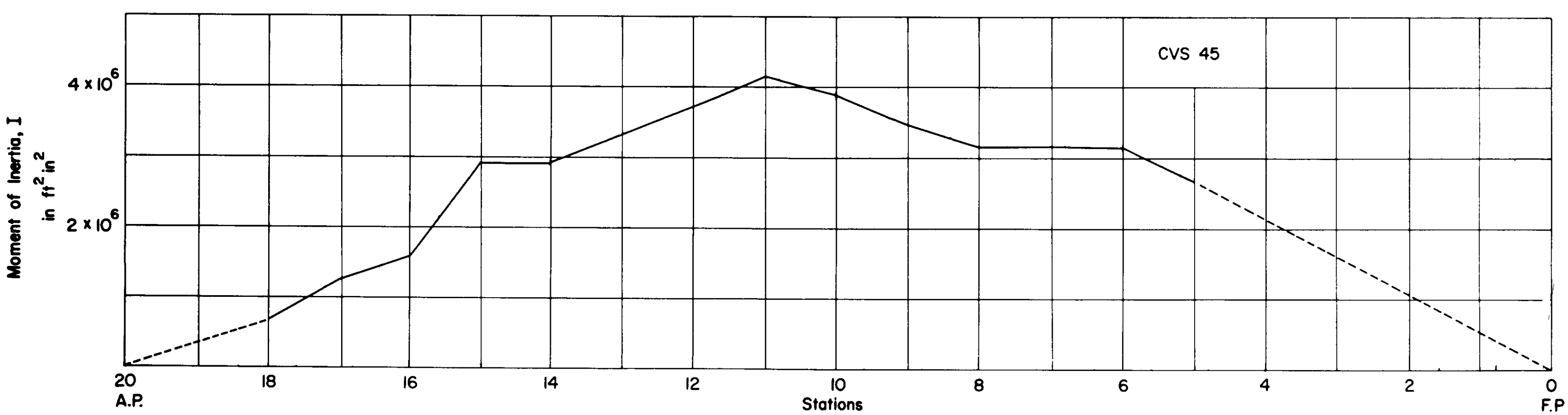

Figure 26 - Moment of Inertia of Hull Girder of USS VALLEY FORGE (CVS 45)

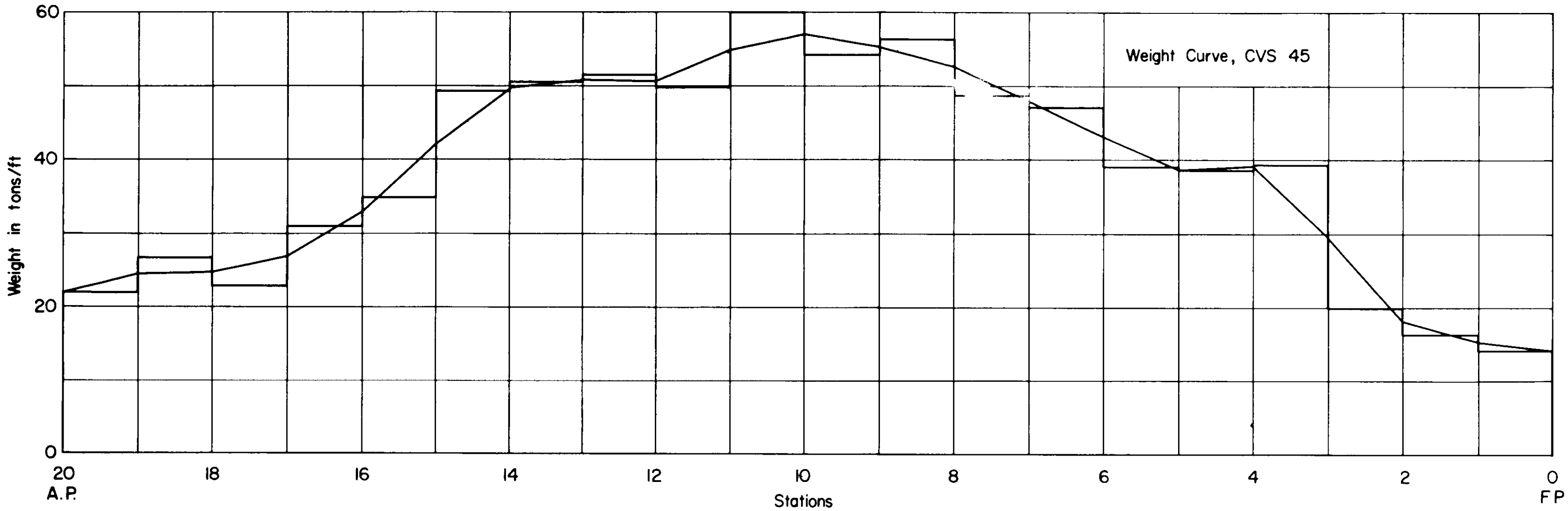

Figure 27 - Weight Curve at Time of Docking USS VALLEY FORGE (CVS 45)

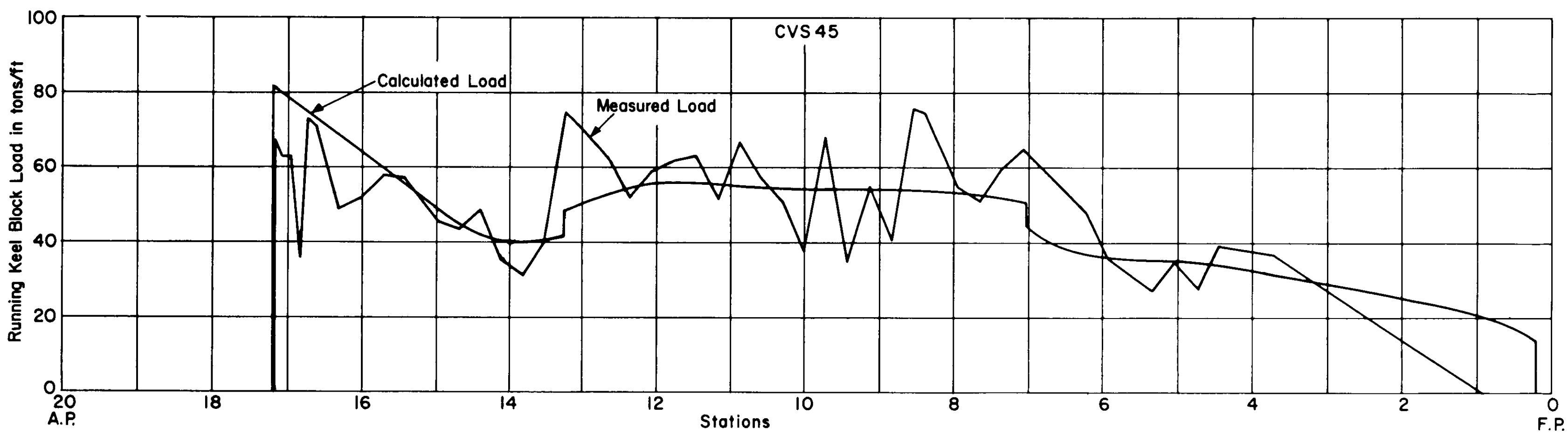

Figure 28 - Comparison of Measured and Calculated Keel-Block Loads for
USS VALLEY FORGE (CVS 45)

The following numerical values were used to calculate the load on the aftermost block by the TMB approximate method.[4]

Length of stern overhang to A.P.	114 ft
Weight of stern overhang	2720 tons
Center of gravity of overhang, from aftermost keel block	56.2 ft
Foundation modulus of keel blocks	50 tons/in/ft
Moment of inertia of hull girder (at Station 15)	2.91×10^6 in.^{2}/ft^2
Young's modulus of hull	1.34×10^4 tons/in.^{2}
Keel-block load due to dead weight	22.8 tons/ft

The maximum block reaction determined from the approximate method is 85 tons/ft. This value is approximately the same as the value of 81 tons/ft which was obtained from the more complex Yeh-Ruby method.

The Yeh-Ruby method and the TMB approximate method for calculating load are slightly conservative when calculating the effect of the stern overhang. The measured value near the stern keel blocks was approximately 73 tons/ft.

USS FORRESTAL (CVA 59)

Keel-block loads were calculated for FORRESTAL by the method of Yeh and Ruby, using the following input information:

1. The moment of inertia of the hull girder, I(x); see Figure 29.
2. The weight distribution for the ship, $q_o(x)$; see Figure 30.
3. The foundation modulus of the keel blocks, K(x); see Figure 31.

Calculations were carried out as described in References 3 and 5, and the results are shown in Figure 32. Measured loads are shown for comparison. The maximum calculated load of 165 tons/ft occurs at the aftermost block. The maximum measured load was 149 tons/ft near amidships. The maximum measured load in the skeg area was 116 tons/ft.

In general, the calculated loads are larger than the measured loads near the stern but are less than the measured loads near amidships.

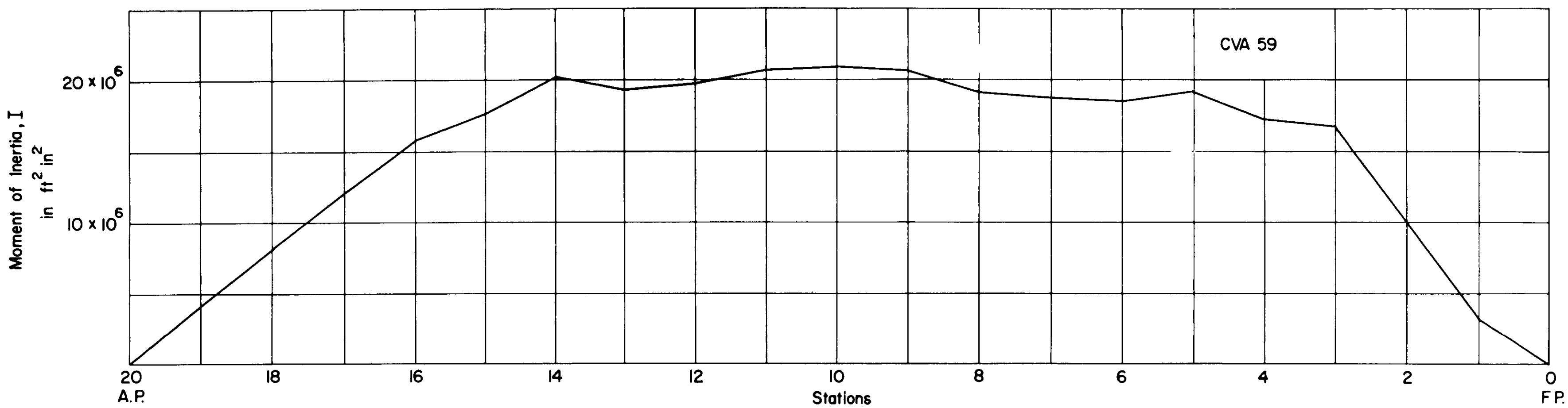

Figure 29 - Moment of Inertia of Hull Girder of USS FORRESTAL (CVA 59)

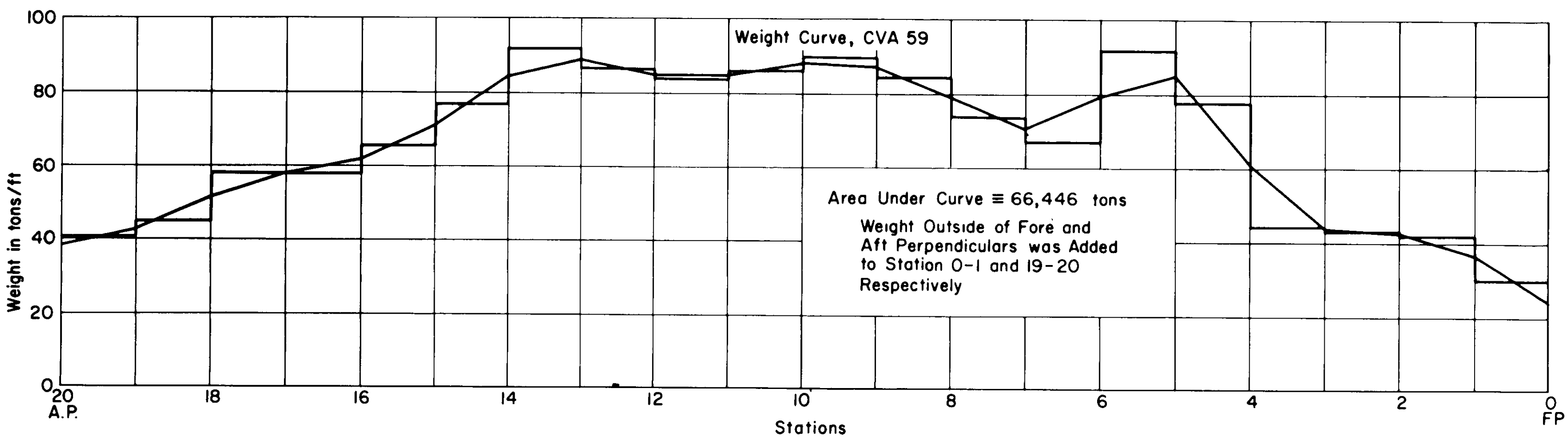

Figure 30 - Weight Curve at Time of Docking of USS FORRESTAL (CVA 59)

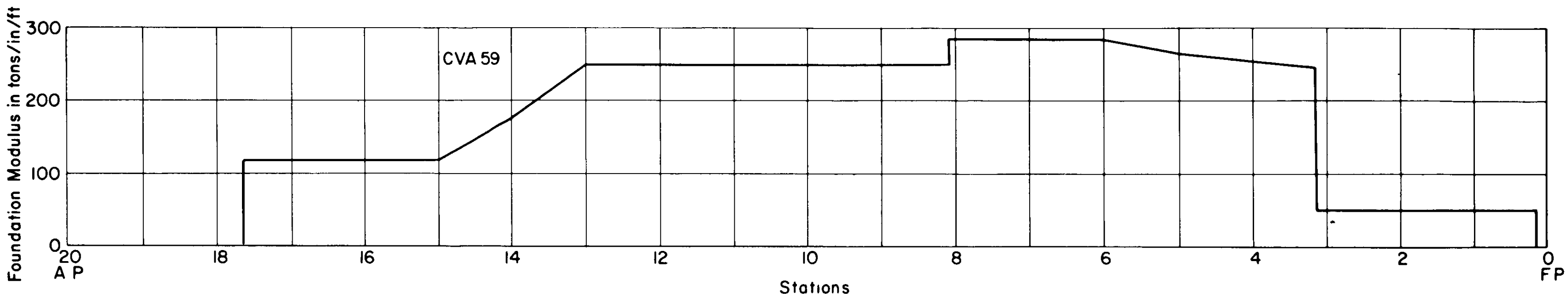

Figure 31 - Foundation Modulus of the Keel Blocks Used in Docking
USS FORRESTAL (CVA 59)

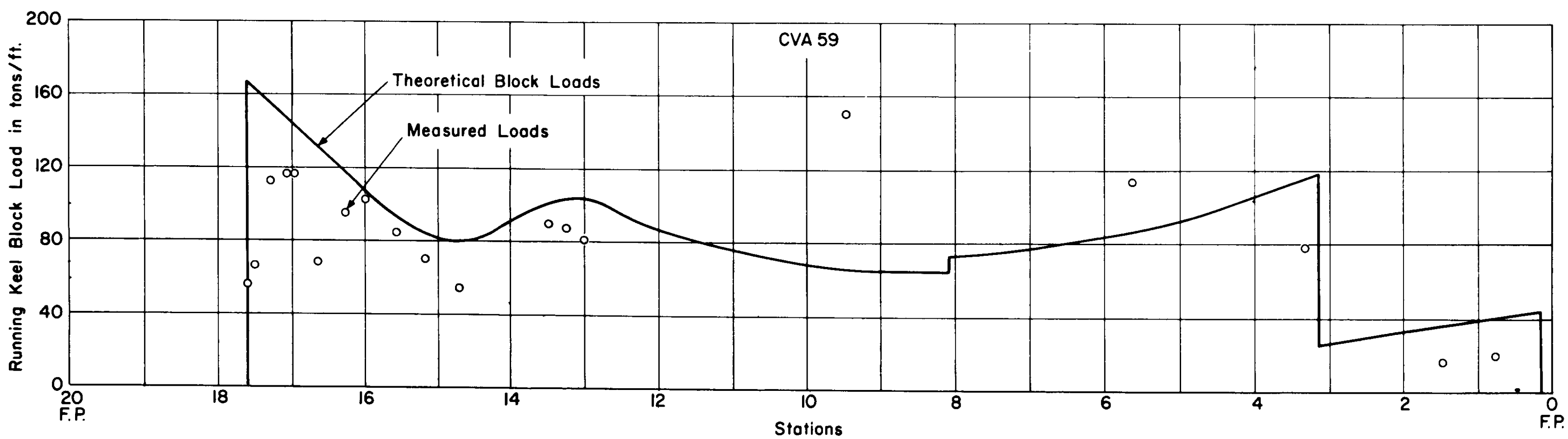

Figure 32 - Comparison of Measured and Calculated Keel-Block Loads for
USS FORRESTAL (CVA 59)

The load at the aftermost keel block was also calculated by the TMB approximate method from the following numerical values.

Length of stern overhang to A.P.	116	ft
Weight of stern overhang	5240	tons
Center of gravity of overhang, from aftermost keel block	54.5	ft
Foundation modulus of keel blocks	117*	tons/in/ft
Moment of inertia of hull girder (at Station 15)	15.8×10^6	$in^2 - ft^2$
Young's modulus of hull	1.34×10^4	$tons/in^2$
Keel-block load due to dead weight	58	tons/ft

The maximum block reaction determined from the approximate method is 148 tons/ft. This is about 10 percent less than the value obtained from the Yeh-Ruby method. It is somewhat conservative as compared to the maximum measured load in the skeg area of 116 tons/ft. Since results of the approximate method agreed well with results of the Yeh-Ruby method and were conservative with respect to measured values, the former method was used to determine the effect of shortening the skeg on the keel-block loads. The calculated block load at the aftermost block as a function of skeg cutback is shown in Figure 33. Shortening the skeg by 12 ft would result in an increase of 10 percent in the block loads. This increase in load would be entirely acceptable because the block loads are not excessive for this ship.

The maximum measured load on Block 4 of 730 kips (326 tons) is approximately 2.4 times larger than the nominal block load of 302 kips.

The diurnal temperature effect is very pronounced and extends for more than 100 ft from the aftermost block, as shown in Figure 6. A drop in temperature of 21°F reduced the maximum load in the skeg area from 122 tons/ft to 92 tons/ft. This maximum occurs about 30 ft from the aftermost keel block, and the effect increases toward the stern. The change in load on the aftermost block due to the diurnal effect was 47 tons/ft.

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*Value determined from measured block deflections.

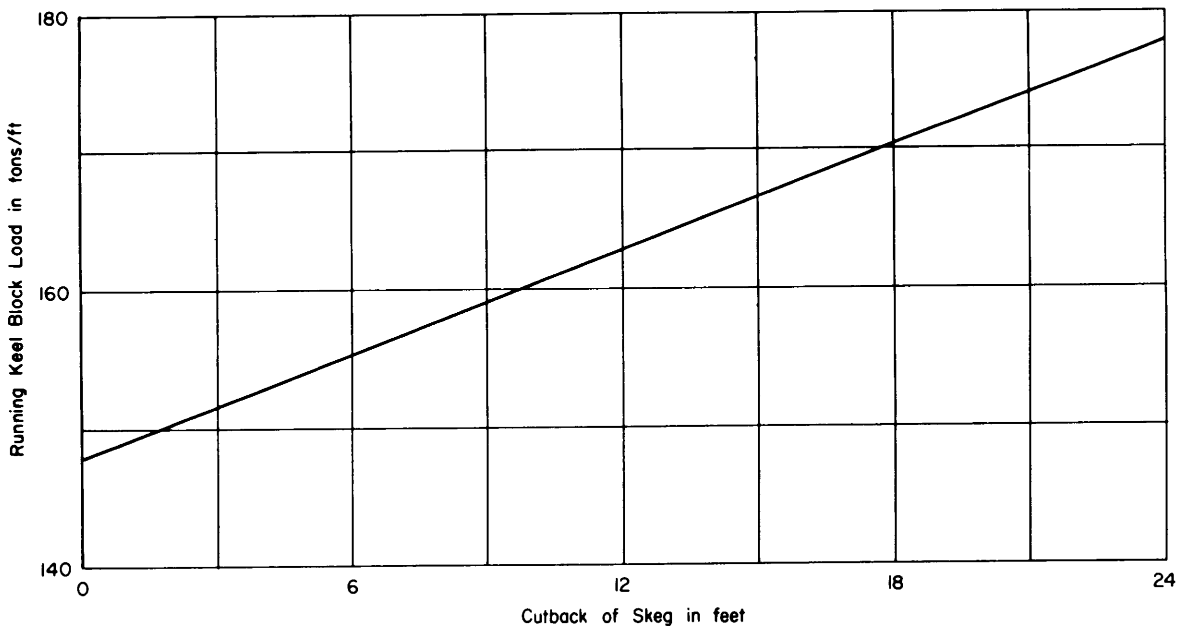

Figure 33 - Calculated Effect of Cutback of Skeg of CVA 59-Class Aircraft Carrier on Keel-Block Loads

This large effect may be attributed to the fact that for this class ship the flight deck is also the strength deck and is greatly affected by the sun's radiation and attendant temperature changes.

As has been the case for a number of tests, the maximum measured load was not observed at the sternmost block as predicted by theory. This effect may be attributed to the fact that the keel profile is not straight as assumed by theory. This is shown in Figure 8, which indicates a general "turn up" in the keel profile near the stern as determined from the transit survey in dock. The tendency for the keel line to turn up at the skeg is probably universal for all ships of welded construction which are built from the keel upward.

The survey of the dock floor before and after drydocking reveals that the load on the keel blocks cause the following:

1. The dock undergoes a rigid body displacement.
2. The dock undergoes an elastic deformation due to the concentration of the block loads.

Figure 9 shows that the centerline of the dock floor in the keel-block region moves downward approximately 1/4 in. In addition to the general sinkage, the dock deforms into a concave surface. However, the curvature is very slight since the sagitta of the longitudinal centerline over the entire keel-block region is only roughly 1/8 in. Since the initial block deflections were about 3/4 in., Figure 7, it appears possible that the effect of the elasticity of the dock on the keel-block loads would not be large. To confirm this, additional tests were made in a dock which rested on solid rock instead of soft marl (see tests on BENNINGTON).

Since the weight of the stern overhang is in excess of 5000 tons and when the ship is afloat this is partially supported by the buoyancy of the water, it was of interest to determine the magnitude of the shear stress in the hull due to docking. As mentioned previously, this was attempted by placing strain gages on the ship's structure near the neutral axis at Frame 220. Unfortunately, the docking operation required several hours, and in the meantime the temperature changed considerably. The strains due to temperature were large enough to mask out the load strains so that accurate determination of the stress due to docking was not possible. However, the magnitude of the elastic strains appears to be roughly 30 μin./in. This would indicate that the magnitude of the stress due to overhang should be of the order of 1000 psi, which is low enough to be entirely negligible even if it were in error by a factor of three.

Finally, Table 2 shows that the centerline blocks in way of the side blocks (Blocks 1-99) carry more load than the individual side blocks. Thus it is apparent that the centerline blocks should be included as load-bearing blocks and that the assumption that they are primarily for supporting local load is not supported by the measurements.

USS BENNINGTON (CVS 20)

Table 4 shows the variation in the measured loads during the docking period. In general, this table and Figure 17 show that there is considerable redistribution of load as a function of time. The trend is for the peak loads to diminish and for the low loads to increase. This tendency has been observed previously and is mostly[*] due to block creep. The nature of the average creep is shown in Figure 20. One mathematical relation which fits this data rather well is

$$\delta = 0.80 + 0.75\left(1 - e^{-0.6t^{\frac{1}{3}}}\right)$$

The creep is rather rapid for the first 3 or 4 days but continues at a much reduced rate throughout the docking period. Finally, the average block deflection increases approximately 50 percent between 6 hrs and 2 months after docking. The creep is negligible after about a month.

The abrupt change in load between Blocks 16 and 17, (Figure 17), is caused by the change from hard caps to soft caps, Figure 13. The maximum measured load on Block 9 of 934 kips is approximately 2.4 times larger than the nominal block load of 394 kips.

The diurnal temperature effect is shown in Table 5 and Figure 18. Although this effect is appreciable (55 kips or 7 tons/ft at the sternmost block) for the first two or three blocks at the stern, it is not as large as for FORRESTAL (47 tons/ft at sternmost block) because the flight deck is not the strength deck for BENNINGTON. Thus, the flight deck shields the main or strength deck from the sun's radiation. This shielding reduces the dirunal effect considerably as compared to a ship having the strength deck in direct sunlight, e.g., FORRESTAL.

The loads on the keel blocks near the stern overhang were calculated by the TMB approximate method from the following numerical values:

Length of stern overhang to A.P.	116 ft
Weight of stern overhang, from Figure 34	3240 tons
Center of gravity of overhang, from after-most keel block	64.0 ft
Foundation modulus of keel blocks[**]	74 tons/in/ft

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[*] Actual changes in weight such as, e.g., draining of tanks, removal of machinery, and removal of propellers do occur during a docking period and would also affect measured loads.

[**] Determined from load-deflection data for Blocks 1 and 16.

Moment of inertia of hull girder (at Station 15)	2.57×10^6 in^2-ft^2
Young's modulus of hull	1.34×10^4 tons/in.^{2}

The results of this calculation are shown in Figure 35, and the measured values are shown for comparison. The maximum calculated value, 130 tons/ft, occurs at Block 1, whereas the maximum measured values of 119 tons/ft occurs at Block 9. The general agreement is good except for the three aftermost blocks. The low load on these blocks may be attributed to the turn up in

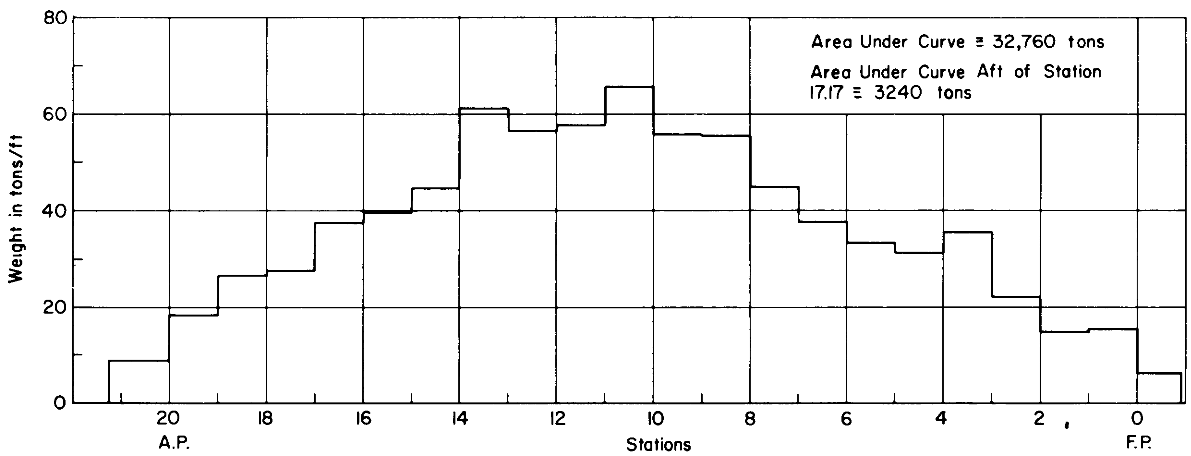

Figure 34 - Weight Curve at Time of Drydocking USS BENNINGTON (CVS 20)

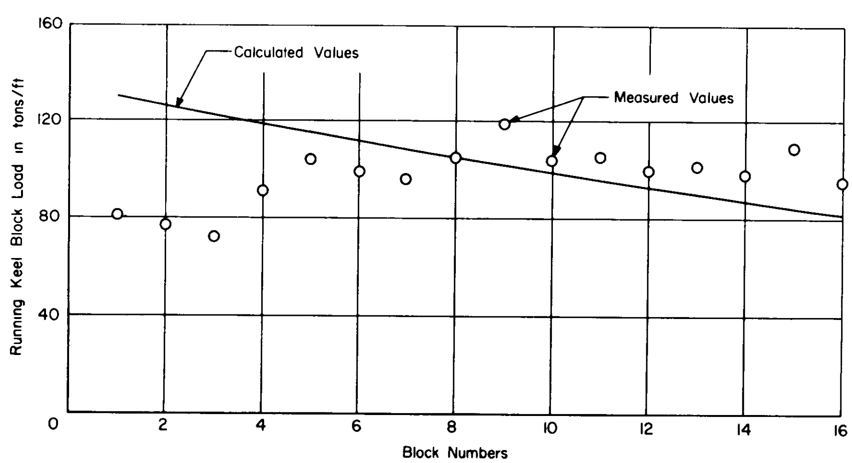

Figure 35 - Keel-Block Loads in Skeg Area of USS BENNINGTON (CVS 20)

the skeg, as shown by the keel survey, Figure 21. The agreement between measured loads and those calculated by the approximate method was good enough so that it was not considered necessary to calculate the loads by the Yeh-Ruby method.

Table 7 compares calculated and measured loads for somewhat similar ships docked in different shipyards. VALLEY FORGE and INTREPID were docked in Drydock 8 in the Norfolk Naval Shipyard and BENNINGTON was docked in Drydock 3 in the San Francisco Naval Shipyard. As mentioned before, the Norfolk dock rests on piles driven into a "soft" marl base whereas the San

TABLE 7

Comparison of Keel-Block Loads for Ships Docked at Different Shipyards

Ship	CVS 45-1st Test*	CVS 45-2nd Test	CVA 11*	CVS 20
Docked at	Norfolk Naval Shipyard			San Francisco Naval Shipyard
Load in Tons/Block				
Nominal Block Load**	182	174	194	176
Max. Observed Load & Location	366 Block 12	346 Block 11	469 Block 6	417 Block 9
Exp. Load on Aftermost Block	201	313	332	282
Calc. Load on Aftermost Block (Yeh-Ruby)	***	378	441	***
Calc. Load on Aftermost Block (TMB app. Method)	***	397	459	455

*Data from Report 1003

**Nominal Block Load = $\frac{\text{Wt. of ship}}{\text{Total block area}}$ x area of typical block

***Not calculated

Francisco dock rests on solid rock. The table shows as much variation in the keel-block loads determined on similar ships in the same shipyard as the variation in the loads for similar ships in different shipyards. Therefore, for practical purposes, the elasticity of the dock is of little consequence unless the dock were more flexible than Drydock 8 of the Norfolk Naval Shipyard.

Figure 16 shows some moderate to severe cracking of the soft cap material of the keel block at Block 19 because, in this region, the keel plate is not as wide as the keel block. The keel plate should be designed to cover the entire top of the keel block to minimize the damage to the cap blocks.

Figure 22 shows the load on the three sternmost keel blocks for BENNINGTON when docking with large trim (4 ft 6 in. by the stern). The measurements were made as a function of time with manually balanced Baldwin strain indicators from diaphragm-type pressure gages and, therefore, the absolute maximum value may not have been noted. However, the data are rather smooth, and any errors in reading should not be large. The maximum load (210 kips) was recorded on Block 2 at a time when the trim had been reduced to approximately one-half of the original value. This is experimental verification for the conclusion reached by Howard and Farrin[9] by analytical methods. The final magnitude of the load on this block was 632 kips, and thus the "knuckling down" load does not appear to be critical.

Figure 23 shows the loads on Blocks 1, 3, 4, and 5 when undocking with large trim (5 ft 4 in. by the stern). Pressures were recorded continuously on an oscillograph so that the maximum value was definitely obtained. The maximum was noted for Block 1. However, the reading from Block 2 was lost due to gage failure. The maximum value recorded on Block 1 was 740 kips at a time when the trim was somewhat less than one-half of the final value. This value is approximately 30 percent larger than the static load on the block before flooding began. Thus, a marked difference exists between the "knuckling down" loads as compared to the "knuckling up" loads. This may be attributed to the fact that creep on the stern blocks during the docking period is very large (Figure 19) and thus, the elastic response in unloading may be considerably different from the response in loading. The difference in the loading and unloading response was pointed out recently in Reference 10. In any event, note that this large load is of relatively short duration while the dock is being flooded. Also at this time the ship is practically waterborne and, therefore, the "knuckling up" load also does not appear to be critical.

SUMMARY AND CONCLUSIONS

1. For all ships tested, the maximum measured block loads were at least two times the nominal block loads.

2. Also for all ships tested the maximum observed block load did not occur at the sternmost block as predicted by theory. This may be attributed to the natural turn up in the keel profile near the end of the skeg of welded ships.

3. The comparison of independently determined keel-block loads for VALLEY FORGE shows that the measurements of block loads for all practical purposes are reproducible.

4. The measurements of keel-block loads for FORRESTAL indicate that the docking plan is adequate but that the centerline blocks in way of the side blocks should be included as weight-supporting blocks. The nominal block pressure is low, 9.66 tons/sq ft; however, the maximum measured pressure was 23.3 tons/sq ft.

5. Strains in the ship's hull measured near the stern overhang of FORRESTAL show that the effect of docking may cause stresses of the order of 1000 psi and are thus negligible.

6. A survey of the dock before and after drydocking showed that, although the dock deforms slightly due to keel-block loads, the deformation is rather small compared to the keel-block deflections. The chief effect is parallel sinkage and thus the dock (Drydock 8 at Norfolk Naval Shipyard) acts almost as a rigid foundation.

7. Based on this test and on calculated loads, it is concluded that the skeg for the FORRESTAL-Class carrier could be shortened in future designs. If the skeg were shortened by 12 ft, the load on the aftermost block would be increased by approximately 10 percent.

8. Keel-block loads determined for BENNINGTON in Drydock 3 of San

Francisco Naval Shipyard, which rests on solid rock, show that the elasticity of the dock has no appreciable effect on keel-block loads.

9. Loads on the stern blocks measured when landing the ship with large trim were not as large as the final loads on the blocks when the dock is dry. However, the load on the knuckle block when undocking was larger (about 30 percent) than the load on this block while in drydock. These loads are not critical for the composite blocks normally used in drydocking naval ships.

10. The diurnal effect of the sun's radiation on the loads on the keel blocks in the skeg area is large for FORRESTAL (causing a change of 47 tons/ft in the running keel-block load at the aftermost keel block). The same effect for BENNINGTON was less pronounced (causing a change of 7 tons/ft at the aftermost block). The difference in magnitude of this effect may be attributed to the fact that for FORRESTAL the strength deck (flight deck) is in the direct rays of the sun whereas for BENNINGTON the strength deck (hangar deck) is shielded from the sun's radiation.

11. A comparison of measured and calculated block loads for all ships tested indicate that the TMB approximate method is slightly conservative and is satisfactory for calculating the effect of the stern overhang on the keel-block loads. The Yeh-Ruby method, which gives the entire distribution of block loads, is also satisfactory but requires a much greater amount of work.

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