R 430

HYDRAULIC-PNEUMATIC FLOATING FENDER — ADDITIONAL IN-SERVICE TESTS, FIRST SERIES

March 1966

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA

HYDRAULIC-PNEUMATIC FLOATING FENDER — ADDITIONAL IN-SERVICE TESTS, FIRST SERIES

Technical Report R-430

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by

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ABSTRACT

Tests of two experimental hydraulic-pneumatic floating fenders, first in a well-protected harbor (Port Hueneme) and then in a relatively exposed harbor (San Diego), are described. Each fender consists of a 50-foot-long bulkhead fronted by two air-filled and two water-filled rubber bags. Also included is information to aid engineers in increasing the energy-absorption capacity of existing dock fender systems.

After 19 months of in-service tests of the floating fender it was concluded that (1) the energy-absorption capacity of the fender is adequate for a well-protected harbor such as that at Port Hueneme; (2) a fender system serving ships under navigation conditions and in a marine environment similar to those at Port Hueneme, requires a minimum energy-absorption capacity of 16 and a maximum of 50 inch-tons per 1,000 tons of ship displacement; and (3) resistance to ship motion, including the hydrodynamic mass effect, is an important parameter which requires further investigation. It is recommended that (1) full-scale tests of berthing impact be continued, particularly at exposed harbors, to determine energy requirements for other fender designs and (2) model tests of berthing impact be initiated, particularly of the resistance to motion, for use in evaluating hydrodynamic mass. Although measurements were not made at San Diego, it is concluded that the fenders provided satisfactory service but were not loaded to capacity.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

CONTENTS

BACKGROUND

Lee (1963, 1965a) describes the initial in-service tests at the harbor of Port Hueneme, California of the two hydraulic-pneumatic floating fenders (camels) treated in this report. As designed by Bowman and Cave (1961) each fender consists of a floating bulkhead, two air-filled and two water-filled bags floating in front of the bulkhead, chains with weights to maintain position, and a keel in the form of an 18-inch-OD pipe filled with concrete ballast. The bulkhead is 50 feet long, 1 foot 8 inches wide, and 11 feet 6 inches high. It has a steel framework, a creosoted-timber covering, and a core of polyurethane foam for buoyancy. The four rubber bags are standard off-the-shelf items, each ·0 inches in OD by 60 inches long. They tend to absorb most of the impact energy of berthing and moored ships. The air-filled bag (Mountcastle, 1961) absorbs energy by air compression and the water-filled bag by water displacement. Water is forced out of the bag through a screen connected by a hose to axial openings in each end of the bag. After compression the bag is restored to its original shape by the spring action of water "hoses" inside the bag. Absorption depends on the magnitude and velocity of the mass of the incident ship.

The total energy-absorption capacity of the fenders is from 490 inch-tons minimum to 2,300 inch-tons maximum. Measurements are based on (1) initial pneumatic-bag pressure of 12 psi per bag; (2) maximum working pressure of 50 psi per bag; (3) total allowable load of 42.5 tons over 15 square feet of the ship's hull; (4) only one pneumatic bag in action at minimum capacity and all four bags in action at maximum capacity; (5) deflection of 70% and/or 28 inches. At 70% bag deflection, the minimum and maximum energy-absorption capacity would be 330 and 1,940 inch-tons respectively.

Lee (1963, 1965a) reported on approximately 30 berthings. Of these, three were selected for reporting as representative of berthing alongside a deep-dock concrete fascia wall protected by standard timber pile fenders. One ship was an oceanographic research vessel of 1,400 tons displacement, with bow propeller for maneuvering; two were naval transports of 15,000 and 17,000 tons. Ship velocity during berthing was correlated with the pressure it induced in the fender bags, and deflection and energy-absorption characteristics were computed. Results from measurements compared reasonably well with those predicted by theory (Risselada and van Lookeren Campagne, 1964). Lee (1965a) concluded that the hydraulic-pneumatic floating fender met BuDocks' requirement of reducing damage to piers, ship hulls, and pier fenders, particularly in protected harbors, but that first cost and maintenance were relatively very high. He recommended modifications and the continuation of in-service tests in a more exposed harbor with heavier traffic than Port Hueneme.

Part I of this report presents an analysis of measurements made in the initial in-service tests at Port Hueneme but not fully reported previously. Part II presents additional in-service tests made in San Diego Harbor.

PART I. TESTS AT PORT HUENEME HARBOR

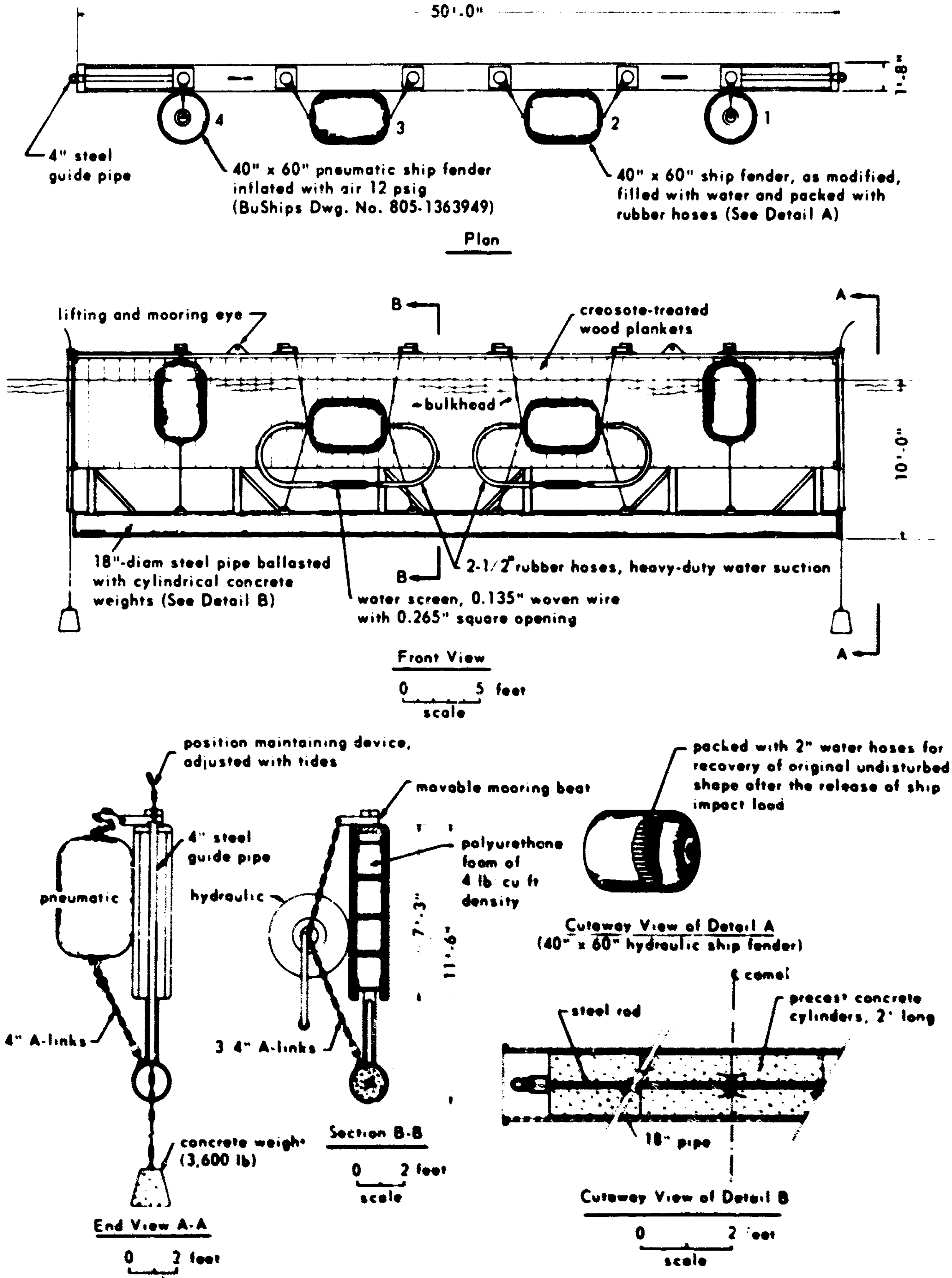
INTRODUCTION

Fourteen naval and merchant ships were involved in the additional in-service tests of the hydraulic-pneumatic floating fender at Port Hueneme Harbor. Multiple impacts occurred frequently. Ship excitation (berthing velocity) and fender response (pressure) were measured for approximately 35 berthings. Energies were calculated from the measured data and analyzed statistically. A relationship was established between berthing force magnitude, location, and absorbed energy. Predictions were made using the relationship and results compared with laboratory measurements made by the Hydraulics Research Station, Wallingford, England (1961, 1962) of a model of a 32,000-ton tanker. The navigation conditions and marine environment, which have significant effect on berthing, are presented for each berthing operation. Load transmission to the dock and ship are discussed. Significant parameters, such as hydrodynamic-mass and water-friction effects, beam-on and tangential speeds of berthing ships, are presented along with findings, conclusions, and recommendations.

EQUIPMENT AND PROCEDURE

Test apparatus is the same as used by Lee (1963, 1965a):

1. Two prototype hydraulic-pneumatic fenders (Figure 1)
2. One pickup of beam-on and tangential ship speeds simultaneously
3. Eight pickups (one pickup per bag) to measure pressure induced in the rubber bags by ship impact, from which measurements of berthing force and energy-absorption were calculated
4. Two accelerometers, one attached to the ship and the other to the ship-velocity meter
5. One pickup of harbor-bottom pressure
6. Two wind-velocity pickups (anemometers), one located 6 and the other 30 feet above the dock floor and near the berthing ship.



Note: This figure was prepared based on Y&D Dwg. No. 946116 and 946117, as modified by NCEL.

Figure 1. Hydraulic-pneumatic energy-absorbing floating fender (camel).

Load-deflection and energy-absorption characteristics (Figures 2 and 3) of individual pneumatic and hydraulic rubber bags as determined from actual measurements and as predicted by theory have been reported previously (Lee, 1963, 1965a). Appendixes A and B also present the actual measurements for selected cases.

The displacement of the berthing ships varied from 1,400 to 17,600 long tons. Further details, such as length, beam, and draft, are given in Table I.

Kinetic energy, E, of a berthing ship in inch-tons (2,000 pounds), upon contact with fenders is:

$$E = \frac{C}{2} M V^2 = \frac{C W V^2}{2g}$$

or

$$E = 0.209 C W V^2 \tag{1}$$

where W = ship displacement at the time of berthing, long tons

V = beam-on ship speed at the gravity center of the ship, feet per second

C = an impact correction factor = $c_e c_g c_d c_c c_m$ (Risselada and van Lookeren Campagne, 1964)

where $c_e = \dfrac{k^2}{a^2 + k^2}$ = eccentricity coefficient (Saurin, 1963) depending upon the point of impact relative to the ship's center of gravity, a, and radius of gyration, k, of the ship about its vertical axis (1a)

c_g = ship geometric coefficient depending upon the curvature of the ship at the point of impact

c_d = ship deformation coefficient depending upon the relative stiffness between ship hull and fender

c_c = berth configuration coefficient depending upon type of berth

c_m = virtual mass coefficient

Methods for determining berthing velocities at the center of gravity of the ship and for selecting the impact correction factor are given by Lee (1965a). Figure 4 shows a typical recording of such measurements as bag pressures, ship velocity, etc.

Table I. Summary of Berthing Ships Characteristics, Navigation Conditions, [illegible]

Ship and Date of Berthing	Ship Length (ft)	Displacement at Time of Berthing (long tons)	Mean Draft [illegible]	Water Depth [illegible]	Clearance Between Ship Bottom and Ocean Bottom [illegible]	Impact No.	Position of Impact From Stern (% ship length)	Max Impact Load [illegible]	Max Impact Energy Absorbed [illegible]	Navi[illegible] Me[illegible]
USNS General William Mitchell (22 December 1963)	622	15,200	19.5	33.0	[illegible]	1	0.468	29.80	[illegible]	wind 14 kno[illegible]
						2	0.470	[illegible]	[illegible]	wave moder[illegible]
						3	0.472	[illegible]	[illegible]	tide [illegible] feet
						4	0.475	[illegible]	[illegible]	broadside be[illegible]
						5	0.477	15.30	[illegible]	
						6	0.480	[illegible]	[illegible]	
						7	0.482	[illegible]	[illegible]	
USNS General Breckinridge (23 April 1964)	622	17,300	22.5	[illegible]	[illegible]	1	0.675	[illegible]	84.[illegible]	wind 25 kno[illegible]
										wave rough
										tide +4.2 ft
										angle of appr[illegible]
USNS Charles H. Davis (21 December 1963)	208	1,400	14.5	[illegible]	[illegible]	1	0.75	6.[illegible]	[illegible]	wind 2 knot[illegible]
						2	0.75	8.[illegible]	[illegible]	wave calm
										tide [illegible]
										angle of appr[illegible]
SS Oregon (1 May 1964)	565	12,000	18.4	33.3	14.9	1	–	[illegible]	[illegible]	not recorded
						2	–	[illegible]	99.10	
						3	–	[illegible]	[illegible]	
						4	–	[illegible]	[illegible]	
USNS Sgt. Jack J. Pendleton (12 May 1964)	455	7,600	14.5	33.7	19.2	1	0.16	[illegible]	30.61	wind [illegible] knot[illegible]
						2	0.50	[illegible]	15.93	wave calm
						3	0.50	[illegible]	[illegible]	tide [illegible]
										broadside be[illegible]
SS Hong Kong Bear (20 April 1964)	550	13,000	20.5	32.0	11.5	1	0.355	[illegible]	50.48	wind [illegible]
										wave calm
										tide +4.0 ft
										broadside be[illegible]
USNS Barrett (15 March 1964)	533	15,100	23.3	33.0	[illegible]	1	[illegible]	[illegible]	[illegible]	not recorded
						2	[illegible]	4.48	[illegible]	
						3	0.70	[illegible]	[illegible]	
						4	0.14	4.65	[illegible]	
SS California (29 December 1963)	563	12,000	18.5	30.6	12.1	1	0.568	32.95	[illegible]	not recorded
						2	0.521	25.59	[illegible]	
						3	0.460	[illegible]	[illegible]	
SS Guam Bear (4 January 1964)	459	[illegible]	15.5	31.5	[illegible]	1	0.675	5.64	[illegible]	wind [illegible] knot
										wave calm
										tide [illegible]
										angle of [illegible]
USNS General William Mitchell (18 April 1963)	622	[illegible]	[illegible]	31.5	[illegible]	[illegible]	0.500	[illegible]	[illegible]	wind [illegible] kno[illegible]
										wave rough
										tide +3.5 ft
										broadside be[illegible]
SS [illegible] Bear (23 April 1963)	453	8,200	16.8	30.5	[illegible]	[illegible]	0.445	[illegible]	20.20	wind [illegible] knot
										wave calm
										tide +2.5 ft
										broadside be[illegible]
SS President [illegible] Buren ([illegible] April 1963)	490	[illegible]	[illegible]	[illegible]	6.0	1	–	[illegible]	[illegible]	wind [illegible]
						2	–	[illegible]	[illegible]	wave calm
						3	–	[illegible]	[illegible]	tide +2.0 ft
		[illegible]	[illegible]	[illegible]	[illegible]	4 [illegible]	–	[illegible]	[illegible]	+2.6 ft
										[illegible]
USNS General [illegible] (6 June 1963)	622	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	[illegible]	[illegible]	not recorded
SS [illegible] (26 April 1963)	570	[illegible]	[illegible]	[illegible]	8.5	[illegible]	–	–	–	wind 25 kn[illegible]
										wave rough
										tide [illegible]
										broadside be[illegible]

thing Ships Characteristics, Navigation Conditions, and Significant Measurements

tance Between ip Bottom and cean Bottom	Impact No.	Position of Impact From Stern (% ship length)	Max Impact Load (tons)	Max Impact Energy Absorbed (in.-tons)	Navigation Condition and Marine Environment	Ship Beam (ft)	Max Berthing Force to Dock (lb/lin ft)	Max Berthing Force to Ship (point loading): Loading Intensity (tons/ft2)	Loading Intensity (psi)	Total Force (tons)
11.5	1	0.468	29.80	147.33	wind: 14 knots, NE	76	1,190	0.80	11.1	11.1
	2	0.470	21.60	122.52	wave: moderate		870	0.82	11.3	11.3
	3	0.472	24.10	140.37	tide: +3 feet		960	0.82	11.3	11.4
	4	0.475	30.50	250.00	broadside berthing		1,580	0.90	12.5	12.6
	5	0.477	35.00	214.27			1,400	0.95	13.1	13.3
	6	0.480	25.80	169.96			1,030	1.24	17.2	11.3
	7	0.482	29.80	113.45			1,190	1.17	16.3	10.7
9.7	1	0.675	87.10	843.0	wind: 25 knots W (gusts to 40 knots)	76	3,480	3.95	55.0	62.2
					wave: rough					
					tide: +4.2 ft					
					angle of approach: 10°					
18.5	1	0.75	6.70	20.75	wind: 2 knots	37	270	0.56	8.1	3.6
	2	0.75	8.10	26.80	wave: calm		320	0.50	6.9	3.1
					tide: +5.0 ft					
					angle of approach: 10°					
14.9	1	–	3.80	6.83	not recorded	76	150	0.92	12.6	1.8
	2	–	17.60	99.10			710	1.16	16.1	7.6
	3	–	19.50	116.83			780	1.25	17.4	9.6
	4	–	15.20	89.20			610	1.16	16.1	7.6
19.2	1	0.16	8.71	30.61	wind: 6 knots, S	52	350	1.00	13.9	5.0
	2	0.50	4.50	15.93	wave: calm		160	1.00	13.0	4.5
	3	0.50	2.65	6.36	tide: +3.7 ft		110	0.94	13.0	2.7
					broadside berthing					
11.5	1	0.355	6.30	50.46	wind: 3 knots, NNW	76	250	0.22	3.0	3.5
					wave: calm					
					tide: +4.0 ft					
					broadside berthing					
9.7	1	0.92	19.36	75.72	not recorded	73	780	1.38	19.2	17.6
	2	0.32	4.48	20.00			190	0.32	4.5	4.5
	3	0.70	2.95	15.40			120	0.20	2.7	3.0
	4	0.14	4.65	37.10			190	0.90	12.4	4.7
12.1	1	0.568	32.95	191.06	not recorded	76	1,320	1.39	19.3	10.9
	2	0.521	25.59	183.45			1,020	1.58	22.0	16.9
	3	0.460	22.11	136.75			880	1.33	18.5	12.3
16.0	1	0.675	5.64	18.16	wind: 4 knots, NE	63	230	0.98	13.6	4.7
					wave: calm					
					tide: +3.5 ft					
					angle of approach: 10°					
8.5	1	0.500	27.60	228.00	wind: 15 knots, W	76	1,100	1.43	19.9	13.3
					wave: rough					
					tide: +3.5 ft					
					broadside berthing					
13.[illegible]	1	0.445	4.10	20.20	wind: 5 knots, NE	62	550	1.01	14.0	4.7
					wave: calm					
					tide: +2.5 ft					
					broadside berthing					
6.0	1	–	7.18	36.2	wind: [illegible] knots, W	70	290	1.12	15.6	7.2
	2	–	13.90	33.6	wave: calm		560	1.06	14.7	5.7
	3	–	6.72	32.2	tide: +2.0 ft (berthing)		270	1.09	15.2	6.7
2.6	4 (Leaving)	–	6.16	28.2	+3.6 ft (leaving)		250	1.08	15.0	6.2
					anchor dropped to control ship speed					
11.0	1	–	8.74	48.4	not recorded	76	350	1.18	16.4	8.7
8.5	1	–	–	–	wind: 25 knots, W	76	–	1.30	12.0	10.1
					wave: rough					
					tide: 0.0 ft					
					broadside berthing					

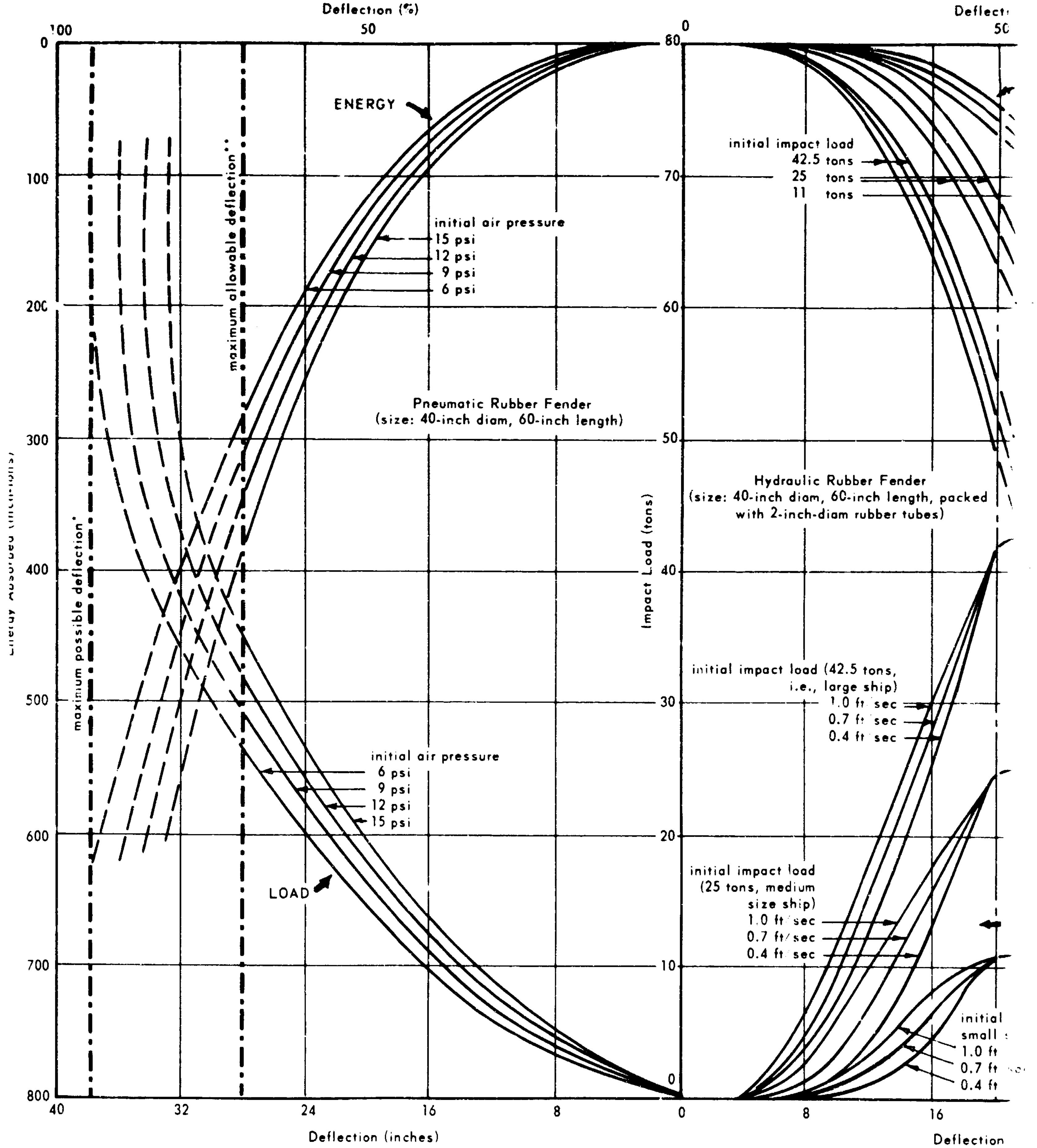
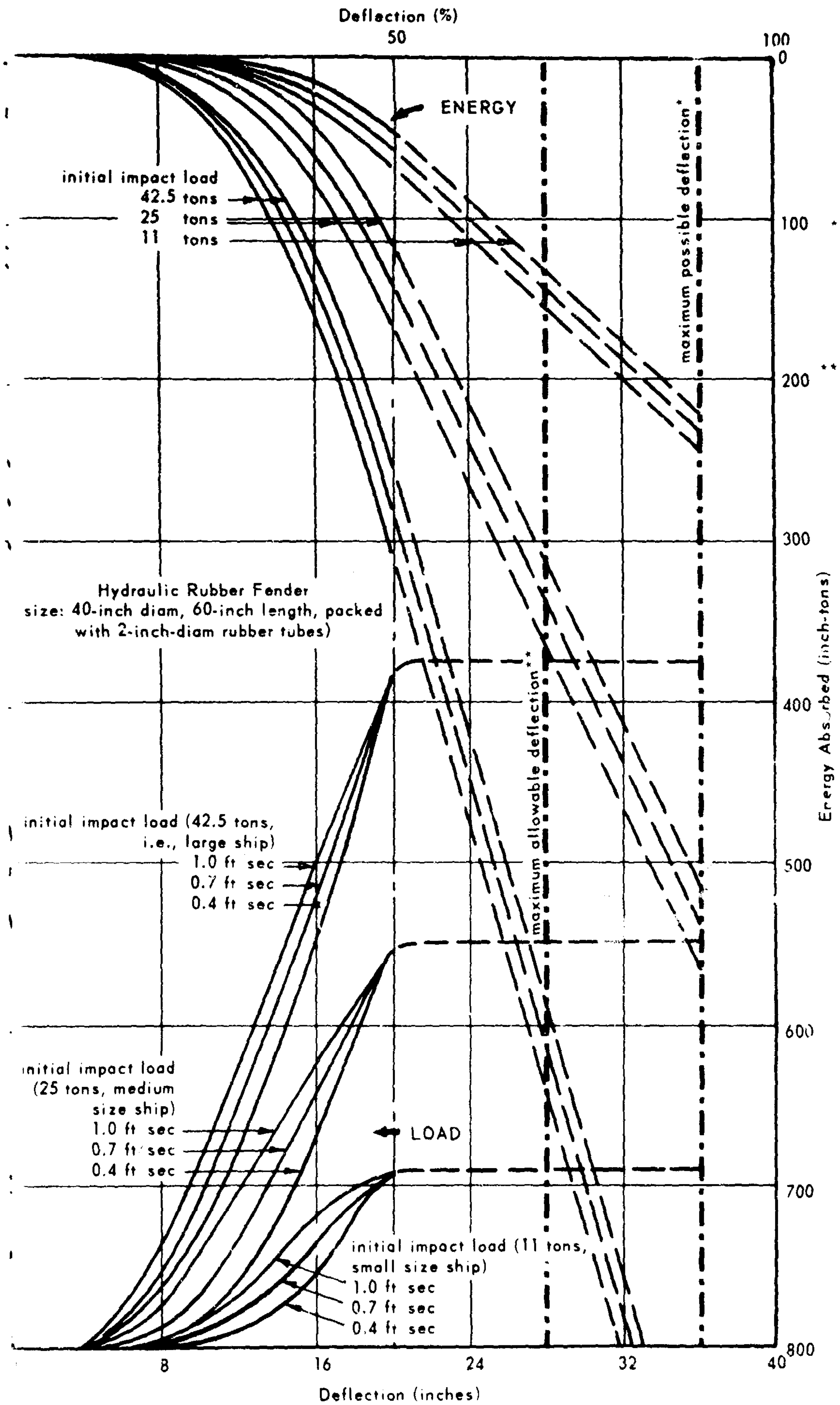


Figure 2. Load-deflection and energy-absorption characteristics of hydraulic fender and p

A



* Maximum possible deflection for hydraulic fender is limited by elastic deformation of rubber tubes inside the fender. Maximum deflection for pneumatic fender is limited by the burst pressure and is dependent upon the initial air pressure.

** Maximum allowable deflection for both the hydraulic fender and the pneumatic fender is limited by the diameter of the steel end flange. Diameter of the flange is 12 inches.

...acteristics of hydraulic fender and pneumatic fender.

B

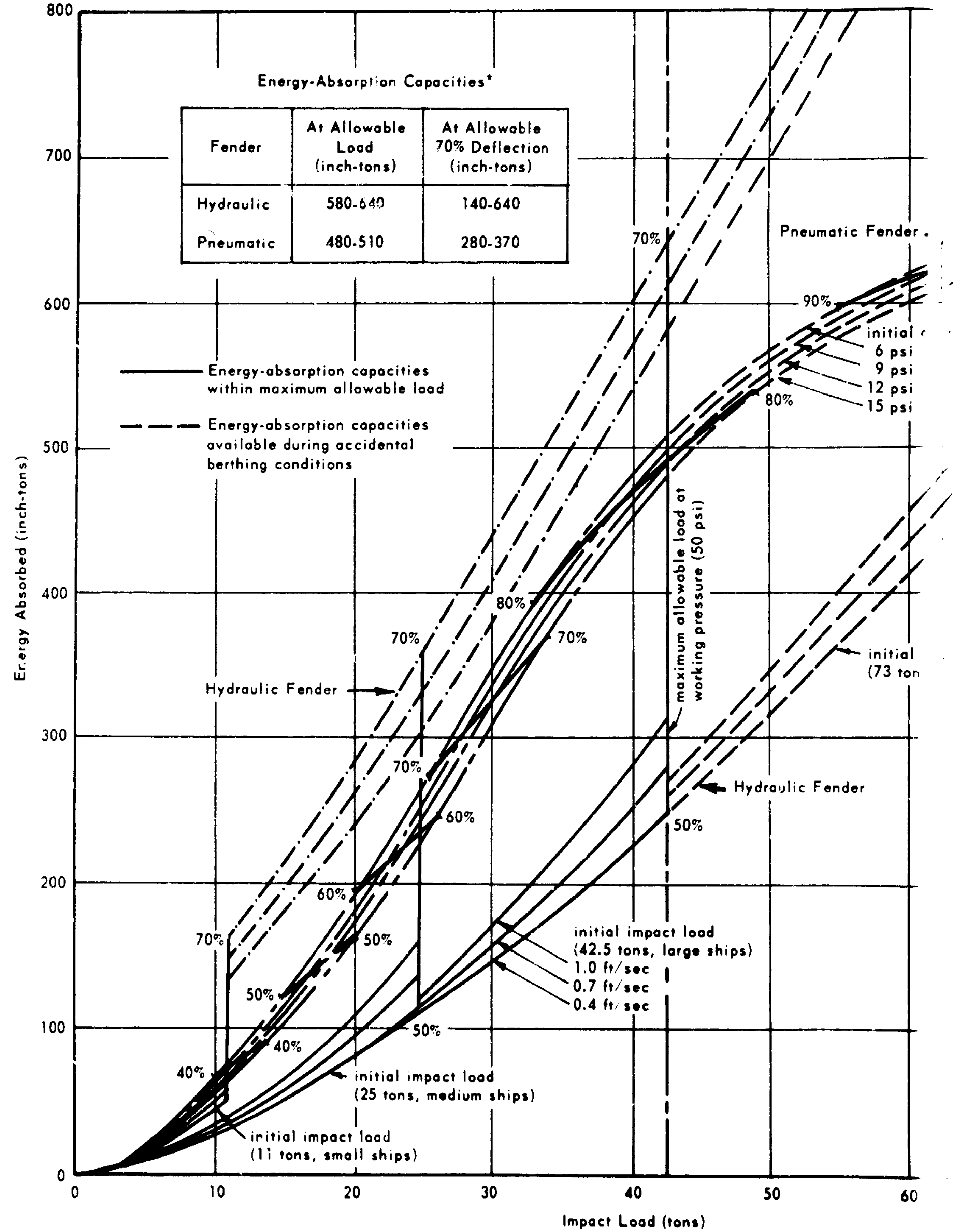
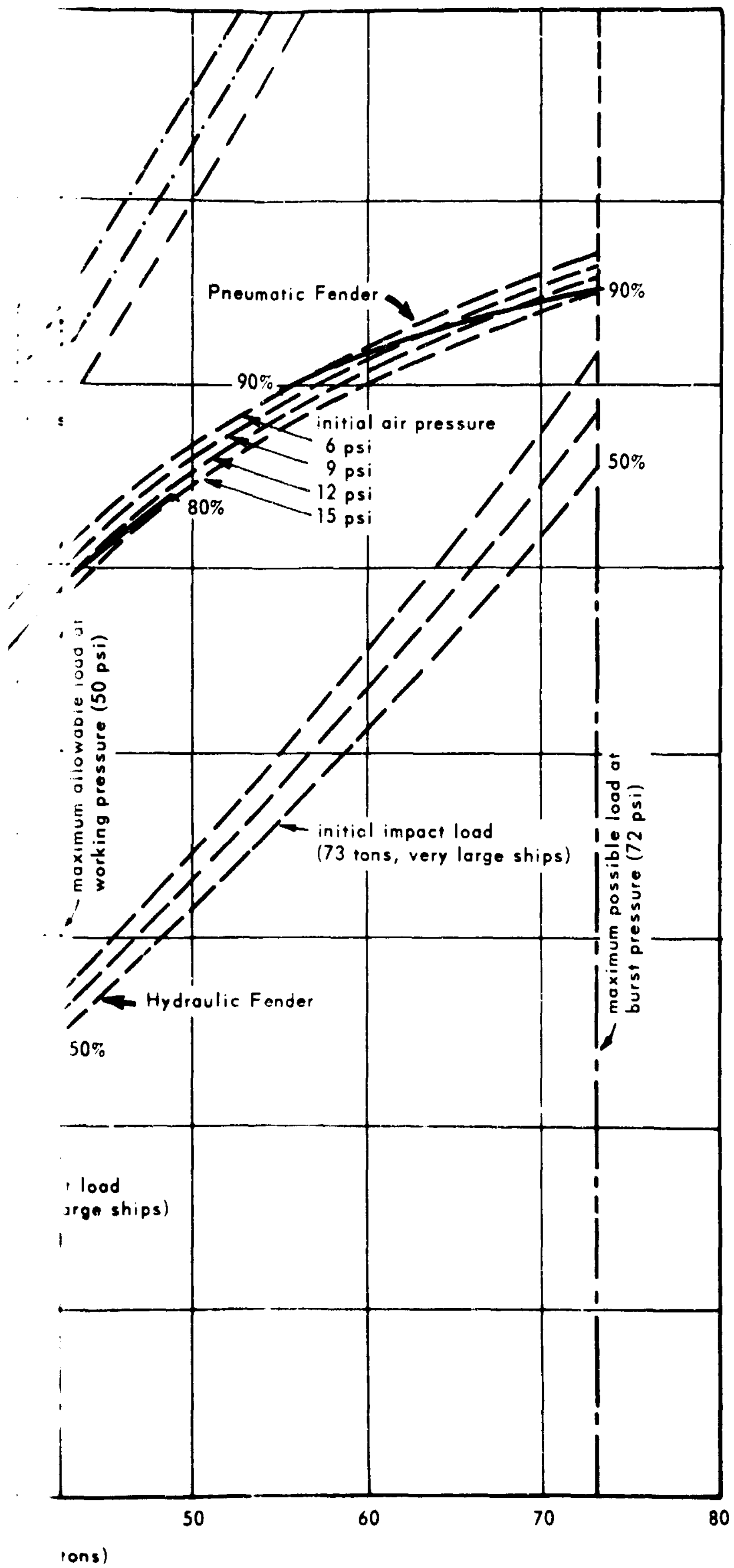


Figure 3. Comparison of load and energy-absorption capacit hydraulic fender and pneumatic fender.

A Figure 3. Comparison of load and energy-absorption capacities of hydraulic fender



nergy-absorption capacities of
umatic fender.

cities of hydraulic fender and pneumatic fender.

* Resistant loads and energy absorption capacities for the hydraulic fender are dependent upon the impact speed and size of the berthing ships.

Resistant loads and energy absorption capacities for the pneumatic fender are dependent upon the initial air pressure and deflection of the fender.

B

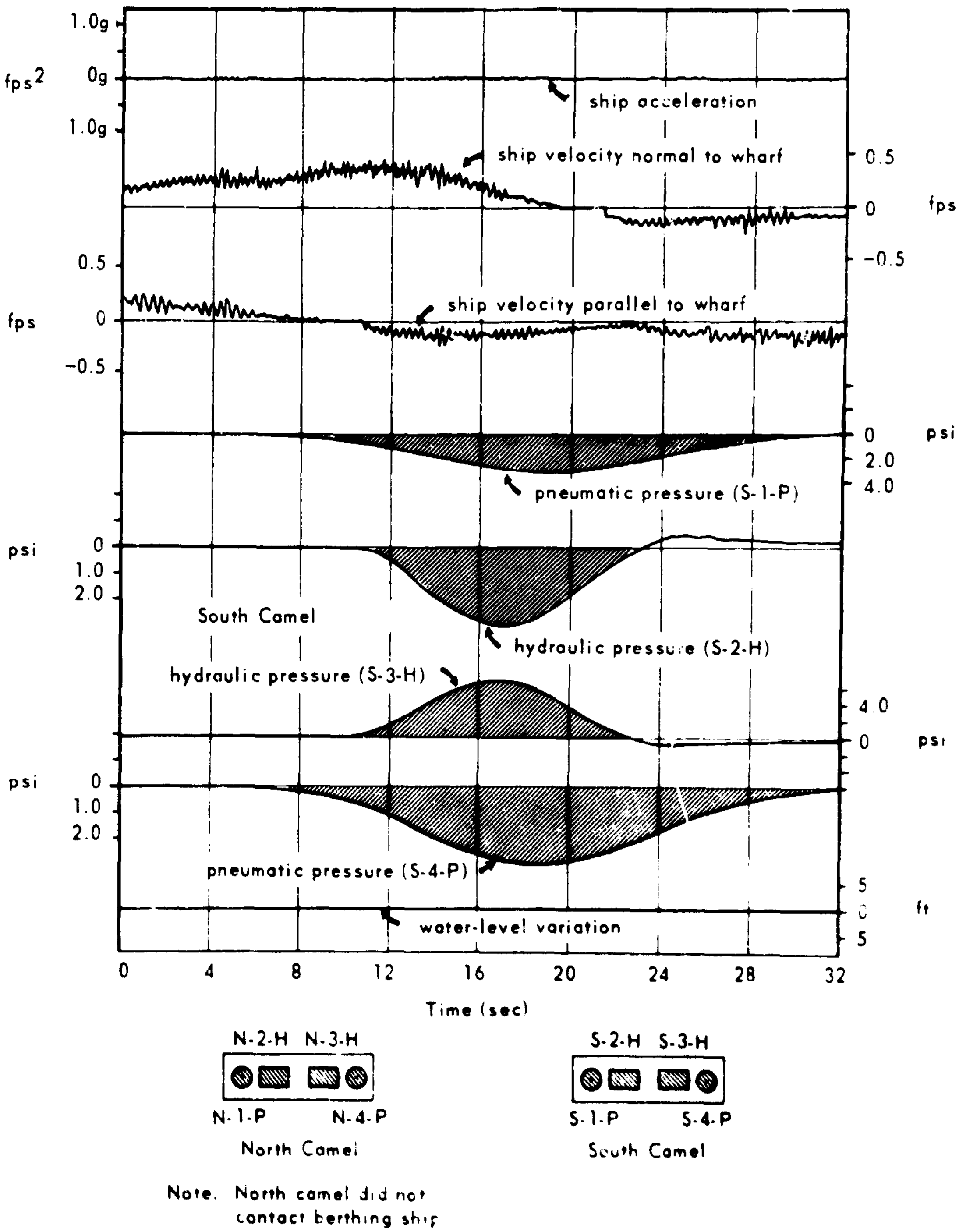


Figure 4. A typical recording of field measurements; these were taken during a berthing of the USNS General William Mitchell, 22 December 1963.

TEST CONDITIONS

The tests were conducted from March 1963 to May 1964 (14 months). Water depth at the time of berthing varied from 28 to 34 feet. Clearance between ship keel and mudline was 3 feet minimum and 19 feet maximum. The ship and dock clearance prior to a broadside berthing was estimated as 50 to 100 feet. Wind velocities ranged from 2 to 40 knots, mostly from NW, that is 45° off port beam of the wharf face. Waves and currents were insignificant.

TESTS

Position of Berthing Impact

Detailed information on test berthings, including point of impact, navigation condition, and marine environment, is given in Table 1. Most berthings were broadside, using two 1,030-horsepower tugs. The point of ship/fender contact, calculated from measurements of initial and final ship positions, varied from 0.14 to 0.92 of the ship length, L, as measured from the stern. There were many impacts at 0.50 (the center of the berthing ship). This method of berthing is favored locally.

For multiple impacts the point of ship/fender contact as well as longitudinal motion of the ship was calculated from measurements of the tangential berthing speeds (Figure 5).

In the calculations the radius of gyration, k, was assumed to be 0.24 L (Figure 6). This seems reasonable since k, for naval and merchant ships, varies from 0.20 L to 0.29 L (Lee, 1965a). Saurin (1963) and Vasco Costa (1964) suggest 0.2 L.

The eccentric coefficient, c_e, was computed from Equation 1a, using the values of a and k as given earlier. This was used in Equation 1, along with the other coefficient, to predict the kinetic energy of the berthing ship upon contact with the fender.

Berthing Force Characteristics

Bag deflection and force on the fender (Lee, 1963, 1965a), as induced by the berthing ship, were calculated from the measured bag pressures. The maximum impact force varied from about 3 tons for a 1,000-ton ship to 40 tons for a 15,000-ton ship. These are loads of 0.06 and 0.8 tons per lineal foot of berth, which is low compared to the design load of 1.2 tons per lineal foot. An exception was an 87-ton impact force in the accidental berthing of the 17,000-ton USNS General Breckinridge (Figure 7).

It is estimated from Figure 7 that for ships of 20,000 tons displacement the maximum force should not exceed 60 tons for a normal berthing or 100 tons for an accidental berthing; that is, 1.2 or 2.0 tons per linear foot of berth.

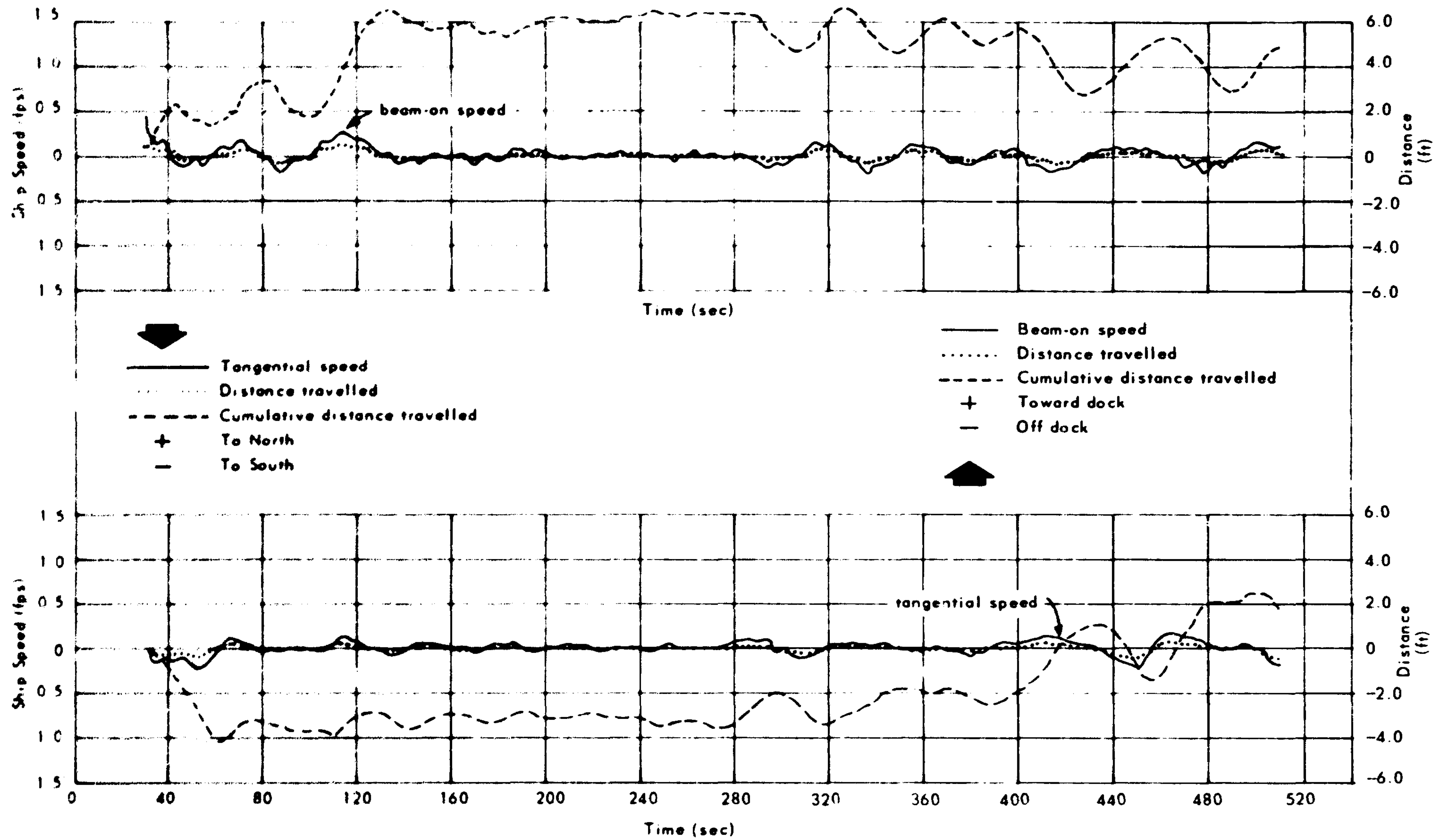


Figure 5. Motion of ship during berthing of the 7,700-ton SS Guam Bear, 4 January 1964.

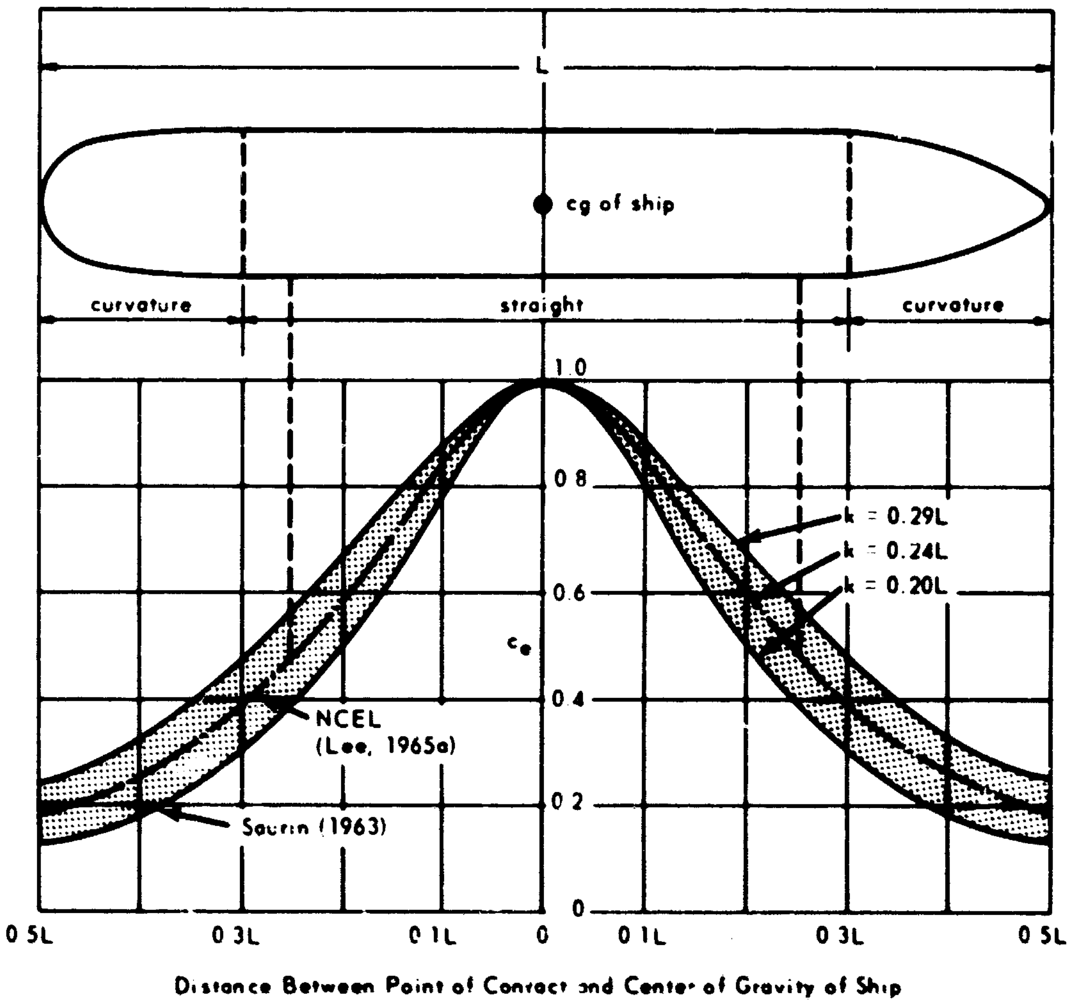


Figure 6. Eccentricity coefficients.

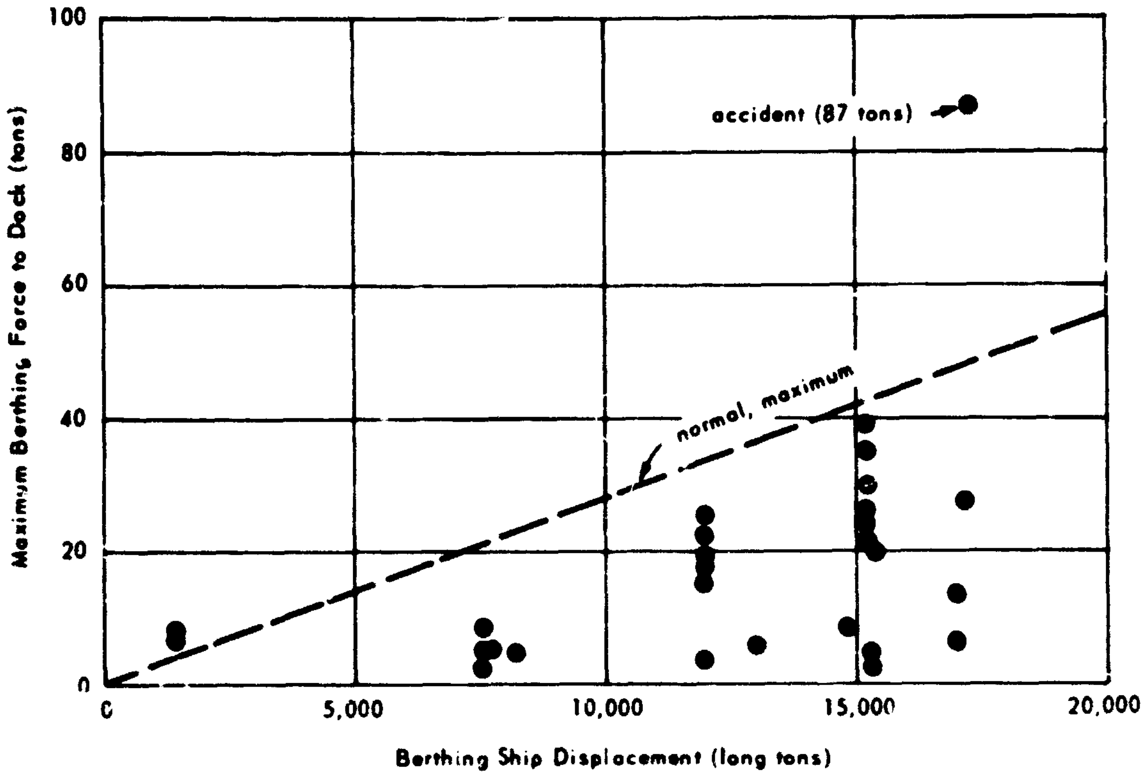


Figure 7. Maximum berthing force to dock.

The frequency of berthing force transmitted to dock and to ship hull was analyzed, using measurements of 33 berthing impacts (Figures 8, 9, and 10). Normally, the berthing force transmitted to the dock did not exceed 1,500 pounds per linear foot of berth where 2,500 is conventional for design. The exception noted above resulted in a load of 1.7 tons per linear foot of berth (Table I); no damage was observed.

Loading to Ship Hull

The berthing force transmitted to ship hull was 0.2 to 4.0 tons per square foot, or 3 to 55 pounds per square inch, averaging approximately 15 pounds per square inch (Table I). No damage to hulls was noted.

Berthing Velocity Characteristics

Berthing speeds both normal and parallel to the dock face were measured either at the point of impact or at the center of the ship. Those normal to the dock varied from 0.1 to 0.4 foot per second under normal conditions; the maximum was 1.0 foot per second. Appendix B presents the typical pattern of the velocities of translation of the berthing ships. It is readily apparent that the magnitude and direction of the motion of a berthing ship varies significantly with time. In many model studies in the laboratory the magnitude and direction of motion are kept significantly constant (Wallingford 1961, 1962, and Saurin, 1963); consequently, these measurements cannot readily be compared with those obtained in actual berthings in harbors.

A general relationship between berthing force and beam-on berthing speed for USNS General William Mitchell was formulated (Figure 11). It indicates that during the initial stage of impact, i.e., when the ship accelerated, the berthing force was low compared to that at a later stage when the ship decelerated at a similar rate. This is probably due to the fact that the pneumatic rubber bag is softer at the initial stage, whereas at the later stage, the bag is compressed more fully and offers more resistance. Both acceleration and deceleration are involved in the process of berthing.

The tangential speed of the berthing ship was low, and its effect was trivial. Figure 5 shows a typical record of both beam-on and tangential speeds, and ship surge and sway motions during the berthing of SS Guam Bear on 4 January 1964.

Effects of Hydrodynamic Mass and Water Friction

Beam-on speed has a significant effect on the resistance to motion in this direction (Figure 12). At lower beam-on speeds (0.1 foot per second or less), resistance effects increase considerably. No attempt was made to separate hydrodynamic mass from these effects; the value recommended by Vasco Costa is shown on the figure for comparison only.

RESULTS

The maximum total kinetic energy absorbed by the floating fender seems to be about 16 inch-tons per 1,000 tons of displacement; i.e., it varied from 6 to 320 inch-tons for ships of about 1,200 to 20,000 tons displacement (with the exception previously noted, which measured 843 inch-tons, or 50 inch-tons per 1,000 tons). See Figure 13. This linearization is an arbitrary method to enclose a scattering of measured points. Its validity is questionable since such nonlinearly related factors as the pilot's ability to maneuver, the navigation conditions, and marine environment have a significant effect on berthing speed and hence on kinetic energy. Nevertheless, for broadside berthing, the estimate of a maximum-required fender energy absorption as 16 inch-tons per 1,000 tons of displacement for normal berthing, and 50 inch-tons per 1,000 tons of displacement at accidental levels is of the same order determined by others (Lee, 1965a, 1965b and Risselada and van Lookeren Campagne, 1964). The probability of occurrence is, respectively, 14 and 1 chances in 100 (from Figure 14a and Table II which define the energy-absorption capacity required in Hueneme Harbor, a well-protected harbor with moderate winds and trivial waves and currents). The recommendation of Lee

(1965b) coincides with 5% probability (Figure 14b). Economics may dictate changes in these values for particular designs. The curves are fitted by eye through points based on measurements; they did not warrant use of such elegant approaches as extreme value theory (Saurin, 1963) since the data collected are rather limited.

Maximum berthing force occurred during a high wharf-on wind with gusts to 40 knots, but there were some fairly high forces during such moderate wharf-off winds as those of 14 knots. Generally, berthing impacts were relatively light during calm weather.

The measured berthing forces and related energy absorption were compared with those measured on models by Wallingford Research Station (1961 and 1962). See Figures 15 and 16. Agreement is fair, but perhaps comparison is not pertinent because of the many differences. The Hueneme test fender is much less stiff than those used at Wallingford; thus, the energy-absorption capacity of the Hueneme fender is also less. Ship size and test conditions (such as berth configurations, relative stiffness of ship hull and fender, and natural environment) were not identical. The model tests at Wallingford are concerned with forces caused by rotation of the ship about the stern rather than those caused by beam-on translation as in the Hueneme tests. Theoretically, in the latter, for an equal velocity at the same point of contact, the amount of energy to be absorbed by a fender is larger when the impact is caused by a ship translation than when it results from a ship rotation (Vasco Costa, 1964). The amount of absorbed energy varies with the position in which the berthing ship contacts the fender; resistance to motion at various berthing speeds is significant.

Many investigators assume that the center of gravity of the ship coincides with the center of the ship length (Wallingford, 1961, 1962; Saurin, 1963; Vasco Costa, 1964; Lee, 1965a). Errors proportional to the difference will result if the center of mass is remote from the center of the ship, as in naval destroyers. Generally the center of mass tends to vary with draft quite independent of any architectural aspects.

Resistance to motion at a ship beam-on speed of 0.10 foot per second varies as much as 600 to 800% from that suggested by Vasco Costa (1964) as due to the hydrodynamic mass effect alone (Figure 12); at 0.26 foot per second the difference is negligible. Full-scale measurements conducted at Finnart, Scotland and Bombay, India indicate a similar effect (Grant, 1965).

Furthermore, the computed or predicted values of the kinetic energies absorbed by the floating fenders compare fair only with those actually measured (Figure 17). The error was ±25% generally. As shown in Figures 18 and 19, the measured energy is considerably higher than predicted ones when a ship's beam-on speed is lower than 0.1 foot per second, but measured energy is lower at ship speeds greater than 0.2 foot per second. Fortunately, the energy-absorption characteristics at extreme low speeds have no significant value in the determination of a fender capacity; therefore, for design purpose, the predicted energy normally induced by a ship at a relatively high speed is adequate.

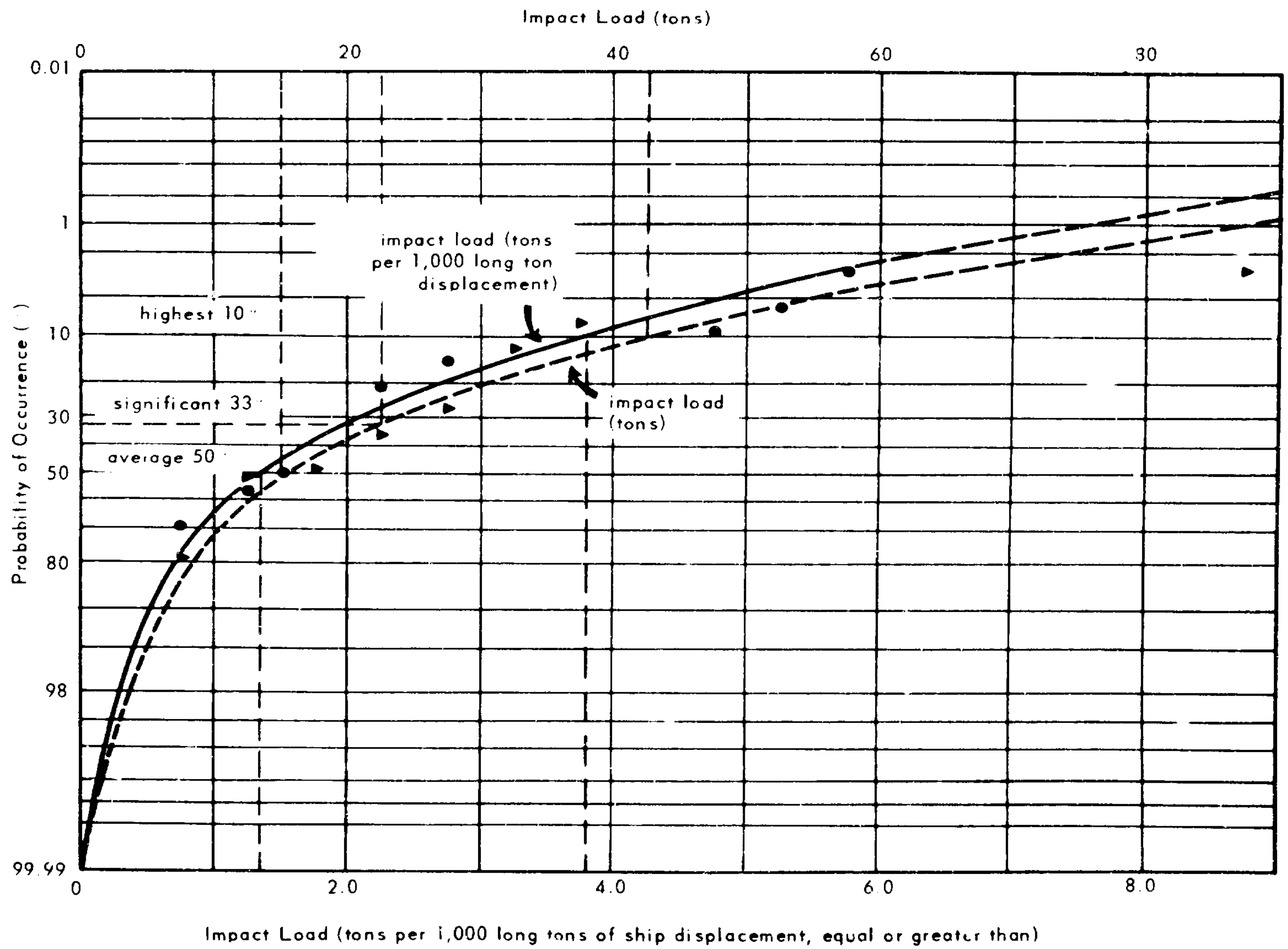


Figure 8. Frequency analysis of berthing force.

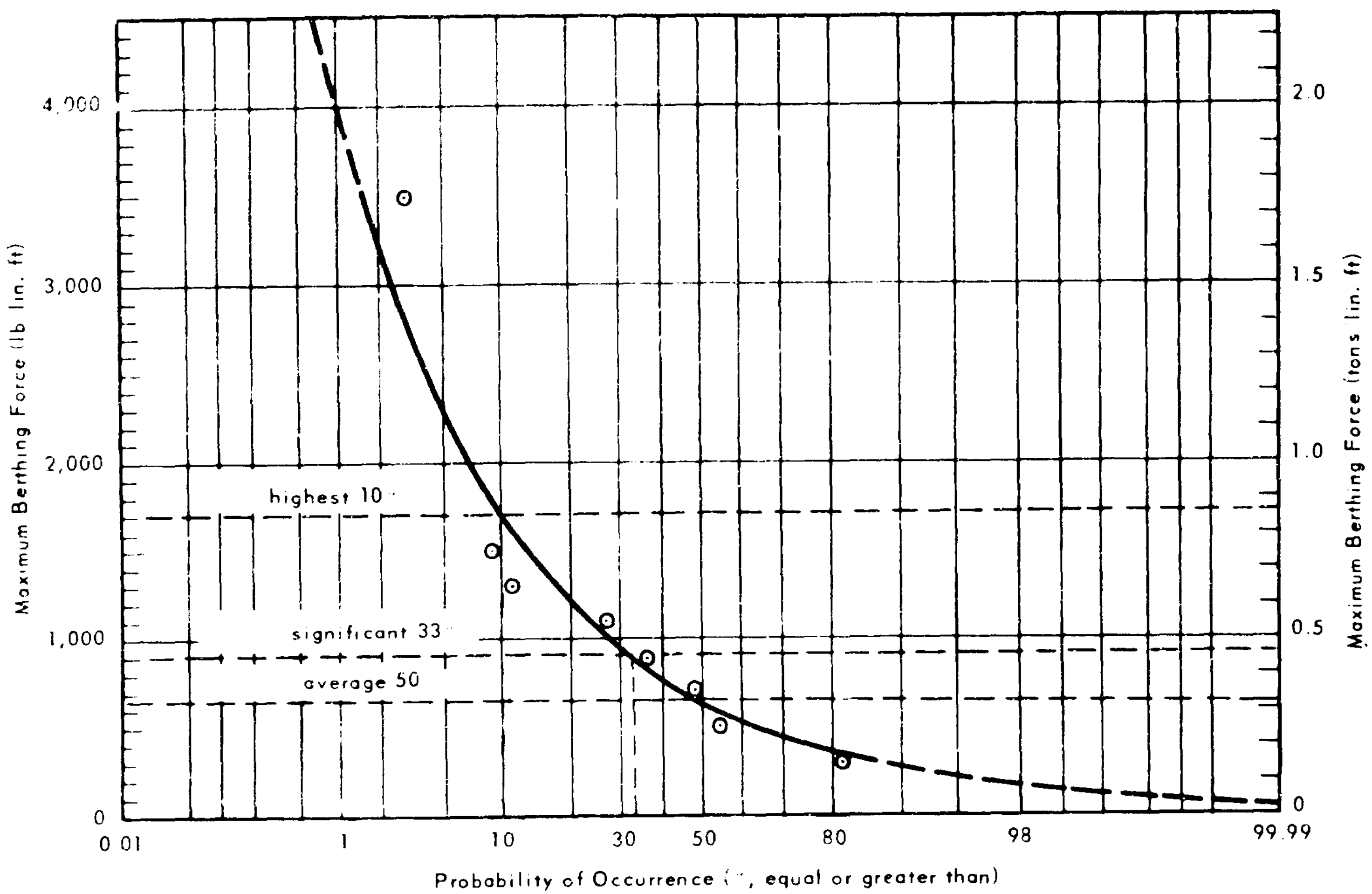


Figure 9. Frequency analysis of berthing force to dock with hydraulic-pneumatic camels.

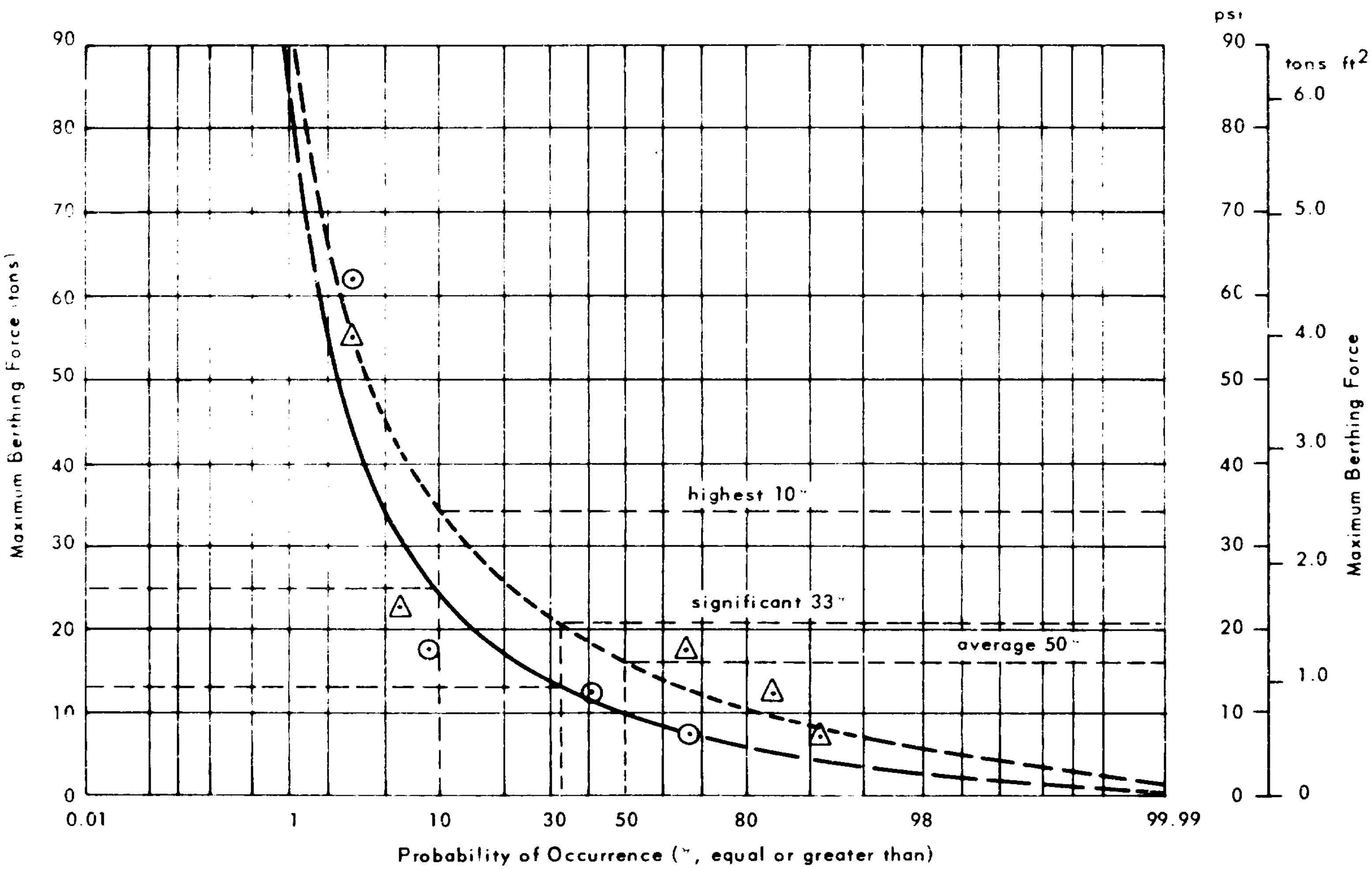


Figure 10. Frequency analysis of berthing force to ship hull.

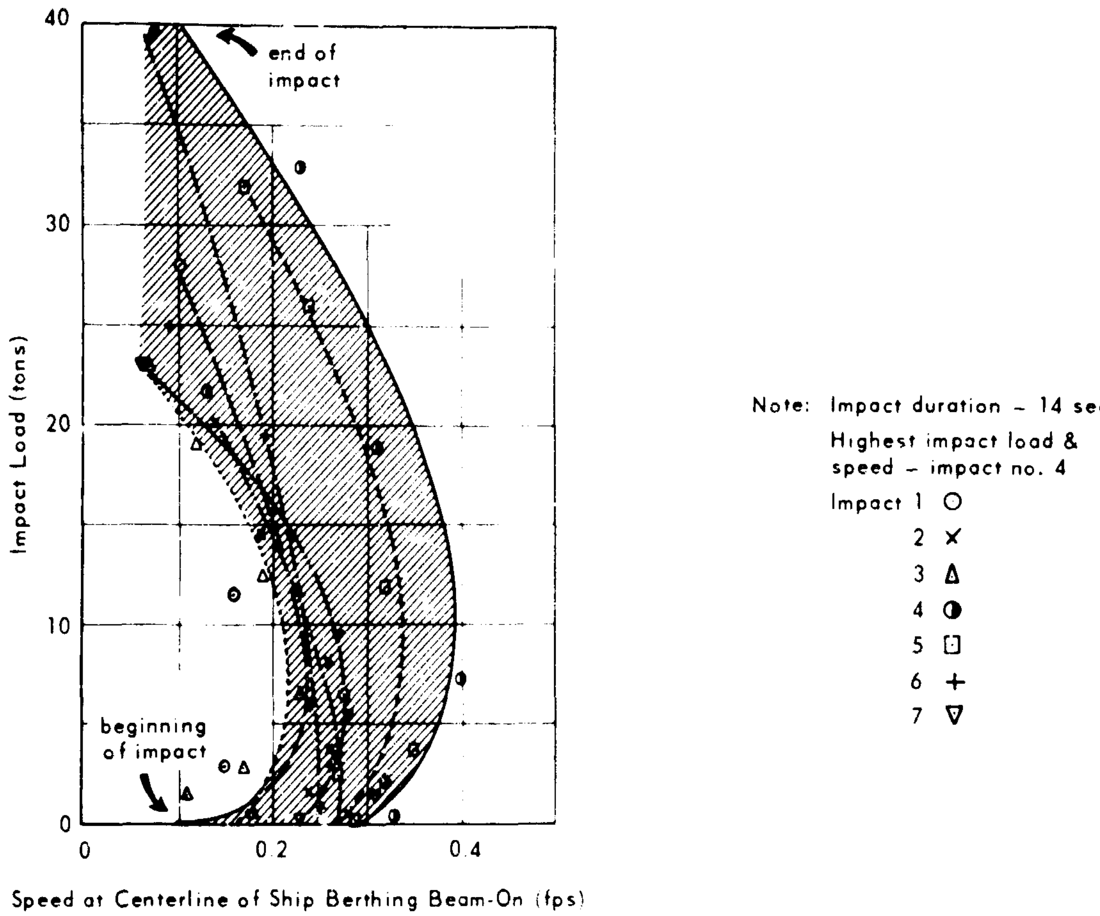


Figure 11. The relationship of berthing force to ship speed from berthing measurements of the 15,200-ton USNS General William Mitchell.

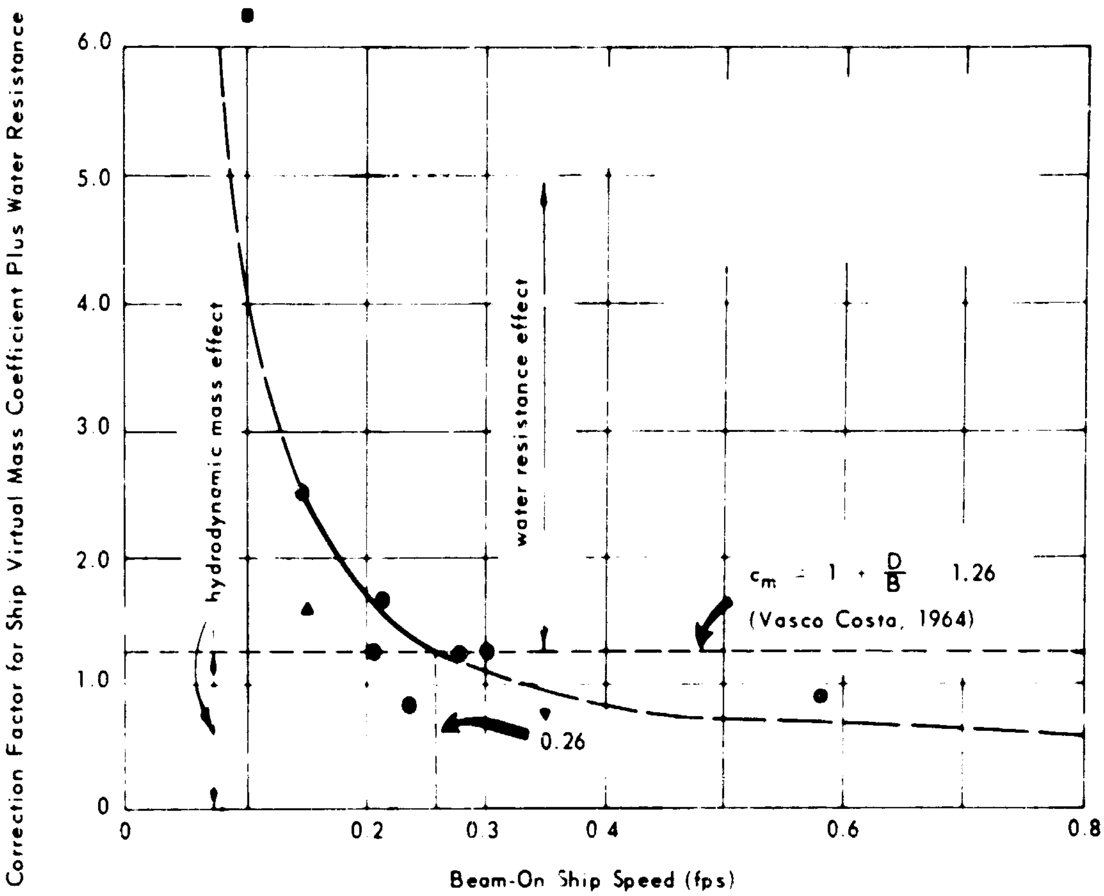


Figure 12. The hydrodynamic effect of virtual mass plus water resistance versus beam-on ship speed, using berthing measurements of the 15,200-long-ton USNS General William Mitchell on 22 December 1963.

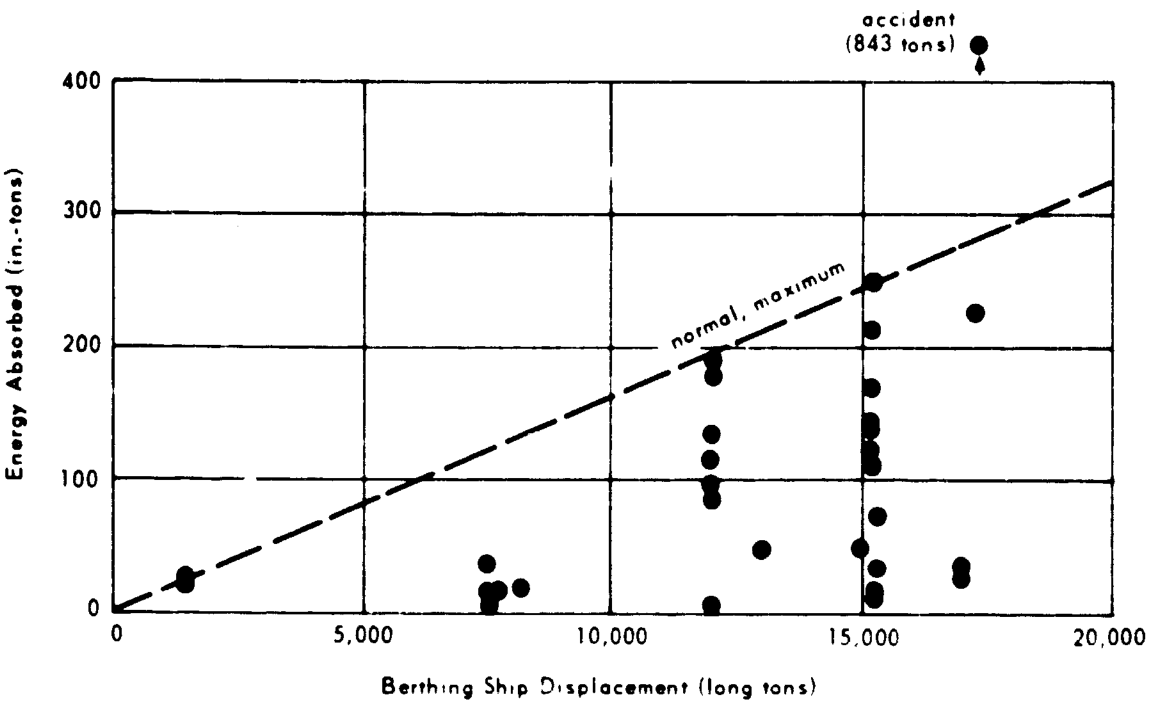


Figure 13. Maximum energy absorbed by hydraulic-pneumatic fender.

Table II. Energy-Absorption Requirements in Protected Harbors with Moderate Winds

Ship Displacements (long tons)	Probability of Occurrence (%)				
	50	33	10	5	1
10,000	70	100	180	220	300
20,000	140	200	360	440	600
40,000	280	400	720	880	1,200
60,000	420	600	1,080	1,320	1,800
80,000	560	800	1,440	1,760	2,400
100,000	700	1,000	1,800	2,200	3,000

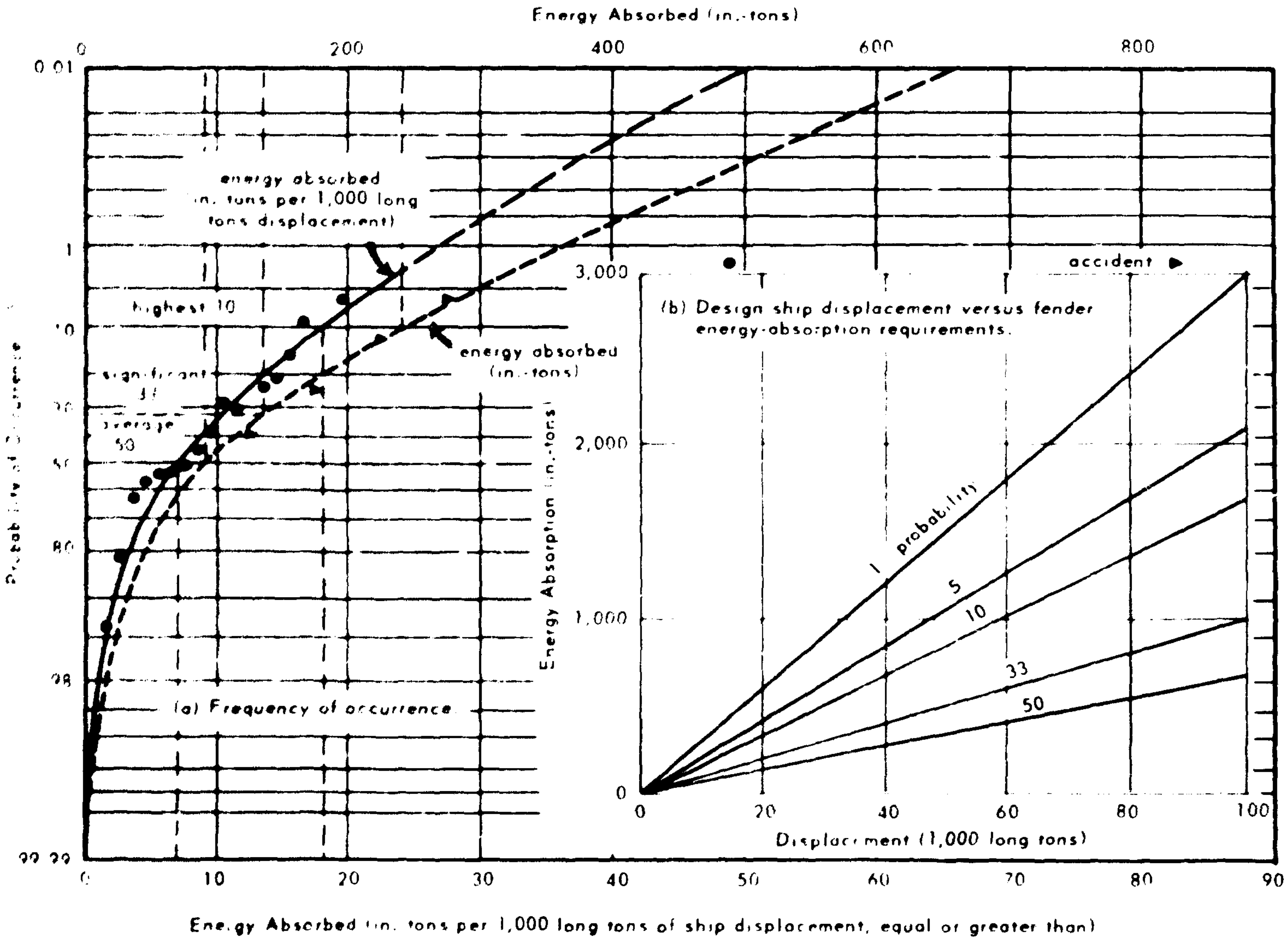
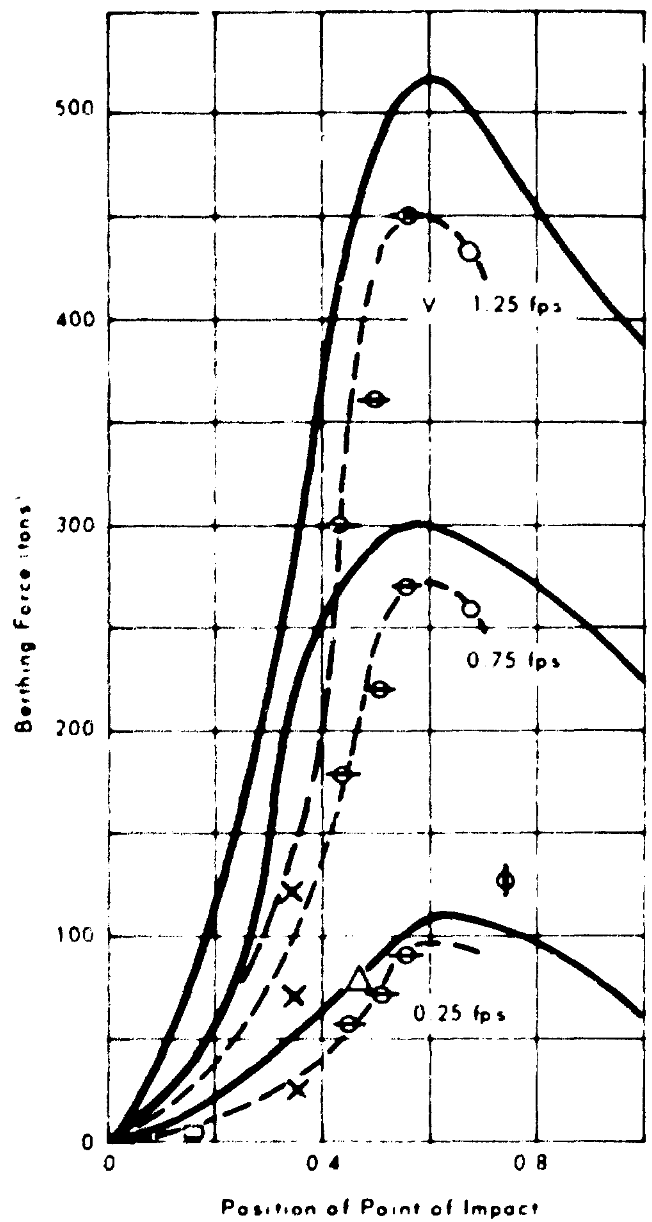


Figure 14. Frequency analysis of energy absorption.



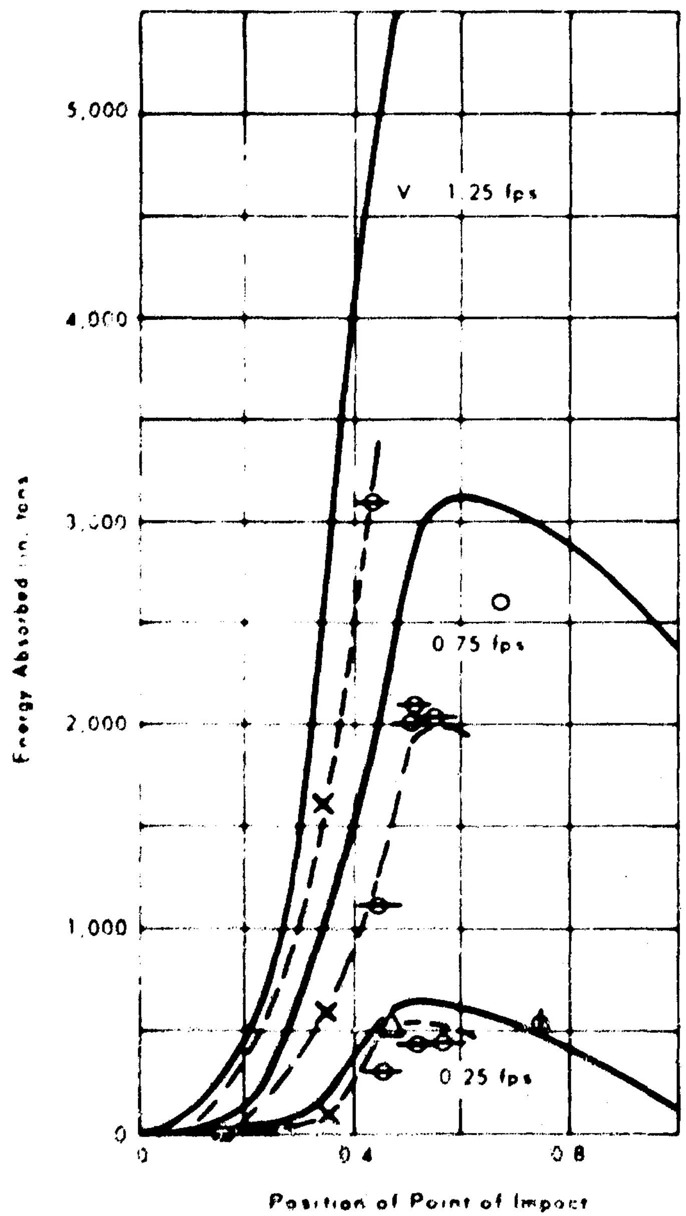
Fender Stiffness
— Wallingford - 9.5 tons/in.
-- NCEL - 0.6 tons/in.

Note: Wallingford data based on 32,000-ton tanker, NCEL data based on following table:

	Name of Ship	Displacement (tons)	Berthing Velocity (fps) 1/
△	USNS General William Mitchell	15,200	0.22
○	USNS General Breckinridge	17,300	0.58
⏀	USNS Charles H. Davis	1,400	0.20
⊖	SS California	12,000	0.28
×	SS Hong Kong Bear	13,000	0.15
□	USNS Sgt. Jack J. Pendleton	7,600	0.04

1/ The solid lines represent data from a model study of the berthing impact of a 32,000-ton tanker at three different velocities. The study was performed at Wallingford, England. The points and associated dashed lines are extrapolated data from actual measurements taken on various ships by NCEL. The actual data was converted to allow a comparison with the three ship velocities used in the model study.

Figure 15. Berthing force characteristics; prototype versus model.



Fender Stiffness
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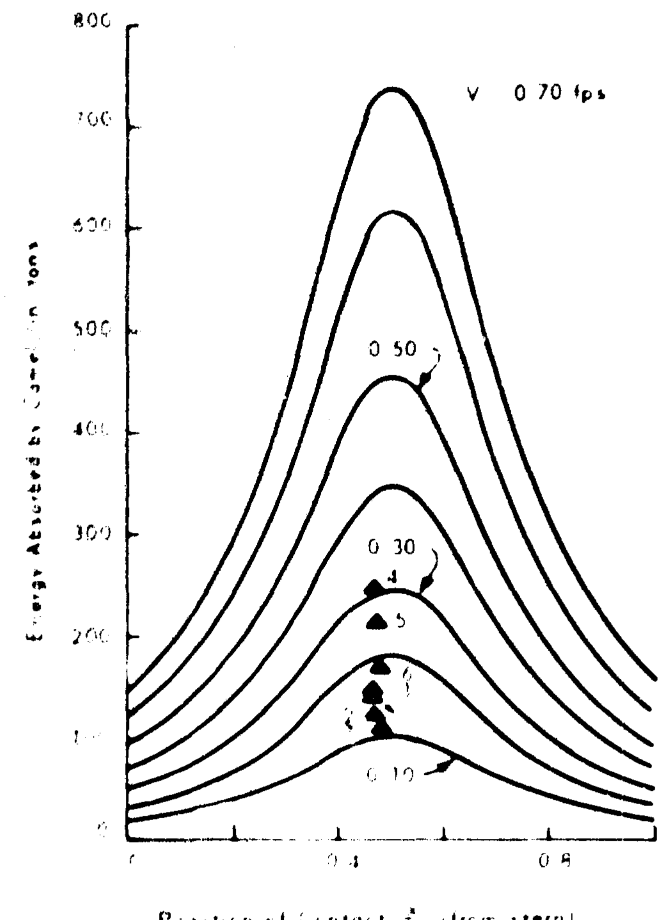
ɸ	USNS Charles H. Davis	1,400	0.20
-ɵ-	SS California	12,000	0.28
X	SS Hong Kong Bear	13,000	0.15
□	USNS Sgt. Jack J. Pendleton	7,600	0.04

1/ The solid lines represent data from a model study of the energy absorption of a fender under three different ship velocities. The study was performed at Wallingford, England. The points and associated dashed lines are extrapolated data from actual measurements taken on fenders by NCEL. The actual data was converted to allow a comparison with the three ship velocities used in the model study.

Figure 16. Fender energy-absorption characteristics; prototype versus model.

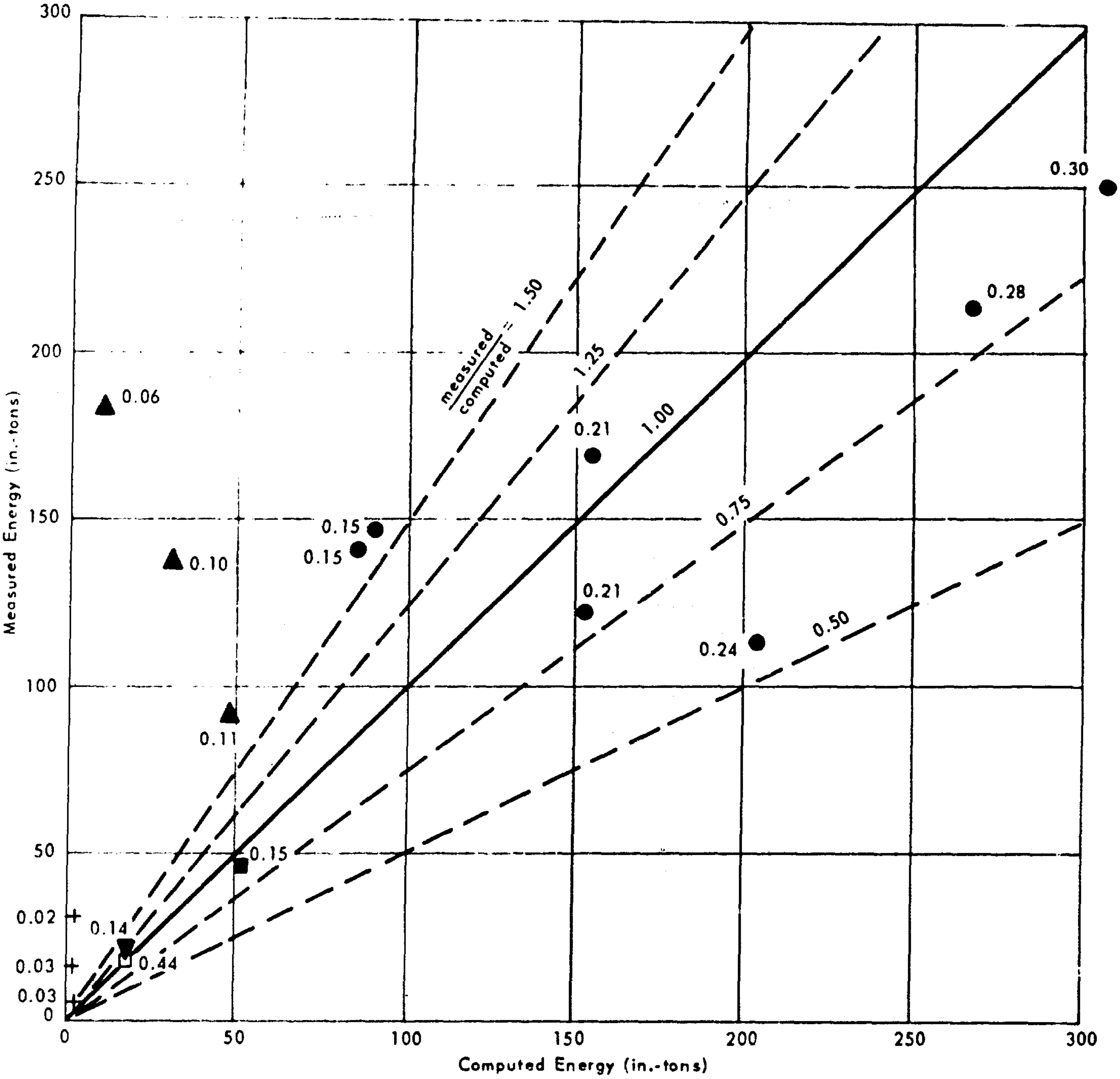


▲ Measured

—— Computed and adjusted for hydrodynamic and friction effects

Impact No.	Average Speed (fps)	Energy Absorbed (in.-tons)
1	0.15	147
2	0.21	123
3	0.15	140
4	0.30	250
5	0.28	214
6	0.21	170
7	0.24	113

Figure 17. Predictions versus measurements of energy absorbed by camel in berthing of 15,200-ton USNS General William Mitchell, 22 December 1963.



	Berthing Ship	Displacement (tons)	c_m*
●	USNS General W. Mitchell	15,200	1.52
▼	USNS Charles H. Davis	1,400	1.80
+	USNS Sgt. Jack J. Pendleton	7,600	1.47
■	SS Hong Kong Bear	13,000	1.54
▲	SS California	12,000	1.50
□	SS Guam Bear	7,700	1.49

Note: The numbers shown beside the points represent average beam-on speed of the berthing ship.

* Virtual mass coefficient based on Vasco Costa, 1964

Figure 18. Relationship of measured and computed (predicted) energy absorption of the hydraulic-pneumatic fender.

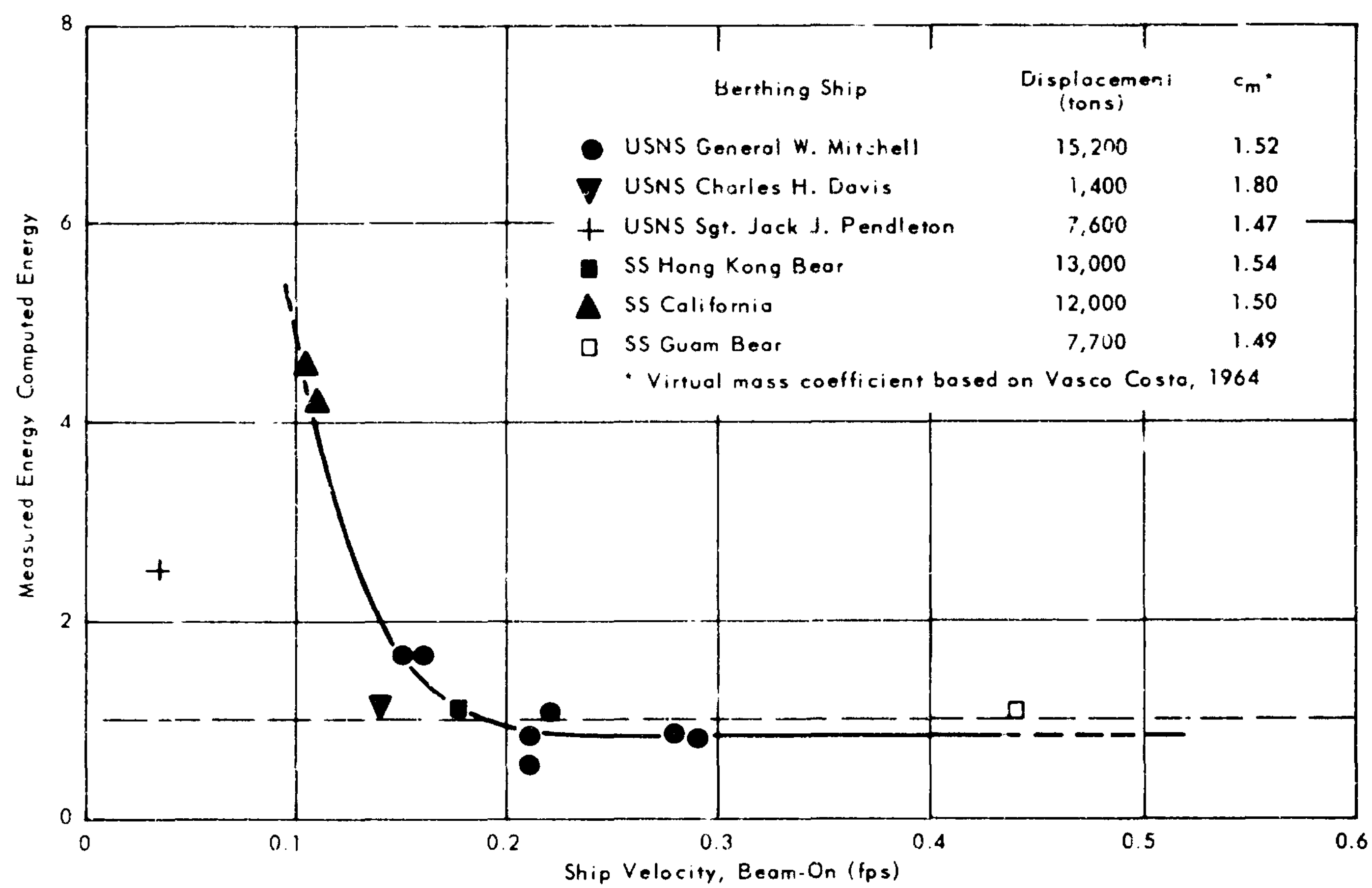


Figure 19. Ratio of measured and computed energy related to ship velocity during berthing.

FINDINGS

1. Water depth, under-keel clearance, and initial ship-dock spacing were, respectively, 28 to 34, 3 to 19, and 50 to 100 feet. These parameters could not be correlated with berthing force.

2. Waves and currents had no significant effects on berthing force.

3. The maximum berthing force occurred during a high wharf-on wind with gusts to 40 knots.

4. The maximum impact forces varied from about 3 tons for a 1,000-ton ship to 40 tons for a 15,000-ton ship, with one exception: an 87-ton impact force during the accidental berthing of a 17,000-ton ship.

5. The highest berthing force measurement was 1.7 tons per linear foot of berth, but the dock was not damaged even though its design load is 1.2 tons per linear foot.

6. The berthing forces transmitted to the hull were from 3 to 55 pounds per square inch with an average of 15; the rise time is approximately 15 seconds, generally. No hull damage occurred.

7. The comparison between berthing force and between fender energy absorption measured during these tests and on models in the laboratory (Wallingford) shows fair agreement.

8. Berthing speed of the center of gravity of the ship normal to the wharf was usually from 0.1 to 0.4 foot per second, with a maximum of 1.0.

9. During each berthing operation, the speed and direction of the ship varied significantly with time. Normally the ship accelerated during the initial stage; however, the berthing force was lower than that at a comparable deceleration.

10. The tangential component of berthing speed caused no operational difficulties.

11. It was significant that resistance to motion varied inversely with broadside ship speed. The effect of hydrodynamic mass was not separated from the other effects.

12. The maximum energy absorbed by the fenders varied from about 6.0 inch-tons for a 1,200-ton ship to 320 inch-tons for a 20,000-ton ship, with one exception: 843 inch-tons during the accidental berthing of a 17,000-ton ship. Although a linear relationship between these two quantities is suggested (Figure 14), it may not be tenable due to the probable nonlinear effects of navigation conditions, marine environment, and pilot's ability to maneuver.

CONCLUSIONS

1. The energy-absorption capacity of the floating fenders is adequate for a well-protected harbor such as that at Port Hueneme.

2. A fender system for a well-protected harbor should be designed with a minimum absorption capacity of 16 inch-tons per 1,000 tons of ship displacement for normal berthing, and with a maximum capacity of 50 inch-tons per 1,000 tons displacement. This also seems a sensible maximum for coping with accidental berthings.

3. Resistance to motion in berthing is a very important parameter which needs to be investigated further. It includes the effect of hydrodynamic mass which is important in the analytical treatment of berthing problems.

RECOMMENDATIONS

1. That full-scale tests of berthing impact be continued, particularly in exposed harbors, and that simpler instruments be developed for the purpose. The objective is to determine the energy requirements for other fender designs for exposed harbors.

2. That model tests or berthing impact be initiated, particularly of the resistance to motion for consequent evaluation of the pertinent hydrodynamic mass.

PART II. TESTS AT SAN DIEGO HARBOR

INTRODUCTION

After the in-service tests of the hydraulic-pneumatic floating fender (camel) at Port Hueneme in 1963-64, it was concluded that the fenders are effective in harbors with only moderate swell and wind, such as that at Port Hueneme, but that their initial cost and maintenance cost was high compared with that of conventional log camels. It was recommended that the fenders be modified in order to eliminate or ameliorate (1) these high costs, (2) the undesirable distance (up to 5 feet) between moored ship and wharf face caused by width of fender, and (3) the high rebound forces resulting from the rubber bags used for the fenders.

A substitute for the separate bags of air and water was proposed and designated "HYNEU" (Lee, 1963, 1965a). It involves an air-filled bag within a water-filled bag.

Although approved by BuDocks, these improvements were not made because of a shortage of funds. Instead, the unmodified fenders were reconditioned and installed for further in-service tests in a more exposed harbor than that at Port Hueneme, specifically in the harbor at San Diego, California. The results of those tests are reported in the following pages.

INSTALLATION

The fenders were reconditioned in the NCEL shops; the metal parts were recoated, the rubber bags replaced, and minor repairs were made on the fittings and securing assemblies. They were then transported to San Diego on a Navy barge and installed on 21 January 1965 at Pier No. 4 (Berth 45) of the U. S. Naval Station. This location was assigned by the U. S. Navy Public Works Center, San Diego. Location and appearance are shown in Figures 20, 21, and 22.

Figure 20. Installation of the test fender.

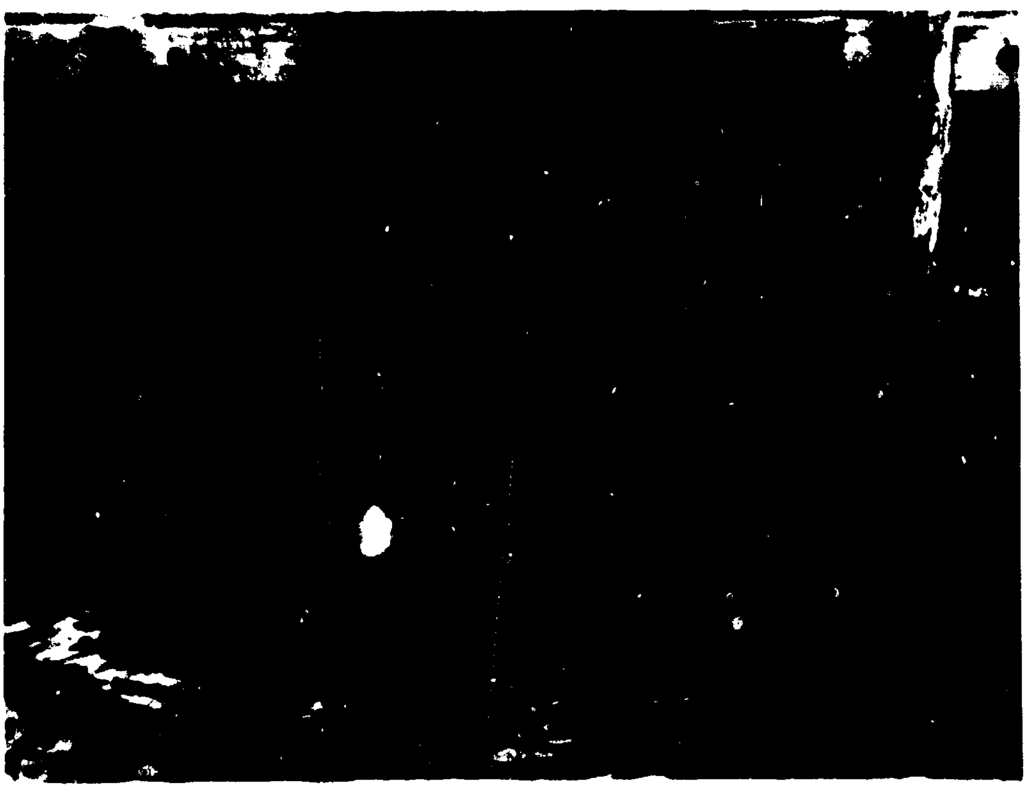


Figure 21. Test fender in operational position at
Pier No. 4, Naval Station, San Diego.

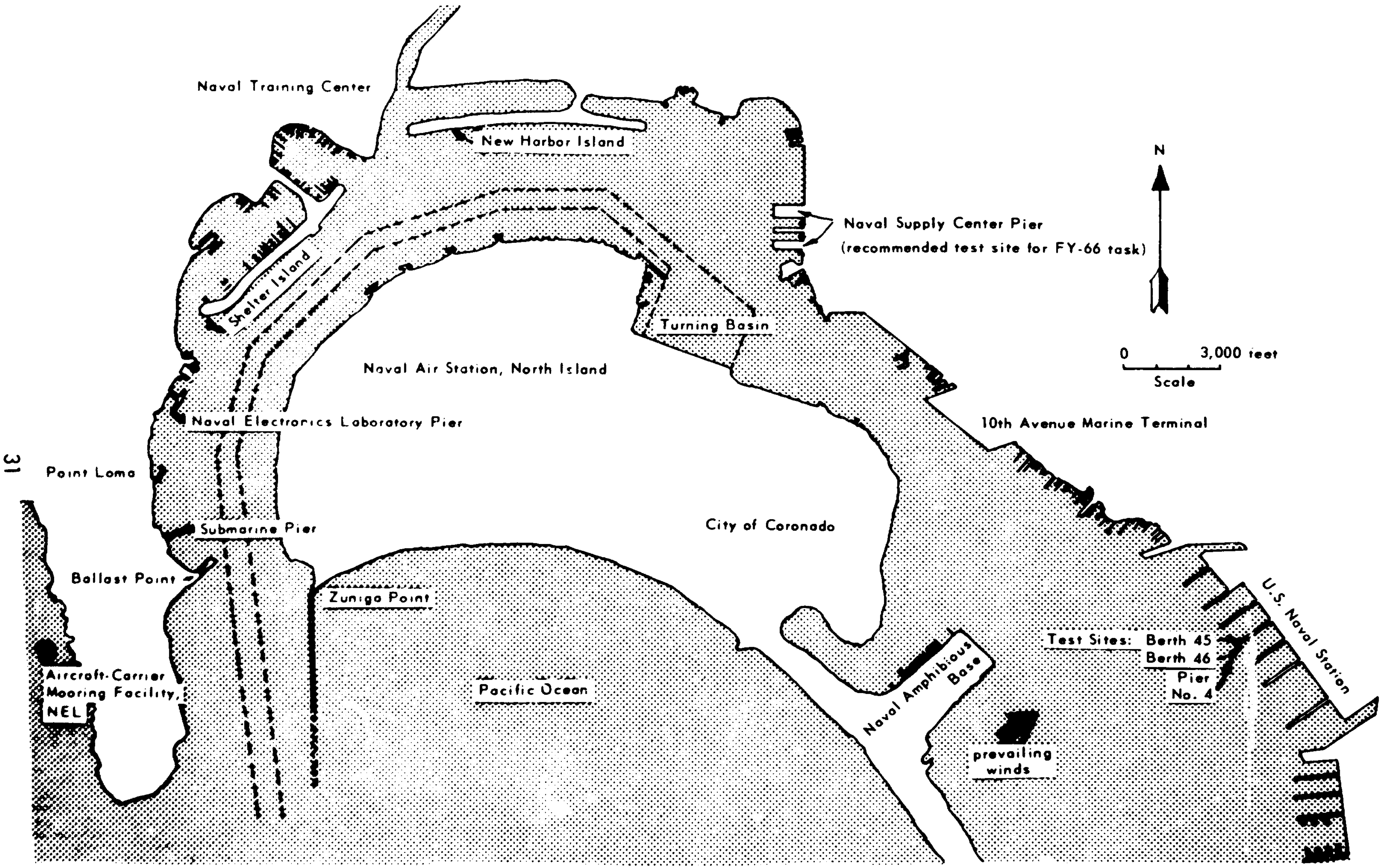


Figure 22. Location of the test site at U. S. Naval Station, San Diego Bay.

TEST CONDITIONS

Winds

The camels were located approximately parallel to the prevailing winds, which are from the southwest at about 17 knots about 98% of the time (Figure 22). Southwest winds at speeds greater than 17 knots occur less than 2% of the time; those from the northwest at 35 knots occur 1% of the time, during which berthing on ships of APA and LST classes is considered unsafe. Storm winds up to 45 knots are probable but infrequent. Wind velocities were not measured during the fender tests; however no unusual winds were reported.

Wave

There is no significant wave data available for the test site. However, in a mooring area offshore from Pt. Loma and about 10 miles from the sheltered test site, waves less than 1.5 to 3 feet high prevail about 40% of the time. Although not measured during the fender tests, the waves were reportedly insignificant.

Current

Currents were not measured at the test site but are believed to be minor. Observations indicate wave-induced currents of up to 0.7 knot and tidal currents of up to 2.5 knots. Neither constitutes a problem.

Tide

The tide at San Diego Bay has a range of approximately 10 feet with a maximum height of 8 feet above sea level. The tide had no significant effect on berthing and mooring operations.

Berthing and Mooring Ships

Naval vessels which are normally berthed against the camels include those listed in Table III. As a general rule, two or three tugs of 450 to 750 horsepower are used to assist berthing of APA's and AKA's and one for destroyers, destroyer escorts, and LST's. The broadside berthing impact speeds of 0.5 to 1.5 feet per second were estimated (Table IV). These speeds are considered to be safe by port pilots.

Table III. Types of Berthing Ships

Type	Description	Displacement (long tons)
APA	Attack Transport	8,000 - 10,000
AKA	Attack Cargo Ship	8,000 - 10,000
DD	Destroyer	1,100 - 2,400
DE	Escort Vessel	1,100 - 2,400
LST	Landing Ship Tank	1,700 - 2,600

Table IV. Safe Impact Speeds

Ship Type	Approach at an Angle to Wharf Face		Broadside Berthing Speed Normal to Wharf Face (knots)
	Speed (knots)*	Angle (deg)	
APA, AKA	1.0	10	0.5
DD, DE	2.0	10	1.5
LST	2.5	10	1.5

*Speed along long axis of ship

Arrangement of Fenders

The two hydraulic-pneumatic fenders were spaced about 85 feet apart. Conventional log camels were placed in between. Log camels were also placed at the inshore and offshore extremities of the test fenders. The fenders were secured by chains to pier fender systems, as shown in Figure 23.

TESTS

General

Visual observations during tests included environment, berthing ship characteristics, and berthing procedures. In addition, field inspections were made for corrosion, biological deterioration, and physical damage to fenders. Opinions of ship captains and/or officers, port pilots, Port Services Officer, and other docking and maintenance personnel were solicited chiefly with respect to the in-service performance of the fenders. Comments on effectiveness and economic aspects were secured. However, no instrumentation measurements were attempted.

The camels were occupied for most of the time during the 5-month testing period, 21 January to 22 June 1965, during which they served nine ships ranging in size from 7,000 to 10,000 tons displacement (Table V). Pertinent information was obtained during three field inspections and numerous interviews (Table VI).

Special Test Operation

The fenders were subjected to special tests by the USS Renville, by arrangements with the Commanding Officer and the Chief Port Pilot on 14 May. The day was sunny and warm with a 5-knot off-wharf wind. The USS Renville, with power off and under the control of three tugs, was berthed broadside to Berth 45 at a speed estimated at 1 foot per second, which is twice that normally used. The inshore fender was contacted first; its pneumatic rubber bags were observed to compress about 8 inches. The hydraulic bags, located lower in the water, were compressed about 6 inches at water line. Because of the stern mooring lines, the ship contacted only one bag of the offshore fender (Figure 24). It was air-filled and compressed approximately the same amount as its inshore counterpart.

The ship rebounded twice before finally coming to rest at Berth 45. The three contacts (initial plus two rebounds) of hull with fenders were visible at the water line, but there was no damage to ship or fender, including bulkheads and bags. The ship's captain later stated that the great force of the first rebound was not desirable, and that although neither ship nor pier suffered damage during the faster-than-normal berthing, the ordinary log-type camel would probably have been just as effective. He said also that cargo-handling problems were not likely, in spite of the 5-foot distance between dock face and ship side.

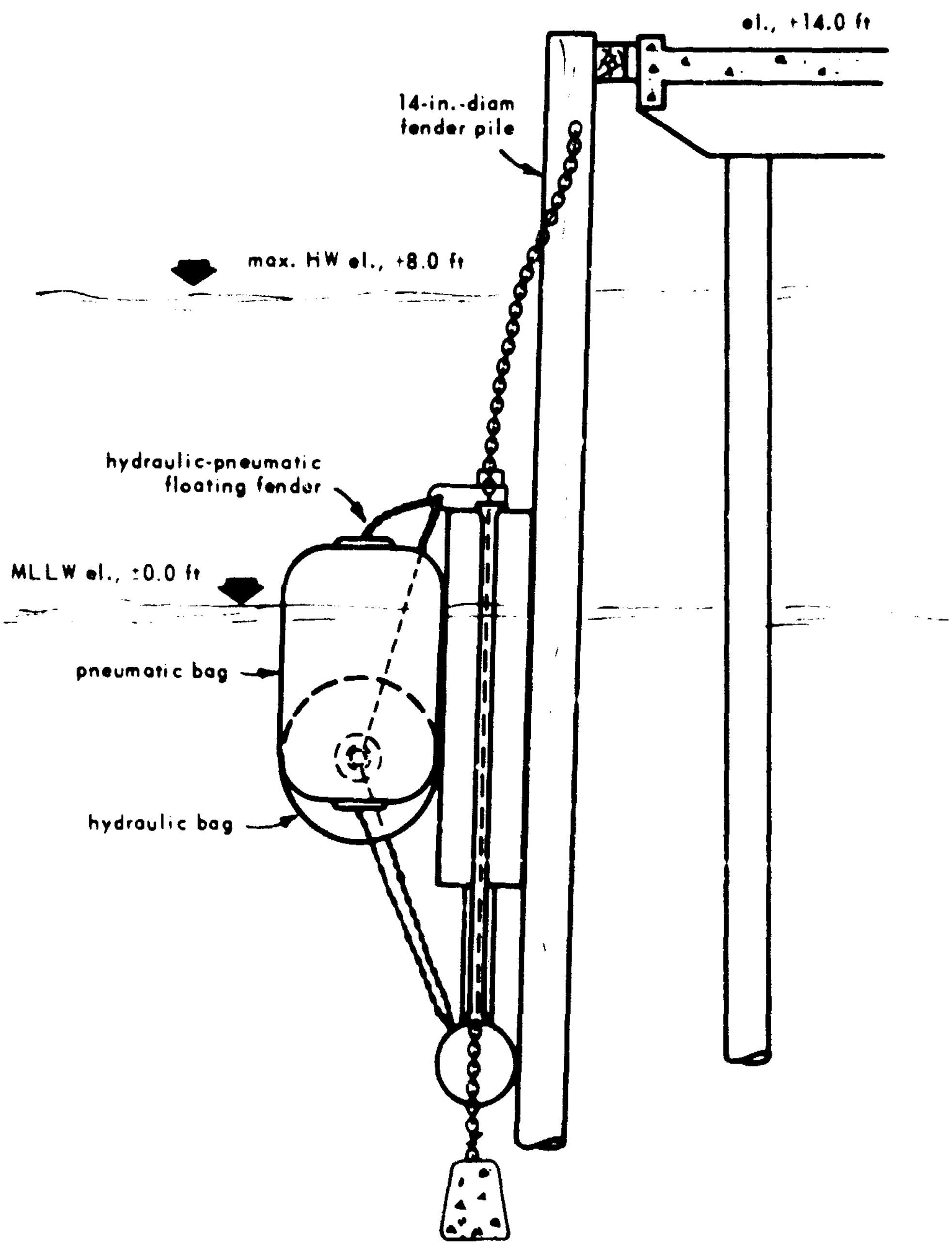
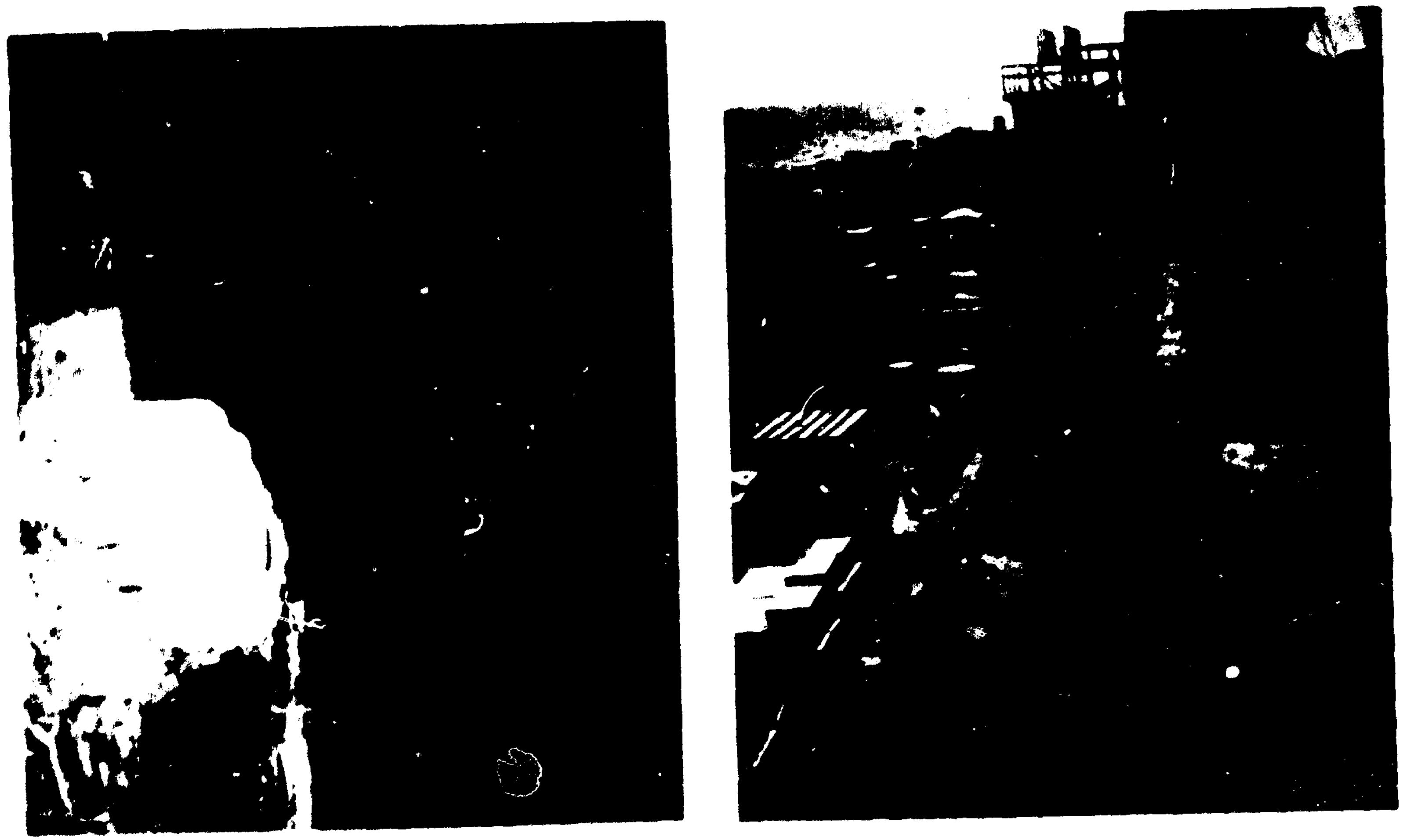


Figure 23. General profile of dock and fender at the test site, Pier No. 4 (Berths 45 and 46), U. S. Naval Station, San Diego.



a. Pneumatic fender.

b. Berthing completed.

Figure 24. Test operation of the fenders by USS Renville on 14 May 1965.

Table V. Berthing and Mooring Characteristics of Ships

Name of Ship	Date (1965)	Type	Length (ft)	Beam (ft)	Draft (ft)	Displacements (long tons)
USS Calvert	27 - 29 Jan	APA	490	70	21	8,860
USS Pickaway*	28 Jan - 1 Feb	APA	455	65	19	7,190
USS Calvert	1 - 5 Feb	APA	490	70	21	8,860
USS Winston	4 - 25 Feb	AKA	460	63	19	7,200
USS Winston	9 - 19 Mar	AKA	460	63	19	7,200
USS Winston	Apr	AKA	460	63	19	7,200
USS Magoffin	28 Apr - 14 May	APA	455	65	19	10,000
USS Renville	14 - May	APA	455	62	19	6,720
USS Tulare	21 May - 1 Jun	AKA	460	63	20	9,050

*Berthed against Calvert.

Table VI. Summary of Comments on BuDocks-Designed Hydraulic-Pneumatic Camels

Field Inspection and Source of Comment	Favorable Comments	Unfavorable Comments
	I – 13 April 1965	
Berthing Supt.	The camels performed well, no complaints were received.	
Asst. Berthing Supt.	The camels functioned satisfactorily, however, they were not loaded excessively during berthing. Prevailing winds were directly off the pier face, thus reducing impact load.	
Port Services Officer (then ship's engineer)	The camels prevented significant damage to USNS General Breckinridge during a violent berthing at Port Hueneme Harbor on 23 April 1964.	
Operations Officers USS Winston	During sudden wind shifts, the camels prevented damage to moored ship during 25 to 35 knot winds in March 1965. This type of fender definitely would have prevented hull damage sustained by USS Winston at Naval Repair Facility, Yokosuka, and at Buckner Bay, Okinawa, on a similar occasion.	Ship cannot use accommodation ladder alongside pier due to excessive horizontal distance from pier to side of ship caused by camels.
	II – 12-14 May 1965	
Inspection Engineer	All visible metal and wood parts were in sound condition. The camels stood up very well during a high-speed (twice normal, 1 foot per second) in-service test on 14 May. The pneumatic and hydraulic bags were compressed 8 inches.	Rubber bags below water line were covered with marine growth. Air pressures decreased from 12 to 6 psi after 4-months operations.
C.O. and Operations Officers, USS Magoffin	The camels performed well while the ship was berthed but were never subjected to excessive loads.	Similar pneumatic fenders burst in Pearl Harbor under normal weather conditions.
Berthing Supt. and Asst. Berthing Supt.	The camels were satisfactory for quiet environment and ready for severe in-service tests.	
Maint. Control Personnel, PWC	The camels were satisfactory since no negative reaction was received.	
C. O. of USS Renville	In spite of the 5-foot distance between the dock and ship, no cargo-handling problem was anticipated.	The ship had a noticeable and undesirable bounce after first impact. The log camel would be just as effective as the test camel.

FINDINGS

Performance

1. The fenders, spaced about 85 feet apart, served nine naval ships of 7,000 to 10,000 tons displacement, and were in use about 50% of the time during the 5-month testing period from 21 January to 22 June 1965. Berthing impact was generally light.

2. The fenders functioned satisfactorily, preventing damage to a ship moored during winds of 35 knots.

3. The standoff distance necessitated by the fender is considered a major drawback by most users, as is the rebound of the ship induced by the pneumatic rubber bags.

Deterioration After Approximately 5 Months In Service

1. There was no marine growth above water line (Figure 25), but fouling covered 80% of the exposed area under water.

2. The air-filled rubber bags showed no evidence of deterioration. Sides of bags making contact with the bulkhead were abraded slightly by rubbing against the floating bulkhead. All pneumatic rubber bags remained fully symmetrical. The pressure in the two bags of the offshore fender after 1 month was 10 and 12 psi, respectively, while that in the inshore counterpart was 11 psi. (The uniform initial pressure of all bags was 12 psi.)

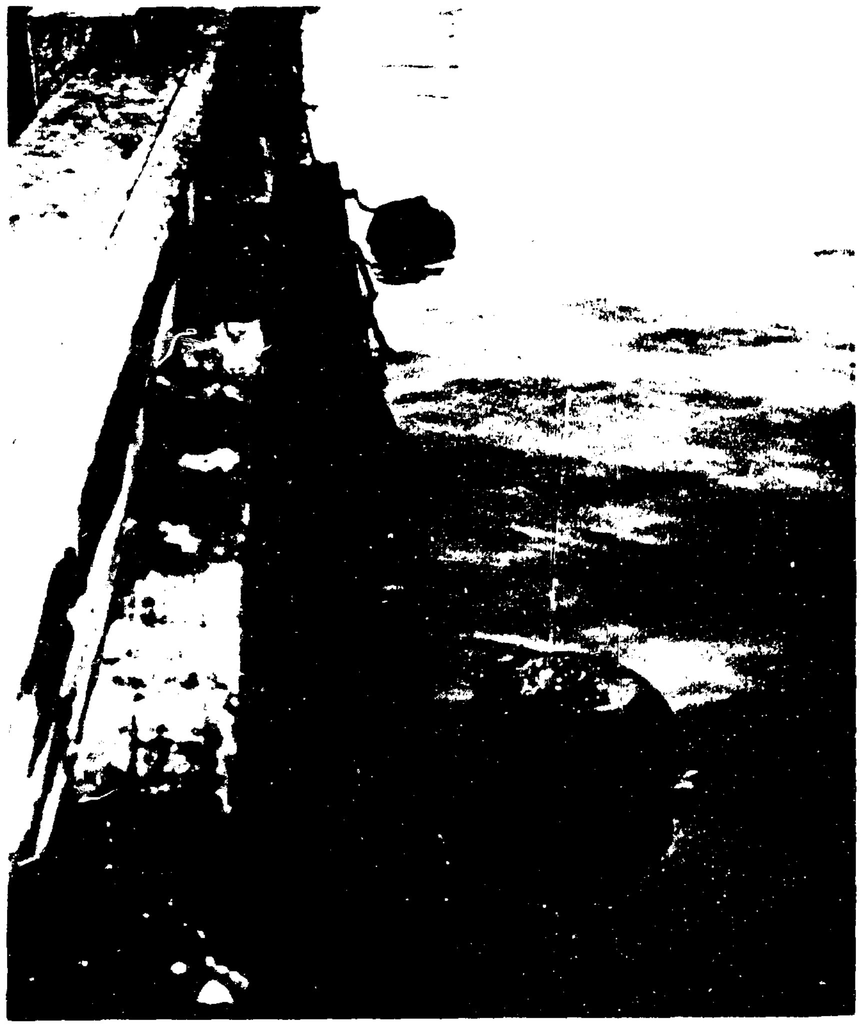
3. Two of the four water-filled bags were found to be collapsed slightly after being lifted from the water (Figure 26). The 2-1/2-inch rubber hose connection at an offshore bag was separated from the bag due to deterioration of the hose clamps. Reconnection of it and reconditioning of two others was routine; galvanized iron seizing wire was used.

4. The 3/4-inch steel chain was separated from the offshore fender due to loss of a pin in the connecting link (Figure 27b). Another pin was about 90% free of its position.

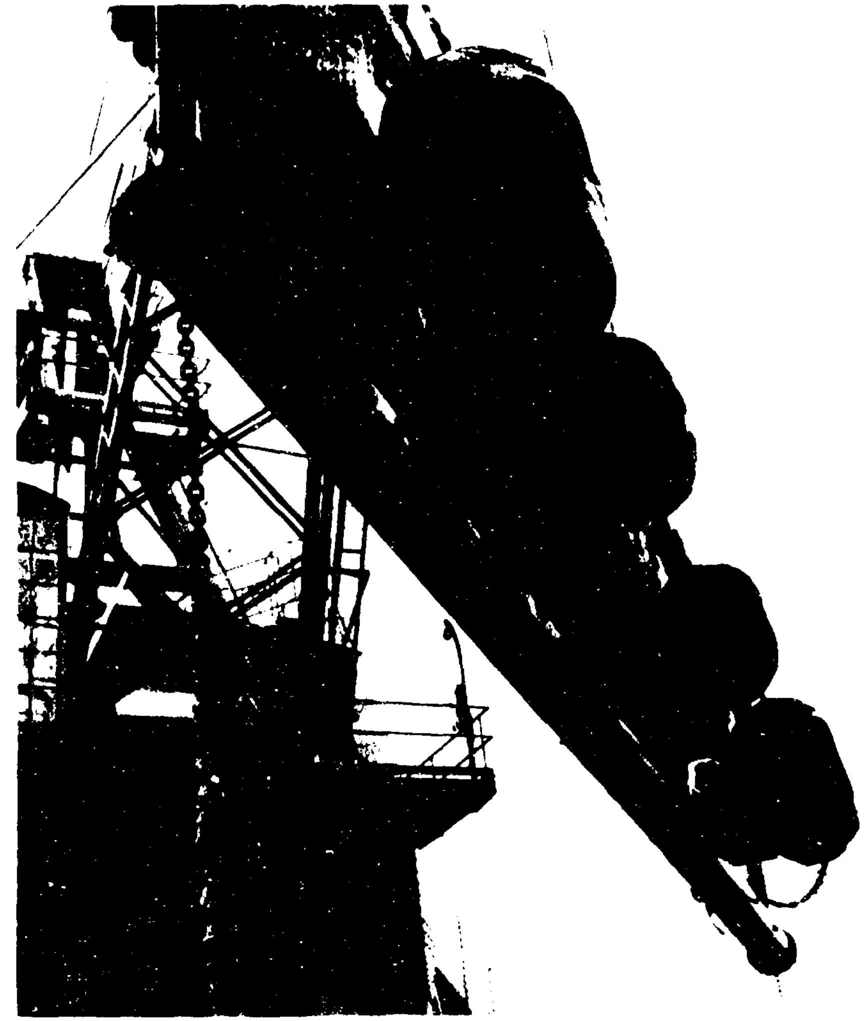
5. Probable Limnoria attack to approximately 3/16 inch was noted in five areas on the offshore bulkhead and one area on the inshore bulkhead (Figure 28a) from water line down. Penetrations appeared to be in the form of spring growth of annual rings; Limnoria channels were evident.

6. The backside of both bulkheads showed signs of wear from constant rubbing against the pier fender system, in six areas on the offshore bulkhead and two areas on the inshore. Bolt heads in the bulkhead were exposed by this rubbing (Figure 29).

7. There was a light encrustation of barnacles on the lower part of both floating bulkheads.



a. No marine growth found above waterline.



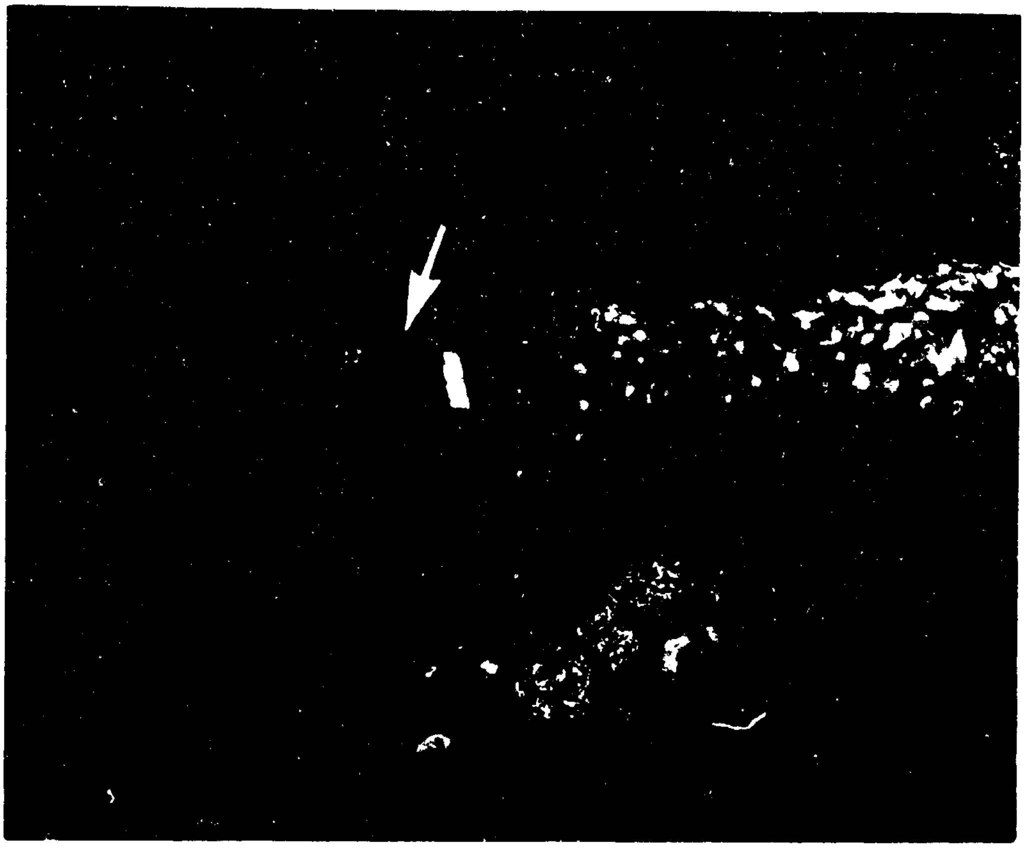
b. Moderate marine fouling below waterline.

Figure 25. General condition of the fenders after five months in water.

a. Arrow shows hydraulic rubber bag slightly collapsed.

b. Arrow shows separated hose.

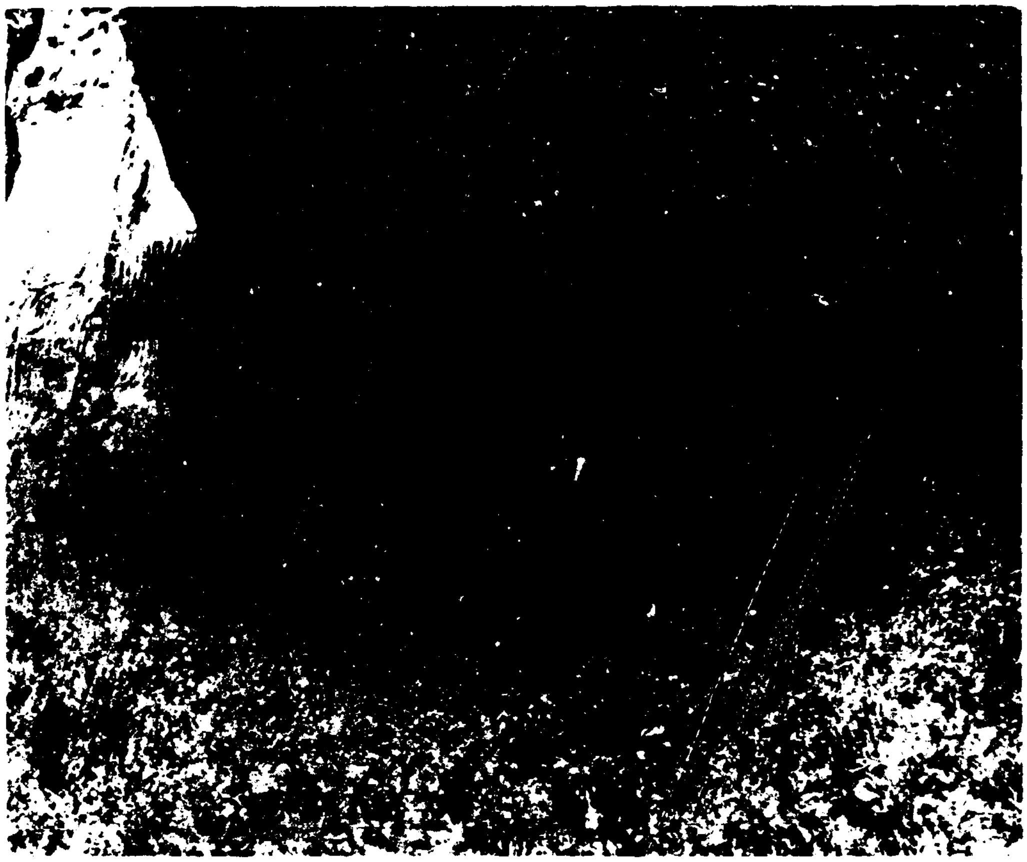
Figure 26. Damage to hydraulic rubber bags.



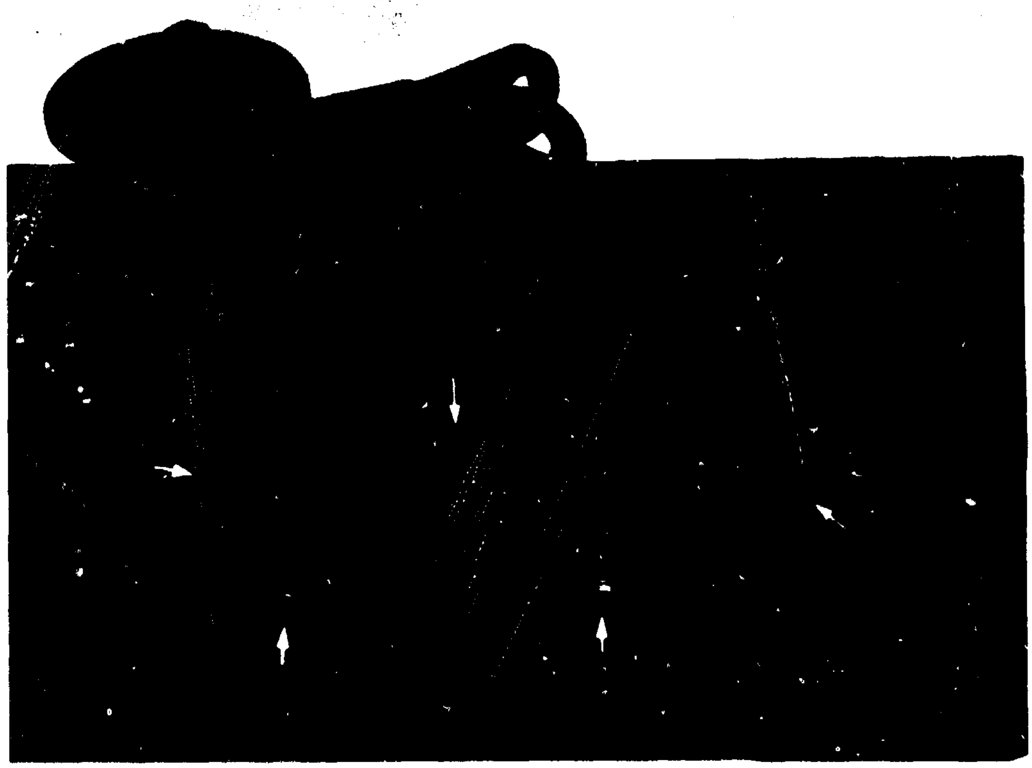
a. Deteriorated hose clamps of hydraulic rubber bag.

b. Loose shackle-pin connections.

Figure 27. Defective connections of hydraulic rubber bags.



a. Probable Limnoria attack on the timber bulkhead.



b. Wear trom rubbing action.

Figure 28. Deterioration of wooden bulkhead.

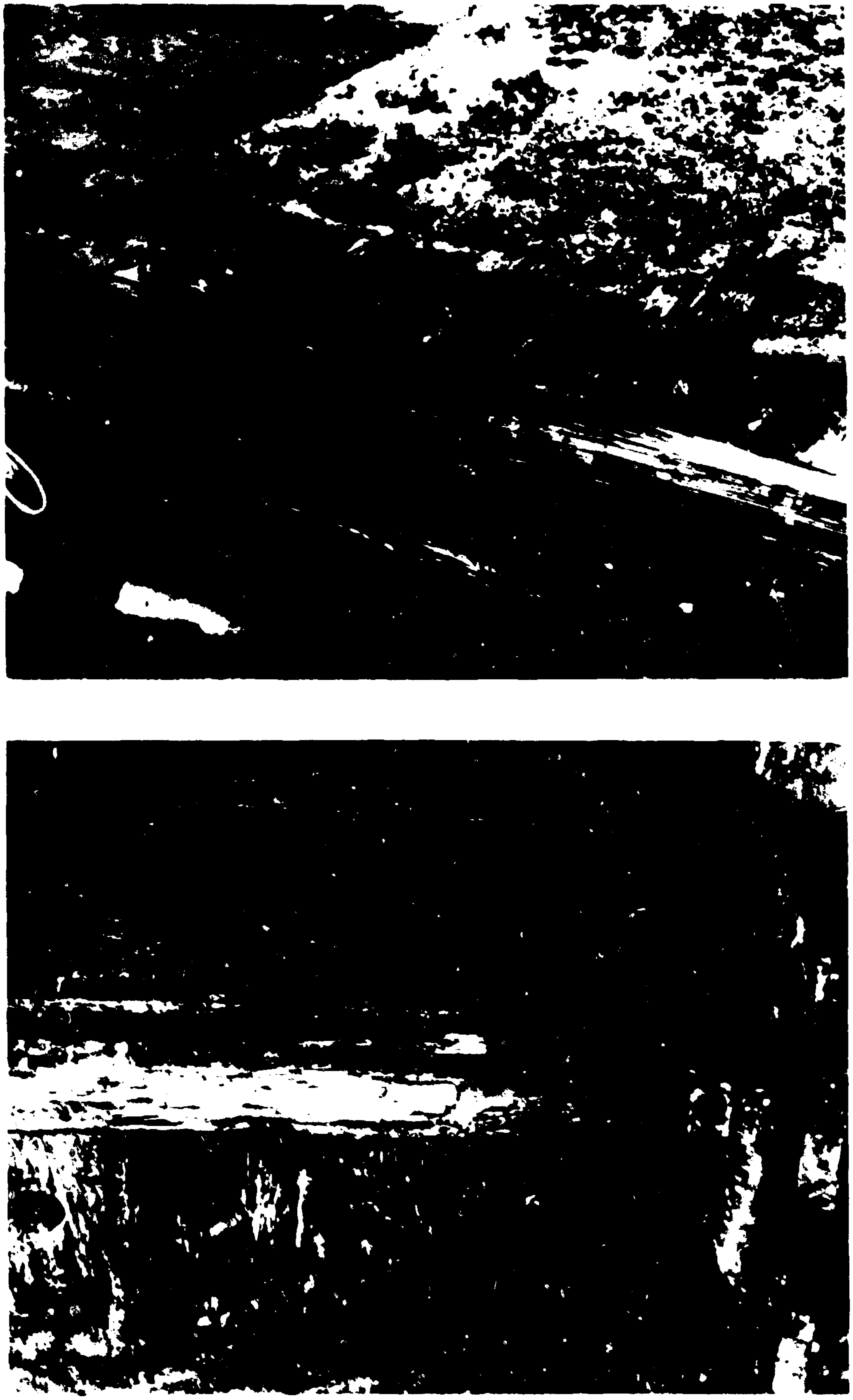


Figure 29. Deterioration of wooden bulkhead; physical damage due to rubbing.

8. The concrete mooring weights were about 90% covered by marine algae and barnacles (Figure 26b).

9. The mooring chains showed signs of rusting and about 40% wear at the point where the chain rubs on the 4-inch steel guide pipe. This pipe was broken and flared out at the offshore end.

10. Two bolts holding the closure plate to the ballast pipe were loose. There was rust at the base of all pad eyes where they were welded to the ballast pipe.

CONCLUSIONS

1. The fender provided satisfactory service during the 5-month test period. The shortcomings mentioned above are not considered serious.

2. Since traffic was limited and impact loading was light, the fender was not tested to capacity.

ACKNOWLEDGMENTS

A number of people assisted and cooperated in the reported work: LCDR R. M. McClenahan, Port Services Officer, NCBC; C. A. Stine, Marine Terminal Division Director; and Captains R. E. Fosse and G. F. Swanson, Port Pilots, all at Port Hueneme.

Gratitude is also expressed for the help of San Diego personnel: E. J. Kiefer, K. G. Karekin, David Vasconcellos, Public Works Center; N. R. Warner, Berthing Superintendent; and the ship captains and naval officers who furnished comments.

J. P. Cosenza, Structural Engineer of the Mechanical and Electrical Engineering Department at NCEL, assisted in the inspection and evaluation of the San Diego tests.

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APPENDIX A

MEASUREMENTS OF BERTHING SHIPS AT PORT HUENEME HARBOR

NOTE: See NCEL Technical Report R-334 (Lee, 1965a) for load deflection and energy-absorption characteristics of the tested hydraulic-pneumatic floating fenders during berthing of USNS General William Mitchell, USNS General Breckinridge, and USNS Charles H. Davis.

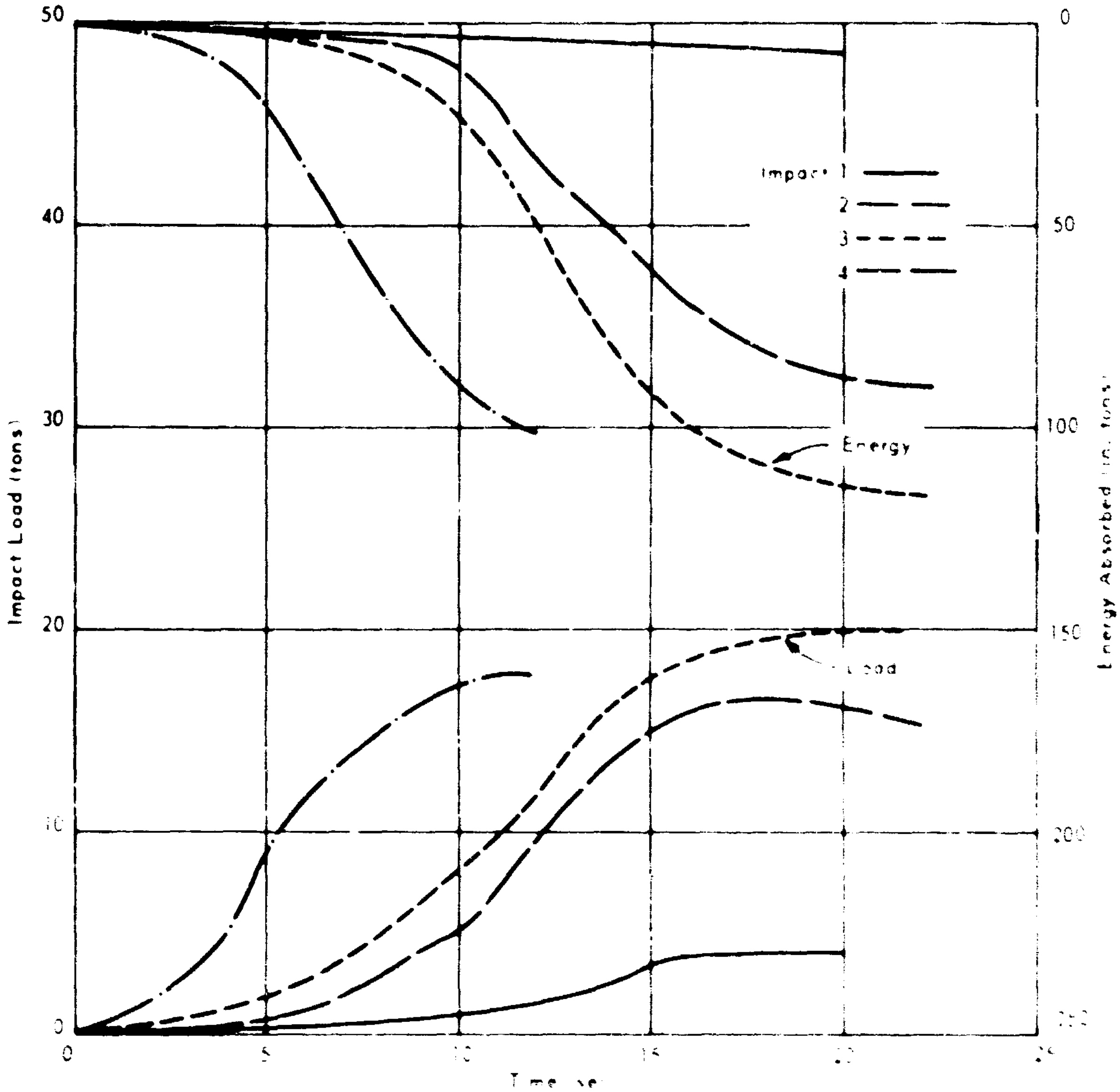

Figure A-1. Time history of load and energy-absorption characteristics of hydraulic-pneumatic fender measured in berthing of SS Oregon, 1 May 1964.

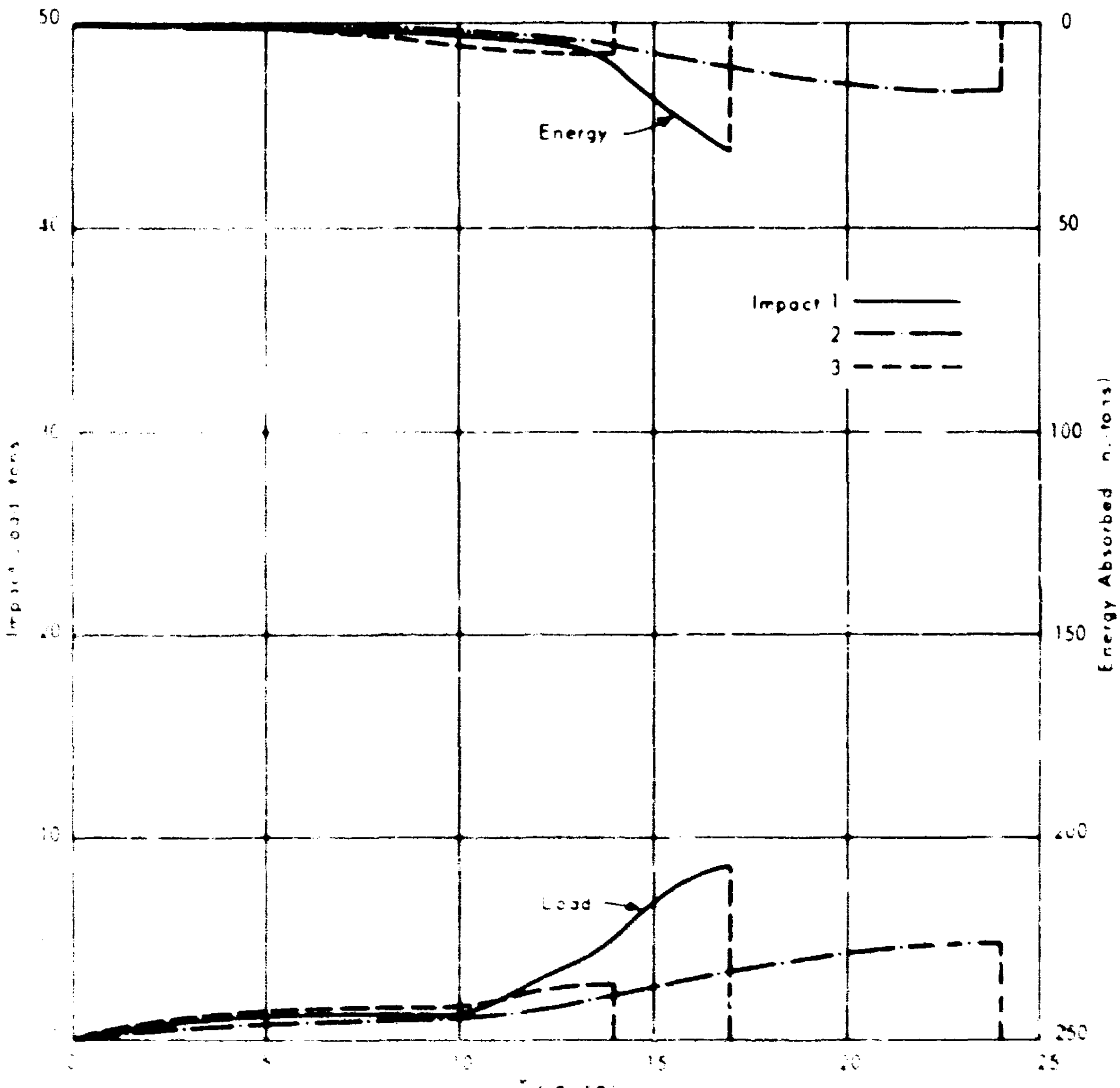

Figure A-2. Time history of load and energy-absorption characteristics of hydraulic-pneumatic fender measured in berthing of USNS Sgt. Jack J. Pendleton, 12 May 1964

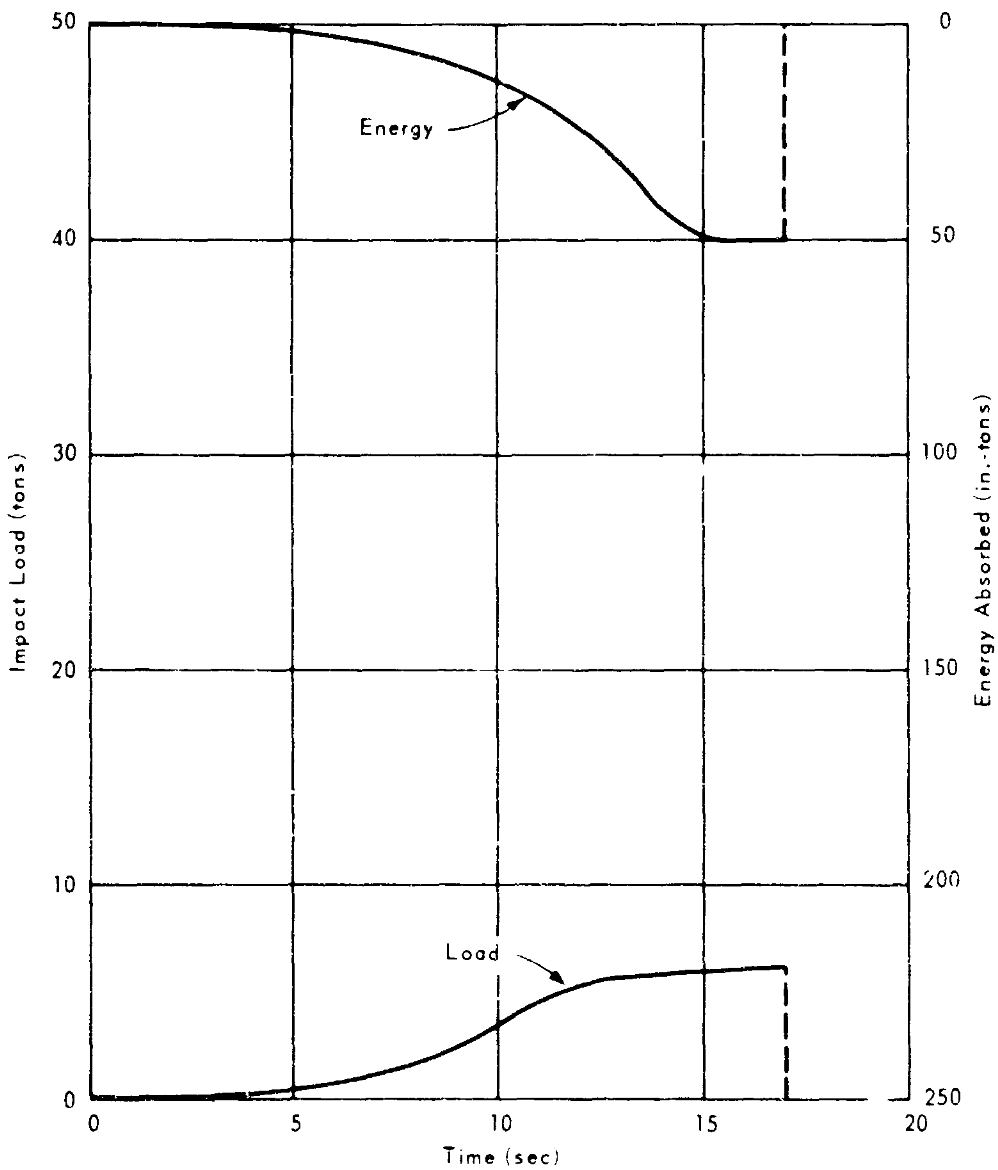

Figure A-3. Time history of load and energy-absorption characteristics of hydraulic-pneumatic fender measured in berthing of SS Hong Kong Bear, 28 April 1964.

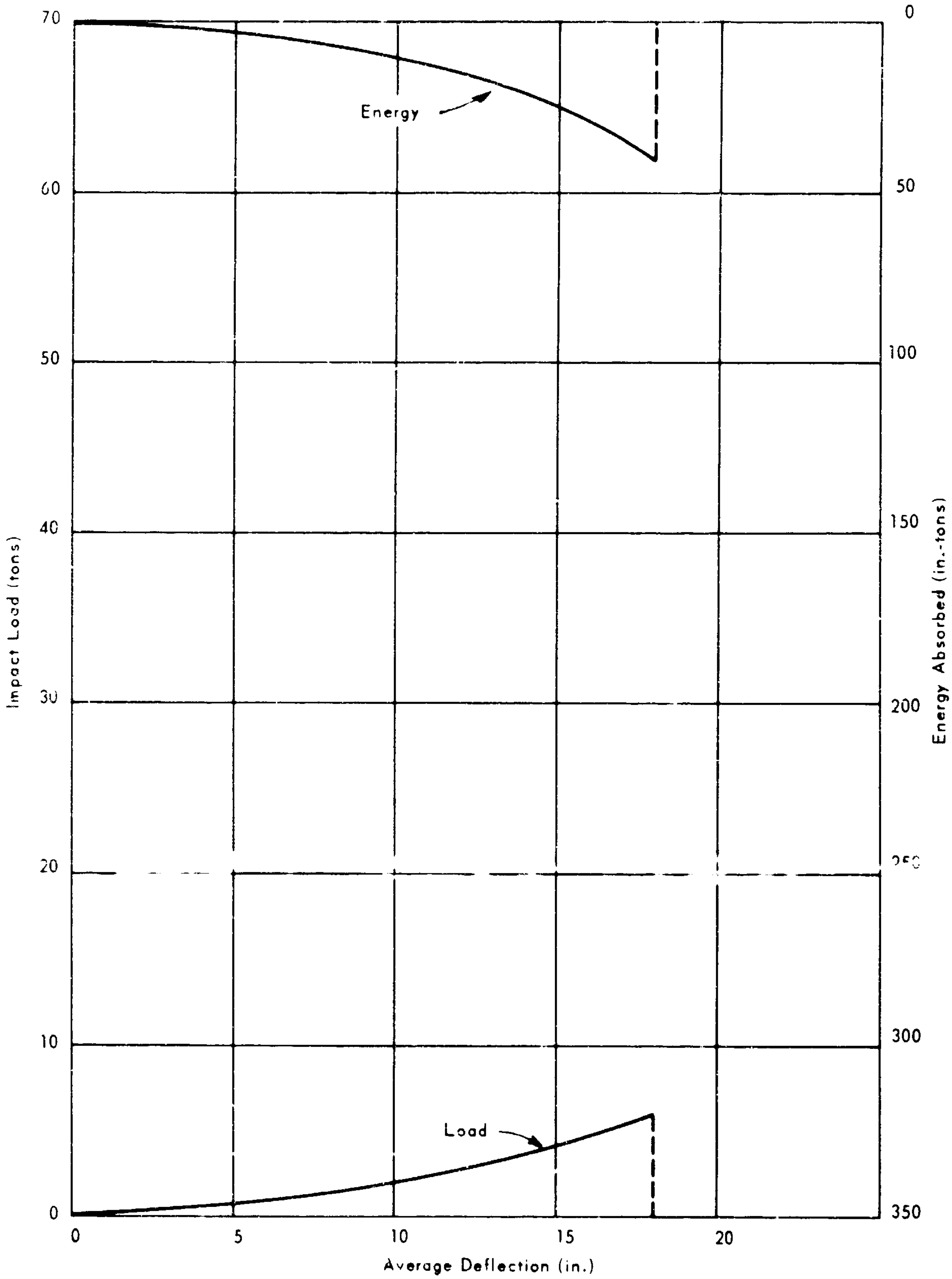

Figure A-4. Ship impact load and energy absorbed versus fender deflection measured in berthing of SS Hong Kong Bear, 28 April 1964.

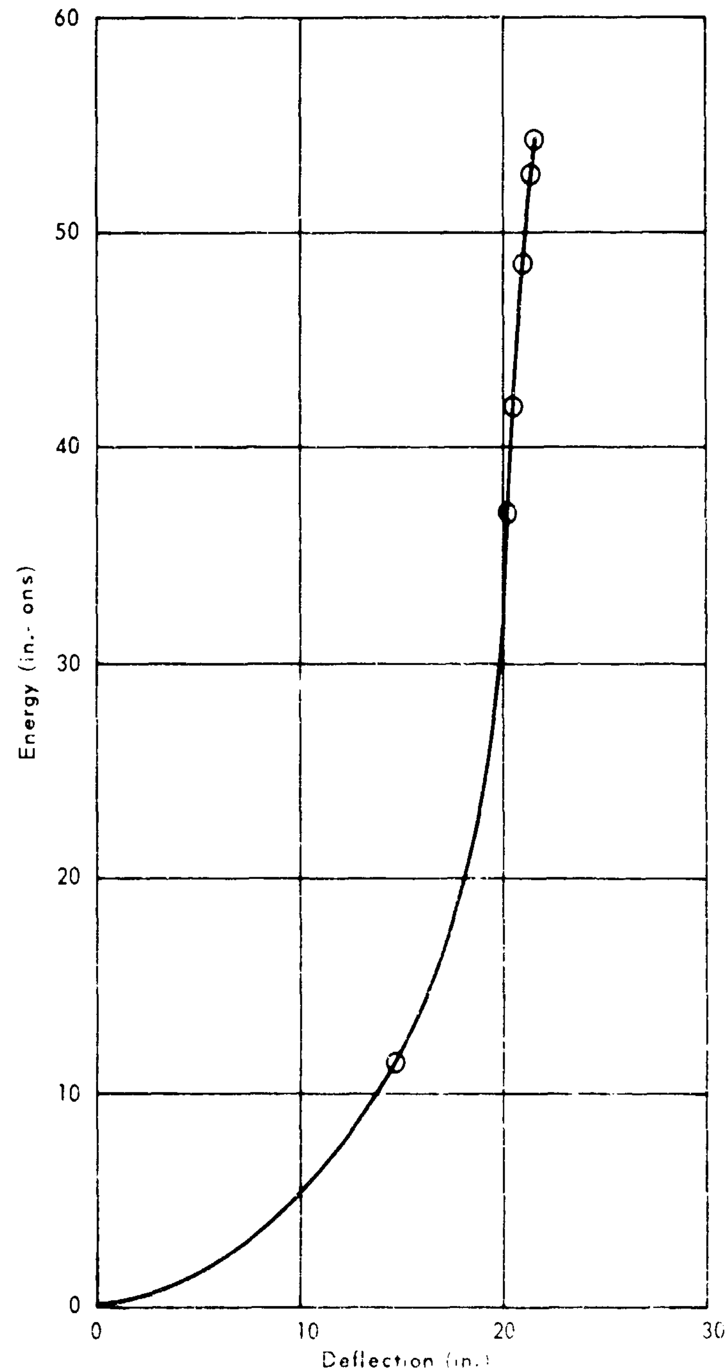

Figure A-5a. Energy absorbed versus fender deflection (Impact No. 1) measured in berthing of USNS Barrett, 15 March 1964.

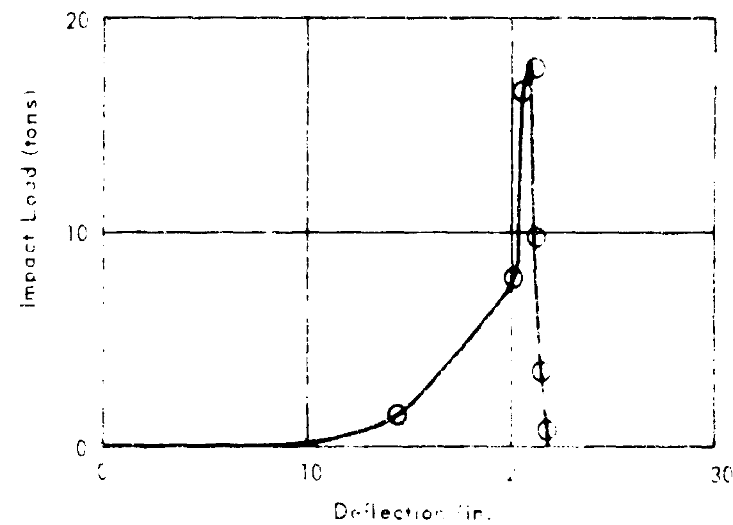

Figure A-5b. Ship impact load versus fender deflection (Impact No. 1) measured in berthing of USNS Barrett, 15 March 1964.

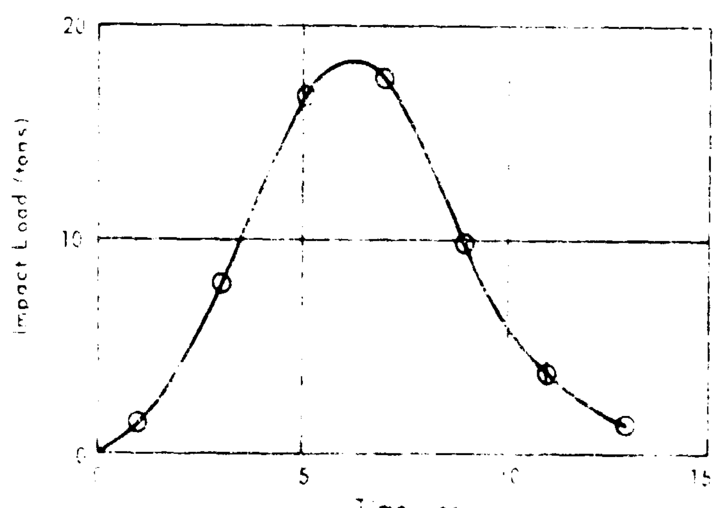

Figure A-5c. Ship impact load versus time (Impact No. 1) measured in berthing of USNS Barrett, 15 March 1964.

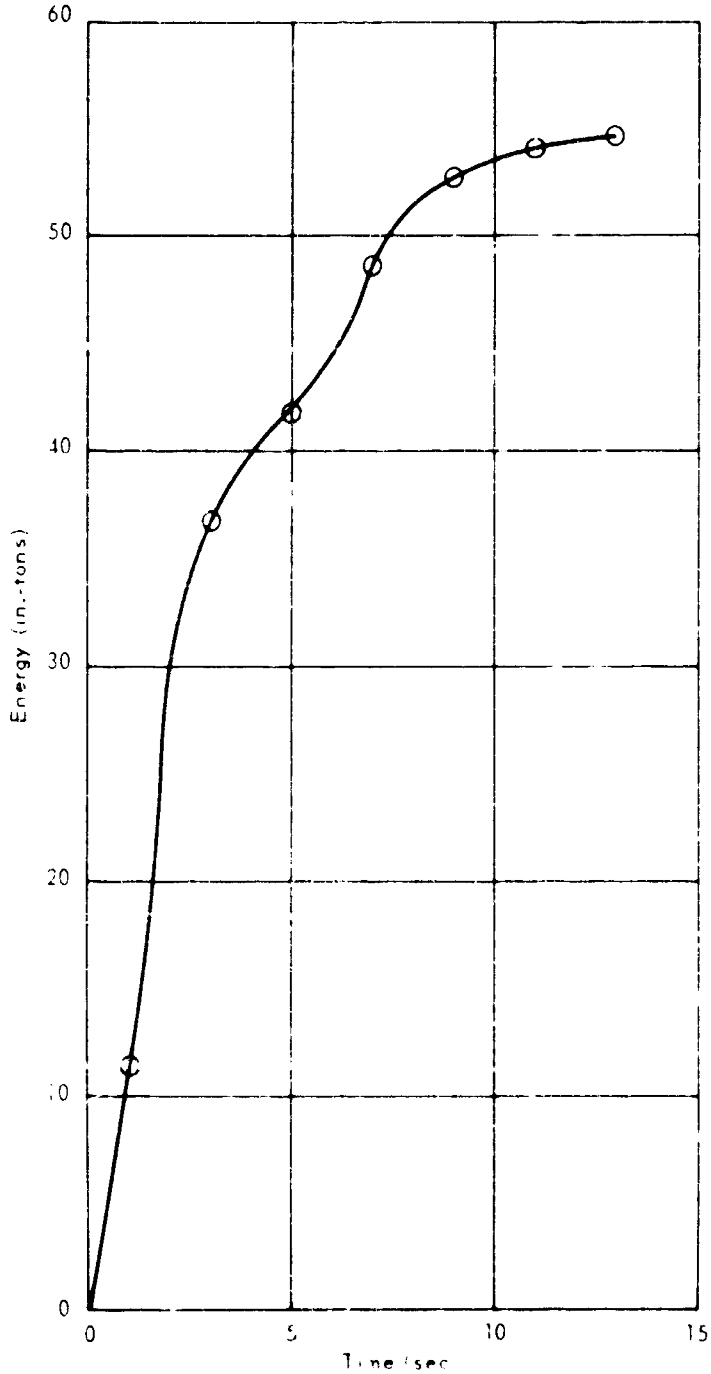

Figure A-5d. Energy absorbed versus time (Impact No. 1) measured in berthing of USNS Barrett, 15 March 1964.

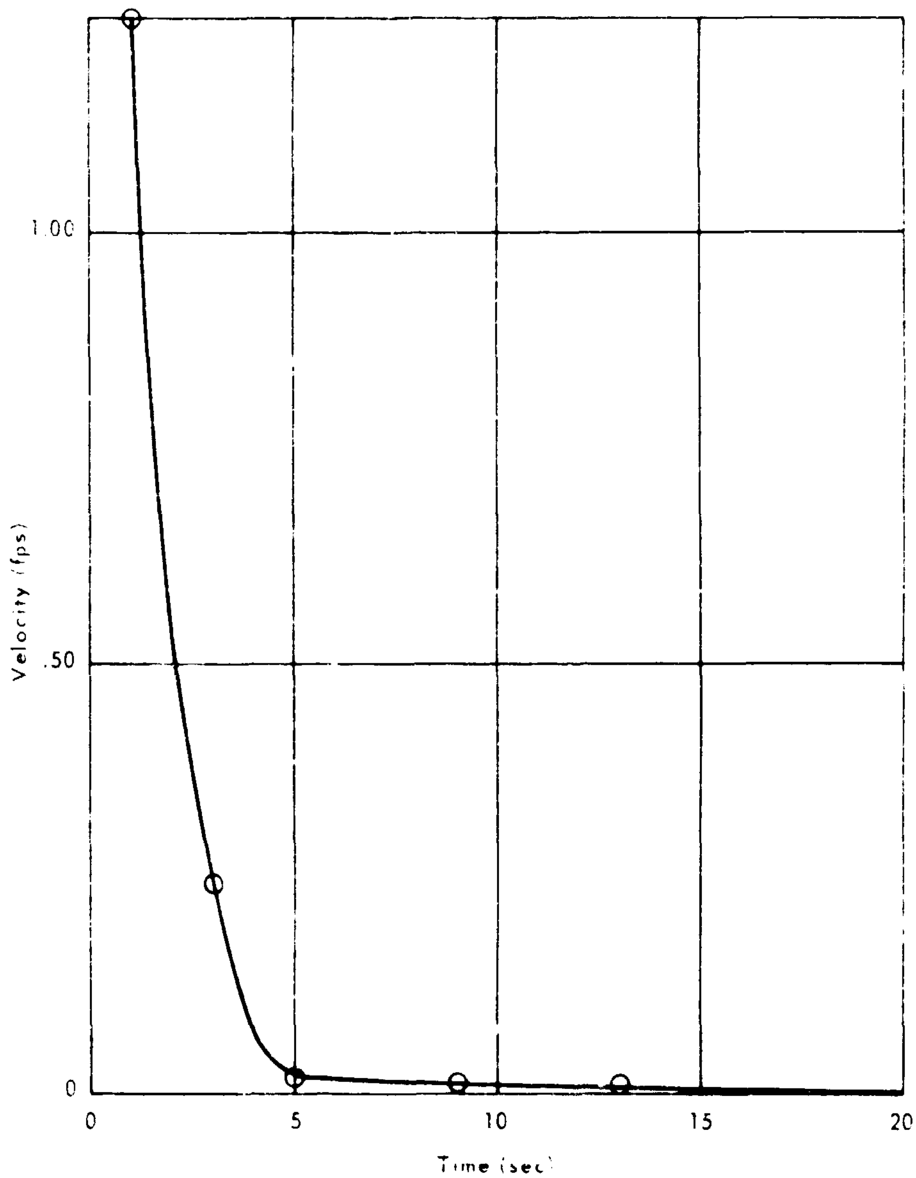

Figure A-5e. Ship velocity versus time (Impact No. 1) measured in berthing of USNS Barrett, 15 March 1964.

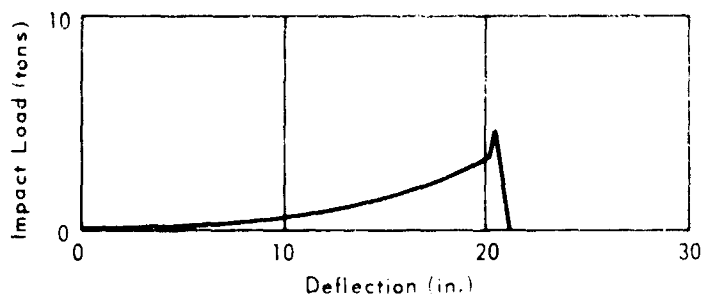

Figure A-6a. Ship impact load versus fender deflection (Impact No. 2) measured in berthing of USNS Barrett, 15 March 1964.

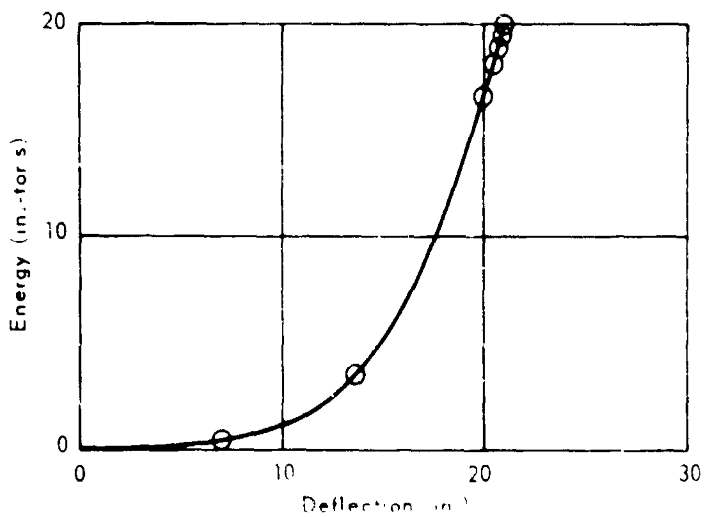

Figure A-6b. Energy absorbed versus fender deflection (Impact No. 2) measured in berthing of USNS Barrett, 15 March 1964.

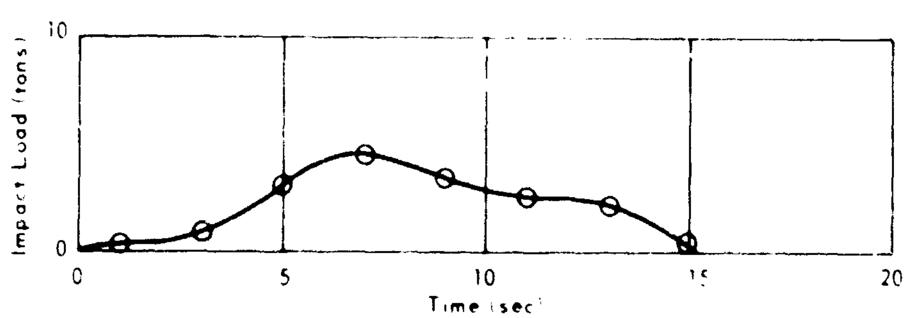

Figure A-6c. Ship impact load versus time (Impact No. 2) measured in berthing of USNS Barrett, 15 March 1964.

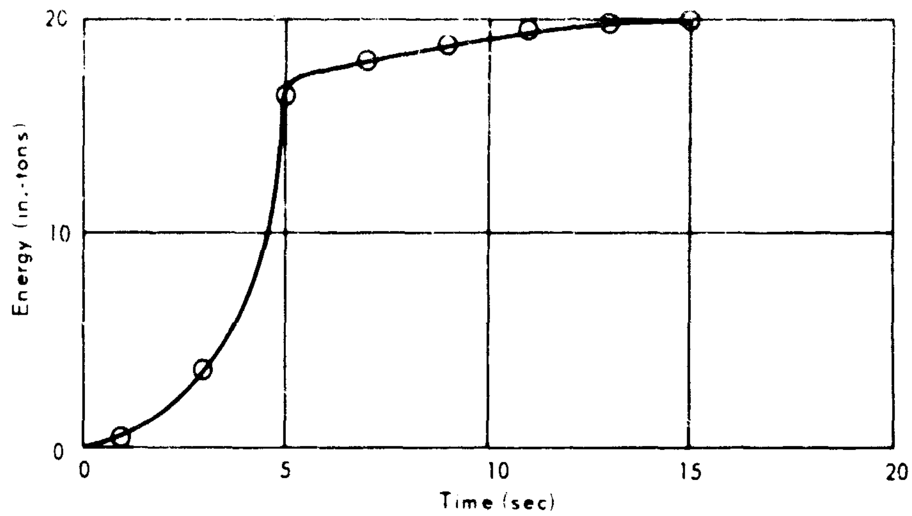

Figure A-6d. Energy absorbed versus time (Impact No. 2) measured in berthing of USNS Barrett, 15 March 1964.

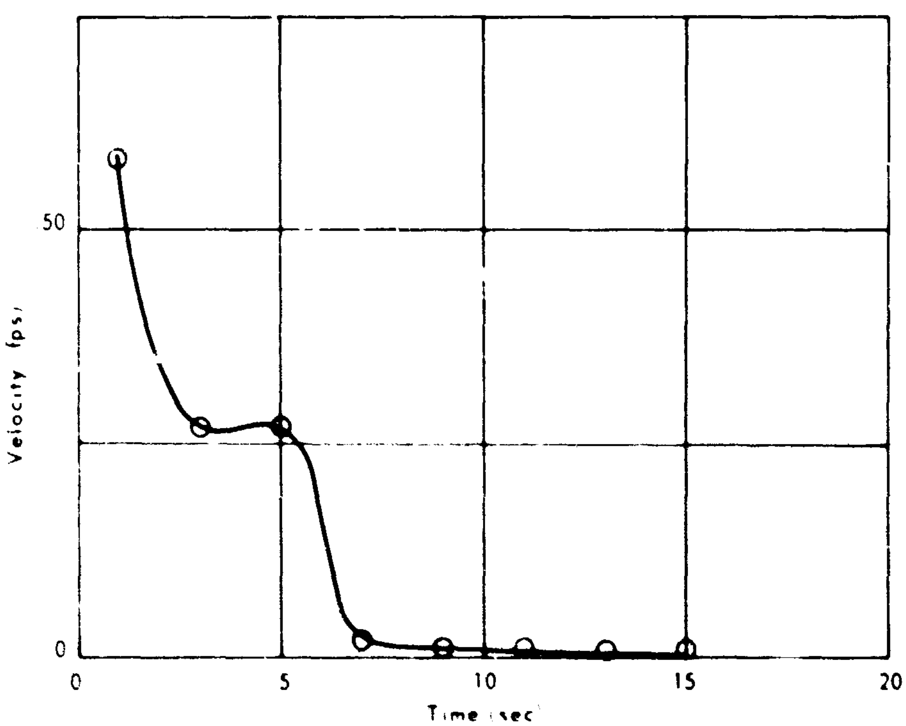

Figure A-6e. Ship velocity normal to dock versus time (Impact No. 2) measured in berthing of USNS Barrett, 15 March 1964.

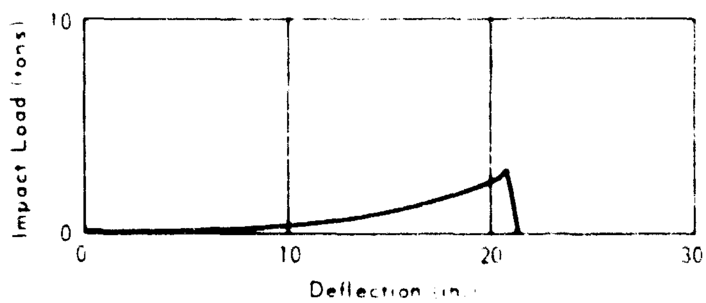

Figure A-7a. Ship impact load versus fender deflection (Impact No. 3) measured in berthing of USNS Barrett, 15 March 1964.

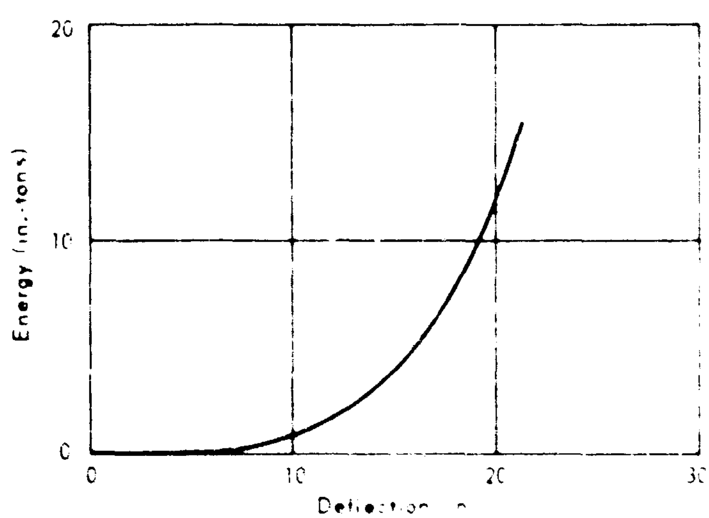

Figure A-7b. Energy absorbed versus fender deflection (Impact No. 3) measured in berthing of USNS Barrett, 15 March 1964.

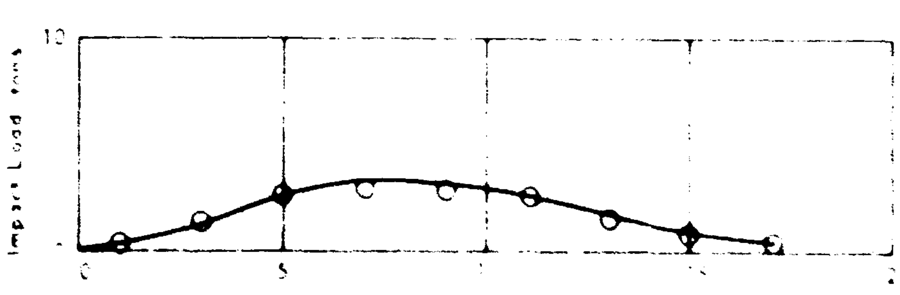

Figure A-7c. Ship impact load versus time (Impact No. 3) measured in berthing of USNS Barrett, 15 March 1964.

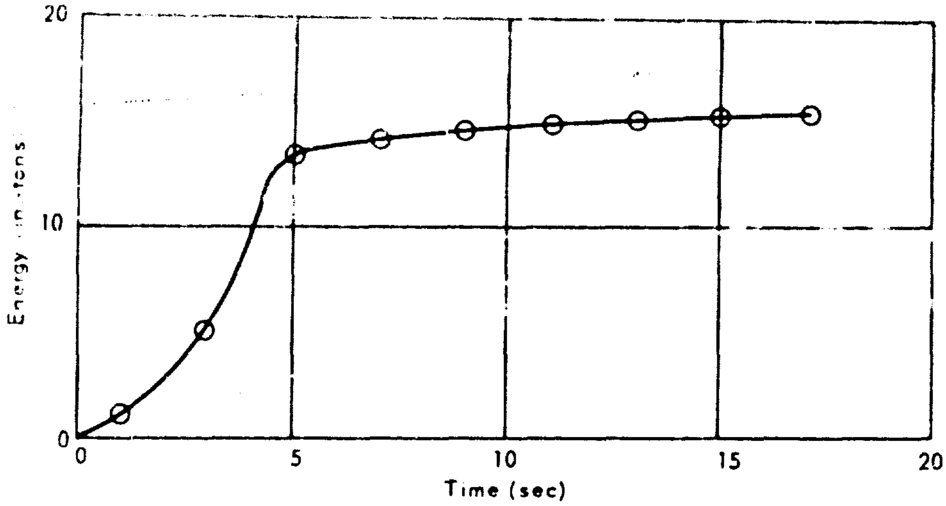

Figure A-7d. Energy absorbed versus time (Impact No. 3) measured in berthing of USNS Barrett, 15 March 1964.

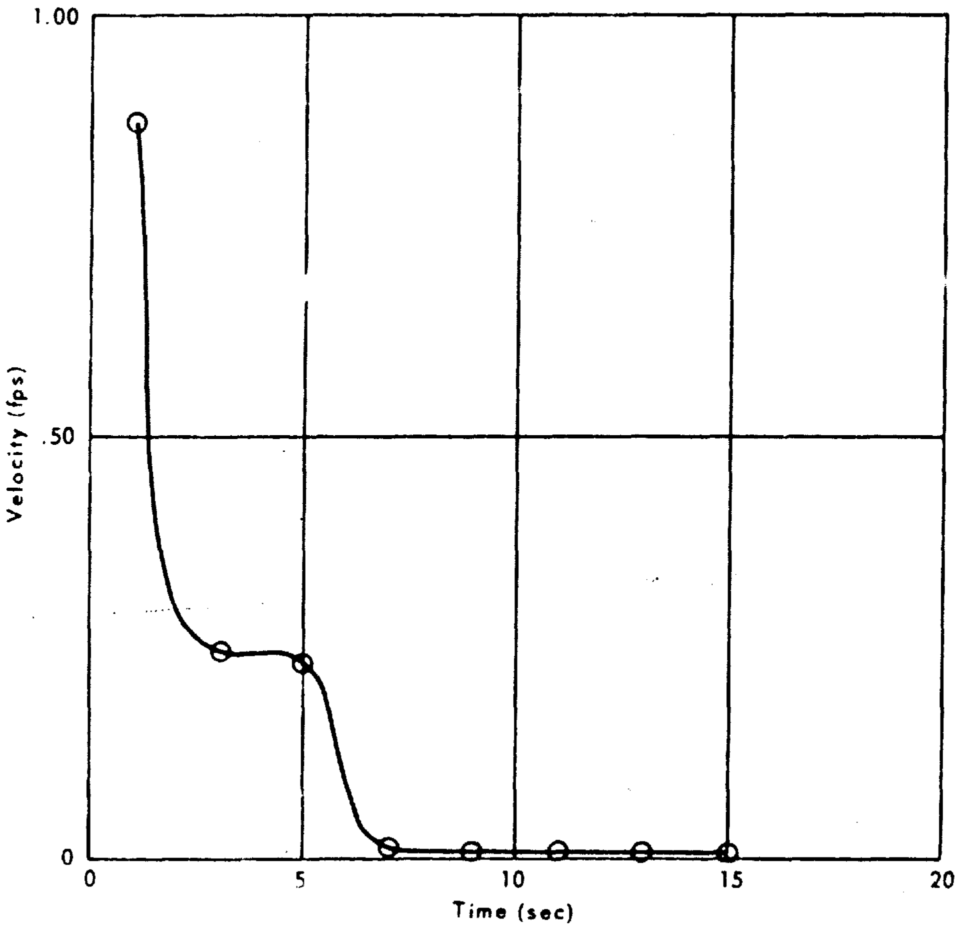

Figure A-7e. Ship velocity normal to dock versus time (Impact No. 3) measured in berthing of USNS Barrett, 15 March 1964.

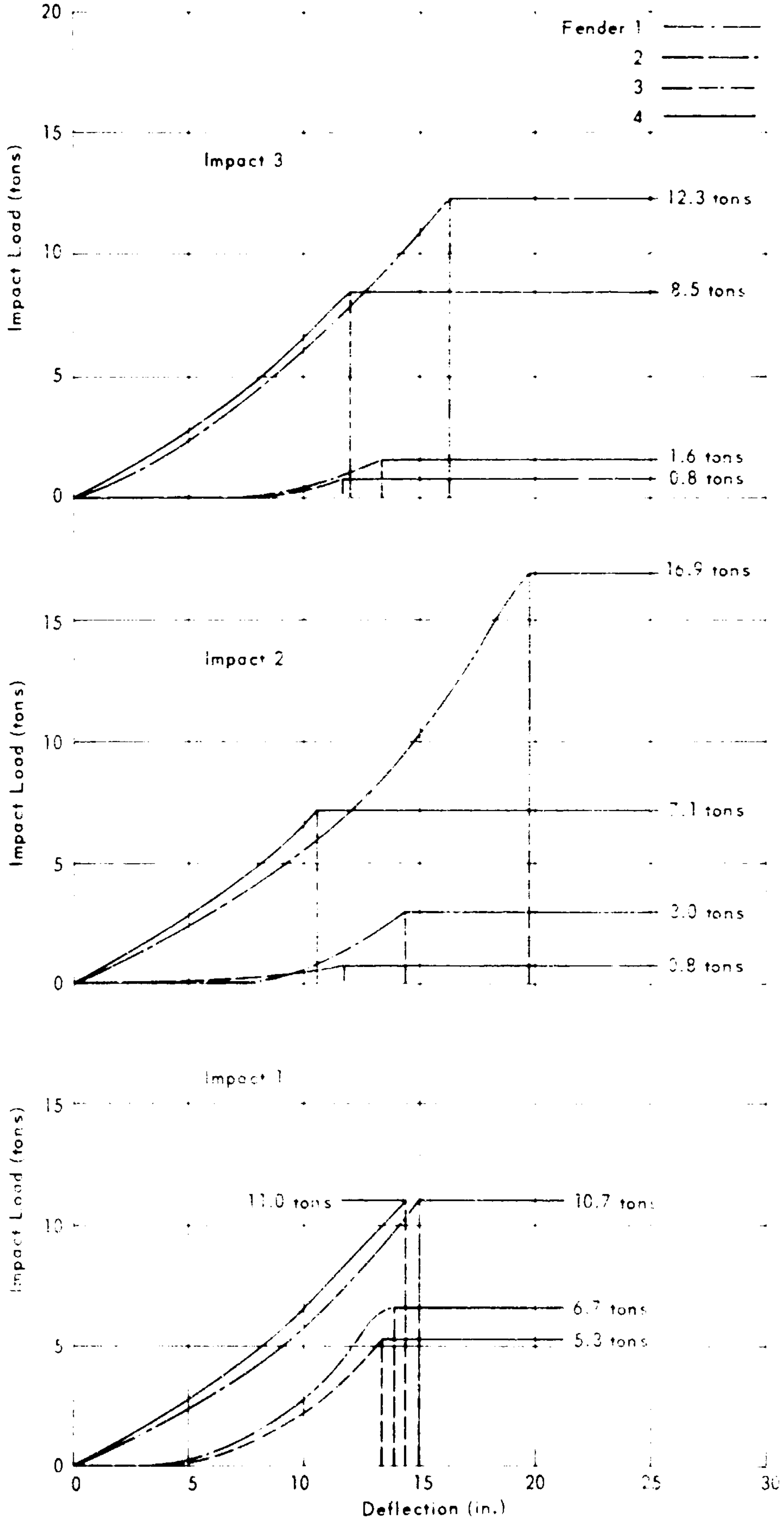

Figure A-8. Ship impact load versus fender deflection measured during berthing of SS California, 28 December 1963.

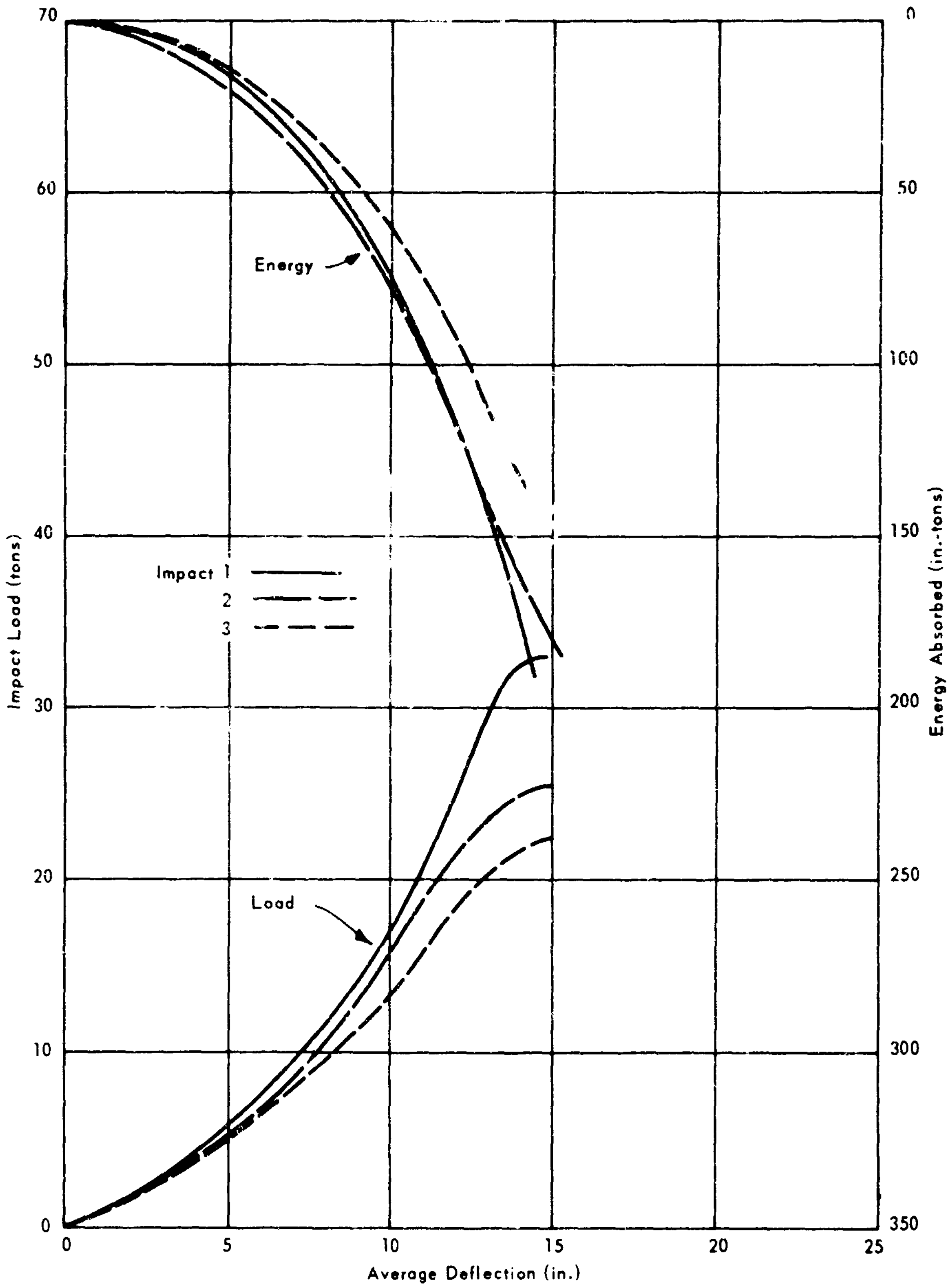

Figure A-9. Ship impact load and energy absorbed versus fender deflection measured in berthing of SS California, 28 December 1963.

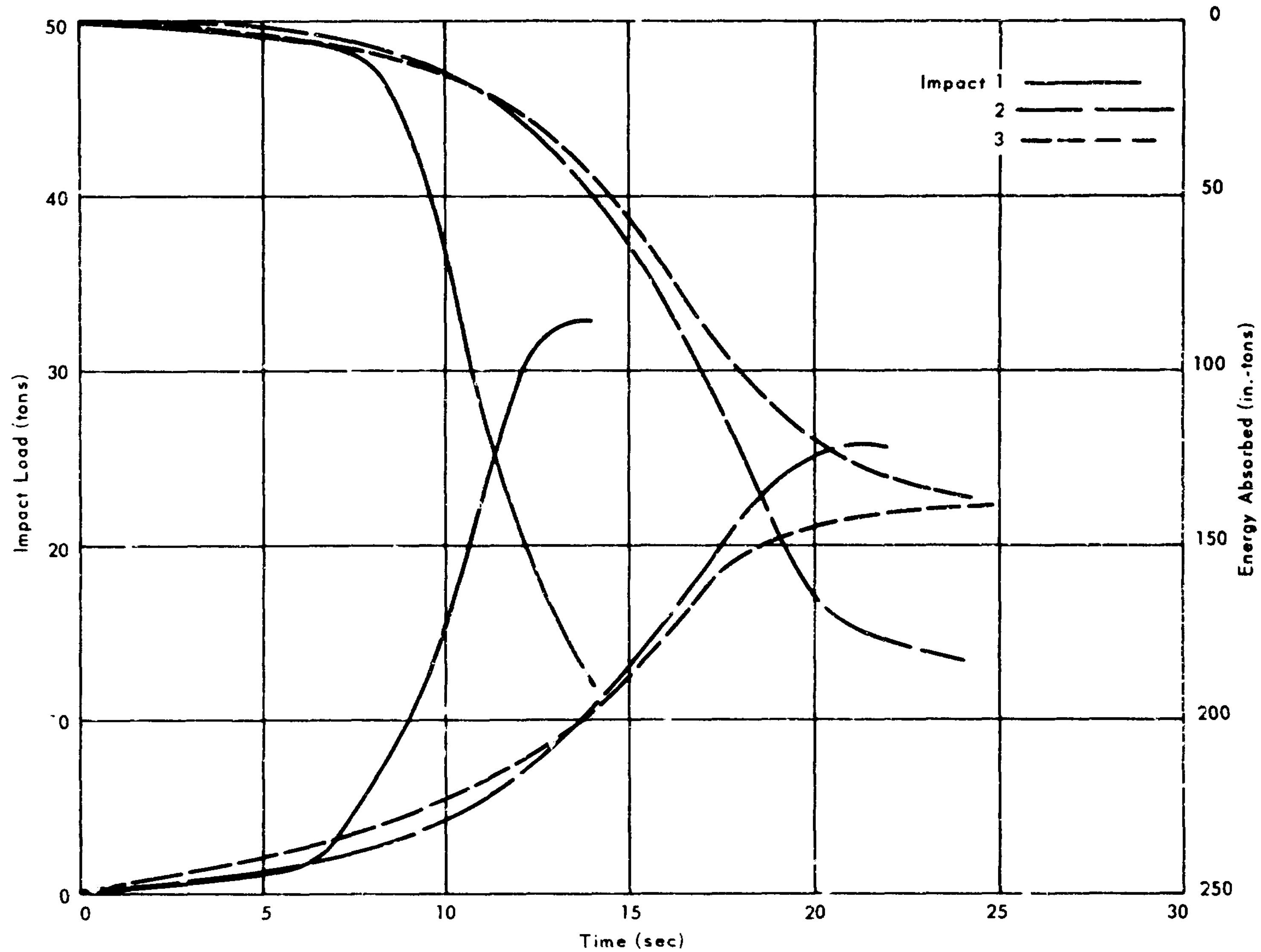

Figure A-10. Time history of load and energy-absorption characteristics of hydraulic-pneumatic fender measured in berthing of SS California, 28 December 1963.

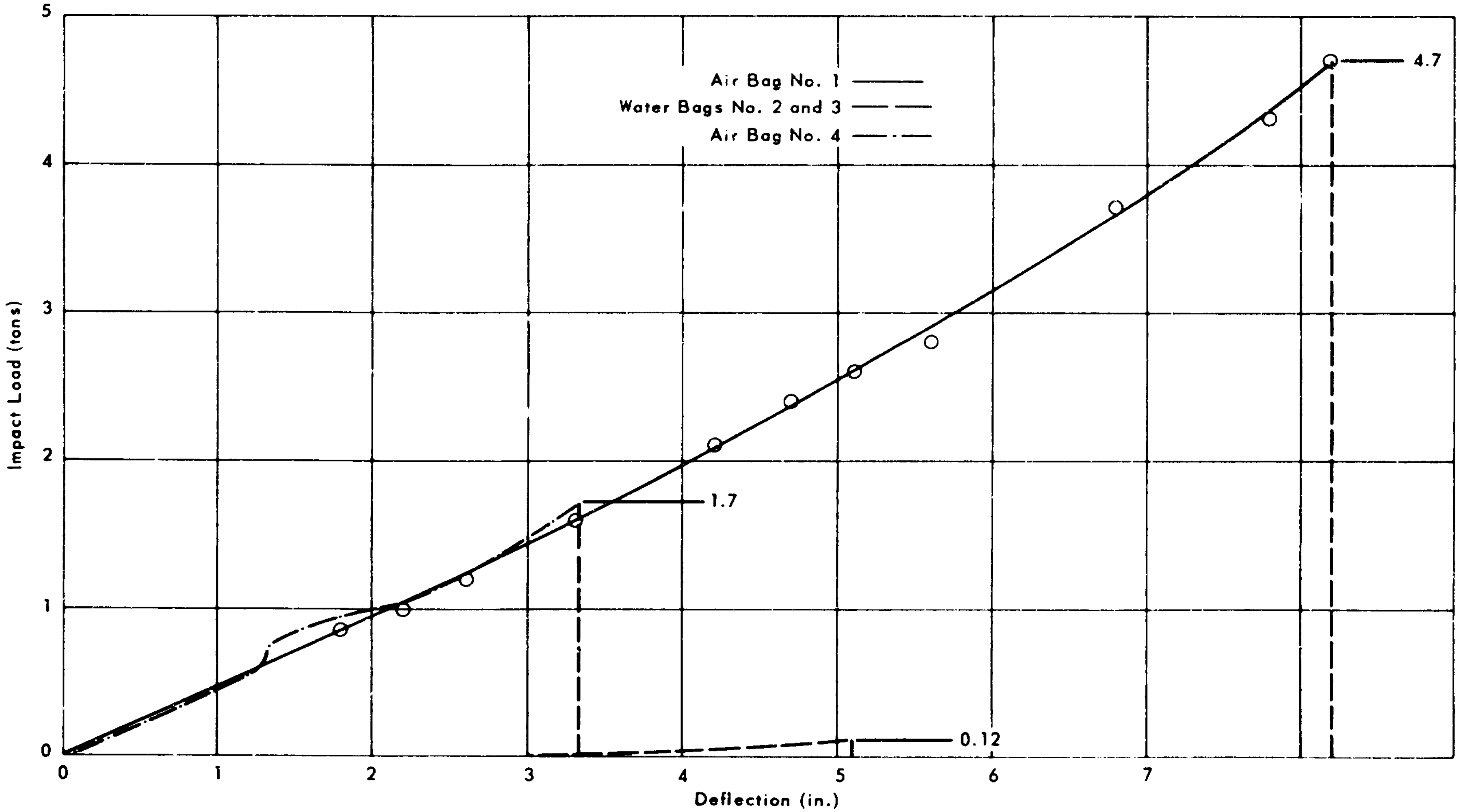

Figure A-11. Ship impact load versus fender deflection measured in berthing of SS Guam Bear, 4 January 1964.

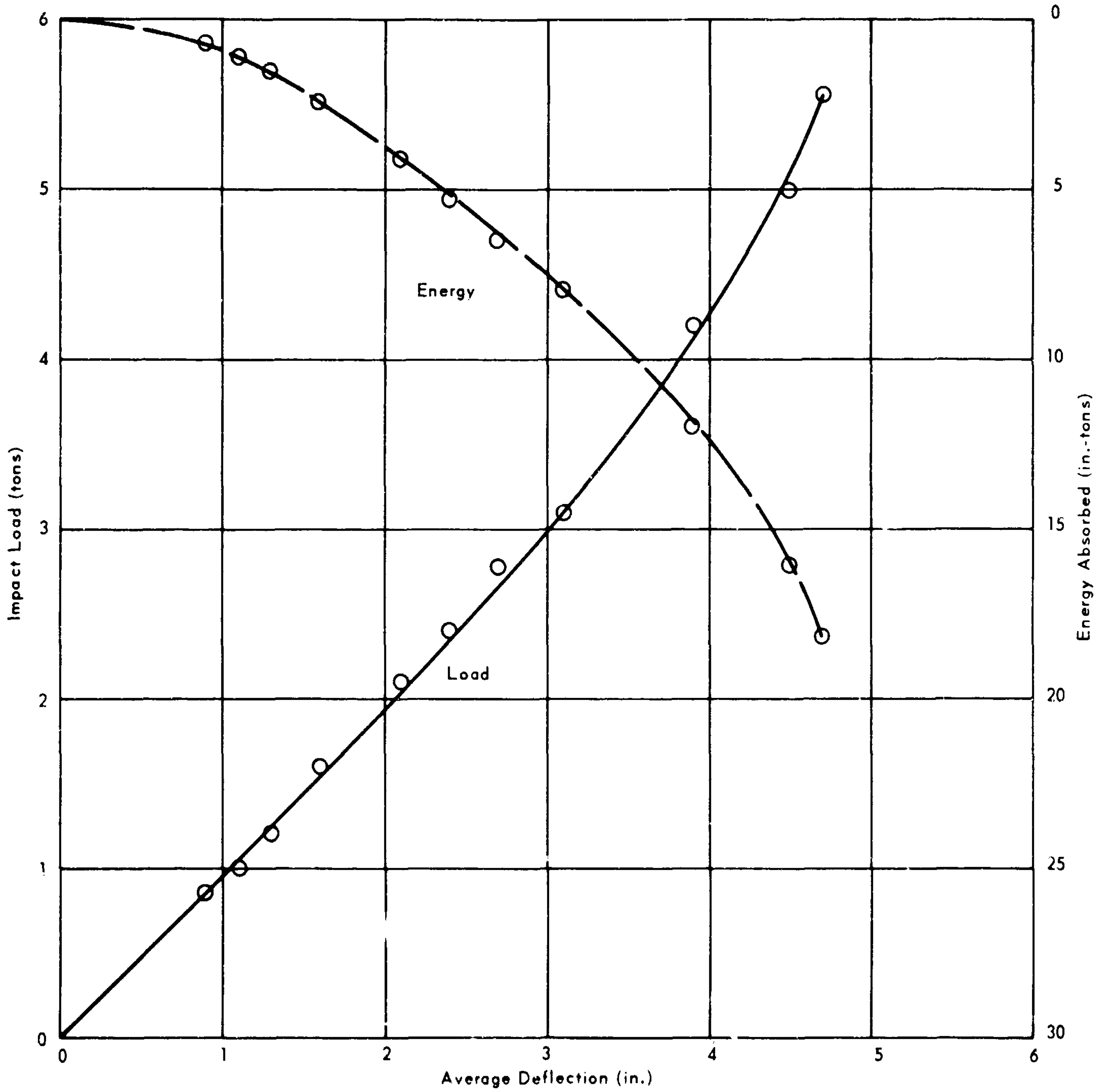

Figure A-12. Ship impact load and energy absorbed versus fender deflection measured in berthing of SS Guam Bear, 4 January 1964.

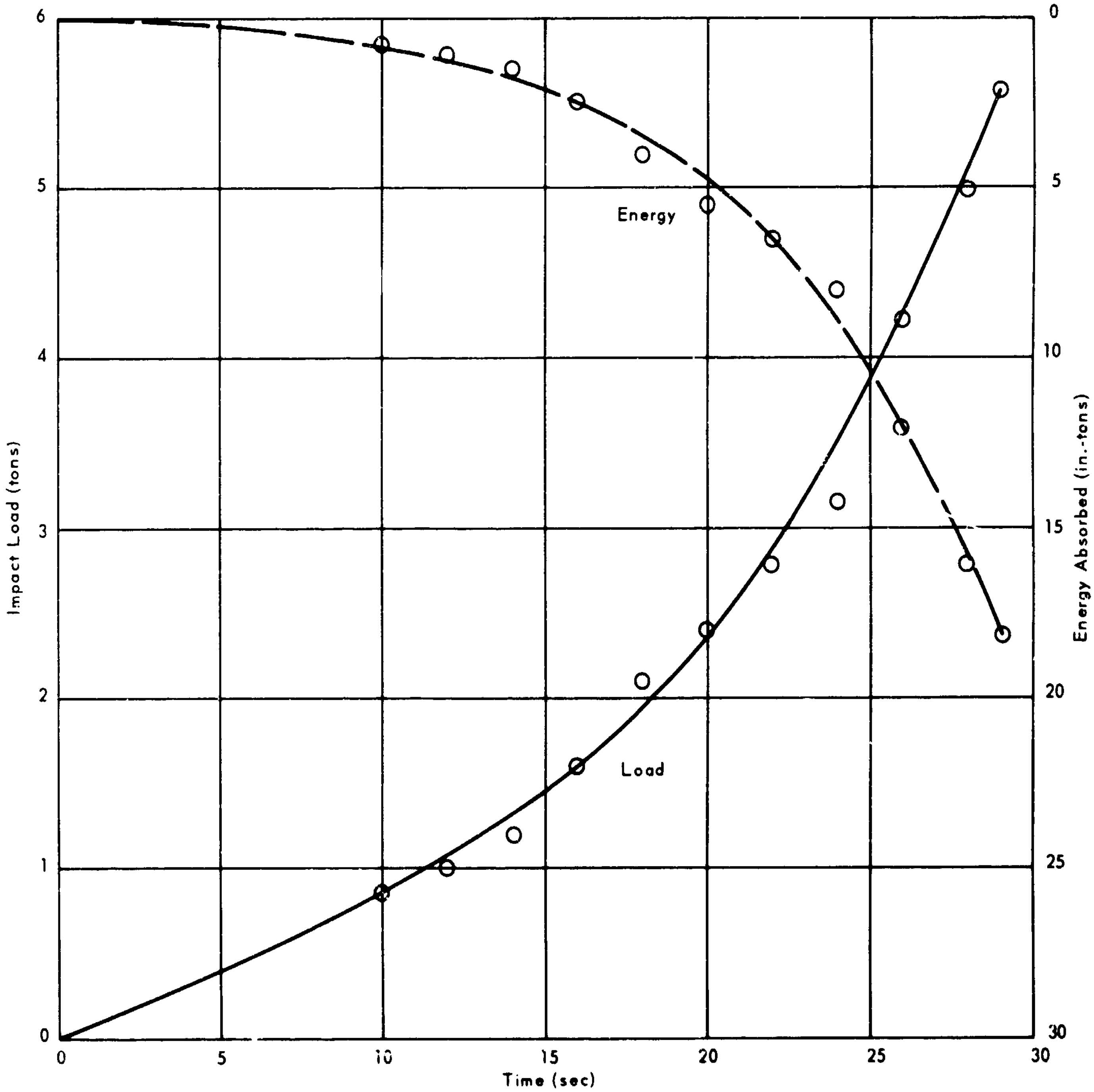

Figure A-13. Time history of load and energy absorption characteristics of hydraulic-pneumatic fender measured in berthing of SS Guam Bear, 4 January 1964.

APPENDIX B

MEASUREMENTS OF BERTHING SHIPS AT PORT HUENEME HARBOR

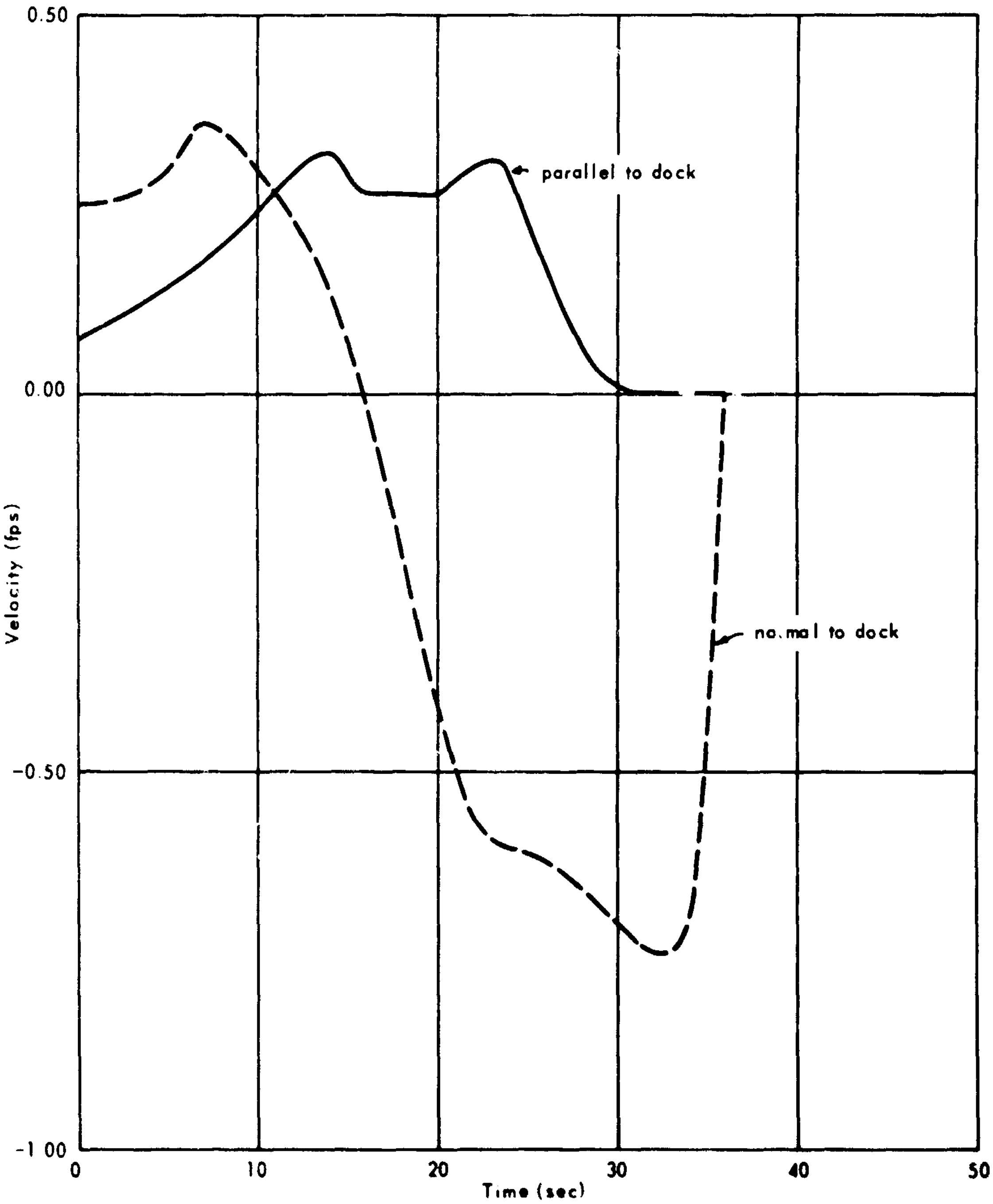

Figure B-1. Ship velocity versus time (Impact No. 1) measured in berthing of USNS General William Mitchell, 22 December 1963.

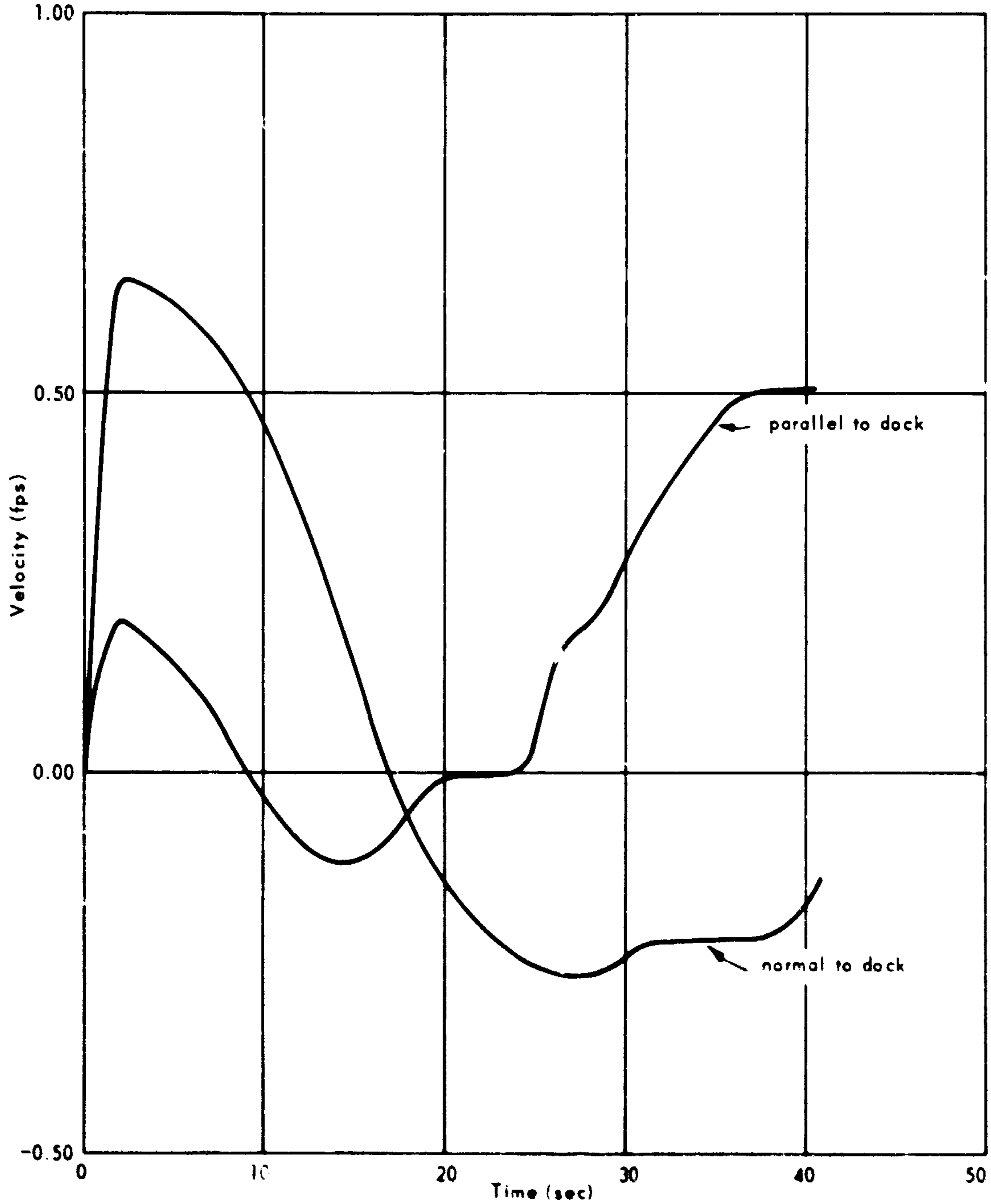

Figure B-2. Ship velocity versus time (Impact No. 2) measured in berthing of USNS General William Mitchell, 22 December 1963.

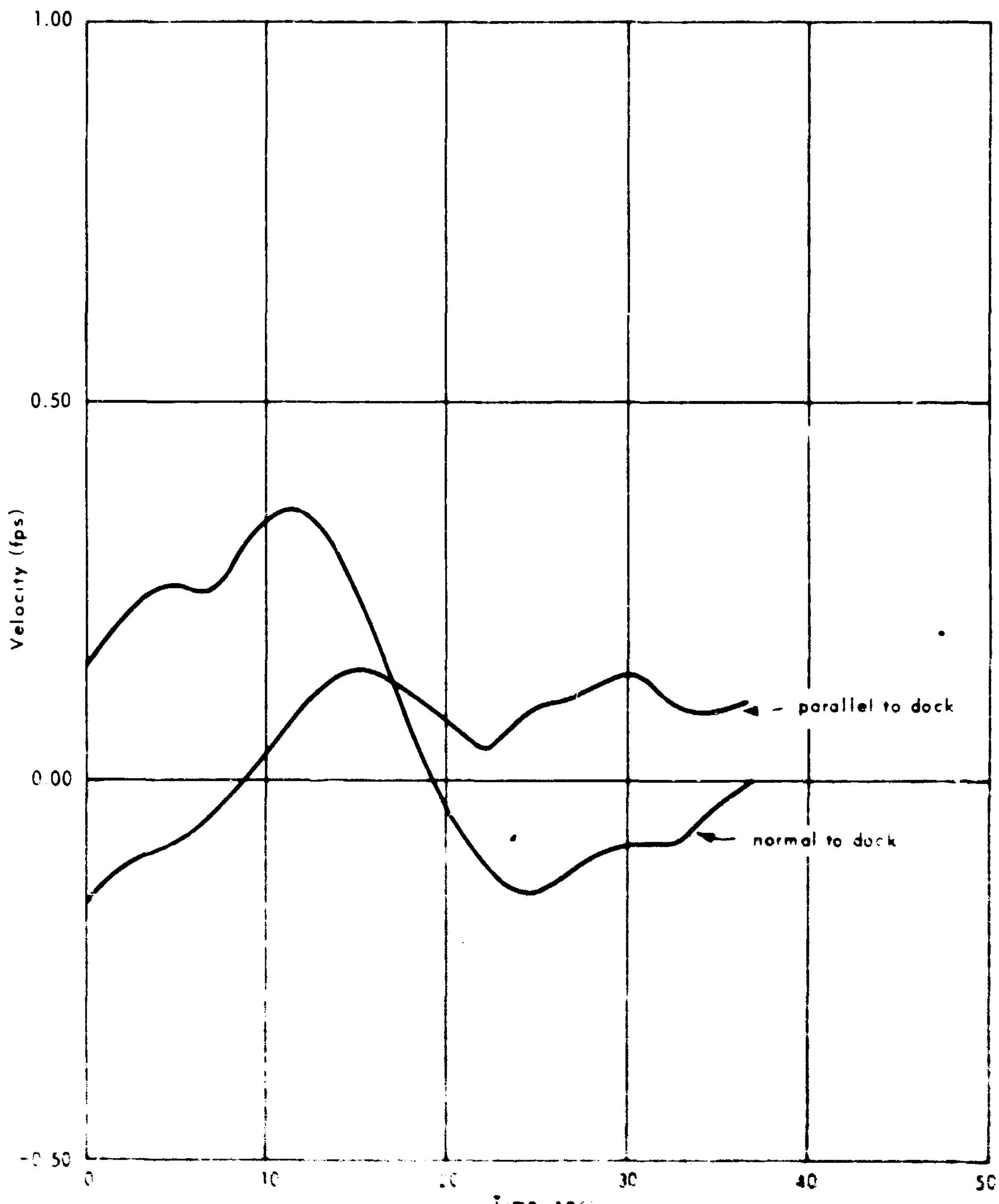

Figure B-3. Velocity versus time (Impact No. 3) measured in berthing of USNS General William Mitchell, 22 December 1963.

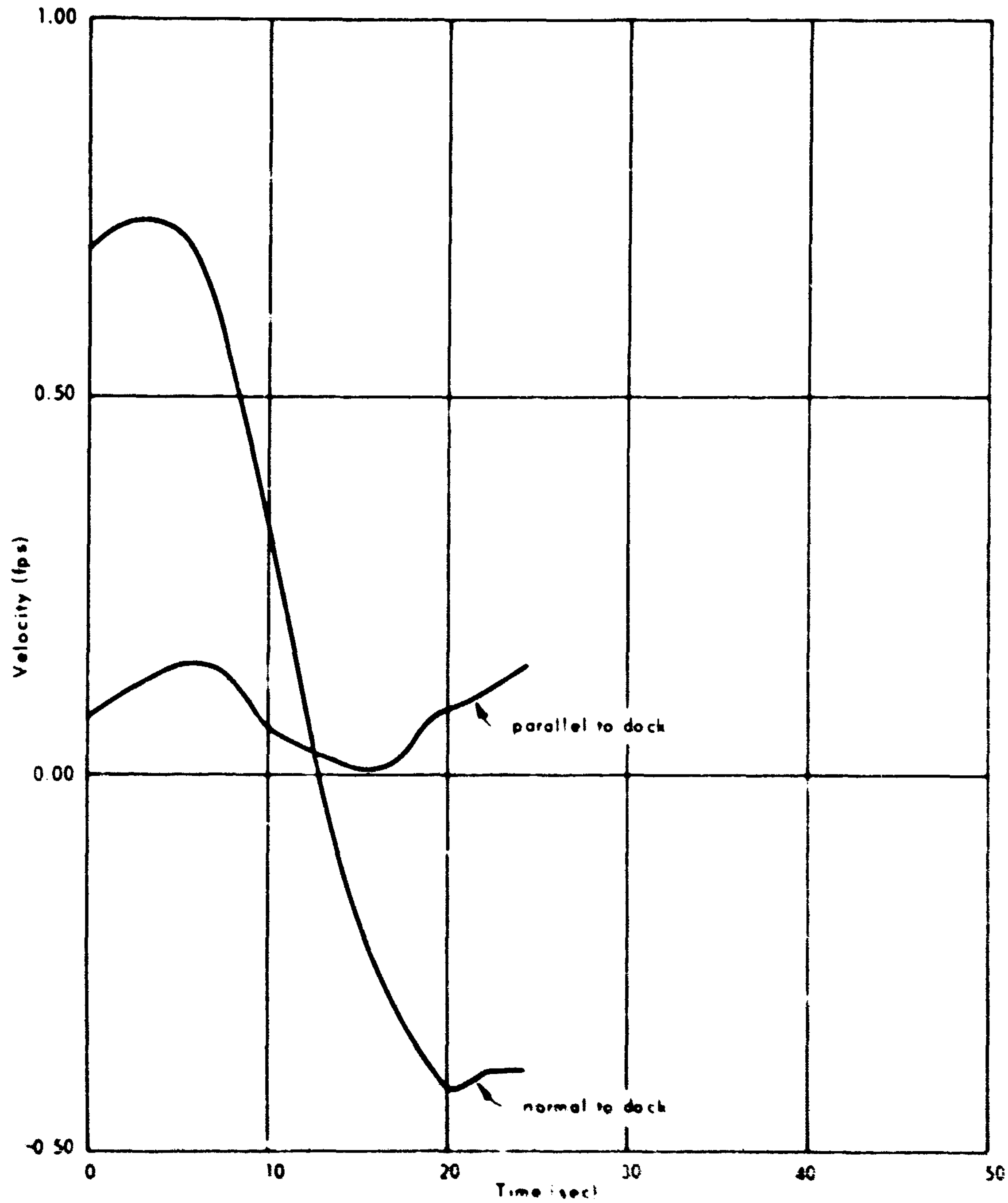

Figure B-4. Ship velocity versus time (Impact No. 4) measured in berthing of USNS General William Mitchell, 22 December 1963.

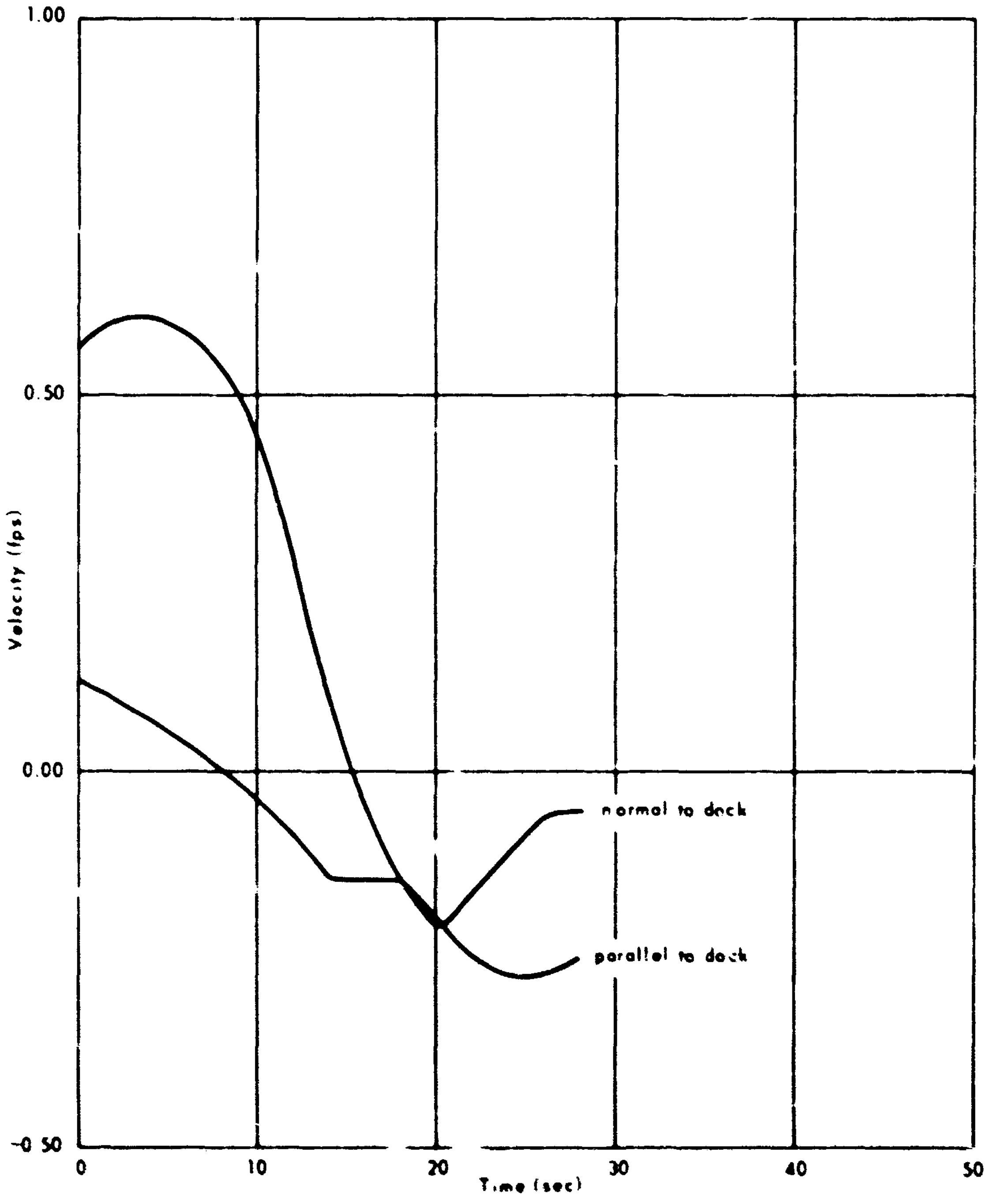

Figure B-5. Ship velocity versus time (Impact No. 5) measured in berthing of USNS General William Mitchell, 22 December 1963.

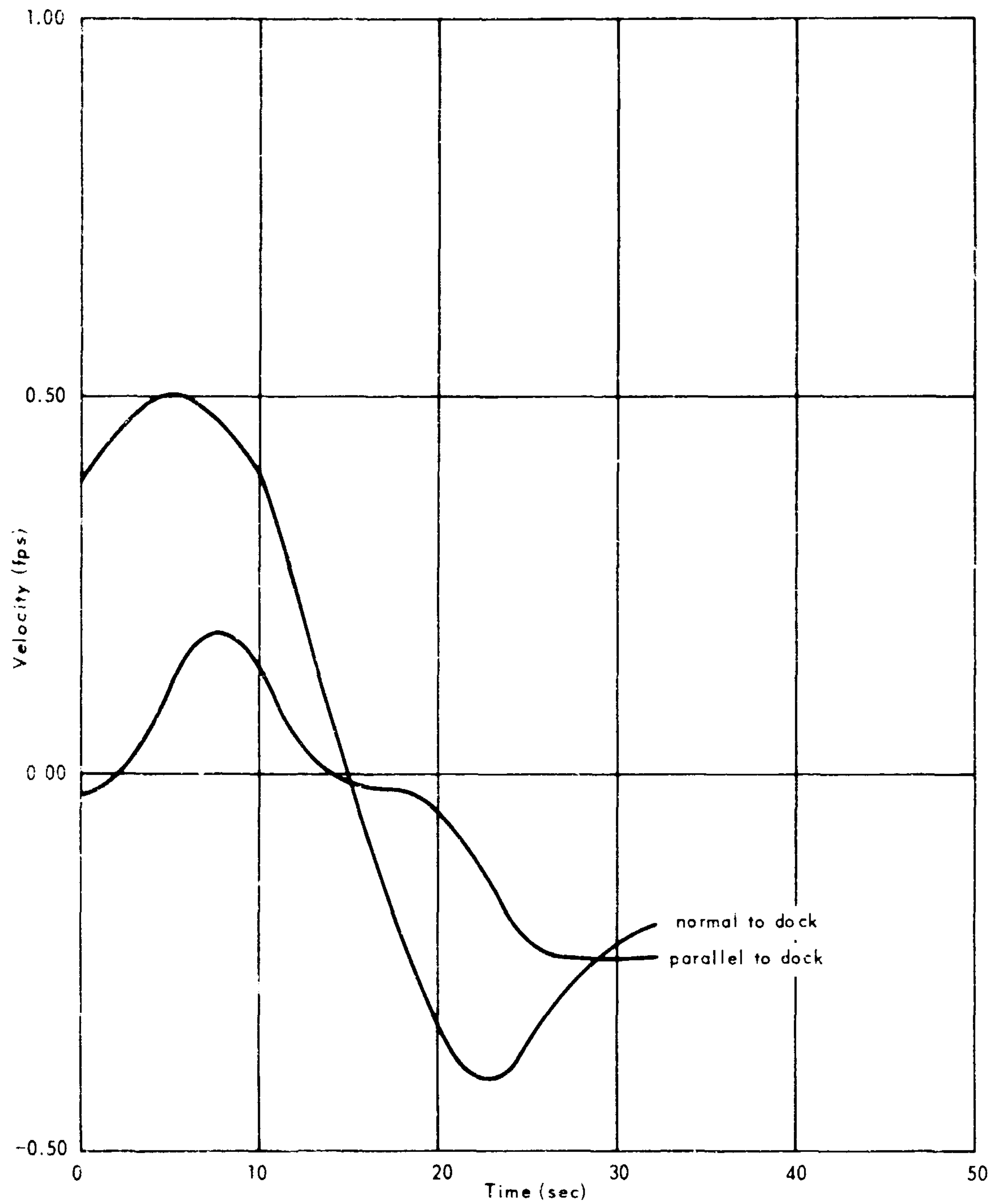

Figure B-6. Ship velocity versus time (Impact No. 6) measured in berthing of USNS General William Mitchell, 22 December 1963.

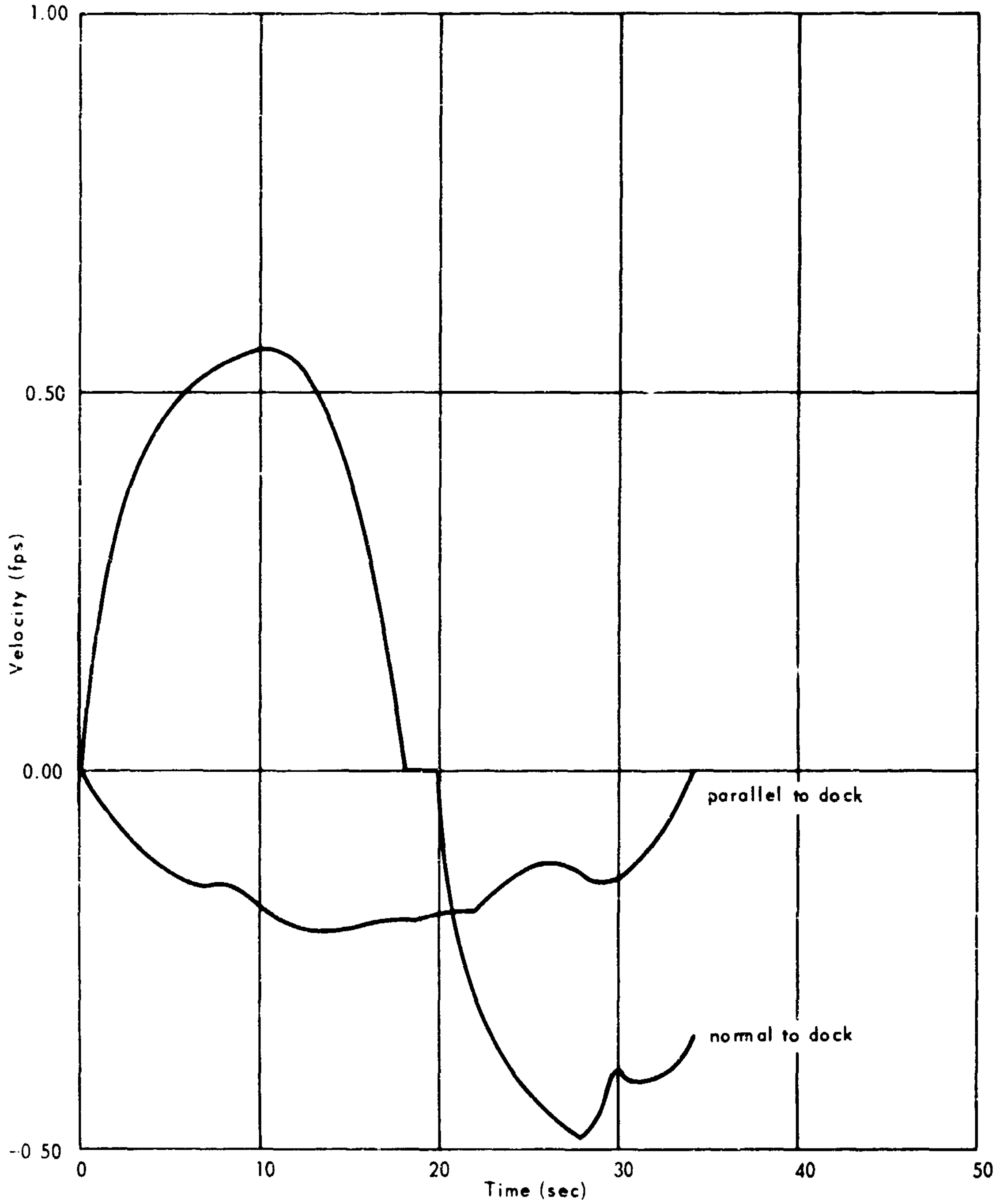

Figure B-7. Ship velocity versus time (Impact No. 7) measured in berthing of USNS General William Mitchell, 22 December 1963.

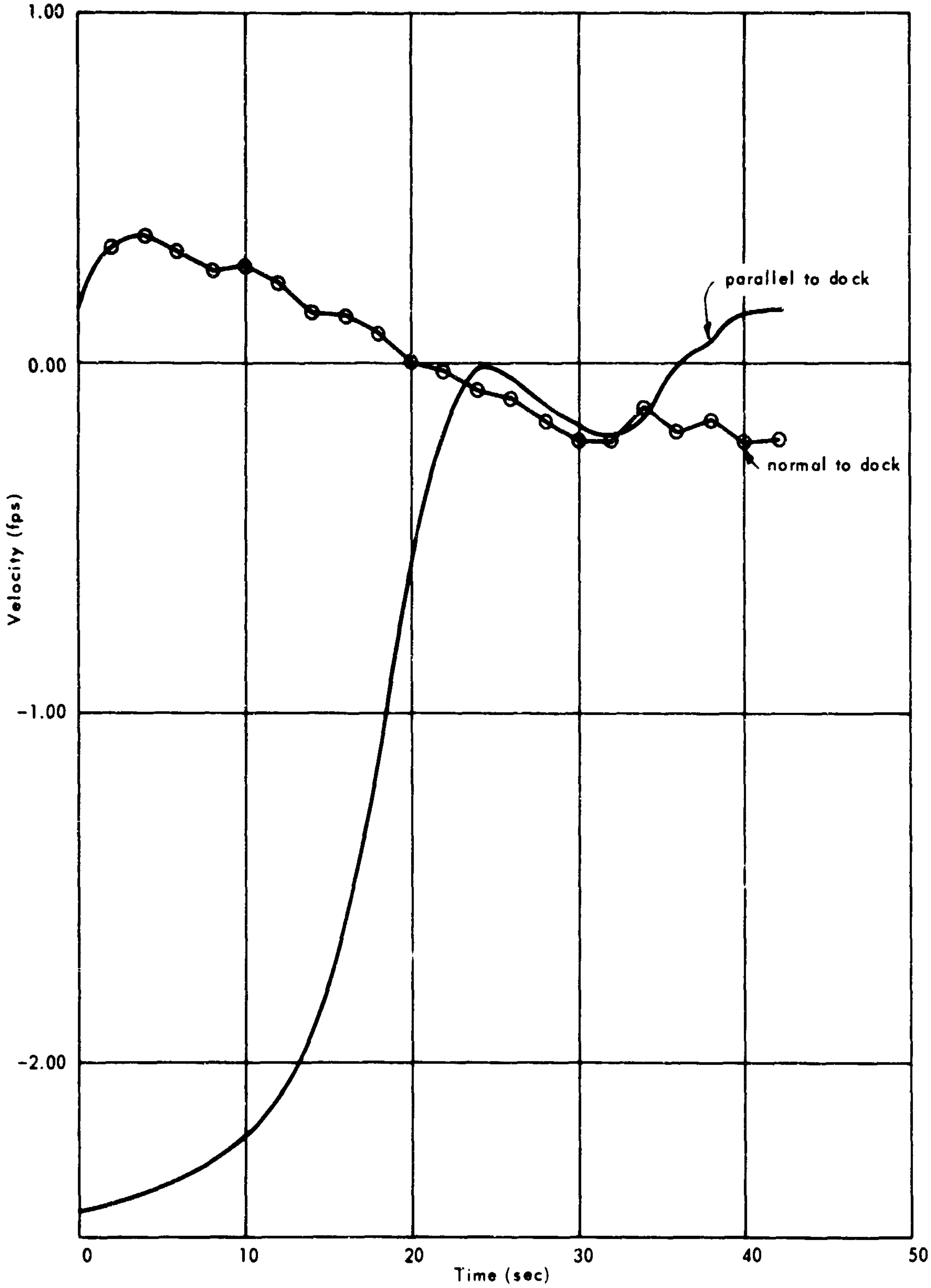

Figure B-8. Ship velocity versus time (Impact No. 1) measured in berthing of SS Oregon, 1 May 1964.

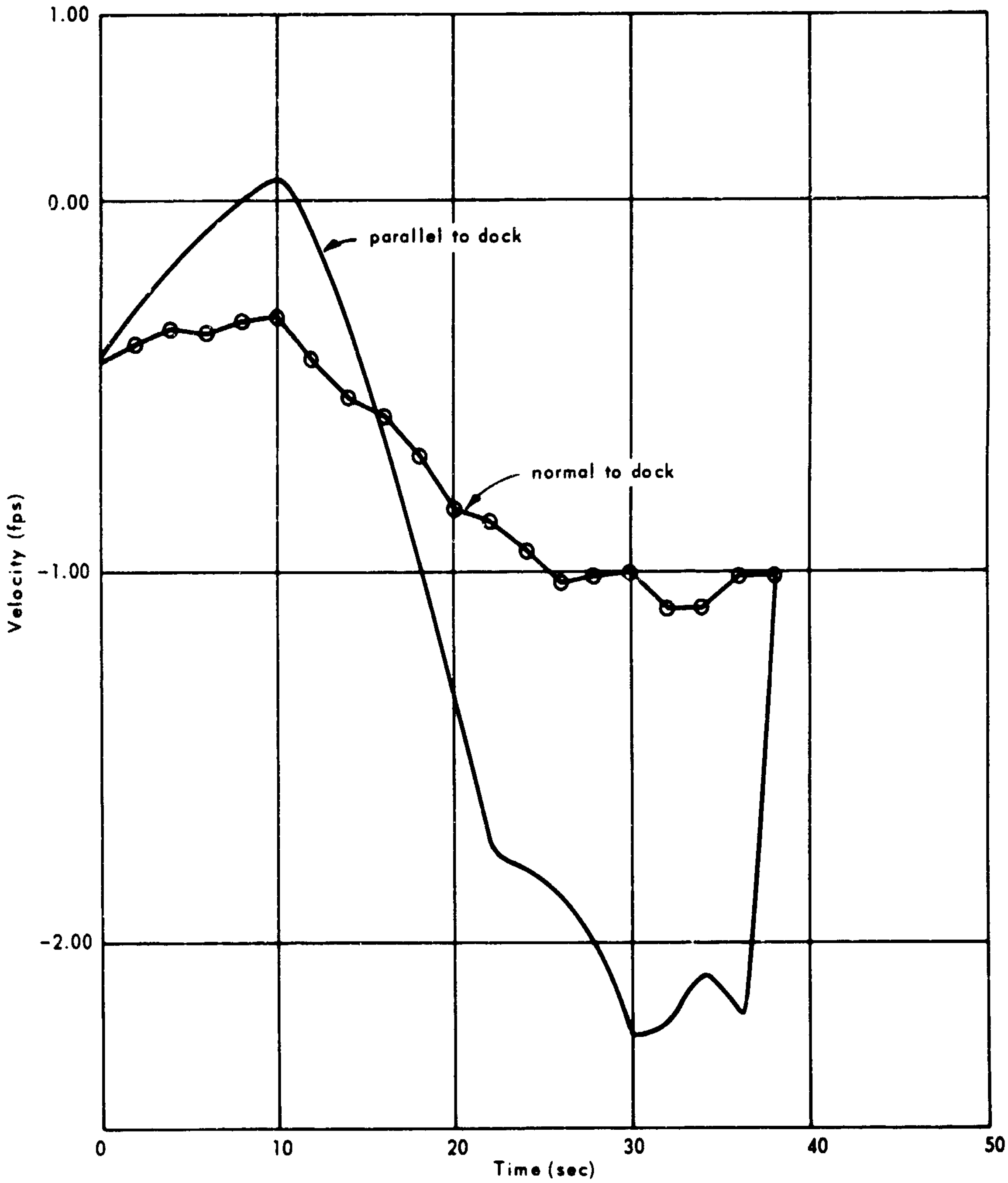

Figure B-9. Ship velocity versus time (Impact No. 2) measured in berthing of SS Oregon, 1 May 1964.

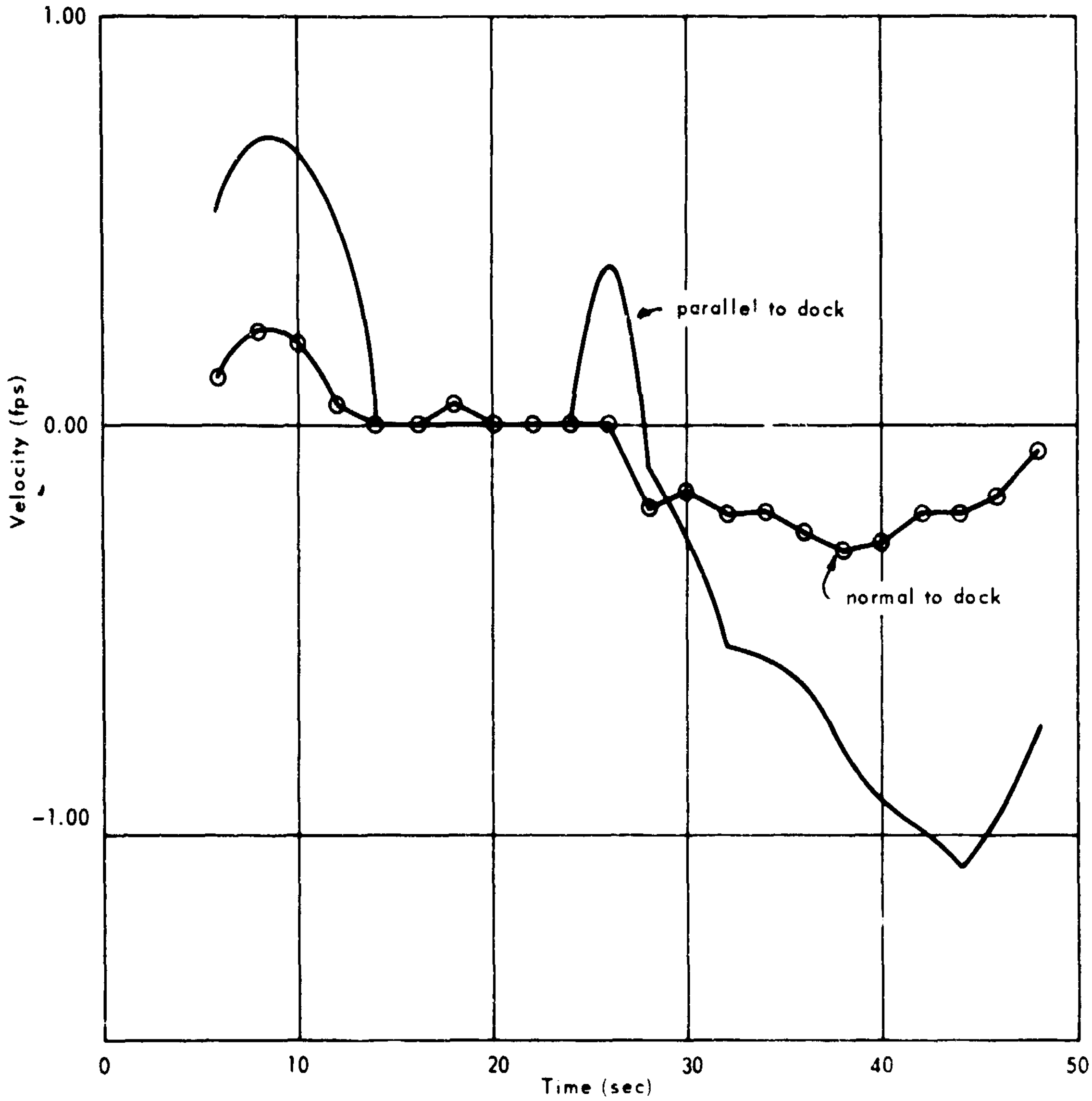

Figure B-10. Ship velocity versus time (Impact No. 3) measured in berthing of SS Oregon, 1 May 1964.

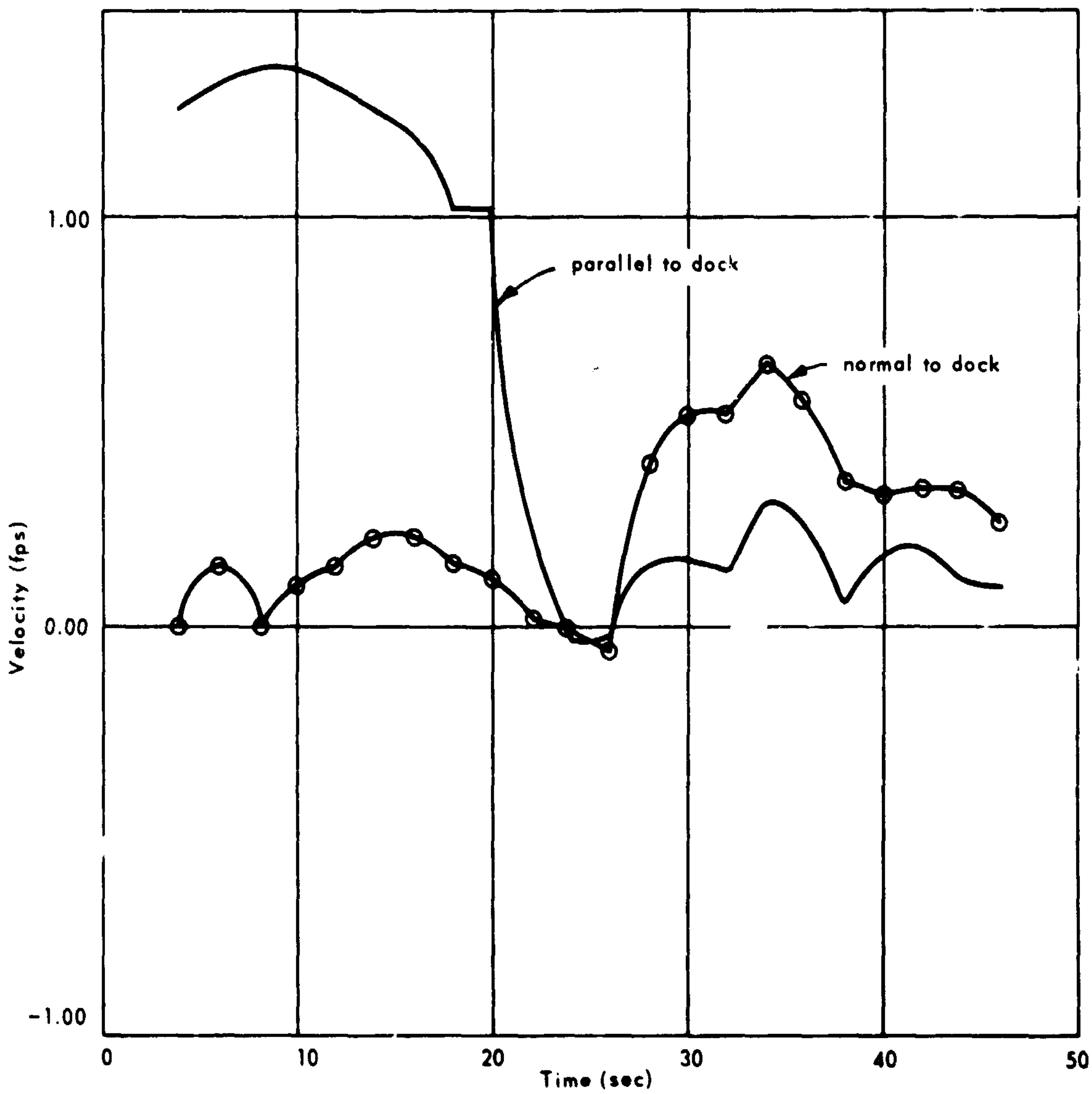

Figure B-11. Ship velocity versus time (Impact No. 4) measured in berthing of SS Oregon, 1 May 1964.

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13. ABSTRACT

Tests of two experimental hydraulic-pneumatic floating fenders, first in a well-protected harbor (Port Hueneme) and then in a relatively exposed harbor (San Diego), are described. Each fender consists of a 50-foot-long bulkhead fronted by two air-filled and two water-filled rubber bags. Also included is information to aid engineers in increasing the energy-absorption capacity of existing dock fender systems.

After 19 months of in-service tests of the floating fender it was concluded that (1) the energy-absorption capacity of the fender is adequate for a well-protected harbor such as that at Port Hueneme; (2) a fender system serving ships under navigation conditions and in a marine environment similar to those at Port Hueneme, requires a minimum energy-absorption capacity of 16 and a maximum of 50 inch-tons per 1,000 tons of ship displacement; and (3) resistance to ship motion, including the hydrodynamic mass effect, is an important parameter which requires further investigation. It is recommended that (1) full-scale tests of berthing impact be continued, particularly at exposed harbors, to determine energy requirements for other fender designs and (2) model tests of berthing impact be initiated, particularly of the resistance to motion, for use in evaluating hydrodynamic mass. Although measurements were not made at San Diego, it is concluded that the fenders provided satisfactory service but were not loaded to capacity.

DD FORM 1 JAN 64 1473 0101-807-6800

Unclassified
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Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
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Fenders						
Camels						
Hydraulic-penumatic						
Floating						
Absorption						
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Berthing						
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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

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