CHAPTER 9

FENDER SYSTEMS

9-1. Function.

The principal function of the fender system is to prevent the vessel or the dock from being damaged during the mooring process or during the berthing periods. Forces during the vessel berthing or anchoring may be in the form of impact, abrasive action from vessels, or direct pressure. These forces may cause extensive damage to the ship and structure if suitable means are not employed to counteract them.

9-2. Types.

General description of and applicable pertinent details associated with various types of fender systems are presented below.

a. Standard pile-fender systems.

(1) *Timber pile.* This system (fig 9-1) employs piles driven along a wharf face bottom. Pile tops may be unsupported laterally or supported at various degrees of fixity by means of wales and chocks. Single-or-multiple-row wales may be used, depending on pile length and on tidal variations. Impact energy upon a fender pile is absorbed by deflection and the limited compression of the pile. Energy-absorption capacity depends on the size, length, penetration, and material of the pile and is determined on the basis of internal strain-energy characteristics (fig 9-2).

(a) Advantages. The advantages are low initial cost and abundant timber piles.

(b) Disadvantages. The disadvantages include: limited energy-absorption capacity that declines as a result of biodeterioration; susceptibility to mechanical damage and biological deterioration; and high maintenance cost if damage and deterioration is significant.

(2) *Hung timber.* This system consists of timber members fastened rigidly to the face of a dock. A contact frame is formed that distributes impact loads (fig 9-3).

(a) Advantages. The advantages are very low initial cost and less biodeterioration hazard.

(b) Disadvantages. The disadvantages are low energy-absorption capacity and unsuitability for locations with significant tide and current effects.

(3) *Steel pile*. Steel fender piles are occasionally used in water depths greater than 40 feet or for locations where very high strength is required.

(a) Advantages. The advantages are high strength and feasibility for difficult seafloor conditions.

(b) Disadvantages. The disadvantages are vulnerability to corrosion and high cost.

(4) *Concrete pile*. Reinforced concrete piles are not satisfactory because of their limited internal strain-energy capacity. Prestressed concrete piles with rubber buffers at deck level have been used.

(a) Advantage. The advantage is that this pile resists natural and biological deterioration.

(b) Disadvantages. The disadvantages are limited strain-energy capacity and corrosion of steel reinforcement through cracks.

b. Retractable fender system. A retractable fender system (fig 9-4) consists of vertical-contact posts connected by rows of wales and chocks. Contact posts are normally spaced 8 feet on centers. The interval between wales is dependent on the local tide range. Wales are fastened to holding posts suspended by pins from specially designed brackets. The fender retracts under impact, thus absorbing energy by action of gravity and friction. Energy-absorption capacity depends directly on the effective weights, the angle of inclination of the supporting brackets, and the maximum amount of retraction of the system. In designing this system, the tide effect on weight reduction of the fender frame should be considered. Use of composite inclined planes of supporting brackets and proper selection of maximum retraction are feasible means for attaining design capacity. Fenders are more easily removed from open pin brackets than from slot-type. In construction, the supporting brackets should be adequately anchored to the associated berthing structure. Deterioration of timber frames does not materially reduce energy-absorption capacity, as is found in timber piles.

(1) *Advantages*. The advantages include: negligible effects of biological deterioration on energy-absorption capacity; no heavy equipment required for fabrication and replacement; and low maintenance cost, plus minimum time loss during replacement.

(2) *Disadvantages.* The disadvantages are loss of effectiveness due to corrosion or damage to supporting brackets and high initial cost for use at open-type piers.

c. Rubber fender systems. Rubber fenders consist of two major types, rubber-in-compression and rubber-inshear.

(1) *Rubber-in-compression*. This fender consists of a series of rubber cylindrical or rectangular tubes installed behind standard fender piles or behind hungtype fenders. The tubes may be compressed in axial or radial directions. Typical arrangements of rubber fenders in radial compression are shown in figures 9-5 and 9-6. Energy absorption is achieved by compression of the rubber. Absorption capacity depends on the size of the buffer and on maximum deflection. Loaddeflection and energy-absorption characteristics of various rubber fenders are illustrated in figures 9-7, 9-8, and 9-9. In design, a proper bearing timberframe is required for transmission impact force from ship to pier. Draped rubber tubes hanging from solid wharf bulkheads may be used as a rubber-in-compression system. The energy-absorption capacity of such a system can be varied by using the tubes in single or double layers, or by varying tube size. The energy absorption of a cylindrical tube is nearly directly proportional to the ship's force until the deflection equals approximately one-half the external diameter. After that, the force increases much more rapidly than the absorption of energy. Consequently, a large enough fender should be used so that the energy of the berthing ship will be absorbed without requiring a deflection of such magnitude that it results in a disproportionate increase in force.

(a) Advantages. The advantages include simplicity and adaptability plus effectiveness at reasonable cost.

(b) Disadvantages. The disadvantages are: high concentrated loading may result; frictional force may be developed if rubber fenders contact ship hull directly; and initial cost is higher than standard pile system without resilient units.

(2) *Rubber-in-shear*. This consists of a series of rubber pads bonded between steel plates to form a series of rubber sandwiches mounted firmly as buffers between a pile-fender system and a pier. Two types of mounting units are available: the standard unit (fig. 9-10), or the overload unit, which is capable of absorbing 100 percent more energy. Load-deflection and energy-absorption characteristics of Raykin rubber-inshear buffers are shown in figure 9-11.

(a) Advantages. The advantages include: capability of cushioning berthing impact from lateral, longitudinal, and vertical directions; most suitable for dock-corner protection; high energy-absorption capacity for serving large ships of relatively uniform size; and favorable initial cost for very heavy duty piers.

(b) Disadvantages. The disadvantages are: Raykin buffers are too stiff for small vessels and for moored ships subject to wave and surge action; steel plates subject to corrosion; problem with bond between steel plate and rubber; and high initial cost for general cargo berths.

(3) *Lord flexible fender*. This system (fig 9-12) consists of an arch-shaped rubber block bonded between two end steel plates. It can be installed on open or bulkhead-type piers, dolphins, or incorporated with standard pile or hung fender systems. Impact energy is absorbed by bending (buckling) the compression of the arch-shaped column. When an impact force is applied, it builds up a relatively high load with small deflection, buckles at still smaller deflections, and maintains a virtually constant load over the range of buckling deflection (fig. 9-13).

(a) Advantages. The advantages are high energy-absorption and low terminal-load characteristics.

(b) Disadvantages. The disadvantages include possible destruction of bond between steel plates and rubber plus possible fatigue problems.

(4) *Rubber-in-torsion fender*. This fender is a rubber and steel combination fabricated in cone-shaped, compact bumper form, molded into a specially cast steel frame, and bonded to the steel. It absorbs energy by torsion, compression, shear, and tension, but most energy is absorbed by compression (fig 9-14).

(a) Advantage. The advantage is being capable of resisting the impact load from all directions.

(b) Disadvantages. The disadvantages are possible destruction of the bond between steel casting and rubber and possible fatigue problems.

(5) *Pneumatic fender*. Pneumatic fenders are pressurized, airtight rubber devices designed to absorb impact energy by the compression of air inside a rubber envelope. Table 9-1 lists pneumatic-fenders that have been used by the US Armed Forces. These pneumatic fenders are not applicable to fixed dock-fender systems but are feasible for use as ship fenders or shock absorbers on floating fender systems. A proven fender of this type is the pneumatic tire-wheel fender, which consists of pneumatic tires and wheels capable of rotating freely around a fixed or floating axis. The fixed unit is designed for incorporation in concrete bulkheads. The floating unit may consist of two to five tires. Energy-absorption capacity and resistance load depend on the size and number of tires used and on the initial air pressure when inflated. Load-deflection and energy-absorption characteristics are shown in table 9-2. The Yokohama pneumatic rubber fender, which utilizes the compression elasticity of air, is shown in figures 9-15, 9-16, 9-17, and 9-18. It is constructed of an outer rubber layer, a reinforcement synthetic cord layer, and an interior rubber layer. To facilitate handling, the fender is slung in a wire rope net. The internal working pressure of these units is 7 pounds per square inch.

(a) Advantages. The advantages are that this fender is suitable for both berthed and moored ships

Table 9-1. Pneumatic Fenders for Military Uses

Pneumatic Fenders for Military Uses

Fender diameter (in.)	Fender length (in.)	Suspension cable diameter recommended (in.)	Initial air pressure recommended (lb/in.^{2})	Application
40	60		3/4	12 US. Navy, Bureau of Ships (Mountcast, 1961), adopted in 1961. Used as hip fenders for Navy vessel to replace cocoa-mat fender.
24	48	3/8	7.5	
10	20	1/4	0	US. Army Transportation Board (1962). Recommended for use on amphibious landing craft and other marine TC vessels to replace old rope fenders.
18	36	1/4	7.5	
28	56	3/8	75	

Department of the Navy

and the fixed tire-wheel type is feasible for pier-corner protection.

(b) Disadvantages. The disadvantages include its use in fixed dock-fendering being limited to bulkhead-type structures and high maintenance cost.

d. Gravity-type fender systems. Gravity fenders (fig 9-19) are normally made of concrete blocks and are suspended from heavily constructed wharf decks. Impact energy is absorbed by moving and lifting the heavy concrete blocks. High-energy absorption is achieved through long travel of the weights. Movements may be accomplished by a system of cables and sheaves, a pendulum, trunnions, or by an inclined plane. The type of gravity fender suited to a given situation depends on tidal conditions, energy-absorption requirements, and other load environmental factors, such as exposures to wind, waves, and currents. Heavy, vertically suspended gravity fenders are commonly used in exposed locations that have large tidal ranges.

(1) *Advantages.* Smooth resistance to impacts can be induced by moored ships under severe wave and swell action. Also, high energy-absorption and low terminal load can be achieved through long travel for locations where the excessive distance between ship and dock is not a problem.

(2) *Disadvantages.* Heavy berthing structure is required; heavy equipment is necessary for installation and replacement; initial and maintenance costs are high; and the excessive distance between dock and ship caused by the gravity fender is undesirable for general military piers and wharves.

e. Hydraulic and hydraulic-pneumatic fender systems.

(1) *Dashpot hydraulic*. This system (fig 9-20) consists of a cylinder full of oil or other fluid so arranged that when a plunger is depressed by impact, the fluid is displaced through a nonvariable or variable orifice into a reservoir at higher elevation. When ship impact is released, the high pressure inside the cylinder forces the plunger back to its original position and the fluid flows back into the cylinder by gravity. This system is most commonly used where severe wind, wave, swell, and current conditions exist.

(a) Advantages. The advantages include favorable energy-absorption characteristics for both berthing and mooring ships.

(b) Disadvantages. The disadvantages are high initial and maintenance costs.

(2) *Hydraulic-pneumatic floating fender*. In this system, a floating rubber envelope is filled with water or water and air, which absorbs energy by viscous resistance or by air compression. This fender seems to meet certain requirements of the ideal fender but is considered to be expensive in combined first cost and maintenance costs.

(a) Advantages. The advantages include favorable energy-absorption characteristics for both berthing and mooring ships.

(b) Disadvantages. The disadvantages are high initial and maintenance costs.

f. Floating fender systems. As a supplement to a number of the fender systems mentioned above, the floating fender, camel, or separator is often used. In its simplest form, the camel may consist of floating logs, which ride up and down against the timber bresting face and are attached to the face by chains or other means. Figure 9-21 shows two rolling type fenders, both built of timber, with one protected by heavy rubber. Another type of camel, occasionally used commercially and often used around naval establishments, is a heavy timber box section made up of timbers dapped and bolted together. This box-type of camel or separator is generally rectangular in shape, sometimes measuring to 30 feet in length, but may have different shapes in the plan designed to fit the contours of the ships being docked. This type of device may be used to absorb some of the bresting loads during docking but more generally is used to keep ships away from a dock or to separate ships tied up adjacent to one another.

9-3. Selection of fender system type.

A variety of factors affect the proper selection of a fender system. These include local marine environment, exposure of harbor basins, class and configuration of ships, speed and direction of approach of ships when berthing, available docking assistance, type of berthing structure, and even the skills of pilots or ship captains. It is considered impractical to standardize fender designs since port conditions are rarely identical. Previous local experience in the application of satisfactory fender systems should be considered, particularly as it applies to cost-effectiveness characteristics.

a. Exposure conditions. In exposed locations or in areas subject to seiche, a resilient system, such as a rubber fender system, should be used. In sheltered basins, a standard timber-pile system, a hung system, or a retractable system is generally used.

b. Berthing ship versus moored ship. The choice of a fender is dependent on whether its chief function is to absorb kinetic energy of berthing ships or to keep a ship safely moored during loading and unloading operations.

(1) For locations where berthing operations are hazardous, stiff fender systems with high energy-absorption characteristics, such as Raykin fenders or rubber-in-axial-compression pile fender systems, are advisable. This is the case when berthings are conducted

under action of winds, currents, and waves without tug assistance.

(2) For locations where the behavior of the moored ship is the governing factor, soft fenders combined with soft mooring ropes are successful in minimizing mooring forces and ship motion. A soft type fender system (e.g. rubber-in-radial-compression fenders) tends to increase the natural oscillation period of a moored ship so that a resonance with long-period waves or seiches can be avoided. The foregoing is applicable in harbors where berthings present no difficulty and are assisted with tugs; but oscillation of water in the harbor basin by seiche action is a significant factor governing the choice of fender.

(3) Where berthing operations and the behavior of moored ships seem to pose problems of equal importance, it is best to choose a fender of intermediate type, one that can act stiffly during berthing and softly when the ship is moored. Hydraulic-pneumatic fender systems meet such requirements.

c. Maximum allowable distance between moored ships and dock face. The distance required by the fender system should be limited so as to avoid inconvenience during cargo loading and unloading. Generally, the maximum limit is 4 to 5 feet. No problem exists if the fender system is for a tanker berth that involves fuel supply only.

d. Pier type as related to fender system selection. For mooring or berthing platform, consider a resilient fender, since the length of the structure available for distribution of berthing load is limited. For an open pier, any type of fender system may be applicable. For a solid pier, consider use of resilient or retractable fenders to minimi7e vessel damage.

e. Structural factors. Structural factors related to the fender system selection are indicated below.

(1) *Concentrated loads at pier ends and expansion joints*. Fender spacing should be reduced to half at those bents adjacent to expansion joints. Provide clusters of fender piles at the outboard end and exposed corners of pier. For corners subject to berthing impact or frequent use as a turning point for ship maneuvering, resilient corner fender systems should be considered.

(2) *Projections*. Fender systems should present a smooth face to berthing vessels and bolt heads should be recessed. It is of prime importance that fenders be spaced sufficiently close together to prevent the prow of a vessel from getting between the fenders at angles of approach up to 15 degrees (provide wales and chocks to prevent this).

(3) *Integral construction*. Pile, hung, and retractable fenders will be tightly chocked and constructed as an integral, interlocking unit. Chocks should be recessed back of vertical fender faces.

(4) *Tidal range construction*. Where tidal ranges are in excess of 5 to 6 feet, provide a lower line of fendering near mean low water, if possible. For open piers, lower fendering may be braced to pier structure.

(5) *Rubbing strips*. Where vessels are berthed against separators, use of steel or timber rubbing strips on fendering faces should be considered.

(6) *Hardware and treatment*. For pile and hung systems, use of treated timber and hardware may be optional. Untreated timber piles should be considered only for locations where mechanical damage is significant and where biological deterioration effect is negligible. For resilient systems, timbers should be treated and hardware galvanized, except that galvanizing of ogee washers may be optional. For all systems, cast iron bolt inserts are preferable to screw-type inserts for attaching fenders to concrete structures.

(7) *Moving parts*. Minimize the use of moving parts. When used, they should be greased and made of hard grade steel or fitted with hard bearing points.

f. Miscellaneous factors related to fender system selection. These include resistance to tangential forces, reliability in operation, and cost of maintenance. In addition, evaluation of systems that have given satisfactory service at or near the proposed installation, resistance to longitudinal component of berthing force, and ease and economy of replacement are important.

9-4. Design procedure.

a. General design procedure. The design of a fender system is based on the law of conservation of energy. The amount of energy being introduced into the system must be determined, and then a means devised to absorb the energy within the force and stress limitations of the ship's hull, the fender, and the pier. General design procedure for a fender system are as follows:

(1) Determine the energy that will be delivered to the pier upon initial impact (table 9-3). The selection of a design vessel should be based on recommendations from the Military Traffic Management and Terminal Service and the Military Sealift Command.

(2) Determine the energy that can be absorbed by the pier or wharf (distribution of loading must be considered). For structures that are linearly elastic, the energy is one-half the maximum static load level times the amount of deflection. Allowance should also be made in cases where other vessels may be moored at the pier. If the structure is exceptionally rigid, it can be assumed to absorb no energy.

(3) Subtract the energy that the pier will absorb from the effective impact energy of the ship to determine the amount of energy that must be absorbed by the fender.

(4) Select a fender design capable of absorbing the amount of energy determined above without exceeding

Table 9-2. Load Deflection and Energy-Absorption Characteristics of Fixed-Unit Type of Pneumatic Tire- Wheel Fender (based on Firestone Burleigh Technical Data Sheet)

Load-Deflection and Energy-Absorption Characteristics of Fixed-Unit Type of Pneumatic Tire-Wheel Fender

(Based on Firestone Burleigh Technical Data Sheet)

Standard wheel size (OD, in.)	Inflation pressure (psi)	Maximum deflection of wheel (in.)	Maximum load per wheel (tons)	Energy-absorption capacity per wheel (in. - tons)
30.6	30	6.0	1.5	4.0
38.4	6	6.4	5.0	14.0
54.0	40	21.2	17.0	156.0
62.0	47	19.0	19.2	168.0
68.9	45	20.0	24.0	216.0
75.8	50	22.0	30.3	276.0
77.9	55	26.5	53.0	671.0
83.9	80	26.5	65.5	803.0
114.0	70	46.0	105.0	2,050.0

Table 9-3. Energy to be Absorbed by Fenders

Vessel	Length (ft)	Beam (ft)	Draft (ft) Light	Draft (ft) Deep	DWT (long tons × 1,000)	Velocity ft/sec Sheltered	Energy ft-kips Sheltered	Velocity ft/sec Moderate	Energy ft-kips Moderate	Velocity ft/sec Exposed	Energy ft-kips Exposed
Assault Ships											
LHA	820	106	–	26	–	0.3	91.7	0.4	163.0	0.6	366.7
LPD 4	570	84	17	22	7	0.3	40.3	0.5	111.96	0.7	219.5
LPA 249	564	76	22	27	6.1	0.3	48.2	0.5	133.86	0.7	262.4
LKA 113	575	82	15.1	25.5	14	0.3	31.0	0.55	104.18	0.8	220.3
LSD 36	555	84	15	19	5.5	0.3	31.1	0.55	110.12	0.7	169.6
LST 1179	518	68	11.5	15	3.5	0.35	25.5	0.6	74.88	0.9	168.5
Roll-on/Roll-off											
Comet	500	78	25	29	6.5	0.3	49.9	0.5	138.73	0.7	271.9
Sealift	540	83	19.5	29	12.1	0.3	57.2	0.5	158.88	0.7	311.2
Admiral Callaghan	694	92	19.5	27	13.5	0.3	60.5	0.5	168.00	0.7	329.3
General Cargo											
C-2	455	63	15	27	9.7	0.3	40.4	0.55	135.80	0.8	287.4
C-3	492	70	16	29	12.7	0.3	52.1	0.5	144.69	0.7	283.6
C-4	564	72	20	33	14	0.3	66.3	0.5	184.16	0.7	361.0
Tankers											
T-2	524	68	14	30	14.5	0.3	64.5	0.5	179.23	0.7	351.3
T-5	656	86	16.5	35	23.6	0.3	99.7	0.45	224.22	0.6	398.6
MSTS	595	84	14.5	32.5	25.5	0.3	86.9	0.45	195.52	0.6	347.6
AOR 2	659	96	21	35	25	0.3	86.6	0.45	194.87	0.6	346.4
Universe Ireland	1,135	175	26	79	326.5	0.2	497.5	0.3	1,119.66	0.4	2,984.7
Barge Transports											
LASH	860	107	28	37	44	0.3	161.5	0.35	219.83	0.5	448.6
Seabee	875	106	17.5	32	27.0	0.3	112.2	0.4	199.48	0.55	374.0
Breakbulk Freighter											
VC-2	455	62	15.5	29	10.6	0.3	46.1	0.5	127.91	0.8	327.4
Mariner	563	76	18	30	12.9	0.3	59.4	0.5	164.94	0.7	323.3
Gulf Banker	495	69	18.5	30	11	0.3	50.3	0.5	139.81	0.7	274.0
Freighter/Container											
Seamaster	572	82	21	30.5	12.8	0.3	62.5	0.5	173.60	0.7	340.3
Santa Lucia	560	81	20	30	12.7	0.3	59.1	0.5	164.23	0.7	321.9
Wolverine Mariner	564	76	21.5	32	12.7	0.3	65.7	0.5	182.61	0.7	357.9
Challenger	560	75	20	31.5	13.5	0.3	60.8	0.5	168.80	0.7	330.8
Container with Crane											
Pacific Trader	544	70	21	32	12.2	0.3	68.1	0.5	190.59	0.7	373.6
American Liberty	700	90	21	32	19	0.3	87.3	0.45	196.45	0.65	409.87
Container Without Crane											
Portland	523	72	22	31	9.7	0.3	58.6	0.5	162.64	0.7	318.8
Oakland	685	78	19	30	17	0.3	89.9	0.45	200.0	0.65	414.8
Jacksonville	524	68	19.5	31	11.6	0.3	68.5	0.5	190.34	0.7	373.1

[a] by U. S. Army Engineer
Waterways Experiment Station

the maximum allowable force in the pier. The comparative merits of different construction materials in energy-absorption capacity at allowable working stress due to transient loading is shown in table 9-4.

b. Pile fenders. Spacing, corner clustering, and embedment of pile fenders under various conditions are indicated below.

(1) Spacing. Where consistent with the requirements for strength, pile spacing should be as follows: for light service, 12 feet maximum (10 feet preferred); for cruisers and auxiliaries, 7 to 9 feet, with 8 feet predominating; for heavy service, 5 to 7 feet, usually at one-half the bent spacing. Pile spacing less than 5 feet is undesirable.

(2) Corner clusters. Outboard and exposed corners of piers may be protected by clusters of fender piles. For small vessels, including destroyers up to 3,000 tons, groups of seven to nine piles are arranged in two nesting rows at an exposed corner; for piers accommodating vessels larger than those indicated above, decks at exposed corners should be built in a circular arc with a 4to 12-foot radius. Space fender piles closely in two staggered rows, except in cases of larger ships, for which three rows or even four rows may be provided if the location is severely exposed. The number of piles in these groups may vary from nine to thirty piles. If springs or rubber buffer blocks are used, fender piles are placed in two nesting rows and are bolted to segmental wales that bear against the energy-absorbing units. If tubular rubber absorbers are provided, fender piles are arranged in two separate rows connected by wire rope windings. The number of piles in a group will vary from 20 to 40. Chains or cables should be provided to restrain longitudinal and lateral movement of the entire group. For retractable systems, the corner cluster may be eliminated and a special corner section of retractable rendering substituted. Corner clusters should be tightly blocked and securely wrapped with galvanized wire rope at one or two levels above mlw, depending on the deck height.

(3) *Embedment.* Establish the embedment of fender piles in accordance with bottom firmness and the possibility of future deeper dredging. For firm bottoms below the final dredged depth, a penetration of 10 feet is sufficient. An appropriate increase may be made if deeper dredging is likely in the future. If a shallow layer of soft material less than 10 feet in thickness overlies a firm bottom, fender piles should penetrate the firm strata at least 8 feet and have a minimum indicated bearing of 5 tons by the driving formula. For deep deposits of soft material, fender piles should extend at least to the penetration reached under the weight of the driving hammer and preferably to a bearing capacity of 2 to 3 tons by the driving formula. Experience has indicated that the bearing capacity increases sufficiently after completion of driving to provide the necessary resistance for fender piles.

(4) *Batter and chocking*. Fender piles should not be battered outboard more than 2 inches in 12 inches. Fender piles should be dapped and tightly chocked.

c. Hung fenders. Where consistent with requirement for strength spacing should be about 2 feet less than the values indicated for pile fenders with a minimum of 5 feet. Hung fenders will be tightly chocked. Check to make certain that the cantilever bolts are strong enough to support the suspended weight.

d. Resilient fenders. For springs or rubber buffers, where consistent with requirements for strength, spacing of vertical fenders may be increased to the upper limits of the spacings previously listed for the various classes of ships. For Raykin and dashpot types, spacing should conform to the load and energy-absorption requirements. For resilient fenders, metal or wood rubbing surfaces (or wales) are required, except for rubber bumpers, transversely loaded. Draped rubber bumpers should be provided with drain holes at the low point of the draped section. Eyebolts to hold the chains for rubber bumpers should be recessed into the pier structure.

e. Suspended fenders. Suspended fenders are widely spaced in multiples of the bent spacing and in accordance with the requirements for load and energy absorption. These fenders may be fitted with timber or metal rubbing surfaces. Furthermore, fenders must not swing in reacting to waves. Some motion is unavoidable; therefore, guides should be installed to prevent chattering. Consider any buoyancy acting on the suspended weight. Where possible, the weight will be concentrated above mean high water. Fenders must either resist longitudinal forces or be detailed to roll away from the longitudinal rubbing motion of ships. When possible, the weight of the fender should be formed from removable ballast. A full retraction fender rise may not cause the supports to project beyond the fender face. Full fender retraction force should not exceed the strength of either the pier or the ship's hull.

Table 9-4. Comparative Merits of Different Construction Materials in Energy-Absorption Capacity

Comparative Merits of Different Construction Materials In Energy-Absorption Capacity a

Material	Modulus of elasticity (1,000 psi)	State bending stress		Internal strain[b] energy capacity (each pile)		No. of piles required[c]	Maximum spacing of fender piles[d] (ft)
		At proportional limit (psi)	At allowable working stress due to transient loading (psi)	At proportional limit (in.-tons)	At allowable working stress due to transient loading (in.-tons)		
Douglas Fir 12" x 12".	1,600	4,580[a]	2,640	31.5	10.5	43	3.6
Southern Yellow Pine 12" x 12".	1,600	4,580[a]	2,640	31.5	10.5	43	3.6
Douglas Fir or Southern Yellow Pine 14" diam.	1,600	4,580	2,640	25.2	8.4	54	2.8
Douglas Fir or Southern Yellow Pine 12" diam.	1,600	4,580	2,640	18.6	6.2	73	2.1
Greenheart 12" x 12".	3,200	12,000[a]	6,900	108.0	36.0	13	12.5
Oak 12" x 12".	1,400	3,940	2,270	26.7	8.9	51	3.0
12WF190	29,000	36,000	20,000	. . . .	28.2	16	10.0
12WF65	29,000	50,000	20,000	. . . .	9.6	47	3.2
Steel cylindrical fender 34.5-inch diam by 0.5-inch thick.	29,000	36,000	20,000	. . . .	18.7		
Steel cylindrical fender 34.5-inch diam by 0.5-inch thick.	29,000	62,000	34,400	. . . .	53.0		
ASTM A-242, A-440 (rolled fender piles), A-441 (welded fender pile) 12" x 12" WF190.	29,000	50,000	27,800	. . . .	54.4		
Reinforced concrete 12" x 12" (3.000 psi. n = 10).	29,000	. . . . .	1,200	. . . .	1.16	387	Not suitable.
Prestressed concrete 14" x 14" (17-7/16" diam).	29,000	. . . . .	1,630	. . . .	2.50	180	Not suitable when impact acted near waterline.

a Assume 12% reduction of basic proportional limit of extreme fiber strew in bending at 5,270 psi, allowing for knots.

B Assume the supported length of pile as 50 feet.

c Number of piles required to absorb 450 in.-tons of designed capacity (transient-load allowable working stress) or to absorb 1,350 in.-tons of maximum capacity (stressed at nearly the safe elastic limit of materials).

d Assume the ship berths broadside with a length of contact of 150 feet, which is the shortest parallel wall side of cargo ship

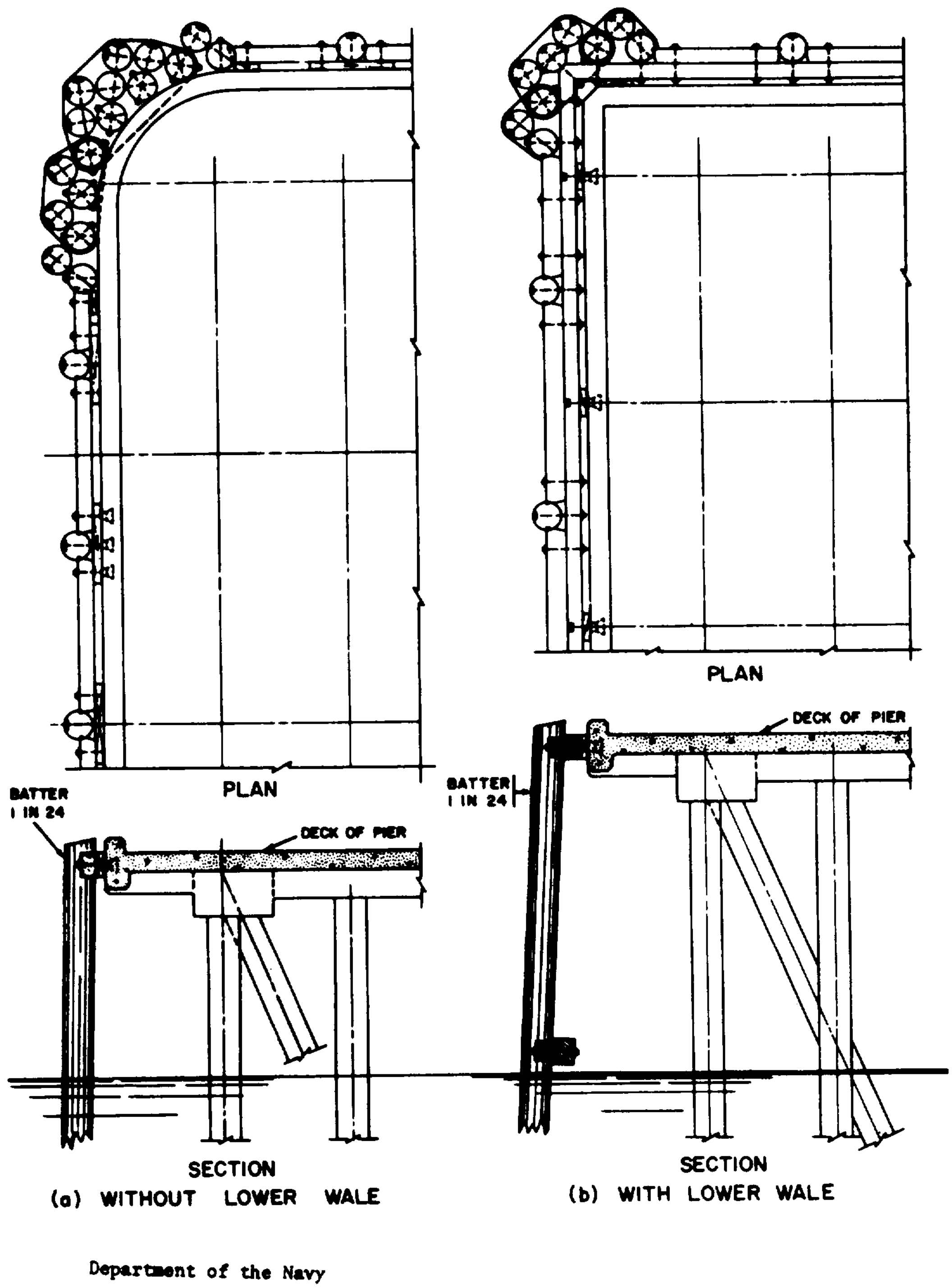
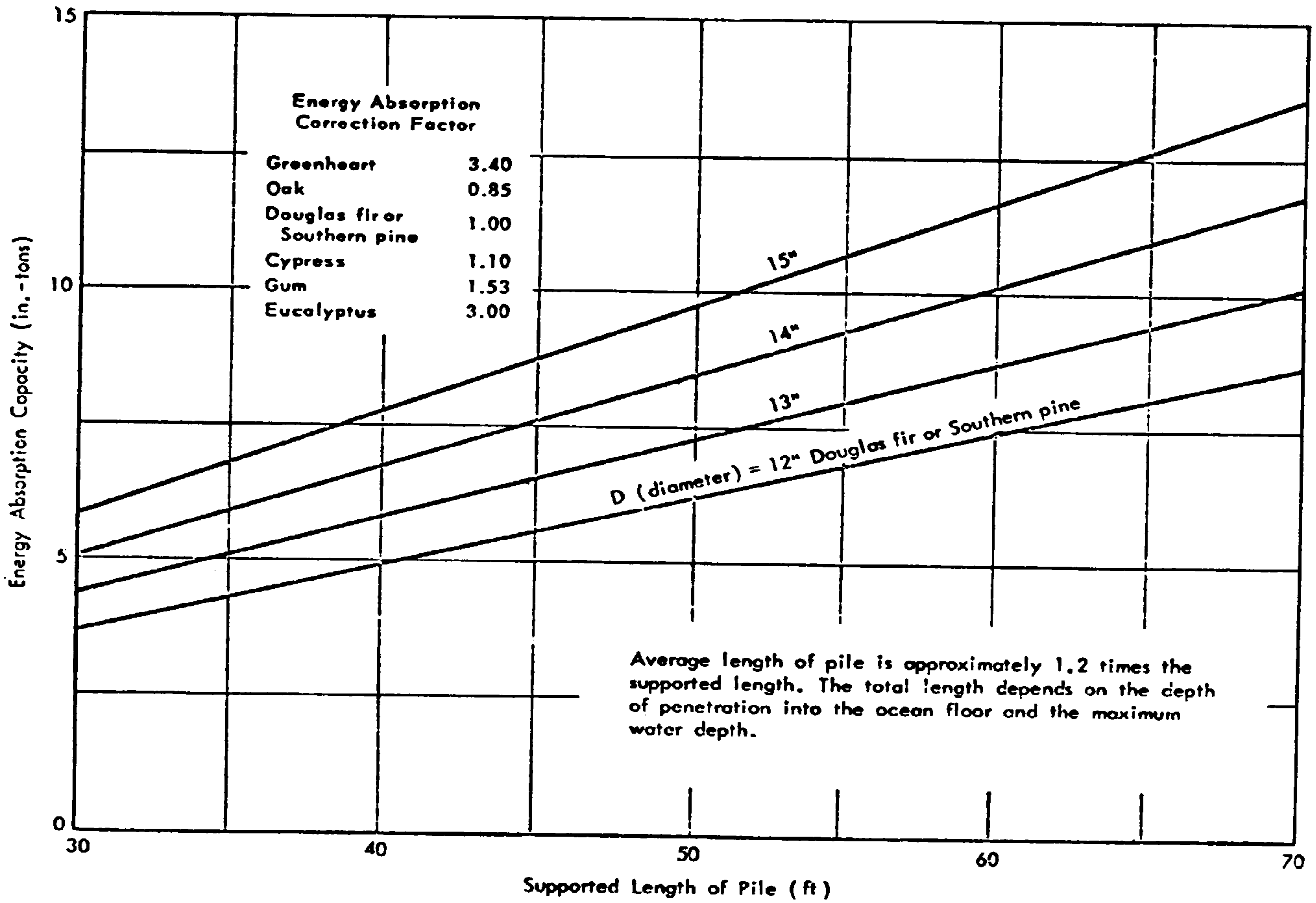


Figure 9-1. Timber pile-fender systems.



Note: The curves are based on Douglas fir or Southern pine.

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Figure 9-2. Energy-absorption characteristics of conventional timber pile fenders.

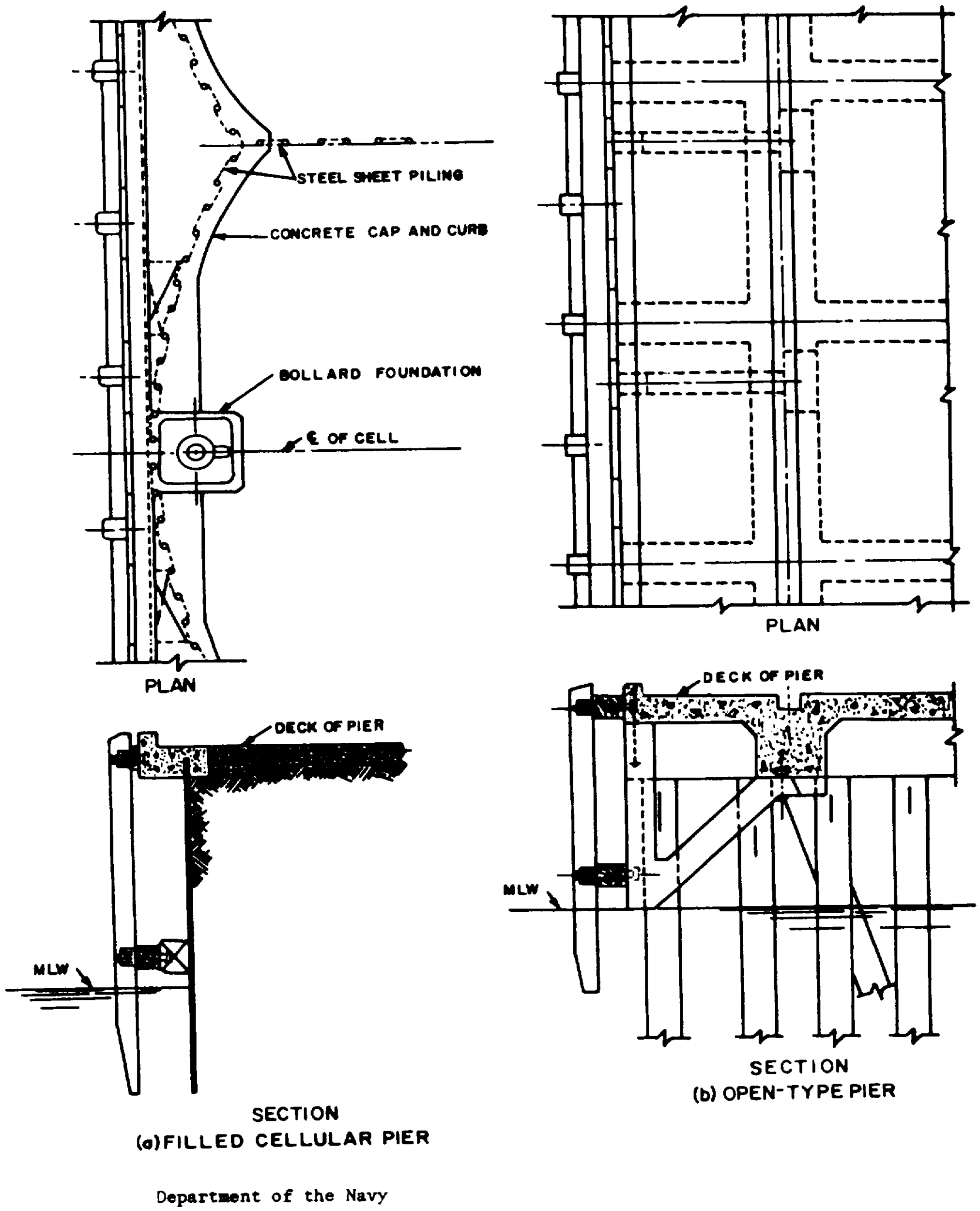
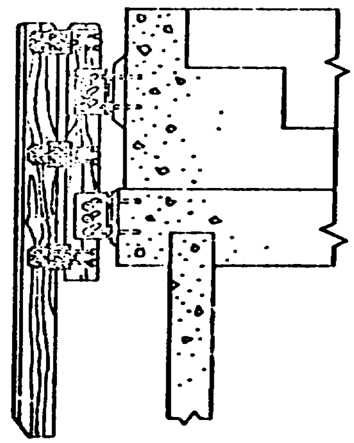
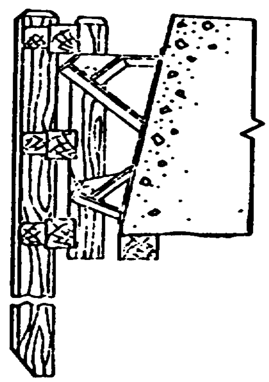


Figure 9-3. Hung timber fender system.



(a) Slotted supporting brackets



(b) Open pin supporting brackets

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Figure 9-4. Typical retractable fender systems.

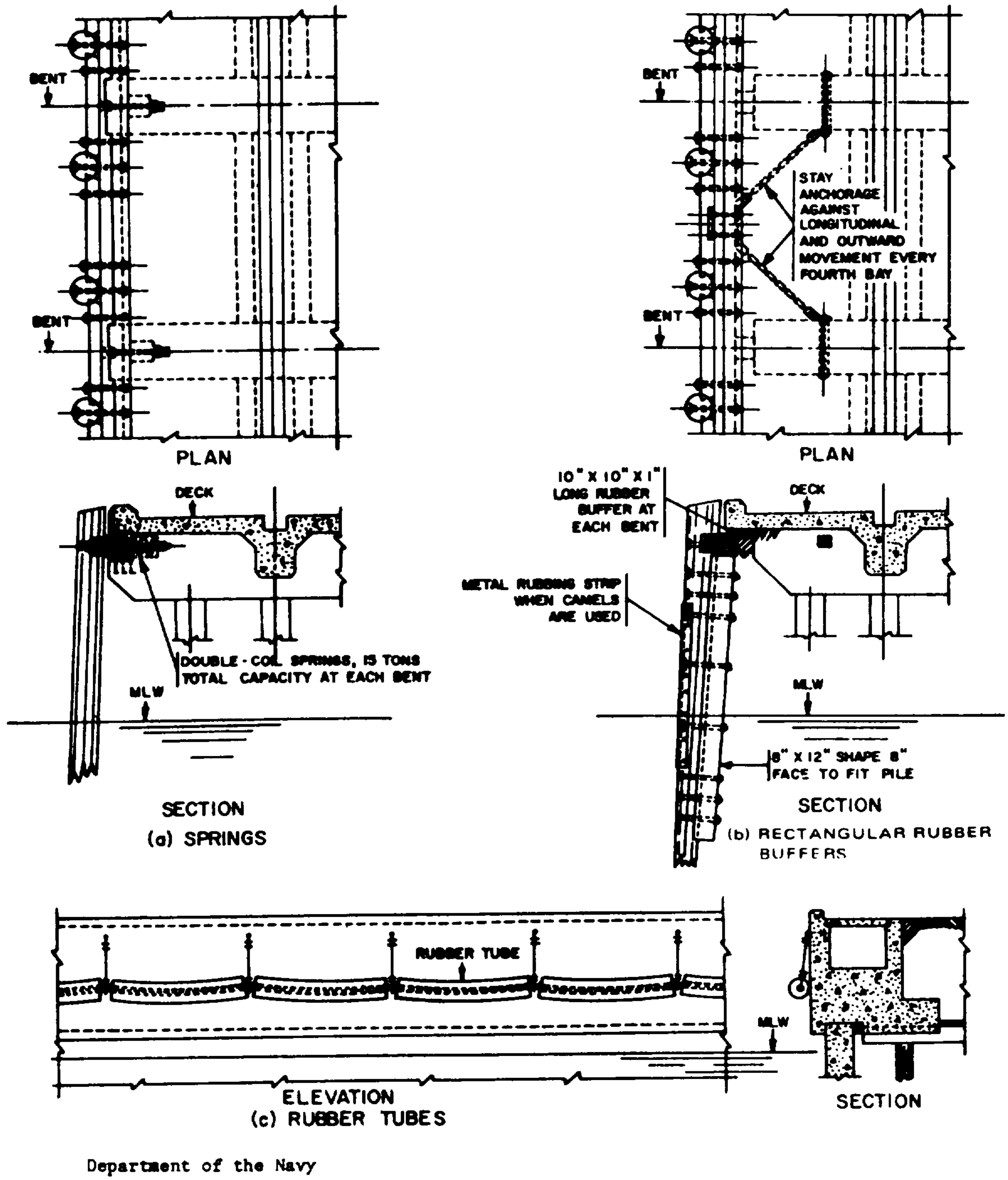

Figure 9-5. Resilient Fender System (spring rubber bumper).

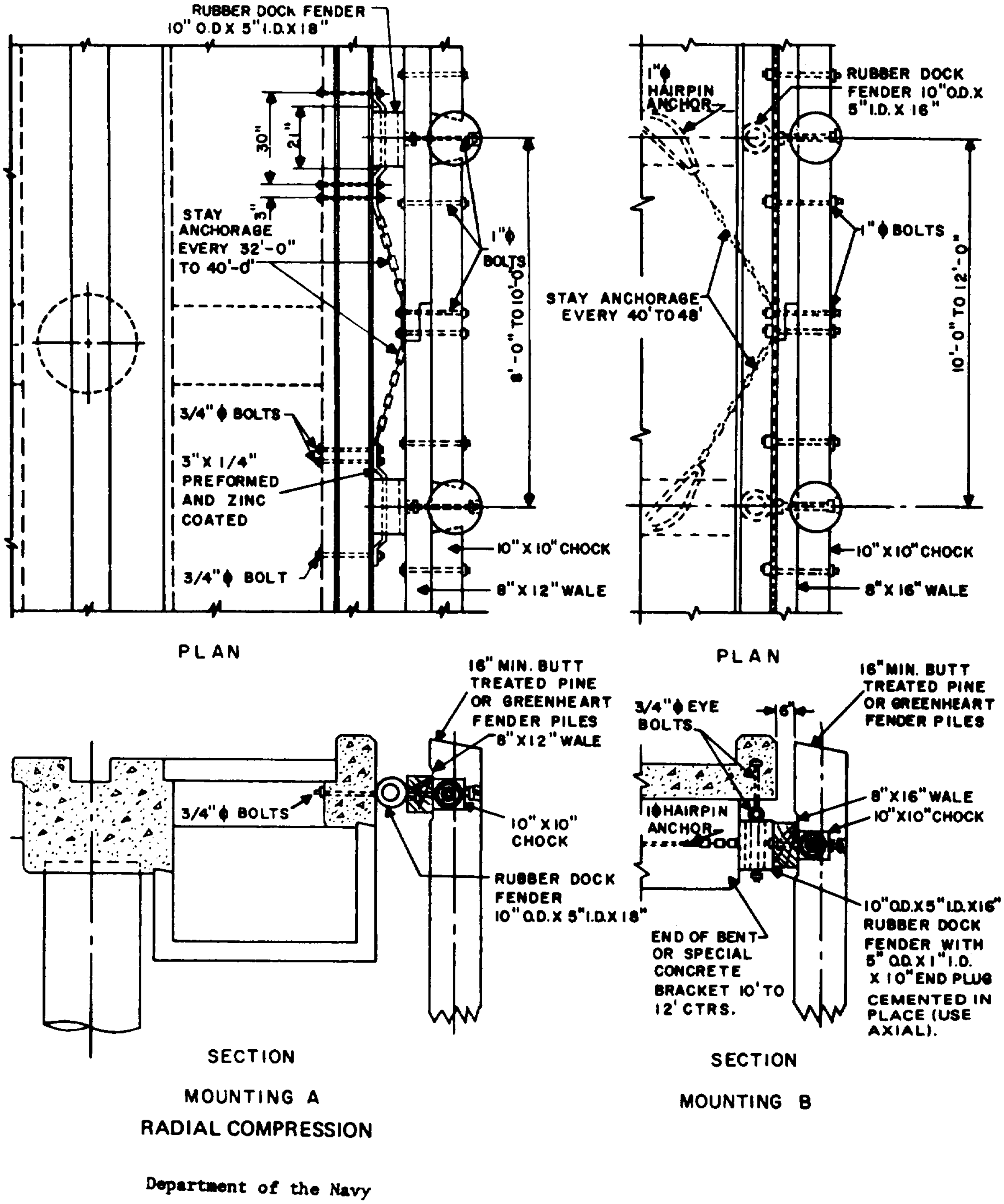

Figure 9-6. Resilient Fender System (rubber-in-compression).

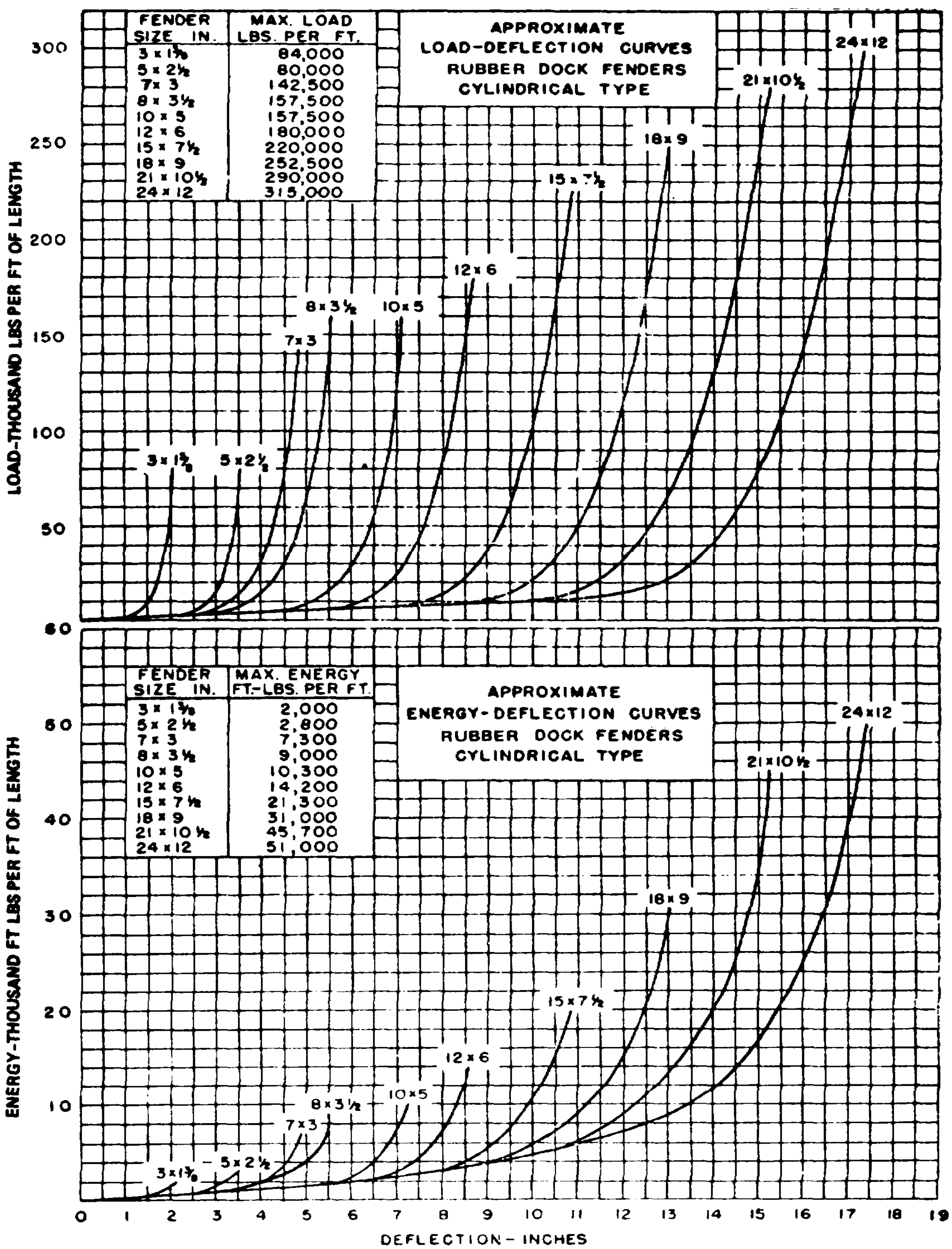

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Figure 9-7. Load-Deflection and Energy-Absorption Characteristics (radially loaded cylindrical rubber dock fenders).

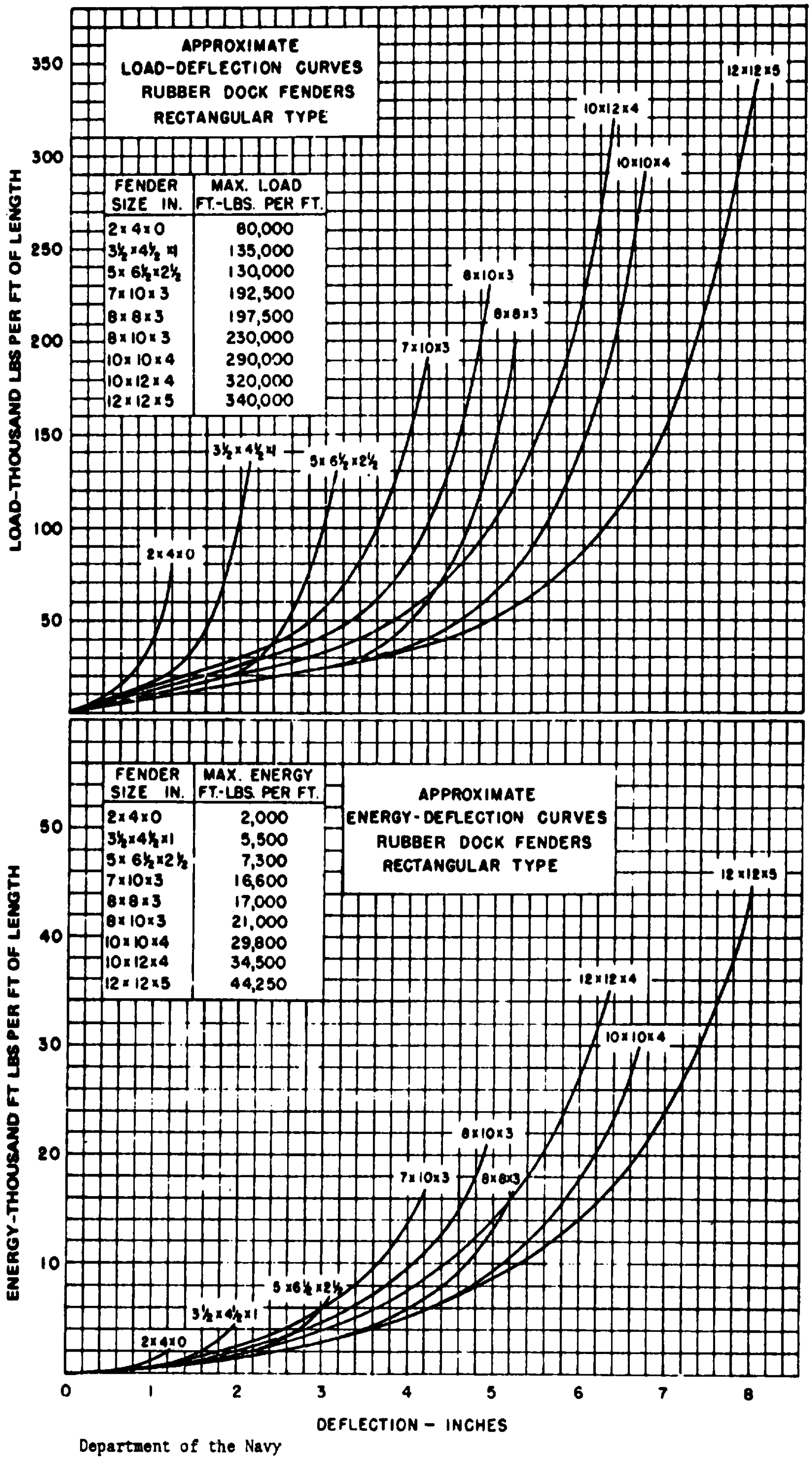

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Figure 9-8. Load-Deflection and Energy-Absorption Characteristics (radially loaded rectangular rubber dock fenders).

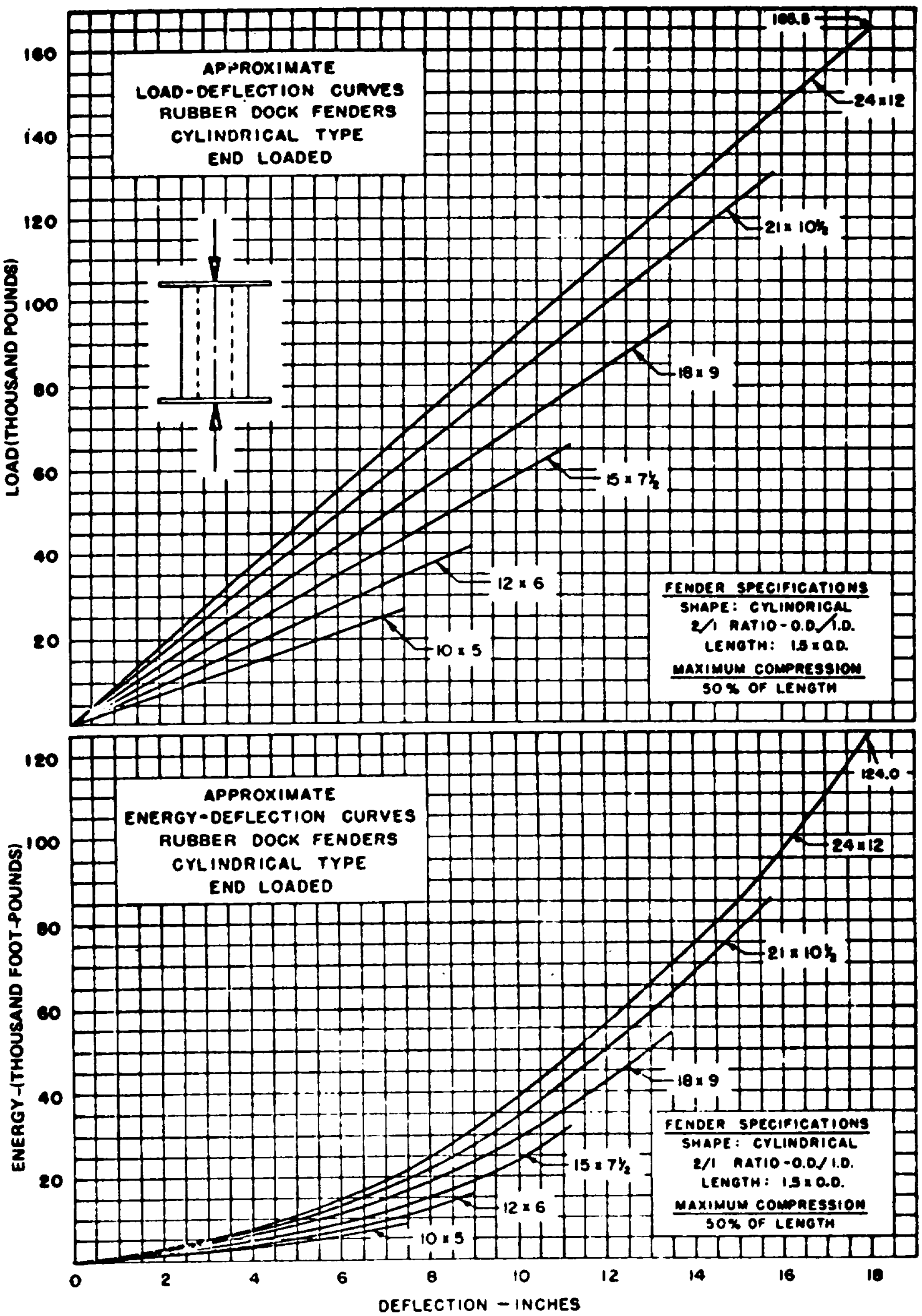

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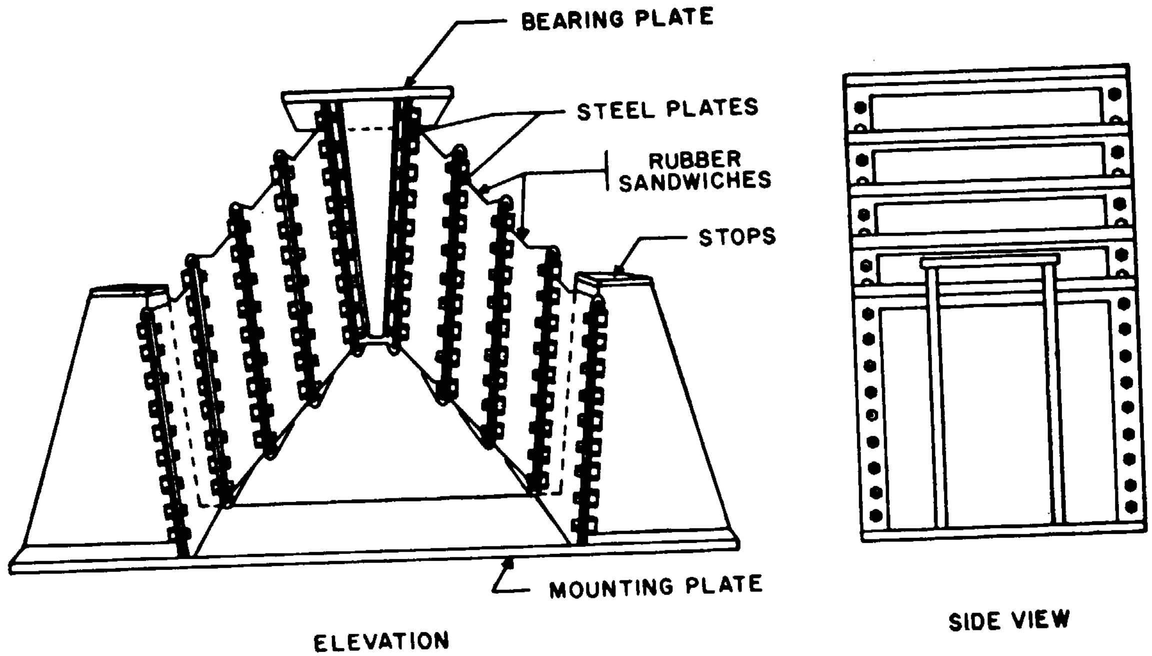
Figure 9-9. Load-Deflection and Energy-Absorption Characteristics (axially loaded cylindrical rubber dock fenders).



NOTE: This patented system is presented for illustration purpose only and does not constitute an endorsement by the Army.

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Figure 9-10. Resilient fender system (rubber in shear) by Raykin

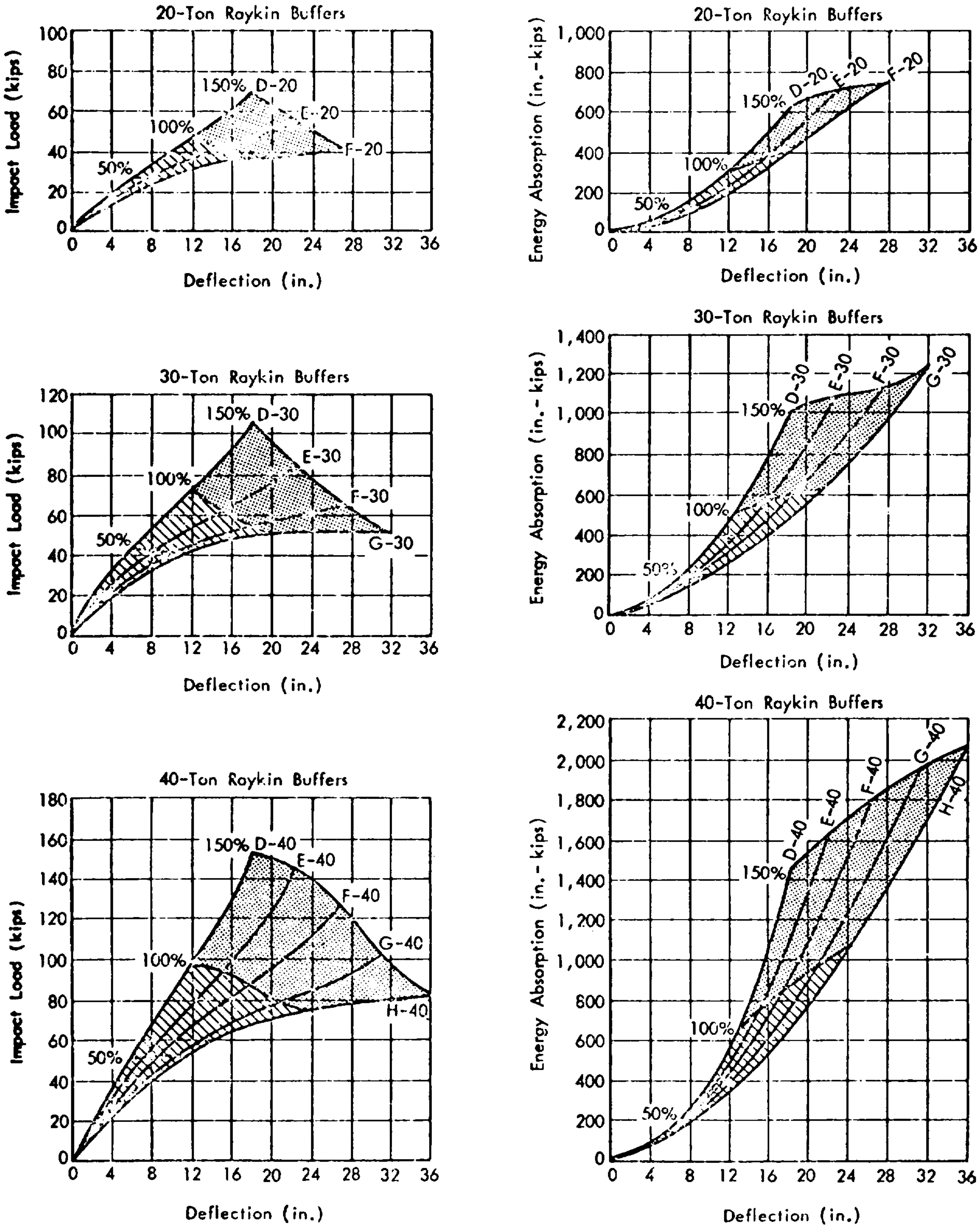

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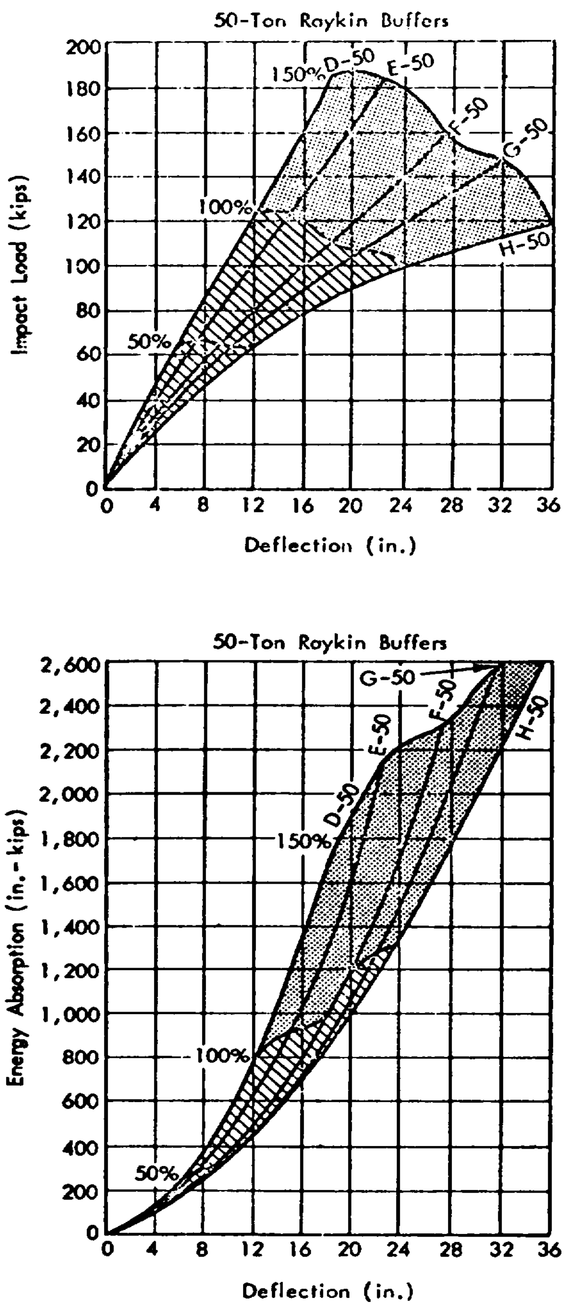
Figure 9-11. Load-deflection and energy-absorption characteristics of commercially available Raykin buffers.



Notes:

- D- 4 rubber blocks on each side
- E - 5 rubber blocks on each side
- F - 6 rubber blocks on each side
- G - 7 rubber blocks on each side
- H - 8 rubber blocks on each side

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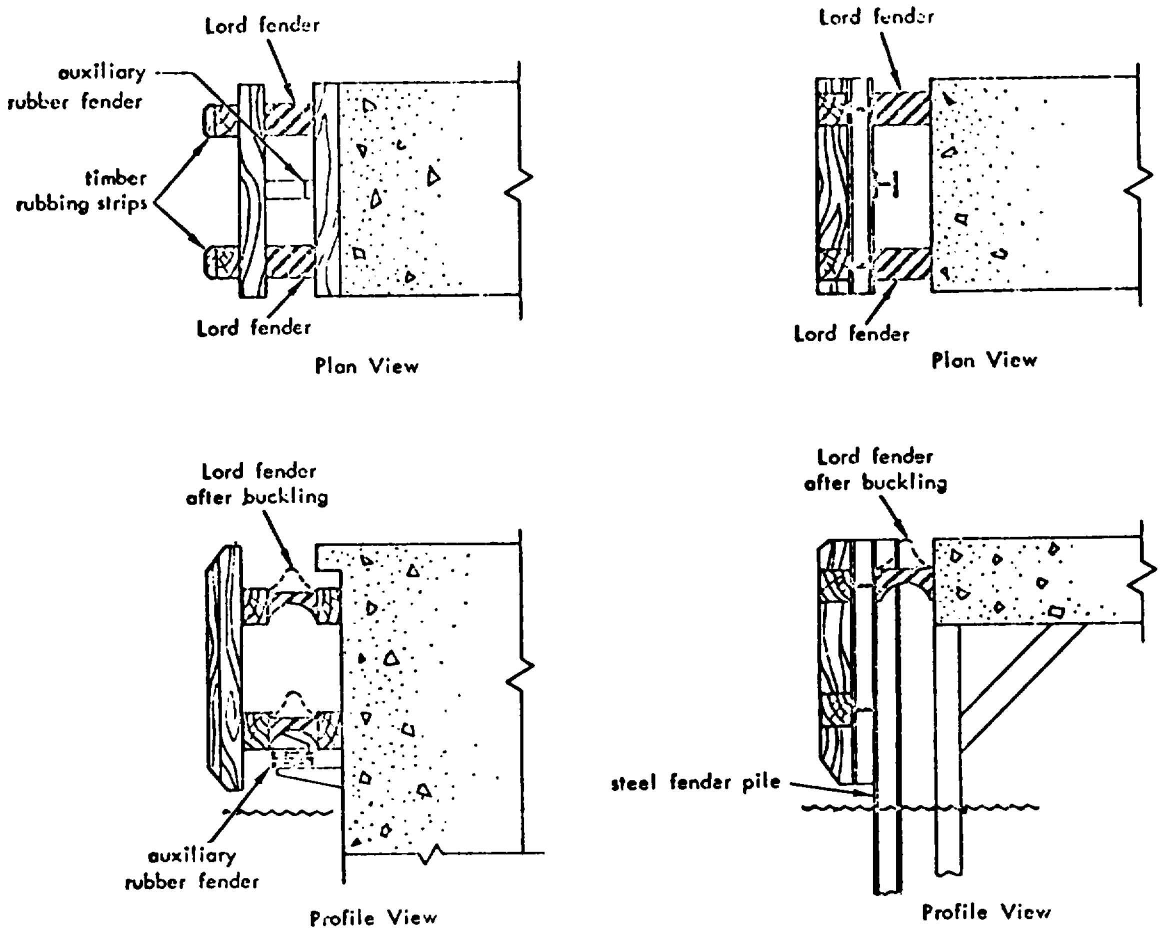
Figure 9-11. Load-deflection and energy-absorption characteristics of commercially available Raykin buffer. (Continued)



(a) Hung-type Lord fender system (b) Fixed-pile Lord fender system

NOTE: This patented system is presented for illustration purpose only and does not constitute an endorsement by the Army.

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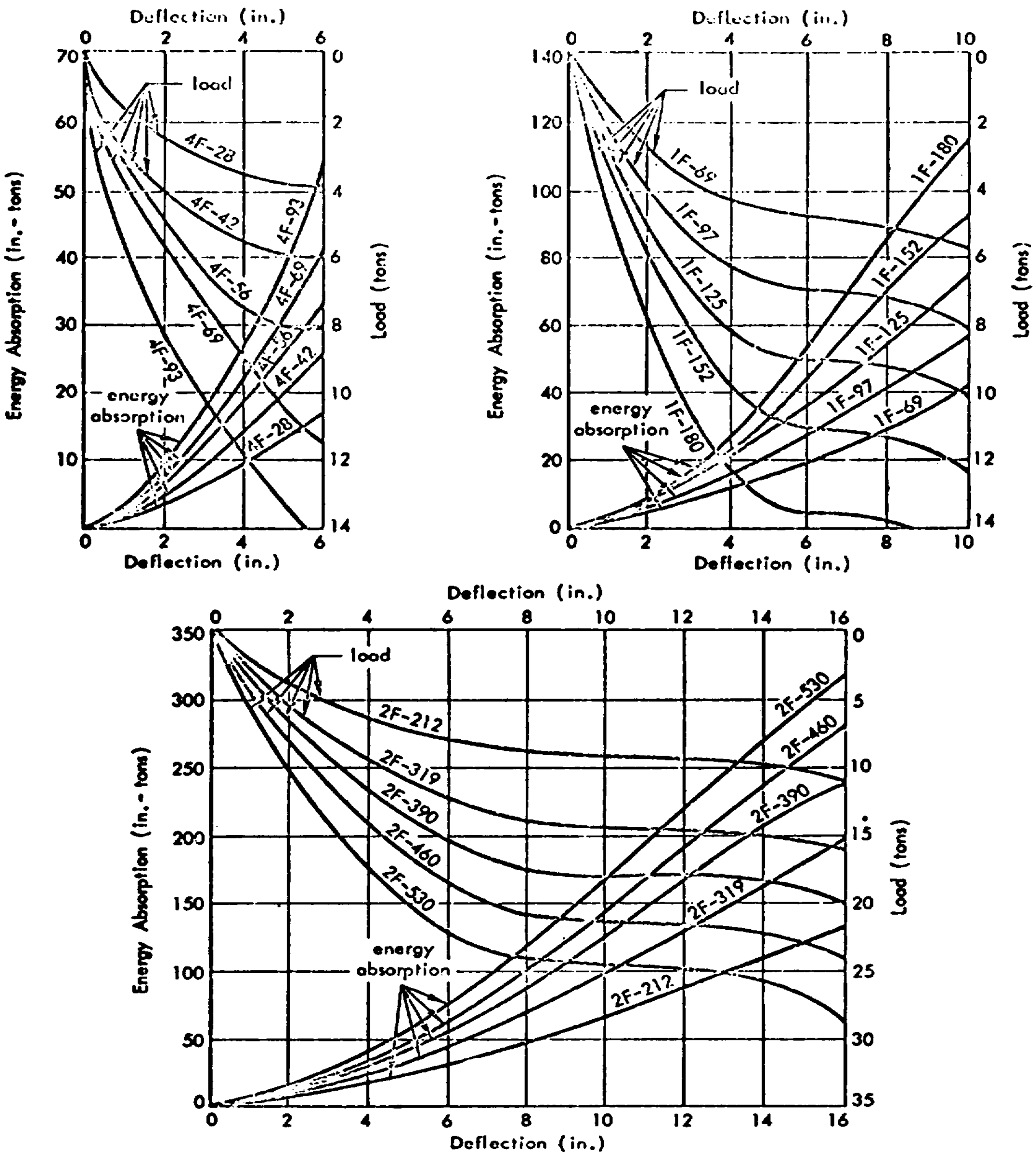
Figure 9-12. Typical Lord flexible fender systems.



Note: **The part number IF-69 is defined as a Lord rubber fender having on energy-absorption capacity of 6,900 foot-pounds at full deflection of 10 inches (for IF series). Full deflection for other series are: 2F series - 16 inches; 4F series - 6 inches.**

NOTE: **This patented system is presented for illustration purpose only and does not D0artment of the Navy constitute an endorsement by the Army.**

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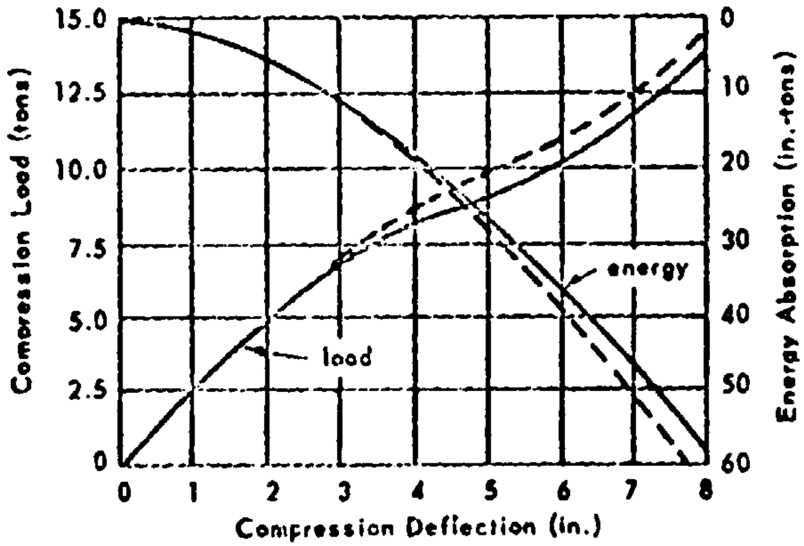
Figure 9-13. Load-deflection and energy-absorption characteristics of Lord flexible fender.



Legend

---------- After one cycle
______ After 1,000 cycles

Load-deflection and energy absorption characteristics

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Figure 9-14. Rubber-in-torsion fender.

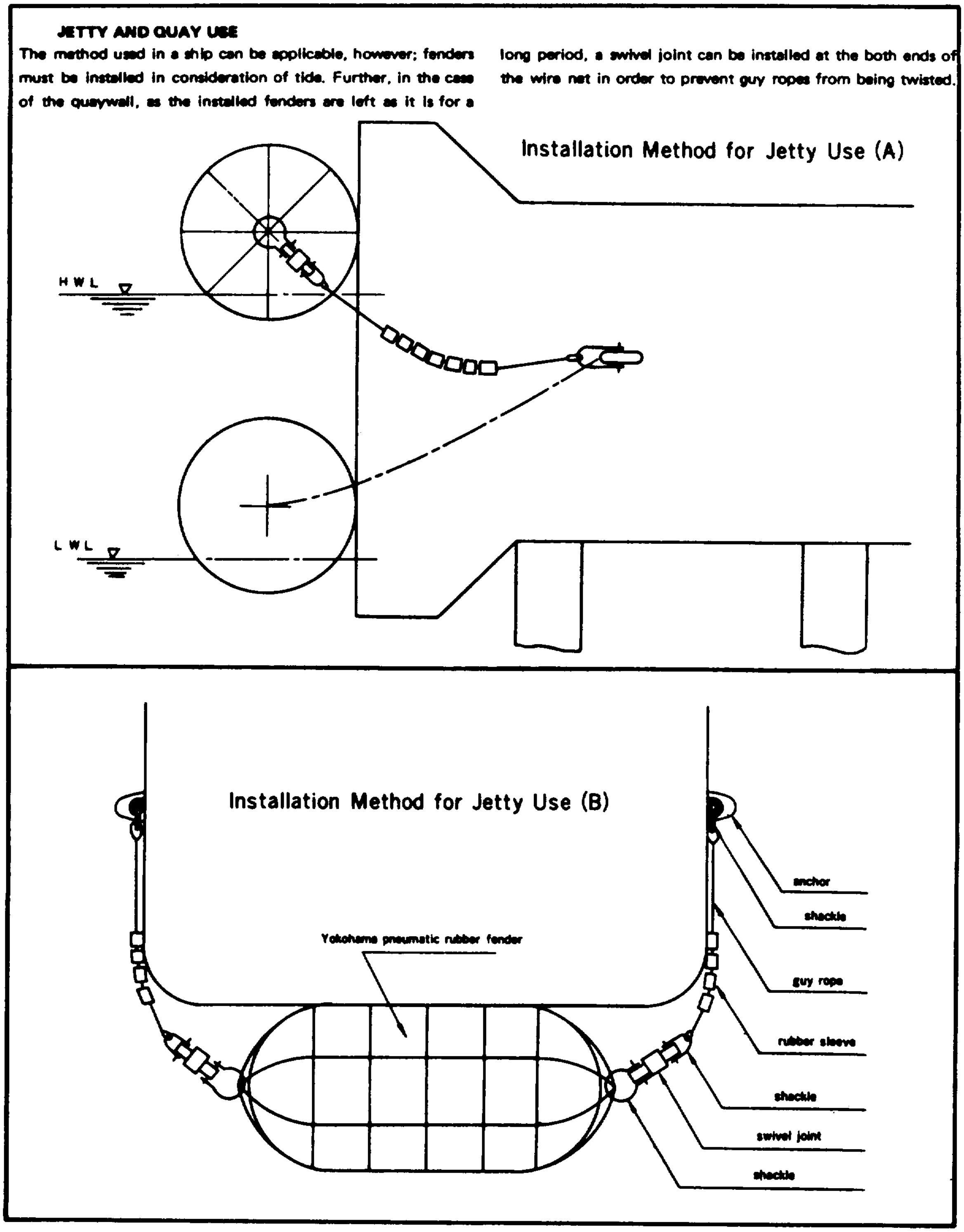

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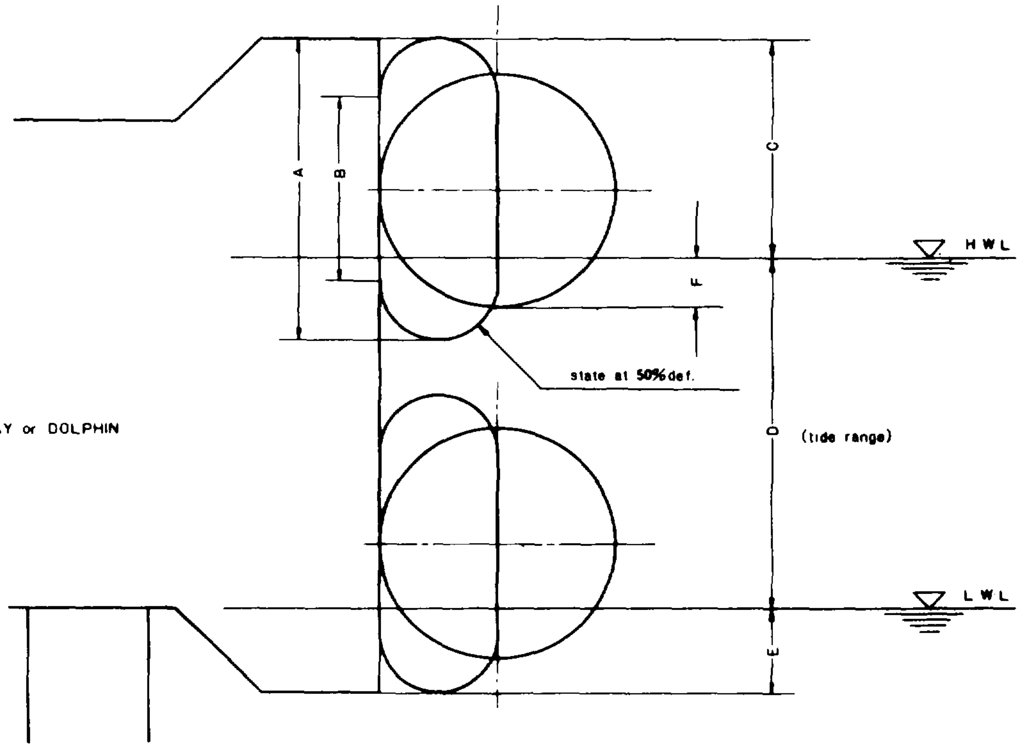
Figure 9-15. Yokohama Pneumatic Rubber Fenders (jetty and quay use).

DIMENSION OF JETTY AT THE TIME OF INSTALLATION.

In order that the pneumatic rubber fender exhibits its performances to the full, it is necessary to be compressed by two planes. In this case, one is the ship's side and the other is the quaywall; however, it is requested to design the quaywall so that the pneumatic rubber fender is in a state of plane contact, as shown below, even when it is being deflected.



[redacted]	A (m/m)	(ft)	B (m/m)	(ft)	C (m/m)	(ft)	E (m/m)	(ft)	F (m/m)	(ft)
	900	3.0	550	1.8	610	2.0	290	1.0	190	0.6
	1,280	4.2	790	2.6	880	2.9	400	1.3	260	0.9
	1,280	4.2	790	2.6	840	2.8	440	1.4	300	1.0
	1,540	5.1	940	3.1	1,030	3.4	510	1.7	340	1.1
	1,730	5.7	1,060	3.5	1,180	3.9	550	1.8	360	1.2
	1,940	6.4	1,180	3.9	1,300	4.3	640	2.1	420	1.4
	2,180	7.2	1,340	4.4	1,480	4.9	700	2.3	460	1.5
	2,580	8.5	1,570	5.2	1,760	5.8	820	2.7	530	1.7
	3,220	10.6	1,970	6.5	2,550	8.4	670	2.2	310	1.0
	4,240	13.9	2,590	8.5	3,340	11.0	900	3.0	430	1.4
	5,780	19.0	3,530	11.5	4,670	15.3	1,110	3.6	470	1.5

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Figure 9-16. Yokohama Pneumatic Rubber Fenders (dimension of jetty at the time of installation).

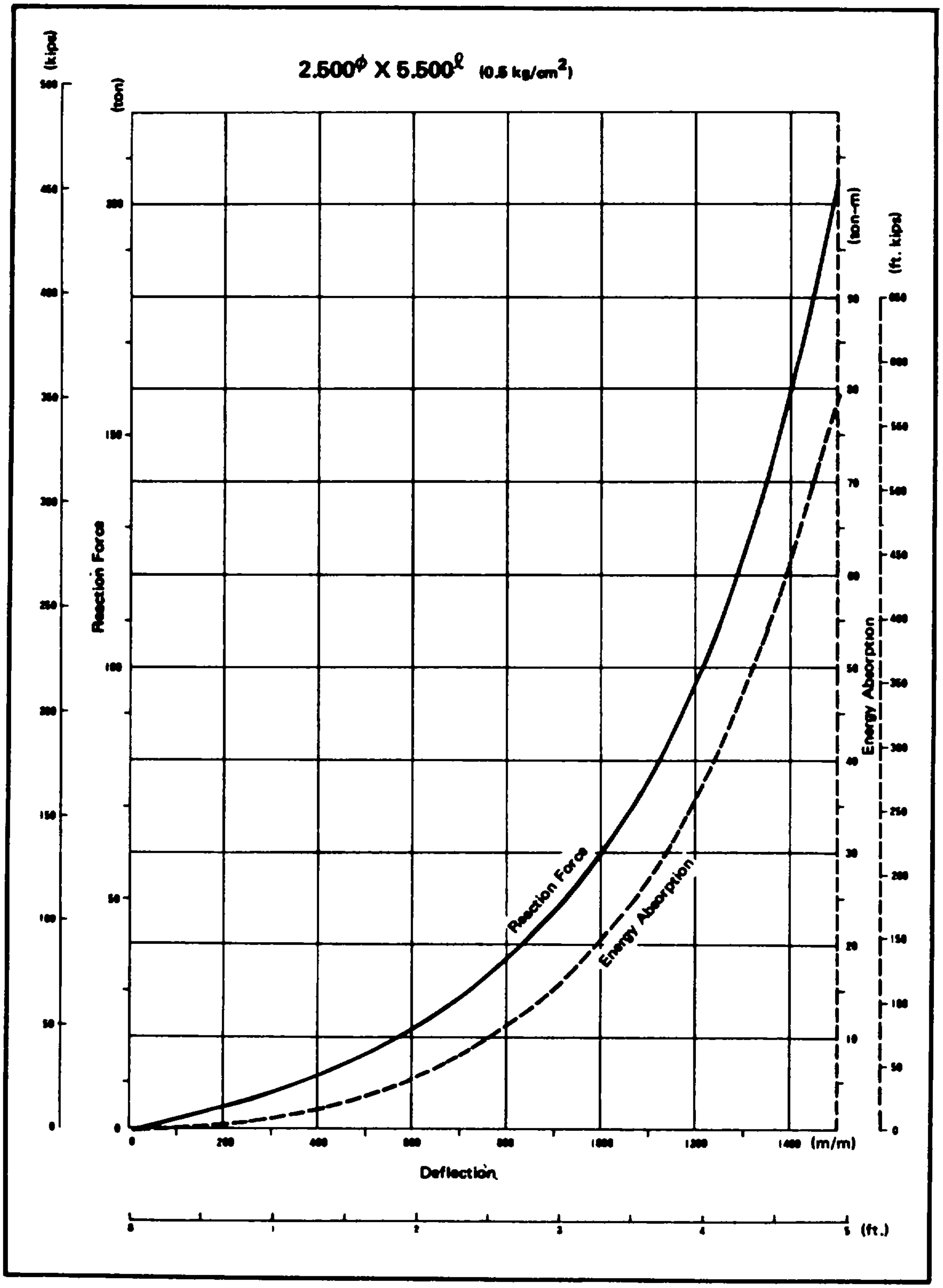

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Figure 9-17. Yokohama Pneumatic Rubber Fender (this size used for berthing 5,000- to 20,000-ton ships)

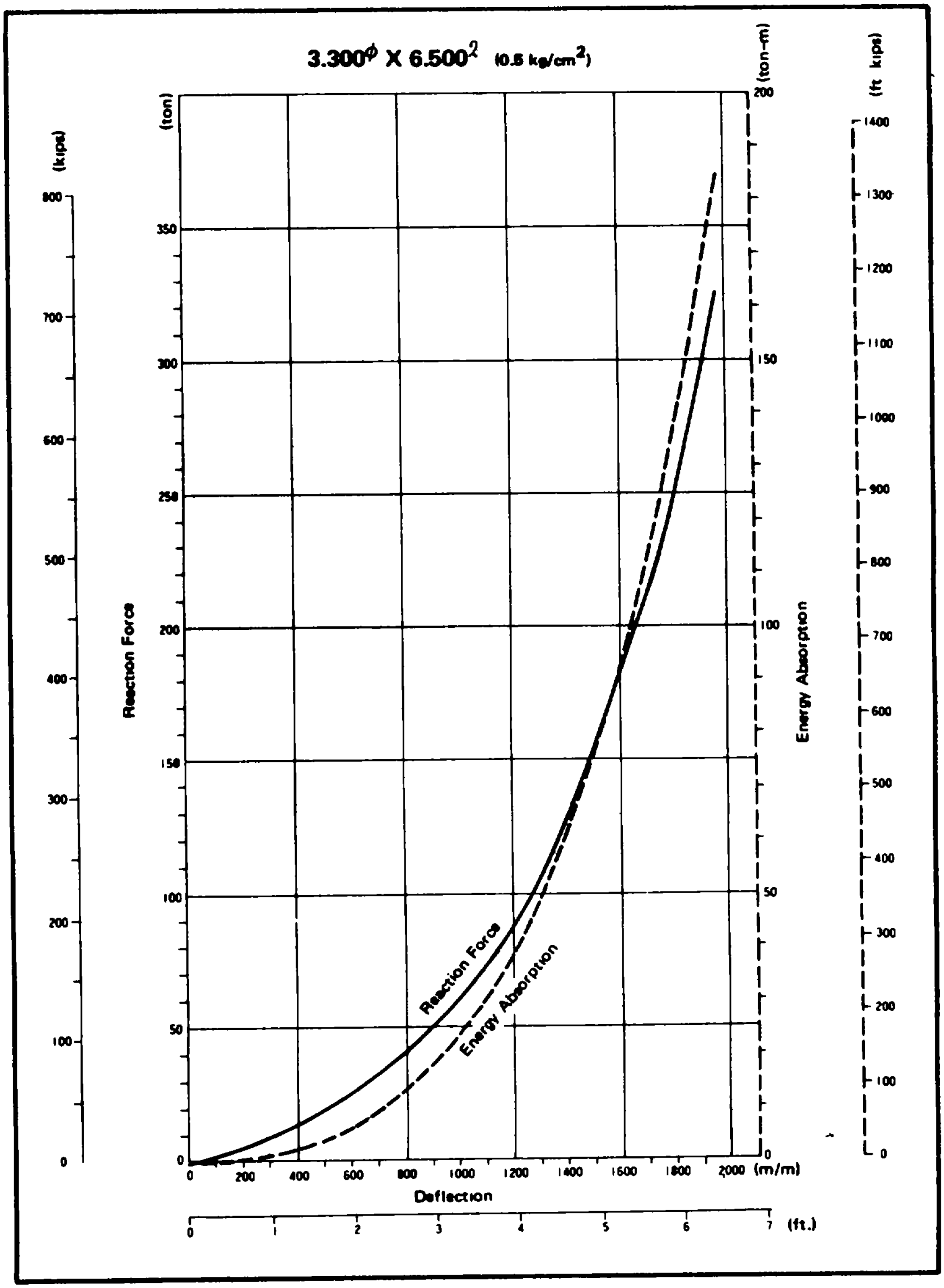

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Figure 9-18. Yokohama Pneumatic Rubber Fenders (this size used for berthing 25,000- to 200,000 ton ship).

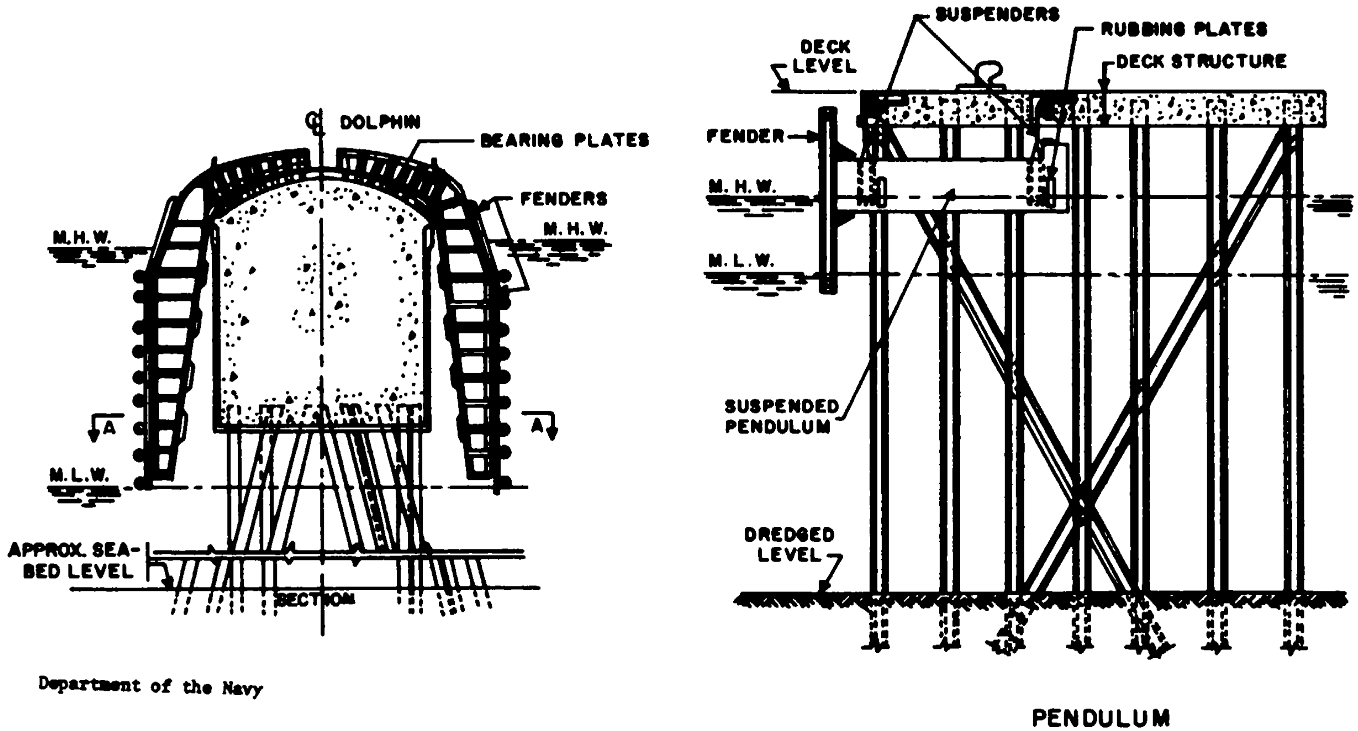

Figure 9-19. Suspended fender.

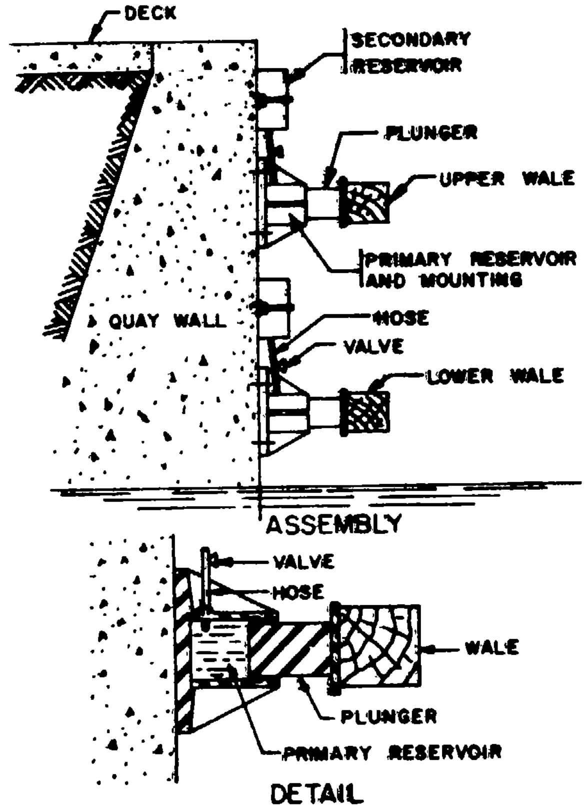

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Figure 9-20. Resilient fender system (dashpot).

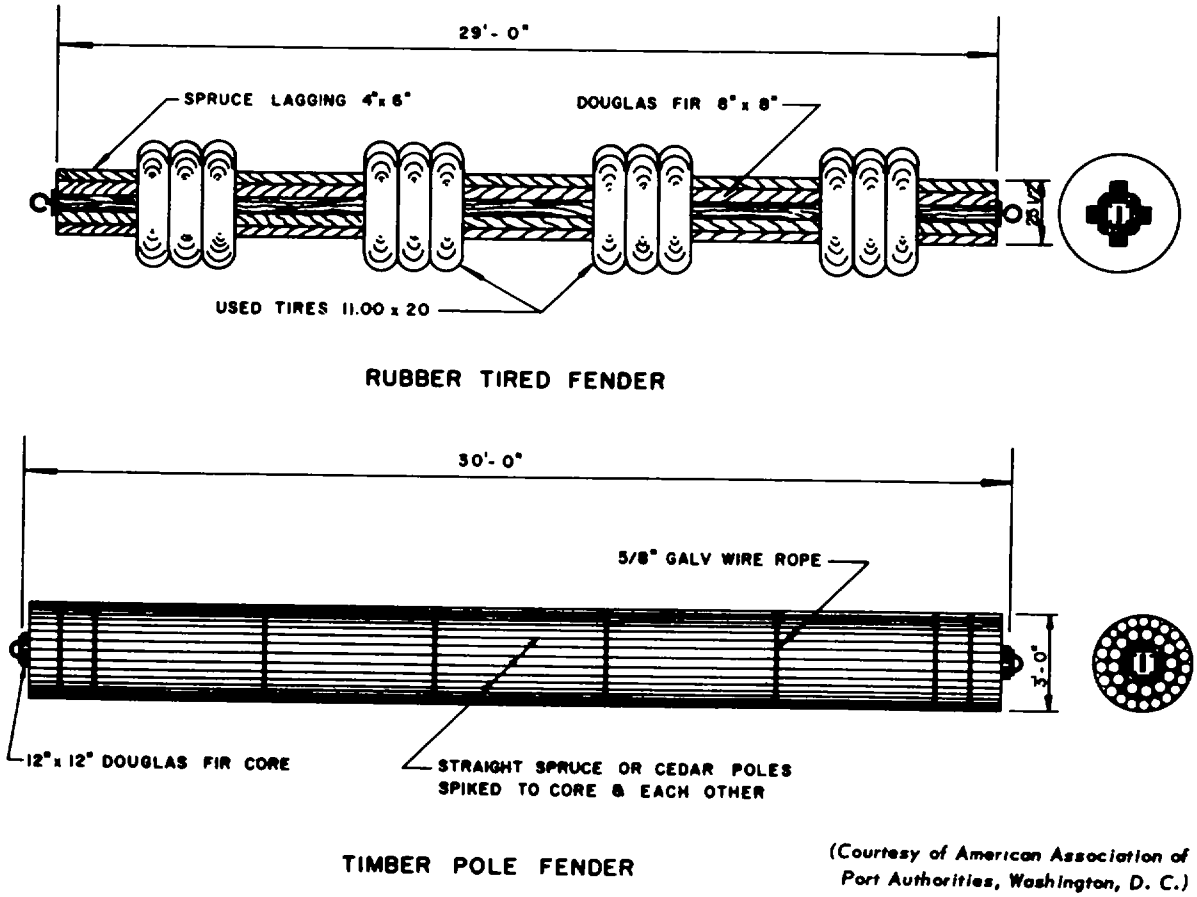

Figure 9-21. Floating camel fenders.