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Revision Memo

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SCOPE

This practice covers fender systems for the berthing of ships and barges at conventional marine pier and sea island facilities. It covers the design of fender systems through the Design Basis Memorandum and Design Specification stage. It does not cover NPQC, Commissioning, or Start-up of the fenders.

REFERENCES

INTERNATIONAL PRACTICE

[IP 4-4-1](#), Marine Piers and Mooring Facilities

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DEFINITIONS

Dead Weight Tonnage - Tonnage expressed by the weight actually loaded on the vessel, such as cargo, fuel, bunker oil, water, passengers and food.

Full Load Displacement - Tonnage expressed by the total weight of the vessel body, engine, cargo (where the cargo is loaded until the draft line reaches the full draft line of the vessel) and all other materials loaded in it.

Light Displacement - Tonnage expressed by the total weight of the vessel before cargo has been loaded.

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INTRODUCTION

Fender systems at a marine pier serve three distinct purposes. The primary function of a fender system is to reduce the loads distributed to the pier and vessel by absorbing some or all of the kinetic energy of berthing vessels. Fendering also distributes berthing and breasting loads along the pier and over a large surface of the ship's hull. Finally, fendering provides a rubbing surface between the pier face and vessel hull, preventing abrasion or other damage from vessel maneuvering or vessel movement due to tides, the environment, or draft changes. Fender systems should be designed to: 1) prevent direct contact between vessels and fixed structures, 2) ensure berthing impact energies are acceptable for berthing structures and fender systems in normal and extreme cases so that risk of vessel and pier damage is minimized, and 3) ensure berthing and mooring loads are within the structural capacity of the individual facilities.

The degree of fendering required depends on many variables, the most important of which are vessel size and approach velocity. The size or mass of a vessel and the speed in which it contacts the pier are directly related to the amount of berthing impact energy that must be absorbed through deflection of the fender system. The selected fender system must be effectively capable of absorbing most of the berthing energy and transmitting as minimal reaction force to the fixed structure as possible. Energy absorption is a function of load and deflection. The larger the deflection, the lower the resulting load to absorb the same amount of energy. Stiff fenders, which are only designed for small deflections, will result in relatively high loads transferred into the structure and ship's hull. Soft fenders, which allow for large deflections will result in relatively low loads. The tradeoff between fender softness and pier strength should be carefully evaluated when designing a new structure, upgrading an existing berth, or assessing alternatives to accommodate decreased structural capacity from damage or deterioration.

GENERAL STEPS IN DESIGNING A FENDER SYSTEM

EXISTING FACILITIES

Many fender system projects involve the design, manufacture and installation of new fender systems on existing marine berths. This type of project often involves the replacement of existing fenders that are severely damaged or no longer adequate for the range of vessels calling at the facility. In some cases, a risk assessment of the facility's operations indicates that new fenders are required to improve the safety of the operations.

Generally, new fender system projects for an existing facility include the following steps through to the Design Specification:

1. Screening Study or DBM
 - a. Develop Alternative Cases for Type, Number, Size and Layout of Fender System.
 - (1) Establish the maximum and minimum vessel sizes to be considered.
 - (2) Determine the load capacity of the berth structure.
 - (3) Consider the layout of the dock facility (i.e., fender spacing, pier orientation and support structure, and tidal elevation changes).
 - (4) Calculate the berthing impact energy.
 - (5) Select a fender system and evaluate the reaction loads (based on catalog information on the selected fender system).
 - b. Determine Requirements for Ancillary Equipment.
 - (1) Size and select materials for construction of the frontal panel.
 - (2) Calculate the shear and tension capacity of the fender system.
 - (3) Determine the requirements for weight chains.
 - c. Gather Budgetary Quotes for Various Alternative Cases.
 - d. Select Best Case and Confirm with Affiliate or Local Project Team.
 - (1) Estimate the investment required for the fender system.
 - (2) Calculate the expected maintenance costs.
 - (3) Develop a schedule for the installation of the fender system, and estimate the length of time the berth will be out of service.
 - (4) Note any safety considerations.
2. Design Specification and Recommended Vendors List
 - a. Develop a Design Specification based on the International Practice - *Fender Systems* (Future).
 - b. Provide a list of vendors based on consultations with ER&E Marine Terminal Engineering Section.



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GENERAL STEPS IN DESIGNING A FENDER SYSTEM (Cont)

NEW FACILITIES

New (grassroots) facilities generally follow the same steps as existing facilities except the design of the fender system is part of the overall design of the berth. In a new facility, the fender system and berth structure shall be optimized based on costs, load capacities, and possible future expansion.

CALCULATION OF BERTHING IMPACT ENERGY

The impact energy of a berthing vessel is used in the design or evaluation of the pier or dolphin structure and its fender system. This section presents guidelines for determining the value of parameters used to calculate the design berthing impact energy. The values presented herein are based mainly on the conclusions developed in Exxon Engineering Report No. EE.16ER.67. The requirements for existing structures should also incorporate previous berthing experience when determining appropriate velocities for use in energy calculations.

The impact energy of a berthing vessel is calculated by multiplying the total kinetic energy of the vessel by a constant of proportionality, as given by the following equation:

$$E = \frac{c W V^2}{2g} \quad \text{Eq. (1)}$$

- where:**
- E = Impact energy of the berthing vessel, ton-ft (tonne-m)
 - W = Actual arrival displacement of the berthing vessel, ton (tonne)
 - V = Berthing velocity of the vessel perpendicular to the marine terminal berthing line, ft/sec (m/sec)
 - c = Constant of proportionality, dimensionless
 - g = Acceleration of gravity, typically 32.2 ft/sec² (9.8 m/s²)

IMPACT ENERGY

The berthing impact energy, E, for any particular portion of a structure is typically controlled by the vessel with the largest displacement upon berthing which will contact that portion. However, there are situations when this is not the case. For example, smaller vessels may berth at higher velocities than larger vessels, and may also contact berthing points closer to their center of gravity. Both of these effects increase the berthing energy to be absorbed. Thus, a full range of vessels that expect to use the berth should be considered.

ARRIVAL DISPLACEMENT

The actual arrival displacement, W, of the berthing vessel, which depends on the vessel draft condition (i.e., quantity of cargo onboard), should be used with the above equation. Typically, the displacement governing the design berth impact energy is for a fully loaded draft, even at loading terminals where the vessel arrives in a ballasted condition. This is to allow for the situation when a fully loaded vessel departs the berth and then has to return due to an onboard emergency. In some cases, partially loaded vessels may control the design berthing energy at facilities where the vessel's draft is restricted by the water depth.

BERTHING VELOCITY

The berthing velocity, V, with which a vessel approaches a berth is a significant factor in the calculation of the energy to be absorbed by the fendering system as the energy is proportional to the square of the velocity. The design berthing velocity of a vessel should be based on consideration of the vessel size, load condition, location and layout of berthing facilities, meteorological and sea conditions, the availability and size of tugboats, and on any existing records of berthing velocities. **Table 1** lists design berthing velocities for vessels. These velocities are recommended for facilities where no previous records of berthing velocities exist. Judgement is required for applying these velocities at a specific location, particularly when evaluating the adequacy of an existing fender system where previous experience indicates different berthing velocities would be appropriate.

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CALCULATION OF BERTHING IMPACT ENERGY (Cont)

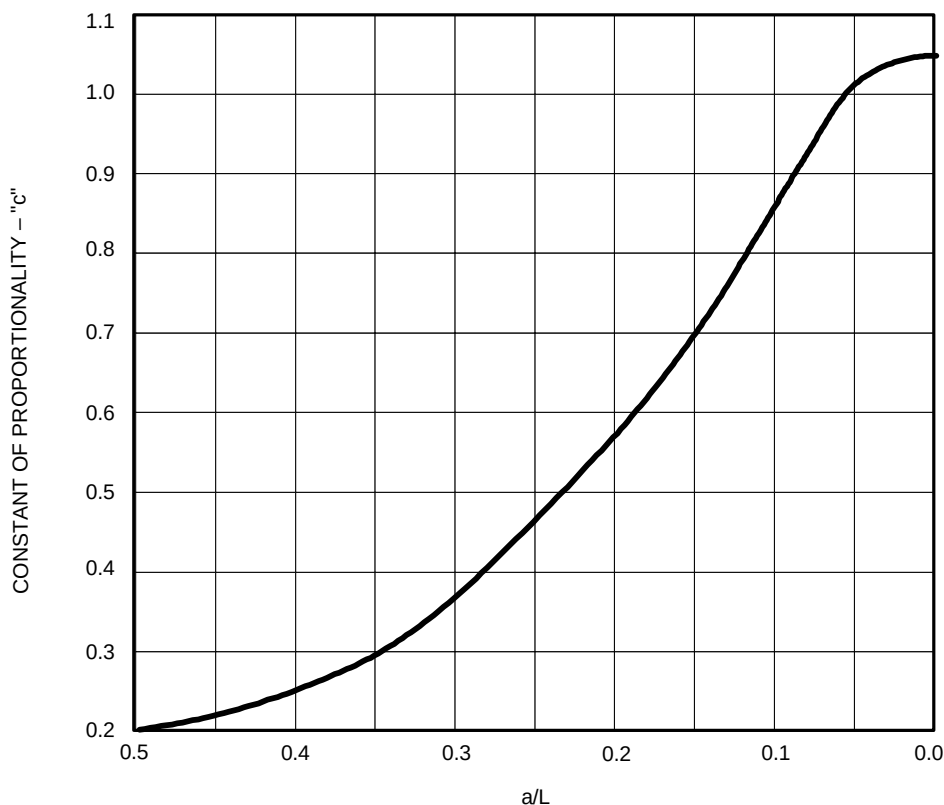
CONSTANT OF PROPORTIONALITY

The constant of proportionality, c , indicates the portion of the normal kinetic energy of the vessel that is to be dissipated by the fender system. It also includes an allowance for energy absorbed by structural deflections of the ship's hull, berthing structure and foundation soils, the damping effect of water between the pier and vessel and the hydrodynamic added mass of the vessel. The added mass can be thought of as the amount of water that moves with the vessel as it approaches the pier. This added mass contributes to the amount of energy the pier must dissipate. The magnitude of " c " will vary according to the following factors:

- Location of the point of contact on the vessel with the fender system (Vessel Offset)
- Depth of water under the keel
- Current direction and speed

The location of the point of contact on the vessel with the fender system affects the amount of vessel rotation after initial impact and thus the portion of the normal kinetic energy that is dissipated by the structure during initial contact and by water resistance during subsequent rotation. The depth of water under the keel (underkeel clearance) and current direction and speed affect the hydrodynamic mass. The value of " c " is directly taken from **Figure 1** when the underkeel clearance is between 4 and 10 ft (1.2 and 3.0 m) and the current is approximately parallel to the pier. For other conditions, adjustments to the constant of proportionality are required as noted in **Figure 1**.

FIGURE 1
CONSTANT OF PROPORTIONALITY



Notes:

- (1) a = Distance of impact point from center of gravity of vessel (assumed to be on transverse centerline).
- (2) L = Vessel length, overall (LOA).
- (3) Increase " c " by 15% if underkeel clearance is less than 4 ft (1.2 m).
- (4) Decrease " c " by 10% if underkeel clearance is 10 to 25 ft (3 to 7.5 m), and decrease by 15% if the clearance is greater than 25 ft (7.5 m).
- (5) Add 0.1 to all values of " c " when the current is pushing the ship towards the pier with an aspect angle between 5 and 10°. Add 0.2 when the angle is greater than 10°.

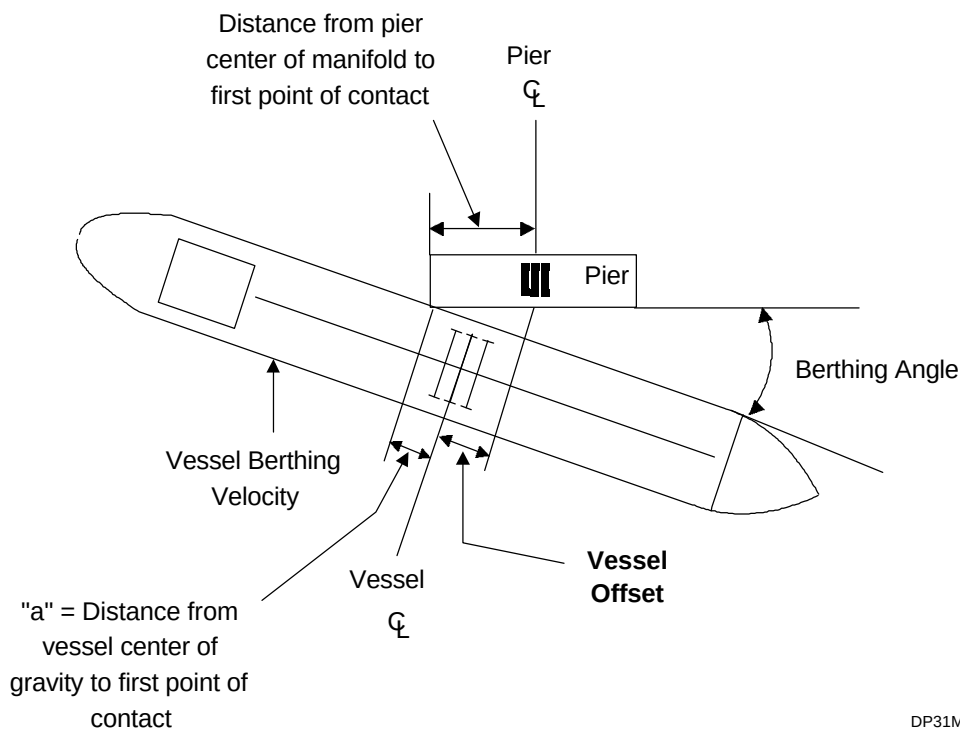


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VESSEL OFFSET

Ideally, the manifold of a berthing vessel would line up with the pier loading equipment which is generally centered on the berth structure. However, experience has shown that the tanker manifold and pier loading point can be offset at initial impact. For marginal piers, an offset distance of 30 - 50 ft (10 - 15 m) is usually used in determining the distance "a" between vessel impact point on the fender system and the vessel's center of gravity as shown in **Figure 2**. This distance generally increases from 30 - 50 ft (10 - 15 m) as vessel size increases. However, local conditions and berthing procedures must be evaluated in determining this value for each individual location.

FIGURE 2
VESSEL OFFSET



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CALCULATION OF BERTHING IMPACT ENERGY (Cont)

TABLE 1
BERTHING VELOCITIES, V⁽¹⁾
BREASTING DOLPHINS AND MARGINAL PIERS⁽²⁾

PROTECTED HARBOR							
BERTHING SITUATION			VESSEL ⁽³⁾				
Vessel Load Condition	Tugs	Pier Parallels Current	Barges, Coasters, Tankers less than 15,000 dwt	Tankers 15,001 dwt through 30,000 dwt	Tankers 30,001 dwt through 50,000 dwt	Tankers 50,001 dwt through 90,000 dwt	Over 90,000 dwt
Full Load	Yes	Yes	0.550	0.450	0.350	0.325	0.300
	No	Yes	0.650	0.550	0.450	0.425	0.400
	Yes	No	0.650	0.550	0.450	0.425	0.400
	No	No	0.700	0.600	0.500	0.475	0.450
Ballasted	Yes	Yes	0.650	0.525	0.425	0.375	0.350
	No	Yes	0.750	0.625	0.525	0.475	0.450
	Yes	No	0.750	0.625	0.525	0.475	0.450
	No	No	0.800	0.675	0.575	0.525	0.500

MODERATELY EXPOSED LOCATION							
BERTHING SITUATION			VESSEL ⁽³⁾				
Vessel Load Condition	Tugs	Pier Parallels Current	Barges, Coasters, Tankers less than 15,000 dwt	Tankers 15,001 dwt through 30,000 dwt	Tankers 30,001 dwt through 50,000 dwt	Tankers 50,001 dwt through 90,000 dwt	Over 90,000 dwt
Full Load	Yes	Yes	0.650	0.550	0.450	0.400	0.375
	No	Yes	0.750	0.650	0.550	0.500	0.475
	Yes	No	0.750	0.650	0.550	0.500	0.475
	No	No	0.800	0.700	0.600	0.550	0.525
Ballasted	Yes	Yes	0.750	0.625	0.525	0.450	0.425
	No	Yes	0.850	0.725	0.625	0.550	0.525
	Yes	No	0.850	0.725	0.625	0.550	0.525
	No	No	0.900	0.775	0.675	0.600	0.550

Notes:

- (1) In units of ft/sec (1 ft/sec = 0.3 m/sec)
- (2) For finger piers reduce the berthing velocity, V, by 20 - 25%. For turning dolphins increase the berthing velocity, V, by 0.050 - 0.100 ft/sec (0.015 - 0.030 m/sec)
- (3) dwt = Dead Weight Tons

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TYPES OF FENDER SYSTEMS

There are many different types and configurations of fender systems available for marine piers. Fender systems can be broadly categorized into three types as listed in **Table 2** and shown in **Figure 3**.

TABLE 2
GENERAL TYPES OF FENDER SYSTEMS

FENDER SYSTEM	DESCRIPTION
Rubbing Strips	Rubbing Strips are timbers or high-density polyethylene material directly attached to a pier face to provide a smooth rubbing surface between the pier and hull of a ship. Rubbing strips absorb almost no energy and therefore must be used on flexible piers that are designed to deflect and absorb the impact energy of berthing vessels. Rubbing strip fender systems are generally limited to small wooden pier or bulkhead type barge facilities.
Flexible Pile Systems	Flexible Pile Systems are steel or timber piles designed to bend in flexure to absorb berthing impact energy. There are many different configurations and a wide range of ship sizes that can be accommodated by flexible pile systems. These systems can range from a single or multiple steel pile breasting dolphin which acts like a cantilever and is entirely independent of any other structure, to a series of angled timber piles attached to the pier which bow in the middle when impacted to absorb energy.
Resilient Buffer Systems	Resilient Buffer Systems are comprised of flexible buffers, such as steel springs, rubber tubes or columns, which are mounted on the face of a platform or dolphin and absorb impact energy by compressing. There are many different configurations and a wide range of ship sizes that can be accommodated by resilient buffer systems. Resilient buffer systems can range from unfaced buffer units which come in direct contact with the ship, to systems which use panels to distribute loads amongst several buffers and over a large area of the ship hull. These panels can either be hung by chains off the pier, supported by the buffers themselves, or supported by piles which can also assist in energy absorption.

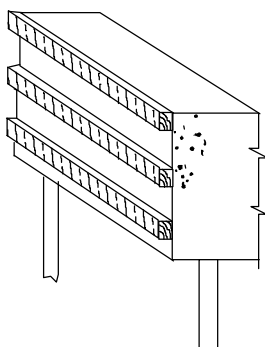
Typically, two or three of these general types of fender systems are combined to work together in order to capitalize on each individual system's advantages. A common example of this is a single steel pile flexible dolphin outfitted with a buckling type rubber buffer and a steel framed panel faced with synthetic rubbing strips.



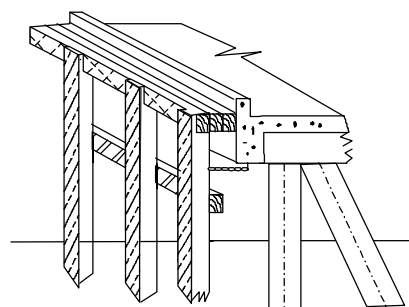
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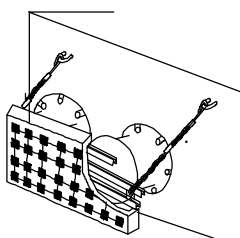
FIGURE 3
TYPES OF COMMON FENDER SYSTEM DESIGNS



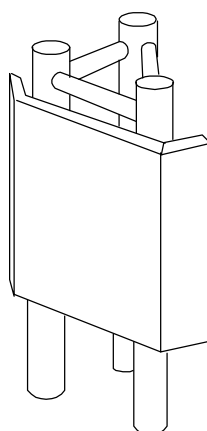
Rubbing
Strip



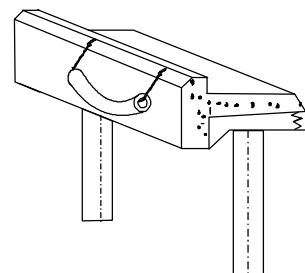
Flexible Pile Fender (Attached
To Breasting Face System)



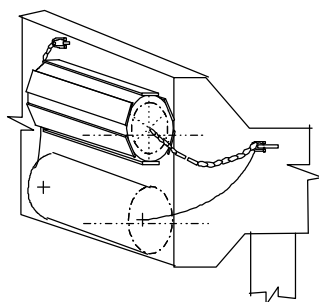
Suspended Panel
Resilient Buffer Fender



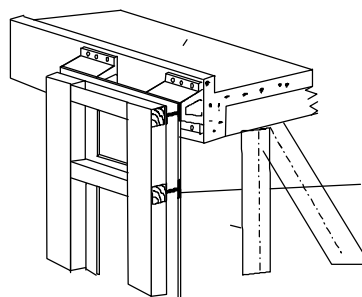
Flexible Dolphin



Unfaced Resilient
Buffer System



Pneumatic or foam filled
Resilient Buffer Fender



Pile Supported Panel
Resilient Buffer Fender

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