TECHNICAL DISCUSSION

Since the purpose of a Dock Fender system is to absorb the energy of a berthing ship, it is necessary to examine the factors that make up the total energy package. These factors are as follows:

1. **Size of vessel in displacement tons.**
2. **Berthing velocity normal to the dock.**
3. **Angle of approach.**
4. **Hydraulic effect.**
5. **Dock design.**

Experience has shown that even though all of the above factors can and do vary, it is necessary to arrive at a reasonable estimation of the energy to be absorbed by the fenders. The amount of energy that can be absorbed by the fenders can be determined with acceptable accuracy; however, the energy being absorbed by the dock and the vessel itself as well as being dissipated by the water can only be approximated. We know, for example, that a dolphin supported by piling will absorb a greater percentage of a given amount of energy than a solidly constructed dock. The fact that the piles are free to deflect allows the dolphin to absorb energy. A wharf that is backed by land is not designed to deflect and therefore a greater amount of the energy must be handled by the fenders themselves.

The kinetic energy possessed by a moving vessel can be determined by the following equation:

$$(1)\ KE = \tfrac{1}{2} \frac{W}{g} V^2$$

Where W = Weight of the vessel in pounds
(Displacement tonnage x 2240 lbs.)

V = Velocity in feet per second normal to the dock.

g = Acceleration due to gravity (32.2 ft/sec^2)

WEIGHT OF VESSEL

It is common to refer to the ship's weight in terms of dead weight tonnage (DWT) or displacement tonnage. Displacement tonnage is the more accurate figure to use in computing kinetic energy because it is the total weight of the ship and its cargo and equipment. If the dead weight tonnage is known, an accurate approximation of the displacement tonnage can be obtained by multiplying the DWT by 1.3

VELOCITY

Since the kinetic energy possessed by a ship is proportional to the square of the velocity, it is important that the velocity be determined with accuracy. The velocity of a ship approaching a dock is affected by a number of factors: the size of the vessel, the skill of the crew members, the wind and current conditions, and whether the ship is making an unassisted berthing or it is being assisted by tugs.

The angle of approach has a direct bearing on determining the kinetic energy, because the velocity used in the equation is that component of the actual velocity that is at right angle to the pier.

Since the velocity of a ship is usually given in terms of knots, it is necessary to convert that figure into feet per second as follows:

Knots x 1.69 = Feet per second.

The normal velocity of a ship is expressed in terms of the actual velocity and the angle of approach. All unassisted vessels will approach a berth at some acute angle, usually 5° to 15°. Large tankers and ore carriers are guided to the docking facility by tugs and their approach angle can be up to 90°. In these cases, the vessel is under control of the tugs and its velocity can be regulated.

The effective velocity of a ship approaching a dock at an angle can be determined by:

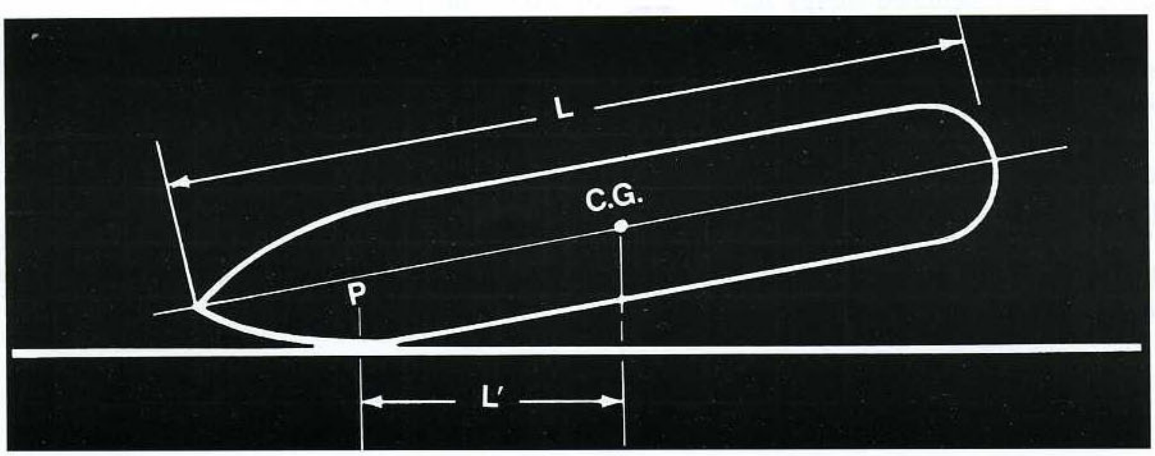
Effective velocity = Actual velocity x the sine of the angle of approach.

Example: A ship approaching a dock at 1½ knots and a 10° angle would have an effective velocity of:

(2) $VE = (1.5)\ (1.69)\ (\sin 10°)$
$= .44$ ft/sec

ANGLE OF APPROACH

The angle in which a ship approaches a dock not only influences the effective velocity, but also affects which part of the ship makes the initial contact with the pier. Generally, the ship will contact the dock at a point near the bow or the stern. In such cases, the reaction force will impart a rotational movement to the ship, dissipating a portion of the ship's energy.



The proportion of the ship's energy dissipated by the rotating ship can be approximated by the following ratio:

$$E_d = \frac{1}{1 + \left(\frac{L'}{r}\right)^2}$$

Where: L' = the distance in feet from the point of contact to the ship's center of gravity measured parallel to the pier.

r = the rotational radius of the vessel from its center of gravity expressed in feet.

Experience has shown that a ship normally contacts the pier at a point 1/4 of its length so that the distance from the point of contact to the ship's center of gravity is also 1/4 L. Therefore, the ratio can be established as:

$$E_d = \frac{1}{1 + 1^2} = \tfrac{1}{2}$$

This ratio is often called the berthing coefficient.

HYDRAULIC EFFECT

In determining the energy to be absorbed by the fenders, it is also necessary to consider the effect of the water. As a ship makes contact with the dock and its movement is suddenly checked, the mass of water moving with the vessel adds to the energy possessed by the ship. Although there are a number of theories relating to the hydraulic effect, they all deal with the length, beam and draft of the ship.

F. Vasco Costa's formula for the "Hydrodynamic Mass" considers a factor of 1 + 2D/B where D = draft and B = beam. The calculated energy should be multiplied by this factor.

Other designers consider the mass of a cylinder of water whose diameter is equal to the draft and whose length equals the length of a ship. The weight of this cylinder is to be added to the ship's displacement when computing the kinetic energy.

These two theories do not result in the same values. Also, the dimensions used for the draft, beam and length will vary because of the different ships and cargo being serviced by the pier. Yet it is desirable to consider the hydraulic effect in the energy computations, and for this reason, it is suggested that an average value be used. By averaging the results obtained by using these two approaches, an approximate factor of .35 can be determined. The amount of energy possessed by the vessel should be increased by 35% to include the hydraulic effect.

Therefore, to compute the total energy to be absorbed by the fenders, including the berthing coefficient and the hydraulic effect, the following formula should be used:

$$(3)\ KE = 1/2\ \frac{WV^2}{g}\ (C_B)\ (H_A)$$

$$= 1/2\ \frac{WV^2}{g}\ (.5)\ (1.35)$$

This equation can be simplified to:

$$(4)\ KE = (23.48)\ (W)\ (V^2)$$

Where W = Displacement tons

V = Velocity normal to the dock.

SAMPLE PROBLEM

Determine the energy to be absorbed for the following conditions:

Displacement tonnage	40,000 tons
Forward velocity	1 Knot
Approach angle	10°

Using Formula 2

$VE = (1)\ (1.69)\ (\text{sine } 10°)$

$= .29$ ft per sec

Using Formula 4

$KE = (23.48)\ (40,000)\ (.29)^2 = 79,000$ ft-lbs

DOCK DESIGN

In order to select the proper size and type of Dock Fender, the design of the dock must be considered. If the dock does not have a separate frontal system, the fenders can be mounted directly onto the dock face. Common methods of attaching fenders to the dock face include:

A. Festooning cylindrical fenders by suspending them with chain.

B. Directly bolting Rectangular, Wingtype, D Shaped, Trapezoidal, or V-Series fenders to the dock face.

The above two methods can be mounted in a horizontal or diagonal pattern depending on the tidal conditions and the type of vessels being serviced by the pier. In areas of relatively high tides, or on piers that will handle barges as well as ships, it is good practice to mount the fenders in a diagonal pattern in order to protect a greater portion of the dock face.

For docks that have a protective frontal system made up of piles and wales, Rectangular, Trapezoidal, or V-Series fenders are generally mounted between the dock face and the wales.

The design strength of the dock also has a bearing on the size and type of fender to be used. Piers and dolphins which are supported by piles often have design limitations as to the reactive load they are capable of withstanding. In these cases, a fender system must be selected that will absorb the computed energy and remain within the design limits of the structure.

Having determined the amount of energy to be absorbed and the type of dock to be protected, the next step is to select the proper size and type of fender to specify. Also, the method of attaching the fender can be determined.

EXAMPLE

Determine the size and type of fenders to be specified for a pile-supported pier having a concrete cap. The vertical face of the concrete cap is 5 feet. The maximum load the dock is designed to withstand is 20,000 pounds per foot. Using the previous example, the energy to be absorbed is 79,000 ft lbs.

Experience has shown that a vessel in the 40,000 ton class would contact a minimum of 20 feet of dock face. Therefore, we can determine the energy to be absorbed per foot of fender will be:

$$\frac{79{,}000 \text{ ft lbs}}{20 \text{ ft}} = 3950 \text{ ft-lbs/ft}$$

Referring to the Energy-Deflection and Load-Deflection curves, the following information can be found:

Cylinder Fender Values

Size	Deflection	Energy	Load
15" x 7-1/2"	7-3/4"	4,000 ft-lbs/ft	37,000 lb/ft
18" x 9"	9"	4,000 ft-lbs/ft	15,000 lb/ft

Rectangular Fender Values

Size	Deflection	Energy	Load
10" x 10"	3-1/2"	4,000 ft-lbs/ft	40,000 lb/ft
12" x 12"	3-3/4"	4,000 ft-lbs/ft	28,000 lb/ft

Trapezoidal Fender Values

Size	Deflection	Energy	Load
10"	4-3/4"	4,000 ft-lbs/ft	28,000 lb/ft
13"	4-1/2"	4,000 ft-lbs/ft	17,000 lb/ft

From a study of these figures, it can be seen that either an 18" x 9" Cylindrical Fender or a 13" Trapezoidal Fender would absorb the energy and remain within the load limitation of the structure.

The most economical and effective means of mounting the Cylindrical fenders would be to suspend them by chain along the dock face. The Trapezoidal fenders would be rigidly mounted by bolting. Either standard Trapezoidal or Wingtype could be used.