Marine fenders – their role in the protection of marine structures and vessels

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MARINE BERTHING STRUCTURES

Berthing structures offer support to vessels that visit a port for the transshipment of cargo or passengers, to be resupplied with water and fuel, to do repair work while floating or to wait for a vacant place at a quay. Berthing structures therefore have three functions:

- Providing a ship with a point of support and eventually the possibility of being tied to the structure.
- Ensuring the connection between the ship and the land.
- Retaining the soils at the edge of the water line in the case of quays.

The function of providing support to the ship is always ensured by the berthing structure, whilst the land provides the possibility of mooring facilities at various mooring points. The connection between the ship and the land is therefore ensured not only by the berthing structure, but also by backfills behind the structure.

The retaining of earth can be provided by the structure itself or by a rock-fill embankment, for example. By definition the structure fulfilling the roles of berthing, mooring, land connection and retaining of soils is designated as a quay, with the dolphins specifically fulfilling the berthing and mooring roles. Obviously a dolphin berthing post requires at least two berthing dolphins and two mooring dolphins.

In certain cases the berthing post does not require any berthing and mooring structures to ensure the transshipment of merchandise, for example when offloading cargo onto barges, or when cargo is offloaded via pipelines (as in the case of liquid cargo). In these cases the ship is moored to buoys or uses anchors dropped onto the sea bottom.

This article deals only with the determination of forces applied to berthing and mooring structures, as well as the physical limitations that affect the design of fenders for marine structures.

The purpose of fenders is to transform the impact from moving vessels into reactions which both the quay structure and the vessel can safely sustain. For vessels the total reaction is less important than the consequent vessel hull pressure.

Where fender reactions are transmitted to quay backfills, the need for fenders capable of absorbing the full energy impact is of less importance than for open piers, jetties and breasting dolphins, where fender reactions are likely to be the decisive horizontal forces in the design of the entire structure.

The need for the development of improved fender types, in particular rubber fenders, was brought about by the closure of the Suez Canal in 1956 and the subsequent construction of the so-called super tankers (in the early 1960s) and container carriers. Prior to this time fenders at many ports consisted of either floating wooden fenders or the roller-tyre fenders which are still in use today.

Super-cell fenders have high energy absorption with low reaction force and excellent multi-directional angular performance; they are also very durable as the internal stresses are dispersed throughout the fender body

Marine fenders are the thickest structural element commonly made from vulcanised rubber

Table 1 Variations in full load displacement (FLD) for tankers

Dead weight tonnage	Loaded displacement tonnage	Length (m)	Width (m)	Depth (m)	Full draught (m)	Additional weight (ton)	Estimated weight (ton)	Berthing energy (ton-m)		
								Berthing speed (at 0.1 m/s)	Berthing speed (at 0.15 m/s)	Berthing speed (at 0.2 m/s)
1 000	1 333	61	8.9	4.5	4.2	866	2 199	0.6	1.4	2.2
5 000	6 667	103	15.1	7.8	6.5	3 501	10 168	2.6	5.9	10.4
10 000	13 333	140	17.2	9.8	7.9	7 030	20 363	5.2	11.7	20.8
20 000	26 667	164	23.7	12.3	9.5	11 909	38 576	9.8	22.1	39.4
40 000	53 333	206	29.7	15.5	11.5	21 920	75 253	19.2	43.2	76.8
60 000	80 000	236	34.0	17.8	12.8	31 111	111 111	28.3	63.7	113.4
80 000	106 640	260	37.3	19.6	13.9	40 419	147 059	37.5	84.4	150.1
100 000	133 333	280	40.1	21.1	14.8	49 347	182 680	46.6	104.9	186.4
150 000	200 000	320	45.8	24.1	16.5	70 097	270 097	68.9	155.0	275.6
200 000	272 000	326	49.8	23.2	17.7	82 178	354 178	90.4	203.4	361.4
250 000	333 333	338	51.8	26.7	20.6	115 410	448 743	114.5	257.6	457.9

The fender system protects not only the berthing marine structure, but also the ship's hull.

THE BERTHING SHIP

A ship approaches a quay with a certain velocity which gives it a kinetic energy. The berthing ship then produces a shock that imposes violent forces on the berthing marine structure. Several factors have a decisive influence in the determination of those violent forces, namely:

- Vessel weight
- Surrounding water
- Berthing speed/velocity
- Limitations from the point of view of berthing conditions
- Limitations from the point of view of the berthing vessel
- Limitations from natural conditions
- Abnormal berthing.

Vessel weight (W_1)

The vessel weight is required to calculate the ship's berthing energy. In order to determine the maximum berthing energy, the maximum weight of the ship must be considered.

The vessel weight, also called Load Displacement and Full Displacement Load, has two components:

- The weight of the vessel itself (Light Weight, LW), which includes the weight of the ship's body, and in the case of steamers includes the water for the boilers, but excludes cargo, bunker oils, fuel, passengers, drinking water and food.
- Weight actually loaded on the ship, including cargo, fuel, bunker oil, drinking water, passengers and food (Dead Weight Tonnage, DWT).

The relationship between Full Load Displacement (FLD), LW and DWT is always:

FLD = LW + DWT

These variables are in metric tons.

The Load Displacement is expressed by the total weight of water displaced by the ship when it is floating, and the Full Displacement Load corresponds to the situation in which the hull water line reaches the full draught line indicated on the ship's hull. Freighters and tankers are generally designated by Dead Weight Tonnage.

Table 2 Variations in full load displacement (FLD) for container carrier

Gross tonnage	Dead weight tonnage	Length (m)	Width (m)	Depth (m)	Full draught (m)	Additional weight (ton)	Estimated weight (ton)	Berthing energy (ton-m)		
								Berthing speed (at 0.1 m/s)	Berthing speed (at 0.15 m/s)	Berthing speed (at 0.2 m/s)
16 240	19 636	187.0	26.0	15.0	10.5	16 596	46 050	11.7	26.4	47.0
17 184	16 977	208.8	23.8	14.3	9.2	14 227	39 639	10.1	22.8	40.4
21 057	20 400	196.0	27.6	16.6	10.5	17 395	47 995	12.2	27.5	49.0
23 600	23 650	212.5	30.0	16.3	10.5	18 860	54 335	13.9	31.2	55.4
40 000	26 100	242.0	32.2	19.6	10.5	21 478	60 628	15.5	34.8	61.9
51 500	28 900	245.0	32.2	24.0	11.0	23 864	67 214	17.1	38.6	68.6
54 500	33 600	252.0	32.2	24.4	11.0	24 546	74 946	19.1	43.0	76.5

Container ships are designated by a different unit called Gross Tonnage, measured in hundreds of cubic feet, which is the volume of the container space available on the ship from keel to top of funnel. Another unit to designate the size of container ships is the number of equivalent twenty foot containers or TEU (twenty foot equivalent unit) the ship can carry.

Generally the Full Load Displacement is used to calculate berthing energy.

In the case of container ships the relationship between the Gross Tonnage of the container carrier and the Displacement Load changes with the difference in shape.

The Full Load Displacement varies for different types and sizes of vessels, as shown in Tables 1 and 2 for tankers and container ships respectively.

The Liquid Petroleum Gas (LPG) and the Liquid Natural Gas (LNG) vessels are defined by Gross Tonnage, Net Tonnage or carrying capacity in cubic metres (m^3) which, as in the case of containers ships, do not have a fixed coefficient to the Displacement Tonnage.

Net Tonnage is a dimensionless index calculated from the total moulded volume of the ship's cargo spaces by using a mathematical formula.

In some special cases where only the vessels in ballast berth, the vessel weight in ballast (BW) is calculated and leads to a smaller berthing energy.

To calculate the weight in ballast, assume the Light Weight to be between 15–18% of Dead Weight Tonnage, and the weight in ballast (BW) is then calculated following the following equation:

$$\begin{aligned} BW &= 0.18 \times DWT + \alpha \times DWT \\ &= (0.18 + \alpha)\ DWT \end{aligned}$$

Where the value of α is generally 50–70% of Dead Weight Tonnage (DWT) when the ship sails in ballast, depending also on sea conditions.

For many vessels 65% DWT ballast seems sufficient for sailing. At the ship yard, the vessel berthed at the fitting-out pier has ballast of approximately 15% of Dead Weight Tonnage.

Surrounding water

When a vessel moves through water, a certain amount of surrounding water also moves with it, and assists the vessel towards the wharf at berthing. As the ship is stopped by the fender, the entrained water continues to push against the ship, effectively increasing its overall weight.

When calculating the berthing energy, an estimated weight of vessel is determined by adding an extra weight of water (W_2) to the actual vessel weight (W_1).

The estimated total vessel weight is then defined by $W = W_1 + W_2$

There are several definitions about such extra weight of water, but the following three globally prevailing formulas are indicated in this article:

Additional weight

Additional weight is generally defined as the weight of water of a cylindrical shape having a diameter equivalent to the ship's draught and a length equal to the vessel's length. In general additional weight is defined by the formula:

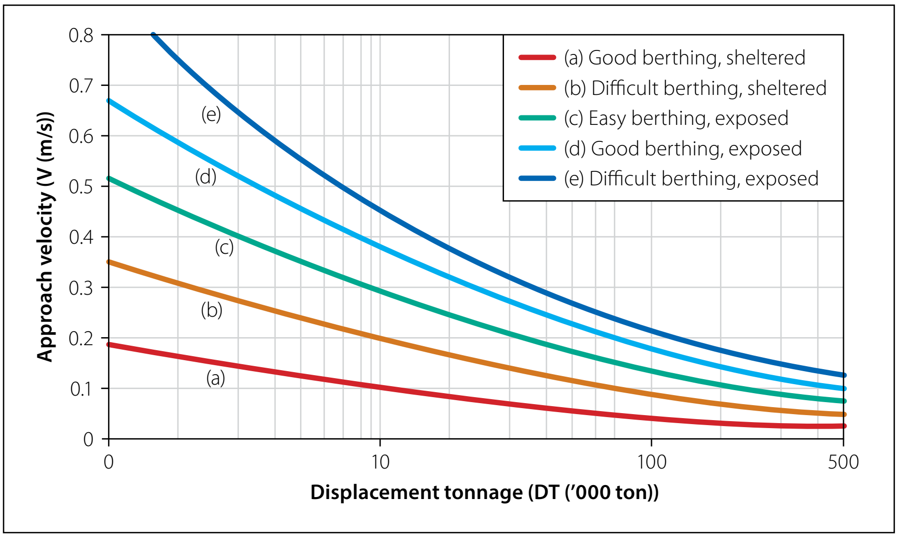


Figure 1 Approach velocity (berthing speed) in accordance with BS6349 Part 4

Table 3 Designated berthing speed

Size of vessel (DWT)	Actual speed (m/sec)	Design speed (m/sec)
Under 10 000 tons	0.1 ~ 0.30	0.20
10 000 ~ 50 000 tons	0.1 ~ 0.20	0.15
Over 50 000 tons	0.1 ~ 0.15	0.15

$W_2 = \rho \times L \times H^2 \times \pi / 4$ (in tons)

or, in the case of bow or stern berthing,

$W_2 = \rho \times B \times H^2 \times \pi / 4$

Where:
ρ = water density (ton/m^3)
H = full ship's draught (m)
B = ship's beam (m)

Mass factor C_M

From model experiments the Mass Factor C_M is estimated as $C_M = 0.3 \times W_1$ and the Total Vessel Weight becomes:

$W = W_1 + 0.3 \times W_1$

Hydrodynamic coefficient C_H

The Hydrodynamic coefficient developed by the late Prof Vasco Costa from IST (Portugal) is defined as:

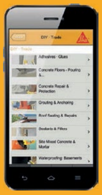
$C_H = 1 + (2 \times D / B)$

Where:
D = ship's full draught (m)
B = ship's beam (m)
Total Vessel Weight is $W = C_H \times W_1$

Berthing speed/velocity

Berthing speed is one of the most important criteria for the design of a fender system.

Berthing speed of the vessel is determined from values measured (or from data previously measured) for berthing speed, taking into consideration the size and loading conditions of the vessel, the



location of the structure at the berthing facilities, meteorological and marine conditions, the presence of tugboats and their size.

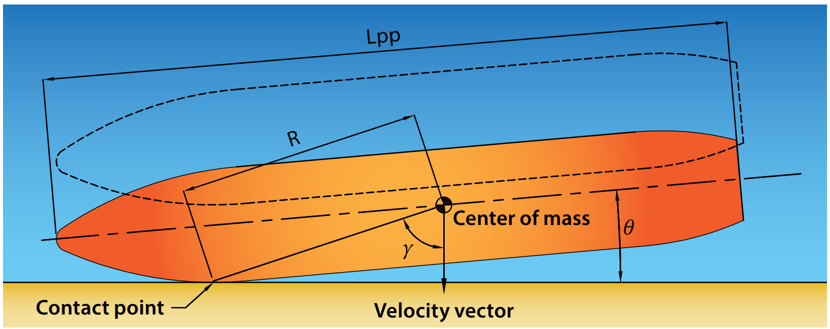
In general, the berthing speed of small vessels under 10 000 DWT is 0.10–0.30 m/s, and that of medium vessels between 10 000–50 000 DWT, and for those above the speed is less than 0.20 m/s.

The berthing speed of large vessels vary, depending on operating conditions. Normally, large bulk carriers, tankers and container ships berth in such a manner that the vessel first stops parallel to the berthing structure at about 10 to 20 metres from the wharf, then gradually approaches the wharf while being pushed by tugboats. If a strong wind blows towards the wharf, berthing is occasionally done by the tugboats pulling the vessel against the wind. When such a berthing method is followed the berthing speed of about 0.10–0.15 m/s is adopted as the designated berthing speed in many cases.

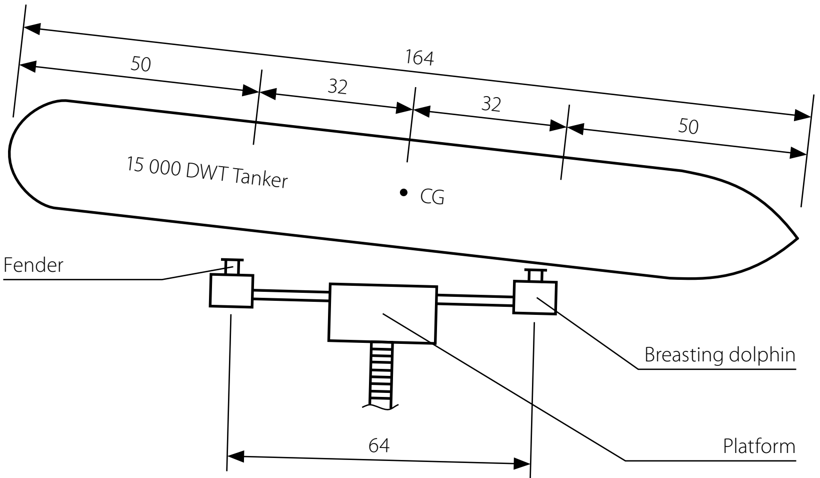
Generally, the berthing speeds as indicated in Table 3 and Figure 1 can be suggested.

Eccentricity Factor and berthing point

In most cases a ship (except a Roll-on-Roll-off ship) berths with its longitudinal centre line at an angle to the berthing line



(2) **Wharf berth**



Dolphins berth
(Mooring dolphins not shown)

(3)

Figure 2 and 3 In most cases a ship berths with its longitudinal centre line at an angle to the berthing line defined by the wharf or by the breasting dolphins

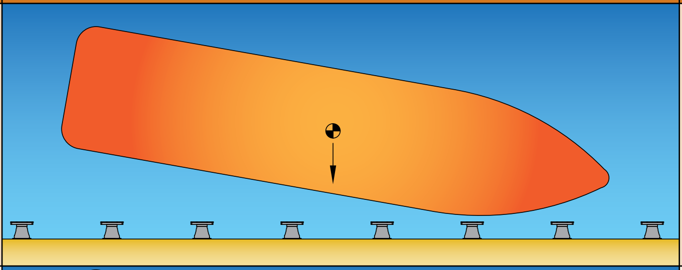
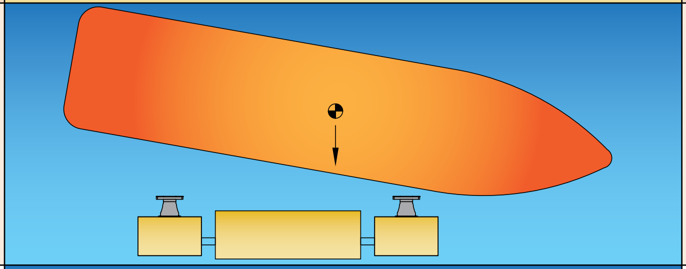
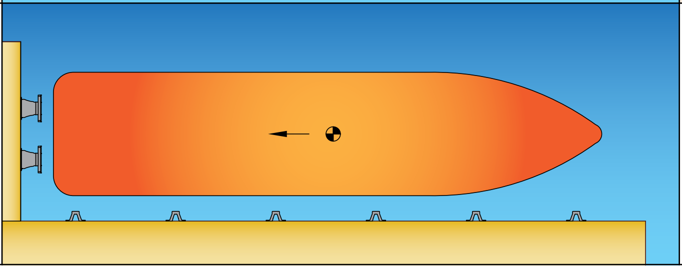
Berthing method	Berthing schematic diagram	C_E
¼ point berthing		0.5
⅓ point berthing		0.7
End berthing		1.0

Figure 4 Schematic illustration of berthing methods

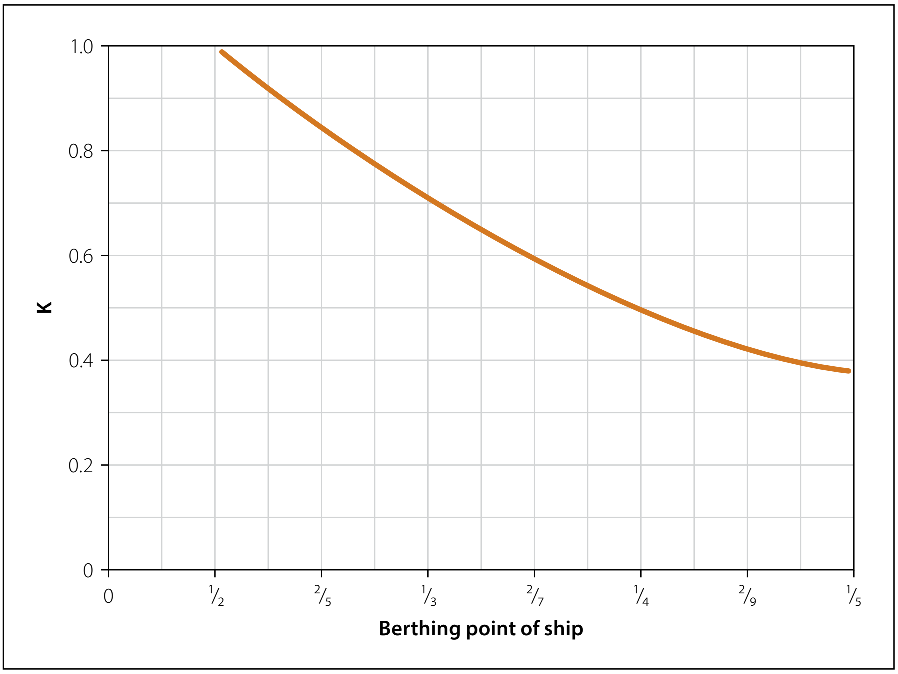


Figure 5 Determining the Eccentricity Factor K

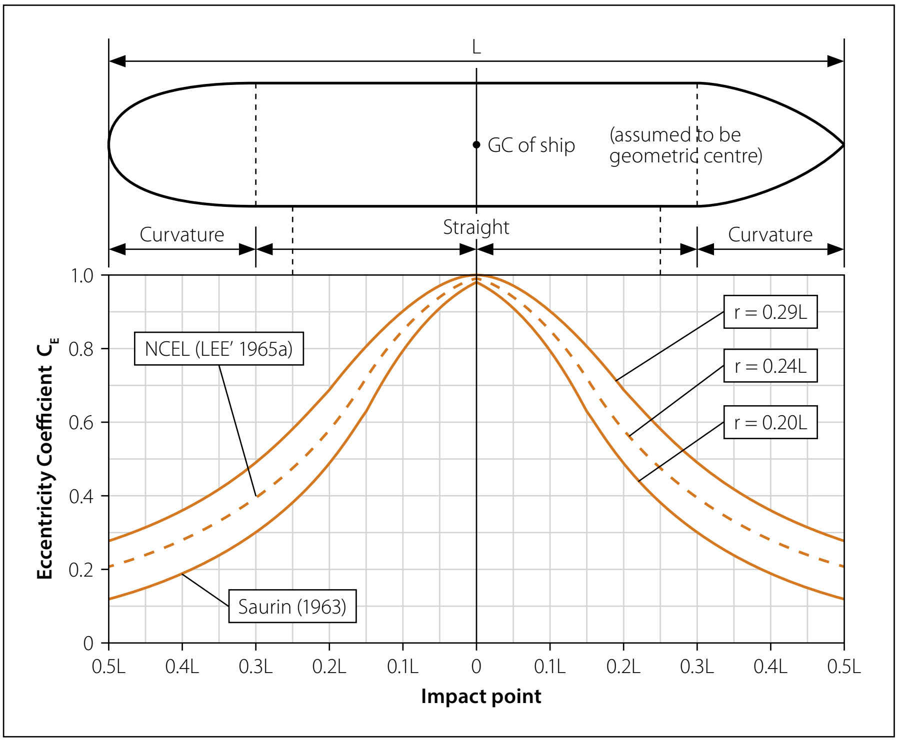


Figure 6 Determining Eccentricity Factor C_E

defined by the wharf or by the breasting dolphins, as shown in Figures 2 and 3.

When the vessel touches the wharf or dolphin fenders, it rotates about its centre of gravity. For this reason the total kinetic energy held by the ship is consumed partially, as the turning energy and the remaining energy are conveyed to the fender and wharf or dolphin. Often the C_E is assumed to be as shown in Figure 4, unless specifically specified.

The remaining energy is obtained from the kinetic energy of the ship affected by a correction factor called the Eccentricity Factor. Two formulas are available to calculate the Correction Factor:

Eccentricity Factor K

The Eccentricity Factor is expressed by the following formula:

$$K = 1 / [1 + (L/r)^2)]$$

Where:

L = length of the vessel
r = turning radius

If the vessel's horizontal cutting surface is assumed to be approximately a lean and elongated ellipse or a rectangle, the tuning radius of the vessel comes up to about a ¼ of the length of the vessel L. In addition, when berthing at the so-called ¼ point, the K value can be read from Figure 5.

In the case of dolphin's post, the value L becomes the distance between the breasting dolphins. In the case of a Roll-on-Roll-off berthing post the value of K = 1.0.

Eccentricity Factor C_E

When the vessel's speed vector is taken into consideration the Eccentricity Factor C_E is expressed by the following equation, as also shown in Figure 6:

$$C_E = (r + m^2 \times \cos^2 \theta) / (r^2 + m^2)$$

Berthing energy calculation

Several formulas exist to calculate the Berthing Energy, of which the following three are mostly used:

Formula I

$$E = \{[(W_1 + W_2) \times V^2] / 2g\} \times K$$

Where:

E = effective berthing energy
W_1 = displacement tonnage
W_2 = additional weight (ton)
V = berthing speed (m/s)
g = acceleration of gravity (9.8 m/s²)
K = eccentricity factor

Formula II

$$E = (W \times Vn^2 \times C_E \times C_H \times C_S \times C_C) / 2g$$

Where:

E = effective berthing energy
W = displacement (long ton)
Vn = translational speed normal to pier (m/s)
C_E = eccentricity factor (approx 0.5)
C_H = hydrodynamic coefficient
C_S = softness coefficient (approx 0.9)
C_C = configuration coefficient (0.8 to 1.0)
g = acceleration of gravity (m/s²)

Formula III

$$E = [(W_1 V^2) \times C_M \times C_E \times C_S] / 2g$$

Where:

E = effective berthing energy
W_1 = displacement tonnage (ton)

V = berthing speed (m/s)
C_M = mass factor (approx 1.3)
C_E = eccentricity factor (approx 0.5)
C_S = softness factor (approx 0.9)
g = acceleration of gravity (m/s²)

Softness Factor C_S

This factor indicates the relation between the rigidity of the vessel and that of the fender, and hence also between the energy absorbed by the vessel and by the fender.

The softness coefficient allows for the portion of the impact energy that is absorbed by the elastic deformation of the ship's hull. Little research has been undertaken into energy absorption by a vessel hull, but it is generally accepted that the value of Cs lies between 0.9 and 1.0.

In the absence of more reliable information a figure of 1.0 for Cs is recommended when a soft fender system is used, and between 0.9 and 1.0 for a hard fender system.

A hard fender system can be considered one in which the deflection of the fenders under impact from design vessels is less than 0.15 m. A soft fender system has fender deflections greater than 0.15 m under the same impacts.

Configuration Factor C_C

This factor expresses the effect of water surrounding the moving vessel rebounding on the structure of the wharf.

The berth configuration coefficient allows for the portion of the ship's energy which is absorbed by the cushioning effect of water trapped between the ship's hull and the quay wall. The value of C_C is influenced by the type of quay construction, the distance from the side of the vessel, the berthing angle, the shape of the ship's hull and the under-keel clearance.

The following values are generally applied in each case (see Figure 7):

- C_C = 1.0 for open pier
- C_C = 0.9–1.0 for semi-open pier
- C_C = 0.8–1.0 for closed pier

Angular effects

When angular approach is expected it is recommended to consider the energy loss of the system due to non-uniform deflection and energy absorption by each fender of the system. Energy loss can occur under angular approaches and should be considered in the analysis. The angle of approach is defined by the angle that the vessel hull makes with the berthing structure or berthing line and should not be confused with the direction of the vessel's motion.

In the case of a dolphin berthing post or a super-structured berth for large vessels, the effect of angular compression on the fender must be considered in the design. On the other hand, in the case of a continuous wharf where many fenders are installed at certain spacings, this effect is not usually considered.

According to the results obtained from field surveys, the berthing angle will be less than 3° in most cases and 6° at maximum. In conservative cases this angle may reach 10°.

The fender system to be chosen must take a correction factor for angular loading. Each correction factor is a ratio of the reaction force (R) and the fender energy absorption (E) value at an angle divided by the corresponding values at zero angle.

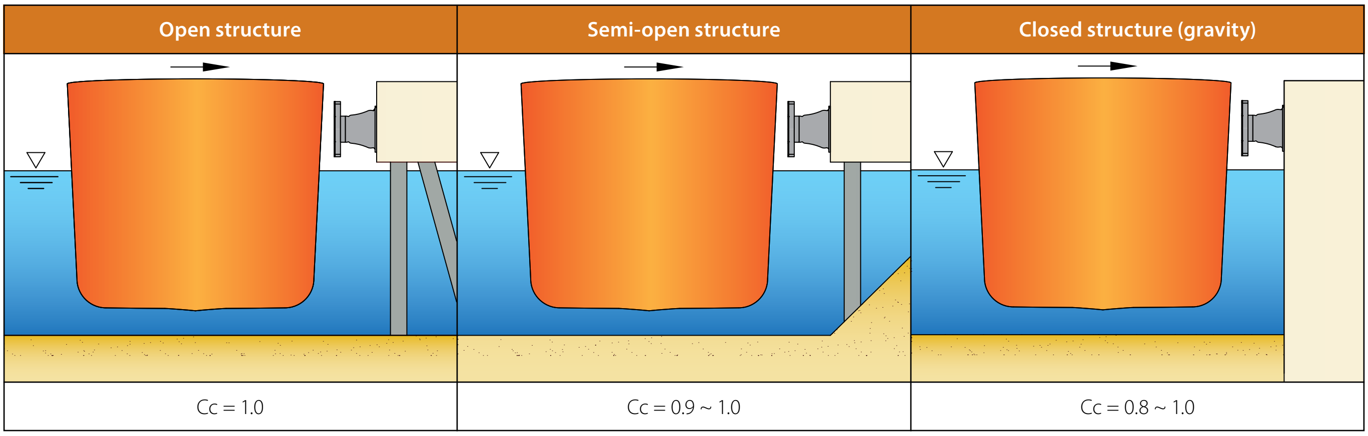


Figure 7 Determining Configuration Factor C_c

Under angular loading the reaction force and energy absorption are reduced below those found for zero angle compression curves.

Besides the angular effect, other effects, such as shearing, also influence performance. Shearing occurs when the ship rubs the fender either horizontally or vertically parallel to the wharf or dolphin faces.

Limitations from the point of view of berthing conditions

Several berthing condition limitations regarding the wharf and the dolphins should be considered when selecting a fender system. Typical limitations include:

- Maximum allowable reaction force on existing structures
- Allowable installation area
- Maximum allowable projection of the fender from the structure face
- Adaptability of the existing wharf.

Maximum allowable reaction force

Kinds and types of berths vary in the reaction force allowed. This applies especially to wharfs and dolphin berths built on piles, as in these cases the allowable reaction force could be severely limited if they had not been designed to resist such force.

Even the gravity-type wharfs sometimes seriously limit the allowable reaction force when considering the strength of the concrete and its thickness.

Allowable installation area

When the installation area is limited due to the thickness of the wharf, the fender system will have a compact layout in a minimum area, while having to satisfy the required performance.

Moreover, when the structure is of concrete, it is normally required for all fenders that the distance from the edge of the concrete to the most outer fixing anchor bolt position should be equal to or larger than the length of the anchor bolts.

The minimum contact area to install a fender should be equal to or larger than the widest footprint of the fender chosen.

Maximum allowable projection of the fender

There are several cases in which the fender projection must be within the stipulated regulation, such as in oil terminal loading arms or the reach of harbour cranes.

In general it is absolutely necessary to design the fender system to prevent the vessel from hitting the wharf, even when the system is compressed up to the designed deflection of the fender.

Adaptability of the existing wharf

When possible, the fender can be fixed on to the existing quay wall. Chemical anchors are recommendable for proper fender fixing. Many of the conventional old wharfs have timber fenders on very thin quay walls. If the upgrading of such wharfs requires heavier fenders, several options have to be taken into consideration.

Limitations from the point of view of the berthing vessel

As the hull of a vessel has a very complicated curvature in horizontal and vertical directions, the fender will be compressed in a complicated shape by such curvature. Typical limitations are:

- Curvature in the vertical direction
- Curvature in the horizontal direction
- Projections from the vessel hull
- Maximum allowable hull face pressure.

Curvature in the vertical direction

Generally, as vessels such as general cargo carriers and tankers have almost straight vertical lines where they contact the fender system, though they have curvature at the bow and stern, it is not necessary to take this into consideration in the design of the fender.

However, as the latest container vessel have a curvature around the contact area, it is necessary to design the fender taking this curvature into account. If the fender is installed in a low position the vessel might hit the wharf before the fender can be compressed to the designed deflection.

Curvature in the horizontal direction

Generally, as vessels have very little curvature around the contact area, i.e. ¼ point of the vessel length for general cargo carriers, it is not normally taken into consideration in the designing of the fender system.

However, if for some container vessels the curved area should contact the fenders, it will be necessary to determine the adequate spacing of fenders required to prevent the vessel from hitting the wharf.

Projections from the vessel hull

Many smaller vessels have projections from the hull, like hull belting. When such a projection contacts a fender directly the fender may be compressed partially or scratched so that serious damage to the fender can occur, such as cracking or cutting. In such cases the fender must be protected by a frontal frame, usually made from steel.

Consideration must also be given to vessels with bulbous bows in order to prevent contact with the berthing structure, especially in the case of piled structures.

Maximum allowable hull face pressure

The average hull/fender face pressure is calculated by dividing the designed reaction force of the fender by the area of the flat surface of the fender frontal frame. The allowable face pressure differs depending on the type and size of the vessel.

Limitations from natural conditions

There are various limitations due to natural conditions which must be taken into consideration in the design of a marine fender system. The following typical limitations need particular attention:

- Tidal range
- Wind force
- Tidal current.

Tidal range

When the tidal range is especially pronounced it is necessary to decide where on the fender system the vessel will definitely make contact, because the contact point of the vessel differs depending on the water level. In general it is recommended that the top of the freeboard of the vessel should make contact with a higher position than the centre of the marine fender frame. The allowable hull contact pressure must also be taken into consideration.

In cases where this is not possible, various options have to be considered, such as using a longer fender protection frame, or a fender/pile system or extending the wharf coping downward.

Wind force

Especially when the freeboard of a vessel is very high, such as when in light weight or in ballast, it is necessary to design a fender system which will not be damaged from over-compression by the vessel under the effect of a strong wind.

The force of wind against a moored vessel can be calculated by the following equation:

$$R_W = \tfrac{1}{2} \times (\rho \times C \times U^2) \times (A \cos^2\theta + B \sin^2\theta) \text{ in kilograms}$$

Where:

R_W = wind force (kg)
ρ = density of air (0.123 kg.s²/m4)
U = wind velocity (m/s)
A = area of hull frontal shadow on water surface (m²)
B = area of hull lateral shadow on water surface (m²)
θ = angle of wind direction to ship centre line
C = wind pressure coefficient

The maximum force of wind in the above equation occurs when $\theta = 0°$. The wind pressure coefficient is 1.2 at this time and the wind force equation becomes:

$$R_W = 0.0.738 \times B \times U^2$$

Tidal current

Tidal current is one of the factors which should in fact be considered together with wind force. However, as the wharf and its mooring facilities are designed not to be affected by tidal current, it is not generally taken into consideration in the design of a fender system. When it is taken into consideration, the equation for Tidal Current Force (R_p) is as follows:

$$R_p = K \times D \times V_t^2$$

Where:

R_p = maximum tidal force (kg)
K = current coefficient (= 1.0)
D = area under the full draught line (draught × vessel length or width × 0.9)
V_t = tidal current velocity (m/s)

Abnormal berthing

An abnormal impact occurs when the normal calculated energy to be absorbed at impact is exceeded. Some reasons for abnormal impacts include mishandling, malfunction, exceptionally adverse wind or current, or a combination of these and other factors.

The factor for abnormal impact may be applied to the berthing energy as calculated for a normal impact, to arrive at the abnormal berthing energy. The factor should enable reasonable abnormal impacts to be absorbed by the fender system without damage. It would not be practical to design for an exceptionally large abnormal impact, and it must therefore be accepted that such impact could result in damage.

Table 4 appears in PIANC (Permanent International Association of Navigation Congress) guidelines as general guidance.

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Type of vessel	Size	Factor of abnormal berthing
Tanker and bulk cargo	Largest	1.25
	Smallest	1.75
Container vessel	Largest	1.5
	Smallest	2.0
General cargo	–	1.75
Ro-Ro and ferries	–	2.0 or higher
Tugs, work boats, etc	–	2.0

SELECTING THE FENDER

The most important thing in selecting a proper fender is that the fender should be able to absorb the berthing energy of the vessel for safe berthing. The following selecting procedure is suggested:

- Calculate the berthing energy.
- Select the fender system suitable for absorbing the berthing energy, taking all the applicable factors into consideration, such as angular effects, etc.
- Select the fender system by considering the various limitations, especially the following:
    - The reaction force of the fender should not exceed the maximum allowable reaction force on the wharf under normal operating conditions.
    - The fender system must be installed in the designated area.
    - The face pressure of the fender system should be less than the allowable hull pressure of the vessel.
    - Decide on the fender spacing by considering the minimum curvature of the berthing vessel that will be contacting it, as well as the existence of hull belting or bulbous bows.

FURTHER DEVELOPMENTS

PIANC guidelines introduced Rated Performance Data (RPD), with an initial velocity of 15.0 m/s decreasing to 0.005 m/s, as its new fender performance basis. RPD was introduced to simulate the decreasing velocity of actual berthing conditions. The large difference in compression velocity when using the constant slow-velocity method causes a corresponding difference in the performance data of the fender (see Figure 8).

The reaction force and energy absorption of rubber, being a viscoelastic material, will be higher when it is compressed with a higher velocity.

FINAL REMARKS

The aim of this article was not to be a comprehensive tool for the design and detailing of marine fenders, in particular rubber fenders, but rather to discuss the main factors affecting the design of fenders in general to indicate a few fender design information sources. The design of fenders should always be done in conjunction with port operators and marine fender manufacturers. ☐

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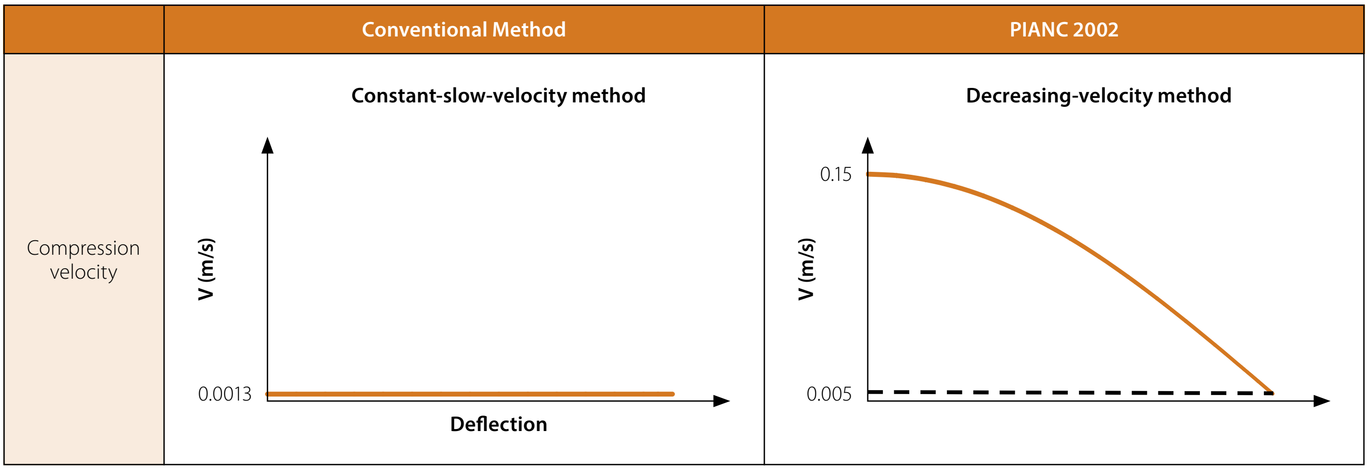

Figure 8 The difference between Conventional Method and PIANC 2002 RPD