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Introduction

Your comments on this draft are invited and will assist in the preparation of the consequent standard.

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BS 6349-4

Maritime works – Part 4: Design of fendering and mooring systems – Code of practice

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Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on XX Month 20XX. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

This part of BS 6349 supersedes BS 6349-4:1994, which is withdrawn.

Relationship with other publications

BS 6349 is published in the following parts:

- Part 1-1: General – Code of practice for planning and design for operations;
- Part 1-2: General – Code of practice for assessment of actions;
- Part 1-3: General – Code of practice for geotechnical design;
- Part 1-4: General – Code of practice for materials;
- Part 2: Code of practice for the design of quay walls, jetties and dolphins;
- Part 3: Code of practice for the design of shipyards and sea locks;
- Part 4: Code of practice for design of fendering and mooring systems;
- Part 5: Code of practice for dredging and land reclamation;
- Part 6: Design of inshore moorings and floating structures;
- Part 7: Guide to the design and construction of breakwaters;
- Part 8: Code of practice for the design of Ro-Ro ramps, linkspans and walkways.

Information about this document

This is a full revision of the document, and introduces the following principal changes:

- The nomenclature in the equations in Section 5 and 6 has been revised to follow Eurocode practice;
- The berthing velocity discussion in Section 5.1 has been deleted and replaced with a discussion in Annex B;
- Section 6 has been revised to include recovery and hardening factors. The manufacturing partial factor has been revised to depend on the amount of testing;
- Annex A specifying the performance testing of fenders has been added;
- Annex C about the durability testing of fenders has been added;
- Annexes D, E and F have been added. This text was previously in BS 6349 Part 1-1;
- Annex G about the testing of mooring equipment has been added,
- Other revisions throughout the document.

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at bsigroup.com/standards, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Use of this document

As a code of practice, this part of BS 6349 takes the form of recommendations and guidance. It is not to be quoted as if it were a specification. Users are expected to ensure that claims of compliance are not misleading.

Users may substitute any of the recommendations in this part of BS 6349 with practices of equivalent or better outcome. Any user claiming compliance with this part of BS 6349 is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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Section 1: General

1 Scope

This part of BS 6349 gives recommendations and guidance on the design of fendering systems and layouts, mooring devices and mooring system layouts, principally for commercial vessels with a minimum displacement of 1 000 t.

NOTE Several provisions in this part of BS 6349 might be applicable to other types of vessels, such as naval vessels, provided that the particular vessel characteristics and berthing/mooring procedures are taken into account.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS 6349-1-1, *Maritime works – Part 1-1: General – Code of practice for planning and design for operations*

BS 6349-1-2, *Maritime works – Part 1-2: General – Code of practice for assessment of actions*

BS 6349-1-4, *Maritime works – Part 1-4: General – Code of practice for materials*

BS 6349-2, *Maritime works – Part 2: Code of practice for the design of quay walls, jetties and dolphins*

BS ISO 17357 (all parts), *Ships and marine technology – Floating pneumatic rubber fenders*

BS EN 1992-4, *Eurocode 2 – Design of concrete structures – Design of fastenings for use in concrete*

BS EN 1990, *Eurocode – Basis of structural and geotechnical design*

BS EN 1991 (all parts), *Eurocode 1 – Actions on structures*

BS EN 1993 (all parts), *Eurocode 3 – Design of steel structures*

BS EN 1995 (all parts), *Eurocode 5 – Design of timber structures*

BS EN ISO 3506 (all parts), *Fasteners – Mechanical properties of corrosion-resistant stainless steel fasteners*

BS EN ISO 898 (all parts), *Mechanical properties of fasteners made of carbon steel and alloy steel*

BS EN ISO 10684, *Fasteners — Hot dip galvanized coatings*

BS EN 1090 (all parts), *Execution of steel structures and aluminium structures*

BS EN 1593, *Non-destructive testing. Leak testing. Bubble emission techniques*

BS EN 1998 (all parts), *Eurocode 8 – Design of structures for earthquake resistance*

BS EN 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*

Other publications

[N1] OIL COMPANIES INTERNATIONAL MARINE FORUM. *Mooring equipment guidelines*. Fourth edition (MEG4). London: OCIMF, 2018.¹⁾

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this part of BS 6349, the terms and definitions given in BS 6349-1-1 and the following apply.

3.1.1 base deflection

fender manufacturer's published maximum deflection of a fender unit when compressed.

3.1.2 base energy

fender manufacturer's published energy capacity of a thermally stabilized fender unit when axially compressed to its base deflection at a constant velocity between 0.33 to 1.33 mm/s

NOTE This is the maximum energy capacity generated by the fender unit when compressed to the base deflection during performance testing in accordance with Annex A.

3.1.3 base performance

fender unit's force-deflection and energy-deflection curves generated by performance testing a fender unit in accordance with Annex A

3.1.4 base reaction

fender manufacturer's published reaction of a thermally stabilized fender unit when axially compressed to its base deflection at a constant velocity between 0.33 to 1.33 mm/s

NOTE This is the maximum reaction generated by a fender unit when compressed to the base deflection during performance testing in accordance with Annex A.

3.1.5 berth

area in a port dedicated to the mooring of a vessel and typically equipped with fenders and mooring equipment

NOTE A berth for a large vessel can be used to moor two or more smaller vessels.

3.1.6 berthing line

seaward face of a berth including the uncompressed fendering system

3.1.7 blend

mixture of rubbers and/or other polymer-forming materials which constitute the polymer content of the finished compound

3.1.8 compound

intimate mixture of a rubber or rubbers or other polymer-forming materials with all the ingredients necessary for the finished product

[SOURCE: BS ISO 1382:2020, 3.105]

NOTE BS 6349-1-4 provides descriptions of ingredients added to rubber and/or rubber blends to form compounds used in the manufacture of fenders.

3.1.9 cope

top edge of a quay or jetty adjacent to a berth

¹⁾ Available at <https://www.ocimf.org/publications/books/mooring-equipment-guidelines-meg4>.

3.1.10 design vessel

vessel for which the fendering and mooring systems are designed to permit it to safely berth and be moored under the environmental operating limits

NOTE Where a berth is to accommodate a range of vessels, there are several design vessels, including as a minimum both the largest and smallest vessels within the range.

3.1.11 fender

item of port equipment designed to keep a vessel from touching the berth structure without damaging itself, the vessel, or the berth structure

NOTE The components of a fender can include one or more of the following:

- energy absorbing unit(s), e.g.:
- moulded/ wrapped/ extruded elastomeric unit(s);
- pneumatic unit(s);
- foam-filled unit(s);
- fender panel;
- facing material;
- fender pile;
- timber sections; and
- fender chains.

3.1.12 fendering system

all the fenders provided for a berth

3.1.13 fender unit

energy absorbing element of a fender

3.1.14 flat side of vessel

part of the side of a vessel between the bow and stern that is flat, vertical and parallel to the axis of the vessel

NOTE Sometimes also referred to as parallel midships or parallel mid-body.

3.1.15 grade (elastomer)

fender manufacturer's designation of compound

3.1.16 hull contact angle

angle formed between the tangent of the vessel's hull at the point of initial contact and the berthing line

3.1.17 minimum breaking load (MBL)

specific value below which the measured breaking load is not allowed to fall in a prescribed breaking load test

NOTE When applied to mooring lines, the minimum breaking load is for new, dry mooring lines for which a ship's mooring system is designed.

3.1.17 working load limit (WLL)

Maximum load that a manufactured item such as a bollard can safely handle under normal service conditions

NOTE The WLL is usually set by the manufacturer as the MBL divided by the applicable reliability factor.

3.2 Symbols

For the purposes of this part of BS 6349, the following symbols apply.

B	beam of vessel, in metres (m)
C	clearance between vessel hull and berth structure
C_b	block coefficient of the vessel hull
C_C	berth configuration coefficient
C_E	eccentricity coefficient
C_M	hydrodynamic mass coefficient
C_S	softness coefficient
D_v	draught of vessel, in metres (m)
d	deflection at the level of the application of the load, in metres (m)
E_{base}	base energy of the fender unit
E_d	design berthing energy to be absorbed by the fendering system, in kilonewton metres (kN·m)
E_F	energy absorbed by the fender, in kilonewton metres (kN·m)
$E_{f,d}$	design energy capacity of the fender, in kilonewton metres (kN·m)
E_k	characteristic berthing energy to be absorbed by the fendering system, in kilonewton metres (kN·m)
g	Acceleration due to gravity, in metres per second squared (m/s ²)
h	compressed height of fender, measured along fender centreline
K	radius of gyration of vessel
L_{OA}	overall length of vessel, in metres (m)
L_{BP}	length of vessel hull between perpendiculars, in metres (m)
L_L	overall length of largest design vessel, in metres (m)
L_S	overall length of smallest design vessel, in metres (m)
M_D	displacement of vessel, in tonnes (t)
R	distance of the point of contact from the centre of mass of the vessel, in metres (m)
R_B	bow radius of the vessel, in metres (m)
$R_{f,d}$	design reaction force of the fender unit, used to design the supporting structure, fender panel and/or fender ancillary items
$R_{f,k1}$	characteristic fender reaction force generated at the characteristic berthing energy for non-buckling type fender units and the characteristic reaction force generated at the first peak of the force-deflection curve for buckling type fender units
$R_{f,k2}$	characteristic fender reaction force generated at the design berthing energy
R_{f1}	reaction force generated at the characteristic berthing energy for non-buckling type fender units
R_{f2}	reaction force generated at the first peak of the force-deflection curve for buckling type fender units
R_{f3}	reaction force generated at the design berthing energy
S_{max}	maximum spacing between fenders, in metres (m)
u	velocity of vessel, in metres per second (m/s) (as used in Froude equation)
V	characteristic velocity of vessel in direction of approach, in metres per second (m/s)
V_B	characteristic velocity of vessel normal to the berthing line at the point of initial contact, in metres per second (m/s)
x	distance from the forward perpendicular to the point of contact, measured along the vessel centreline in metres (m)
α	berthing angle of vessel
λ	geometric scale of a physical model

φ	angle between the line joining the point of contact to the centre of mass of the vessel and the velocity vector for the berthing vessel
γ_E	berthing energy factor
$\gamma_{m,a,e}$	angle factor applicable to the fender energy capacity described in 6.3.1.2
$\gamma_{m,a,r}$	angle of impact factor applicable to the fender reaction force described in 6.3.2.2
$\gamma_{m,h,e}$	hardening factor applicable to the fender energy capacity described in 6.3.1.5
$\gamma_{m,h,r}$	hardening factor applicable to the fender reaction force described in 6.3.2.5
$\gamma_{m,m,e}$	manufacturing partial factor applicable to the fender energy capacity described in 6.3.1.6
$\gamma_{m,m,r}$	manufacturing partial factor applicable to the fender reaction force described in 6.3.2.6
$\gamma_{m,r,e}$	recovery factor applicable to the fender energy capacity described in 6.3.1.4
$\gamma_{m,r,r}$	recovery factor applicable to the fender reaction force described in 6.3.2.4
$\gamma_{m,s,e}$	strain rate factor applicable to the fender energy capacity described in 6.3.1.3
$\gamma_{m,s,r}$	strain rate factor applicable to the fender reaction force described in 6.3.2.3
$\gamma_{m,t,e}$	temperature factor applicable to the fender energy capacity described in 6.3.1.1
$\gamma_{m,t,r}$	temperature factor applicable to the fender reaction force described in 6.3.2.1
γ_{Qc}	partial load factor given in BS 6349-1-2 for the characteristic berthing energy
γ_{Qd}	partial load factor given in BS 6349-1-2 for the design berthing energy
μ	coefficient of friction

3.3 Abbreviated terms

For the purposes of this part of BS 6349, the following abbreviated terms apply.

FEA	finite element analysis
ITP	inspection and test plan
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NDT	non-destructive testing
MBL	minimum breaking load
WLL	working load limit

Section 2: Fendering

4 General principles

4.1 Provision and overall design of fendering systems

Berths should be provided with a suitable fendering system to protect berth structures and vessels from damage, taking into account operating conditions as defined in BS 6349-1-1 and stated in the facility operating manual, unless a clear justification can be made that such a system is not required.

The fendering system should be designed taking account of:

- a) safety of the quayside operatives and vessel's crew;
- b) the range of vessels berthing;

NOTE 1 Vessels might berth in a range of laden conditions, from in-ballast to fully laden.

- c) the methods used to berth the vessel;

NOTE 2 Where a vessel berthing alongside is manoeuvred by tugs and/or the use of thrusters, it is generally stopped a short distance off and parallel to the berth. The vessel is then pushed or warped slowly onto the berth, ideally achieving a gentle contact as near as parallel to the berthing line as possible.

NOTE 3 Tugs, launches and other small vessels tend to approach their berths more directly than large vessels.

NOTE 4 Ferries and roll-on/roll-off (Ro-Ro) vessels approach their berths in a different way, which is explained in 4.5.2.

- d) vessels moored during cargo handling operations;
- e) vessels moored during extreme events caused by adverse metocean or other conditions;
- f) the normal operating conditions of the berth;
- g) the risks and consequences as a result of an extreme or accidental event occurring;
- h) the features appropriate to the location of the berth, as shown in Table 1;
- i) the features appropriate to the characteristics of the vessels that are expected to use the berth, as shown in Table 2; and
- j) the intended service life of the system, making allowance for degradation and wear and tear during operations.

NOTE 5 The fendering system might need to be designed to work with the mooring system to reduce vessel movements.

NOTE 6 Fendering systems are required to be suitable for all operational water levels that might occur, and with large variations this becomes particularly important. Winds, waves, current and other factors also vary depending on the berth location.

Table 1 – Berth features to be taken into account in the design of the fendering system

Berth Location/ Type	Berth features
Impounded basins	Approximately constant water level Usually sheltered from high winds Limited fetch for local wave generation Negligible current Range of vessel sizes limited by lock dimensions
Tidal basins	Greater range of water levels than impounded basins Limited wave exposure Limited current
River berths	Variable water level due to changes in river discharge and possibly tide Limited wave exposure Variable current Possible restricted area available for manoeuvring of vessels Passing vessels (vessel interaction)
Estuarial and coastal berths	Maximum tidal range and currents Greater wave exposure than tidal basins Often dedicated berths with single class or type vessels
Exposed coastal berths	Full exposure to wind, wave and currents Usually specialized trades, e.g. bulk coal, ore, oil (products), LNG, LPG Single type vessels and handling equipment
Locks and lock entrances	Variable water level Limited lateral movement of vessels within the lock Large longitudinal movement of vessels

Table 2 – Vessel features to be taken into account in the design of the fendering system

Vessel category	Vessel features
Bulk carriers	Possible need to be warped along berth for shiploader to change holds Large change in draught between empty and fully laden conditions
Car carriers	Loading ramps, slewed- or end-loading (vessel-mounted or berth-based) High windage areas Vessels might have recessed bollards in hull End berthing
Container vessels	Extensive flared bows and sterns with liability to strike berth-side installations Particularly the larger vessels can have a relatively short length of flat side Potential high windage areas
General cargo vessels	Large change of draught between empty and fully laden conditions Possible long occupancy of berths
LNG/LPG carriers	Low allowable hull pressure Single type vessels using dedicated berth Need to avoid fire hazards from sparking or friction Relatively short length of flat side High windage areas
Miscellaneous tugs, supply boats, barges, lighters and fishing boats	Need robust fenders for heavy use Vessels are usually fitted with belting
Passenger liners	Little change of draught between empty and fully laden condition High windage areas Low allowable hull pressure
Roll on-roll off (Ro-Ro) vessels	Loading ramps, slewed or end loading (vessel mounted or berth based) End berthing High windage areas Vessels are usually fitted with belting Vessels usually berth without the aid of tugs
Tankers	Very low amidships freeboard for coastal tankers Large change in draught between empty and fully laden conditions Need to avoid fire hazards from sparking or friction
Train and vehicle ferries	Quick turnaround End berthing High berthing velocities Intensive use of berth High windage areas Vessels are usually fitted with belting Vessels usually berth without the aid of tugs

NOTE Most vessels have bulbous bows. Vessels from all categories could be fitted with belting, particularly smaller vessels.

4.2 Selection and design of fenders

The fenders should be designed to protect the berth structure against damage from vessels and to limit the reaction forces on the vessel hull to acceptable values.

NOTE 1 The range of available fenders of both proprietary and purpose-made types is considerable.

Selection and design should take account of the factors listed in 4.1 together with:

- a) types and hull forms of the vessels that are expected to use the berth;
- b) velocity and angle at which the vessels berth;
- c) range of water levels and range of freeboards of vessels to be accommodated;
- d) offset of fender face to protect quayside equipment;
- e) limits to the distance between berth cope and side of hull after vessels are moored in relation to the outreach of loading arms, crane jibs, shiploader booms and similar equipment;
- f) spacing between fenders;
- g) movement of vessels while moored;
- h) number of energy absorbing units that absorb the vessel berthing energy;
- i) energy to be absorbed by the fenders, having regard to the location and approach conditions of the berth and its method of operation;
- j) form of fender performance required, e.g. buckling type, quasi-linear elastic;
- k) reaction forces and deflections on both the berth structure and the vessel hull;
- l) reaction forces for smaller berthing energies;

NOTE 2 For buckling type fenders the maximum reaction can occur at a relatively low percentage of the rated energy of the fender, whereas for non-buckling type fenders the reaction increases as the energy absorption increases.

- m) acceleration and deflection limits on berths, in particular those carrying quay equipment such as pipelines, rail-mounted cranes and shiploaders and on susceptible structures where operatives are working when a vessel is berthing;
- n) number of fenders that resist the loads from a vessel when moored alongside;
- o) ease with which the berth can be accessed for the maintenance, repair and replacement of fenders and fender components, including facing materials;
- p) metocean actions on the fenders, including from ice and debris.

The design of the fenders should be integrated with that of the berth structure as not all types of fender are compatible with all types of structure.

NOTE 3 Generally, the berthing energy is the controlling influence on the fender selection. However, for offshore ports and for ports with entrances in exposed locations, vessels might berth only during relatively benign conditions, and the greatest fender loading might occur when the vessel remains at the berth during storm events.

4.3 Vessel characteristics

4.3.1 General

The characteristics of the design vessels for a particular berth should be established.

NOTE 1 Where specific data is not available, the data relating to appropriate vessels for the proposed berth as given in BS 6349-1-1 or similar data sources may be used.

The design should allow for the vessel's hull form.

NOTE 2 For example, large container vessels can have relatively short flat sides and fast ferries can have high sides with low allowable hull pressure. The vessel plans might be available to determine the vessel characteristics.

Where vessels are berthed in a partially laden condition, reference should be made to vessel plans and load-displacement curves or tables to ascertain the hull form and other vessel characteristics such as draught and displacement values.

Where the fendering system is designed primarily for a partially laden or in ballast design vessel, the designer should establish the risk of berthing a more heavily laden vessel, and should take into account the possibility of a fully laden vessel having to return to the berth.

4.3.2 Berthing angles

NOTE 1 It is generally impracticable to provide a fendering system to safeguard the berth structure and vessel against accidental impacts resulting from large berthing angles.

The designer should establish operational values of the berthing angle that are likely to occur in a range of berthing scenarios. These berthing angles should be used in optimizing both the fendering system and the substructure layout.

NOTE 2 For alongside berthing, a value of 2° may be used as a maximum berthing angle for vessels larger than 50 000 DWT.

For smaller vessels and vessels berthing without tugboat assistance, the maximum berthing angle might be larger, for instance:

- feeders/coasters: 6° to 10° ;
- barges: 15° .

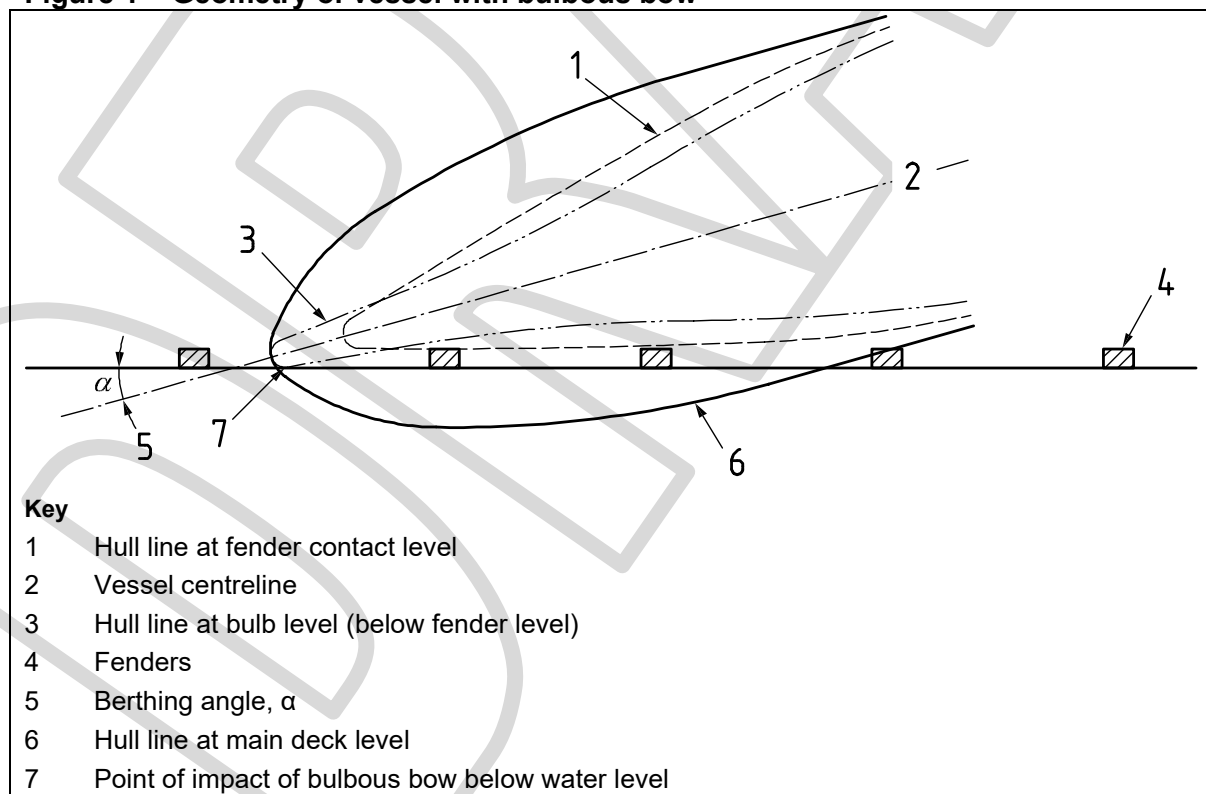
NOTE 3 The maximum berthing angle might be limited by the berth geometry, for instance in narrow basins.

4.3.3 Vessels with bulbous bows

NOTE Modern vessels are typically built with a bulbous bow that protrudes from the bow. This is designed to reduce bow wave resistance at normal vessel speeds.

Where vessels with bulbous bows are to be berthed, the underwater geometry of the bow section should be taken into account in addition to that at the level of contact with the fendering system. The fender spacing, fender outstand after compression and relationship of the berth's substructure to the cope face should be assessed (see Figure 1), to establish a maximum berthing angle α which is acceptable without impact between the bow and the berth structure.

Figure 1 – Geometry of vessel with bulbous bow



4.3.4 Belting

The design of the fendering system should take account of belting. Fender panels should be sufficiently long to avoid belting catching the top or bottom of the panel.

NOTE 1 Ferries, and small craft such as tugs and launches, are often fitted with belting that consists of one or more timber, rubber or steel rubbing strips around the vessel. Occasionally this belting is discontinuous and might be in poor condition. On some vessels it might occur at more than one level, particularly towards the stern of the vessel.

NOTE 2 Belting might give highly concentrated loads, catch on edges causing large vertical loads, and cause localized compression of the fender.

4.4 Fender layout for berths and other locations

4.4.1 General

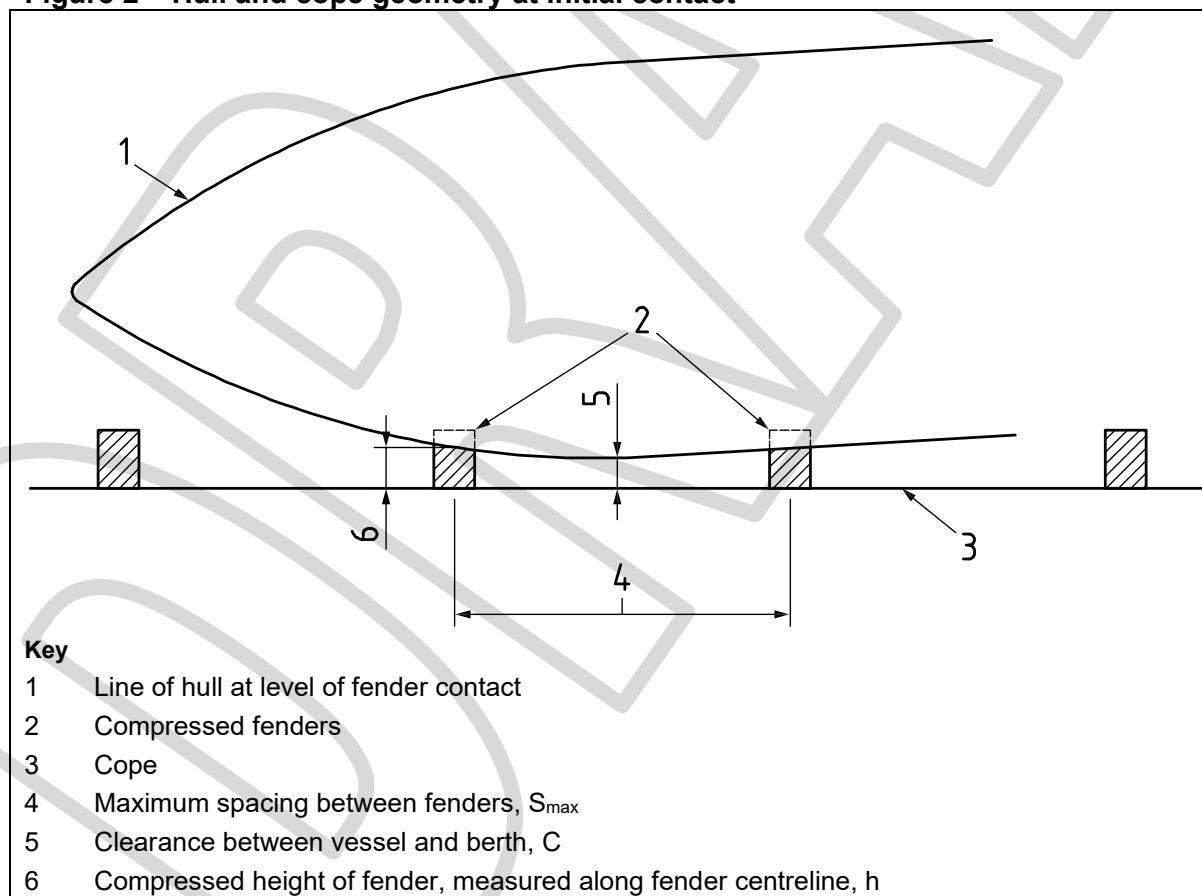
The design of the fendering system should take into account the berth layout.

NOTE 1 Fendering systems can be classified into three general categories, i.e. those for continuous quays, those for island berths and those for lead-in jetties and locks. Other systems are generally variants of or combinations of these three categories. Fendering systems can be formed of individual fenders, groups of fenders of the same type and size or a combination of fenders of differing types and / or sizes.

The fendering system should prevent the vessel striking the berth structure and cargo handling equipment (see Figure 2). The positioning of equipment during berthing should be discussed with the port operator and the agreed positions should be documented in the facility operating manual.

NOTE 2 Generally, vessel captains and pilots prefer to berth vessels on the bow shoulder. The exception to this is for Ro-Ro vessels when berthing stern onto berth, when vessels generally berth on the stern quarter.

Figure 2 – Hull and cope geometry at initial contact



NOTE 3 A typical minimum clearance (see Figure 2, item 5) is 250 mm at the design deflection.

The fendering system should allow vessels to lie alongside with adequate support from the fenders along the flat side of the vessel hull.

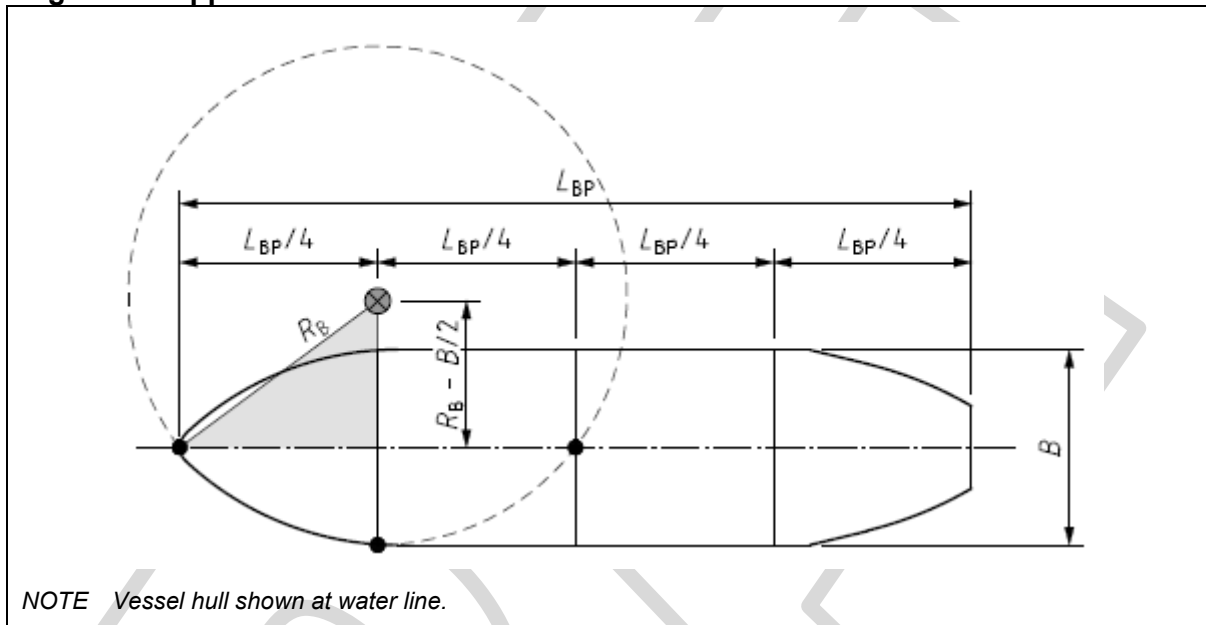
For conventional shaped hulls berthing on the bow shoulder, the maximum spacing/pitch of fenders should be determined based on the hull geometry of the smallest design vessel and the geometry of the selected fendering system using the following equation:

$$S_{\max} \leq 2\sqrt{R_B^2 - (R_B - h + C)^2}$$

NOTE 4 Where there is no information on the vessel hull, the bow radius, R_B , can be approximated from the following formula (see Figure 3):

$$R_B = (B/4) + (L_{BP}^2/16B)$$

Figure 3 – Approximation of bow radius



Where less conventional hull shapes are expected, such as Ro-Ro vessels or vessels with a large bow and/or stern flare, or where stern quarter berthing is expected, the maximum spacing of the fenders should be determined from specific vessel plans/profiles.

NOTE 5 Bow and stern vertical flare varies depending upon the vessel type and design. Vertical flare up to 15° is common on container vessels.

4.4.2 Continuous quays

NOTE 1 For the purposes of this subclause, a continuous quay is one that provides a straight continuous berthing line for more than one berth.

NOTE 2 On continuous quays there is often no precise delineation of individual berths in order to give flexibility of operation and the accommodation of a wide range of vessels.

On continuous quays where individual berths are not delineated, the fendering system should allow a vessel to berth at any position along the length of the quay by providing a continuous fendering system. The fendering system usually consists of a series of individual fenders, the positioning of which should be in accordance with the general recommendations given in 4.4.1. In addition, the fender spacing should not exceed 0.15 L_S for conventional hull shapes.

In establishing the fender layout the designer should take into account the berthing angle and the shape of the vessels using the berth to establish the number of fenders being utilized in absorbing the vessel's berthing energy.

NOTE 3 By providing a continuous fendering system, one or more fenders might be utilized in the absorption of the vessel's berthing energy. For example, the smallest-sized vessel using the berth might contact on a single fender, whereas the largest-sized vessels might contact on a number of fenders.

The designer should take into account design situations where a vessel might contact the fenders with a berthing angle greater than the design value, resulting in fewer fenders being utilized.

4.4.3 Island berths

The spacing of primary fenders should take account of the actual geometry of the vessels to be berthed. At least two fenders (one at either side of the platform) should make full face contact with the flat side of the vessel hull to provide a sufficient lever arm in the horizontal plane.

The berthing arrangement should accommodate any longitudinal eccentricity in the position of the vessel during berthing or mooring.

NOTE 1 Such eccentricity might arise due to:

- the manifolds of liquid bulk vessels, or other vessels that are bunkering at a berth, not being located amidship;
- the vessels berthing either port or starboard to the berth;
- the loading arms or other fixed equipment on the berth being positioned away from the berth centreline; and
- vessels needing to be warped along the berth such that fixed equipment can reach all of the vessel holds.

NOTE 2 Warships and naval auxiliary vessels typically have eccentric manifold locations and loading points.

NOTE 3 Following a risk assessment, it might be determined that a minimum of two primary fenders either side of the platform are required to provide a back-up in case of an individual fender failure.

NOTE 4 A symmetrical fendering arrangement is typically provided for most situations.

The layout and distance between fenders should where possible be established by reference to specific vessel plans/profiles.

NOTE 5 This is particularly the case for non-typical vessels that have shorter flat sides.

In the absence of detailed vessel data the following criteria should be met:

- For typical bulk vessels, the spacing of berthing (breasting) dolphins should be in the range of $0.25L_{OA}$ to $0.4L_{OA}$ for the complete range of design vessels (see Figure 4 and Figure 5).
- For LNG vessels the maximum spacing between berthing (breasting) dolphins should not exceed $0.35L_{OA}$.

Where more than two fenders are to be provided a straight berthing line should be adopted to provide optimum support to the flat side of the hull of a moored vessel. Primary fenders should be selected so as to prevent any overloading of secondary/inner fenders at full compression of the primary fenders under design berthing and mooring conditions.

Design of the fendering system should take particular account of:

- prevention of direct impact between vessels and equipment on the loading platform;
- restriction of lateral deflection of the structures to limits acceptable for the equipment;
- prevention of small vessels snagging the primary fenders, taking account of tide levels and waves; and
- the risk to port operations due to the damage or failure of one or more fenders.

Figure 4 – Fender layout for three island berth

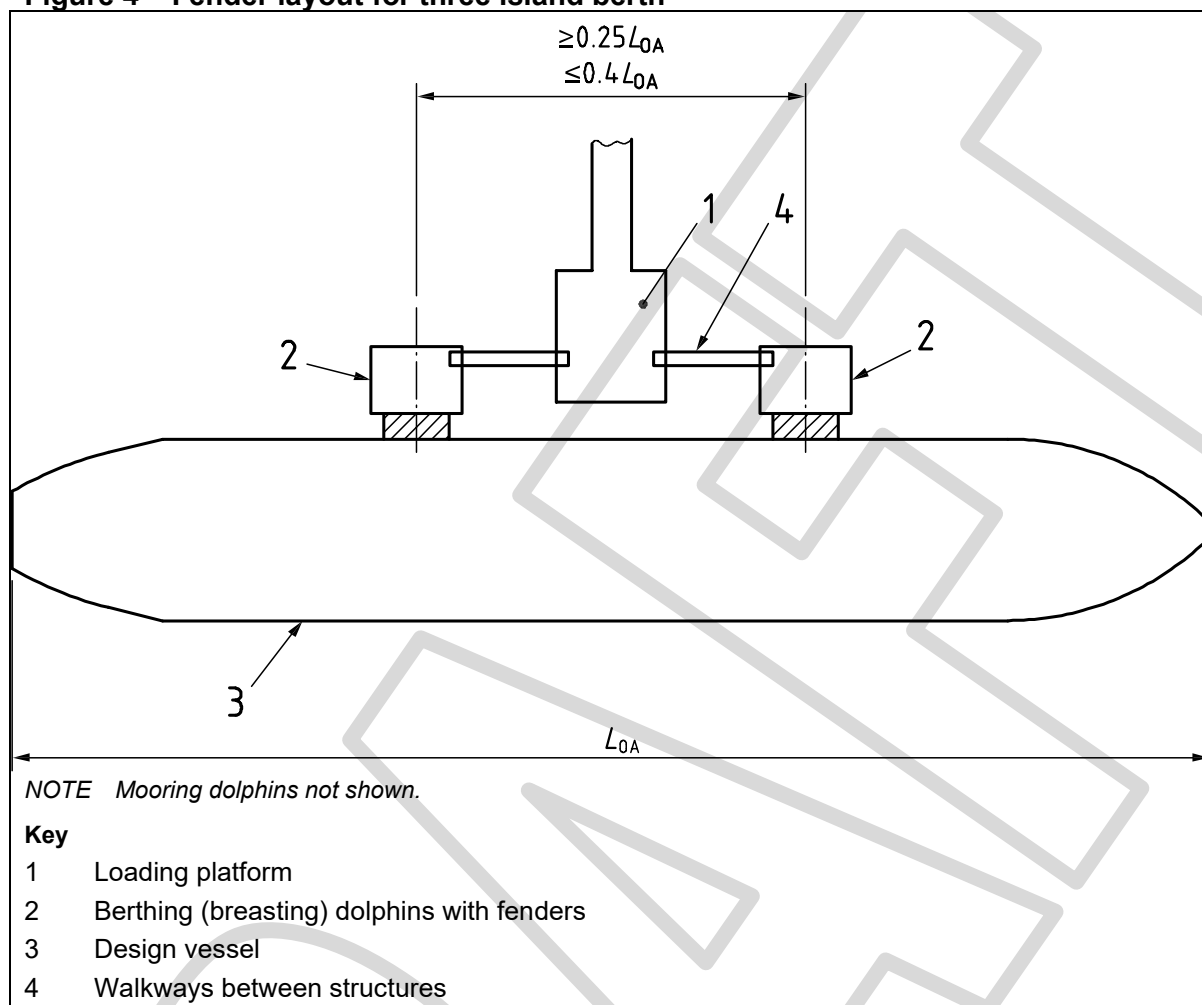


Figure 5 – Fender layout for five island berth

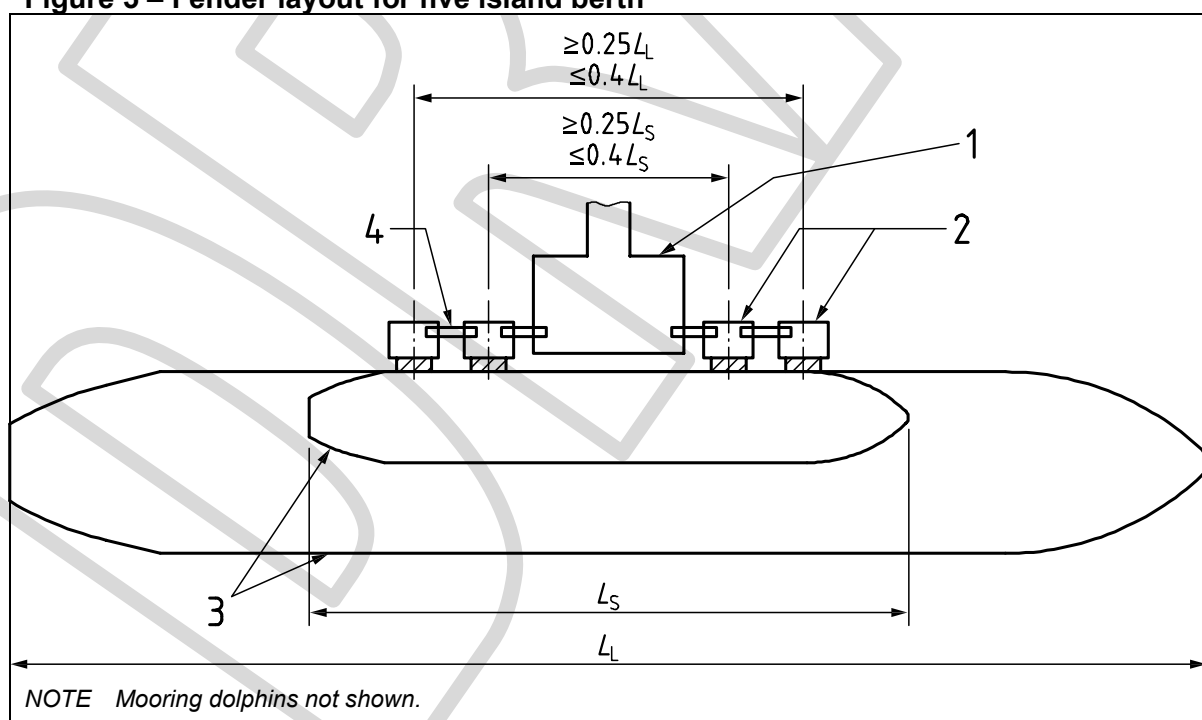


Figure 5 – Fender layout for five island berth

Key

- | | |
|---|--|
| 1 | Loading platform |
| 2 | Berthing (breasting) dolphins with fenders |
| 3 | Design vessels |
| 4 | Walkways between structures |

4.4.4 Lead-in jetties and lock entrances

Fendering systems for lead-in jetties/approaches, for vessels entering into confined entrances such as locks, dry docks, ship lift systems and passageways, should be grouped into one of the following categories:

- a) Fendering for moored vessels in layby berths awaiting entry into confined entrance. The provision of fendering at layby berths is similar to other berths, except that extra attention should be given to the increased likelihood of vessel wash and surge effects from passing vessels.
- b) Fendering on the approach to a confined entrance.

NOTE 1 Approaches to confined entrances can comprise either a continuous faced structure or fendering system.

Particular attention should be given to the potential interaction between vessel bow flare and structures, including lock gates, at or near the lock entrance.

NOTE 2 Approach walls and lead in jetties are not always common practice for entering confined areas. Guidance on lead-in jetties and approaches to locks is given in PIANC Report No. 106 [1].

- c) Fendering required inside the confined area. Within a lock, the principal movement of a vessel as it enters or leaves a lock is almost parallel to the fender line. As lock water level is raised or lowered, the principal movement of the vessel is vertical. Therefore shear, as opposed to compression of the fender, is the principal effect and hence a different design approach should be adopted.

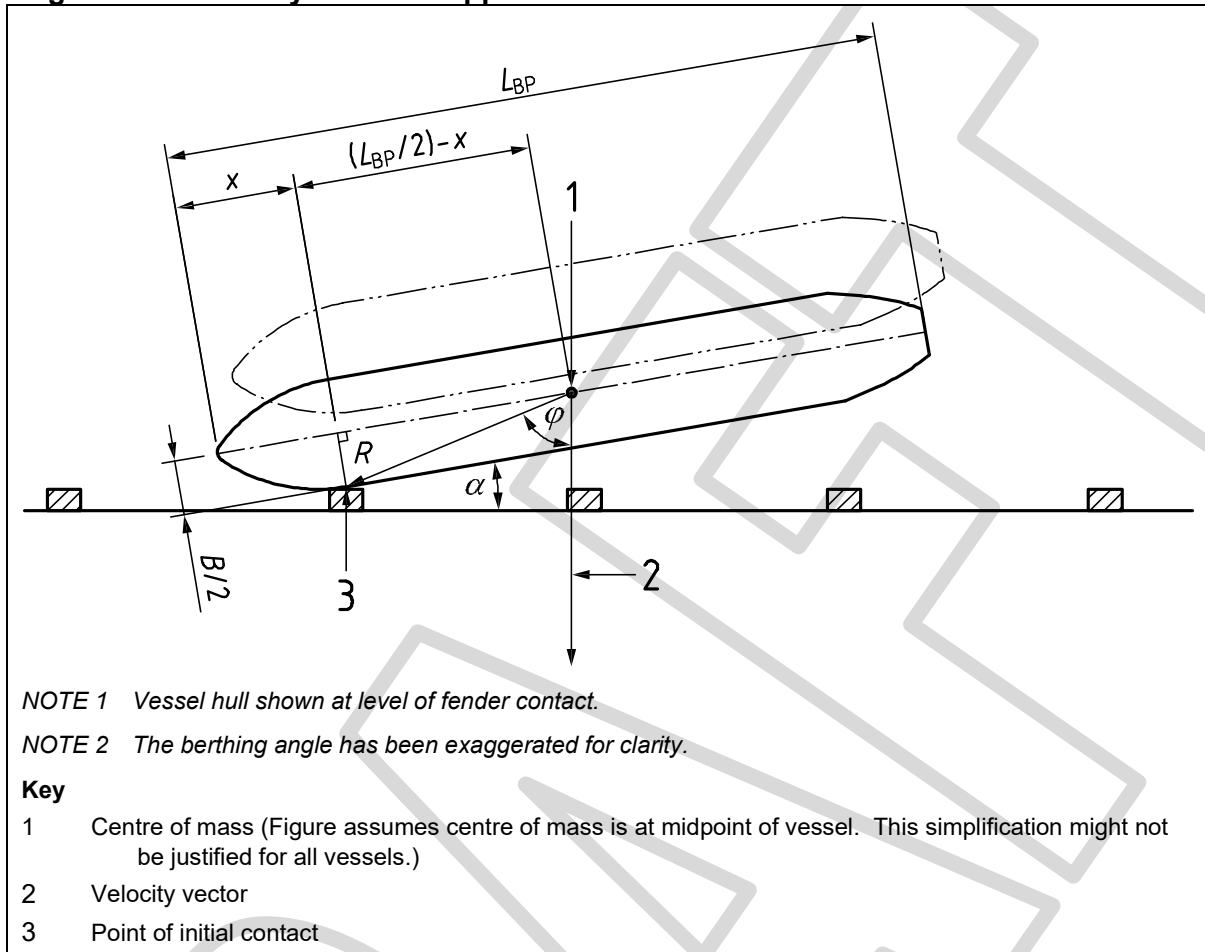
4.5 Berthing procedure

4.5.1 Alongside berthing

The maximum berthing angle to be used in the design should be specified in the facility operating manual (see 4.3.2 for guidance on values).

NOTE Typically for vessels that are berthing alongside, the vessel's movement is perpendicular to the berthing line with the vessel almost parallel to the berth, as illustrated in Figure 6.

Figure 6 – Geometry of vessel approach to berth



4.5.2 Ferry and Ro-Ro berths

The fender design for ferry and Ro-Ro vessels should be based on the berthing mode established following consultation with the facility owner or operator, of which the three in common use are:

- a) parallel approach to a row of berthing (breasting) dolphins or quay and after coming to rest moving slowly longitudinally to berth end-on against a berth ramp structure;
- b) direct longitudinal approach to berth end-on against or close to a berth ramp structure but using side berthing (breasting) dolphins or a quay as a guide; and
- c) parallel approach to berth alongside a quay and using the vessel's own side or quarter ramp for vehicle access.

Where there is a possibility that more than one of these modes might be used, the designer should allow for the most onerous mode or modes. The fendering system design should take into account the first point of contact.

NOTE 1 These three modes of berthing are illustrated in Figure 7a), Figure 7b) and Figure 7c).

NOTE 2 The berth layouts for modes a) and b) are similar and therefore both types of approach could occur at the same berth, possibly by the same vessels in different weather conditions. Vessels with bow ramps might approach the berth using a variation of mode a) or mode b). Mode c) is most likely to be adopted by the larger Ro-Ro vessels where the vessel's bow and stern are not specifically designed for berthing forces. Mode b) is most likely to be adopted by ferries where the vessel's bow and/or stern are designed for end berthing. It is important that the berthing provision is suitable for the vessel's characteristics and the appropriate method of approach.

Figure 7 – Ferry and Ro-Ro vessel berthing

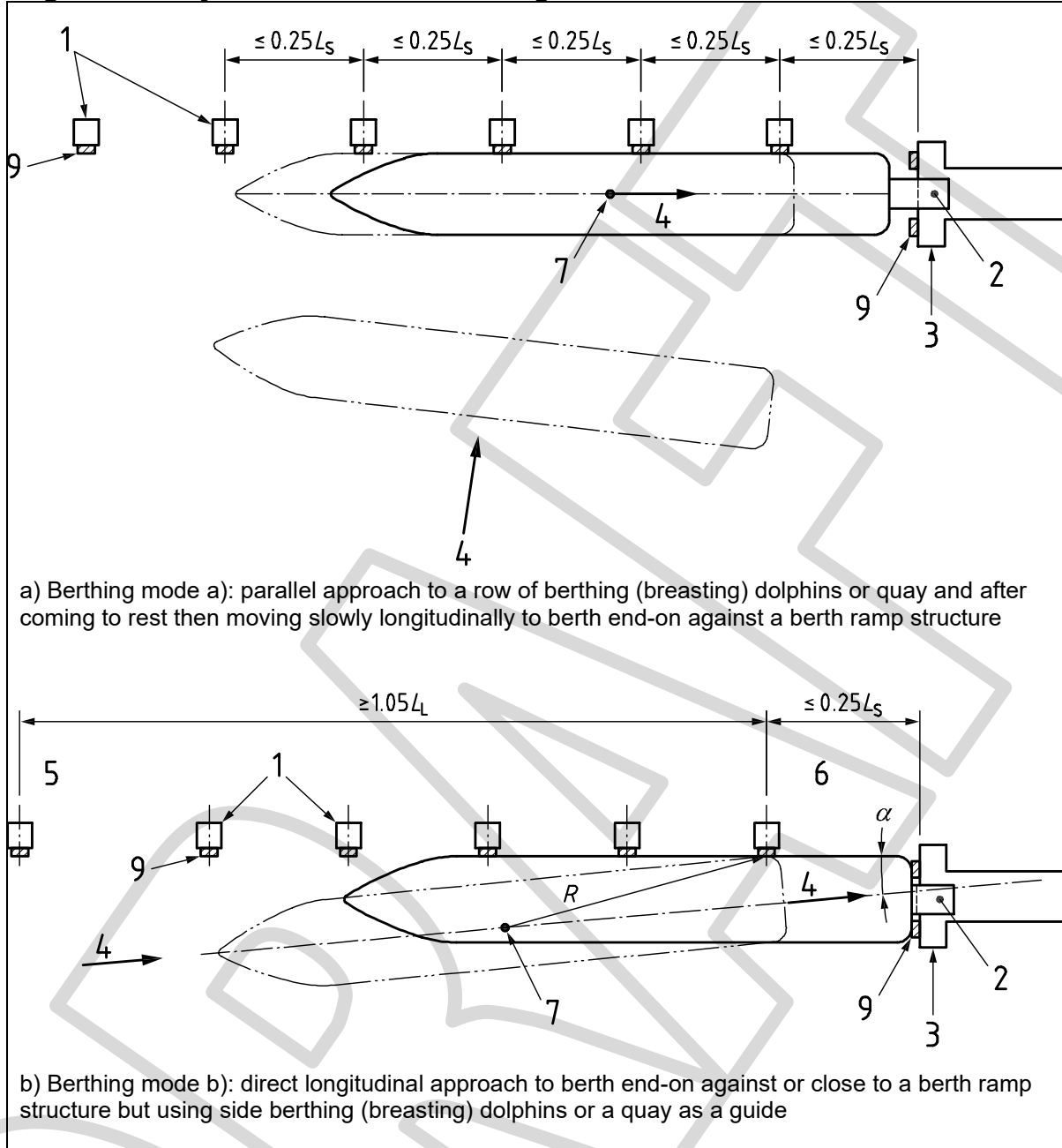
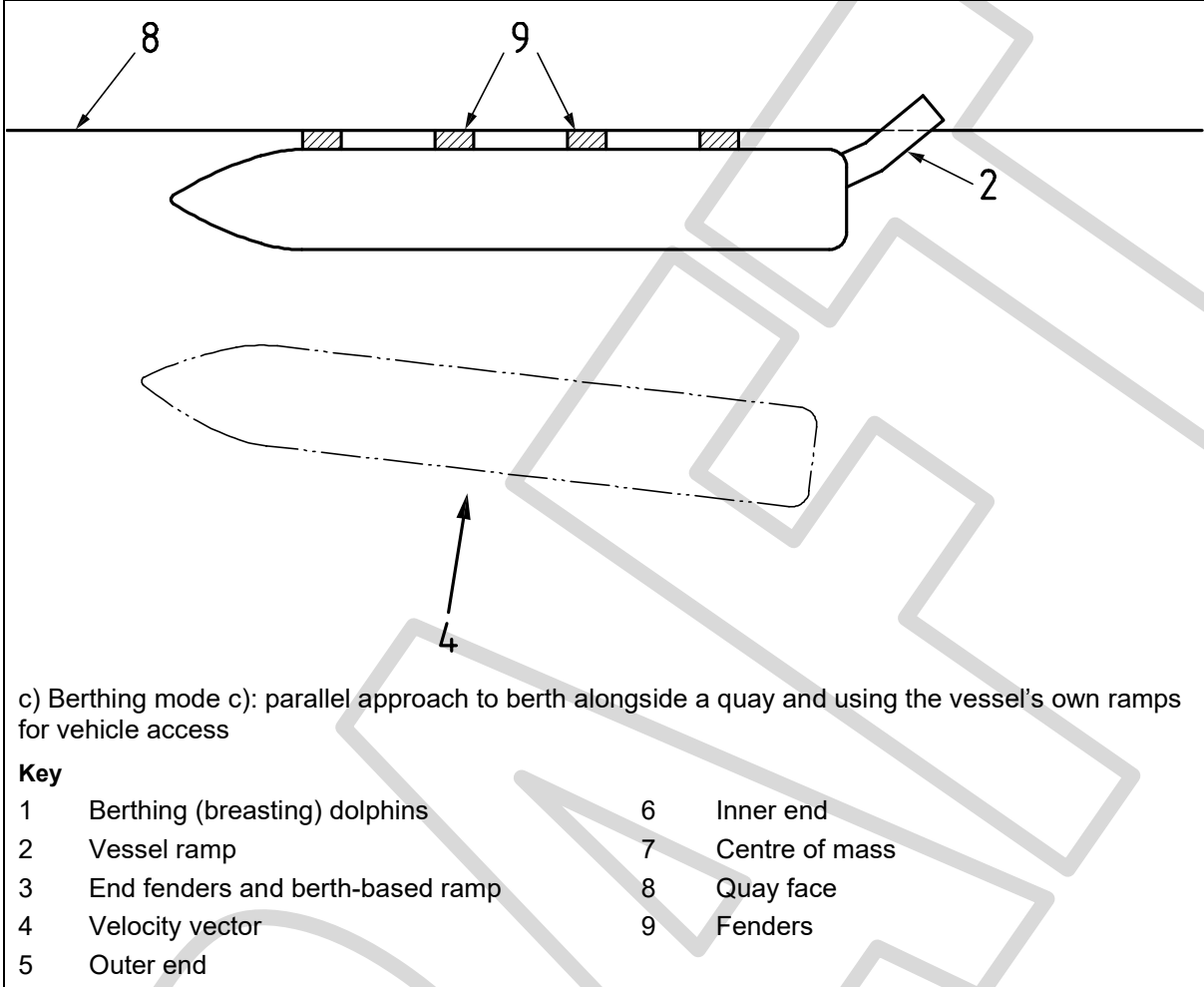


Figure 7 – Ferry and Ro-Ro vessel berthing



4.6 Berthing reactions and load distribution

4.6.1 General

Berthing reactions should be distributed in such a manner that:

- a) contact pressures on the vessel hull are kept within acceptable limits;
- b) direct contact between the hull and berth structure is prevented;
- c) the capacity of the fender is not exceeded; and
- d) the berthing structure can accommodate the fender reaction loads both locally and globally.

NOTE Berthing reactions are a function of the berthing energy and the deformation characteristics of the fendering system and berth structure.

4.6.2 Hull pressures

The contact pressure between the hull of the vessel and the fender should be limited so as to avoid damage to the vessel.

NOTE 1 The maximum characteristic contact pressure between the hull and fender is influenced by many factors, including the type and size of vessel, the nature of the fender bearing surface (i.e. rigid or flexible) and the position of the contact area relative to the hull frames.

Hull pressure values should be based on the worst case of full or partial contact with the fender face allowing for tides, loading conditions and vessel freeboard when berthing.

NOTE 2 In the absence of definitive data, Table 3 may be used for preliminary design.

Table 3 – Guidance on hull pressure

Type of vessel	Characteristic Hull pressure (kN/m ²)
Container vessels	<200
General cargo vessels:	
≤20 000 DWT	<200 to <300
>20 000 DWT	<200
Oil tankers:	
≤60 000 DWT	<300
>60 000 DWT	<200
Gas carriers (LNG/LPG)	<130 to <200
Bulk carriers	<200
Cruise vessels	<150
Ferries and Ro Ro vessels (non belted) ^{A)}	<200
<i>NOTE</i> Smaller vessels might be able to accept higher hull pressures (up to 400kN/m ²), particularly for designs where a fender bearing surface (panel) is not used.	
^{A)} Vessels that are belted, such as ferries, produce highly concentrated loads on the fenders/fender panels. Typical allowable loads sustainable by ship's belting are 2 500 kN/m to 5 000 kN/m.	

Where belting contacts on the fender resulting in a secondary contact with the vessel's hull away from the belting, the design of the fender panels (see **6.8**) and hull pressure should allow for both the primary and secondary contacts.

NOTE 3 Where vessels with belting are expected, and the fendering system is mounted such that it is rotationally free, the belting can contact the fender unit above or below the fender axis and cause rotation.

NOTE 4 Berths where vessels with belting are frequent typically have either parallel motion fenders or piled fender panels to reduce the risk of double contact.

Care should be taken at locations where swell conditions cause cyclic fender loading that cause fatigue failure of hull plates, especially where the same fender and mooring configuration is maintained over successive calls. Particular attention should be applied to berths for bulk carriers and other vessels with single skin hulls. Where found necessary, pneumatic fenders or other systems that spread the load and vary the point of application to reduce the number of high stress loading cycles should be used.

4.6.3 Fender energy absorption and reaction due to parallel and angular berthing

The designer should assess the energy absorption and the reactions from the fendering system on the supporting structures for both parallel and angular berthing.

NOTE 1 For a parallel berthing case multiple fenders might be compressed and this can result in the maximum reaction on the supporting structure(s).

NOTE 2 Unless the point of initial contact is on the flat side of the hull and the vessel is completely parallel to the berth, the fender receives an angular loading.

The hull geometry over the contact area should be reviewed (see Figure 2 and Figure 8) to establish:

- the hull contact angle at each fender;
- the number of fenders that are deflected during berthing;

NOTE 3 The fenders either side of the point of initial contact might be fully or partially compressed, thus providing combined energy absorption capacity.

- The deflection of individual energy-absorbing units within the fendering system and hence the aggregate amount of energy absorbed by the complete fendering system; and

NOTE 4 In calculating the energy capacity provided by an individual fender, the berthing angle, the shape of the hull and the spacing of the fenders are key variables in the fender layout. The number of fender units

compressed during the berthing will depend on the spacing and size of the fenders as well as the shape of the hull.

d) clearance between hull and berth structure.

Under angular compression (vertical and/or horizontal), elastomeric fenders provide different reactions and energy absorption characteristics compared to axial compression, and these should be taken into account in the selection of the fender.

NOTE 5 Where circumstances dictate that angled approaches are the general practice at a particular berth, it might be necessary to angle the individual fenders relative to the berth, in order to create a closer approximation to parallel berthing conditions and hence more efficient performance of the fender.

Figure 8 – Hull and fender geometry at contact

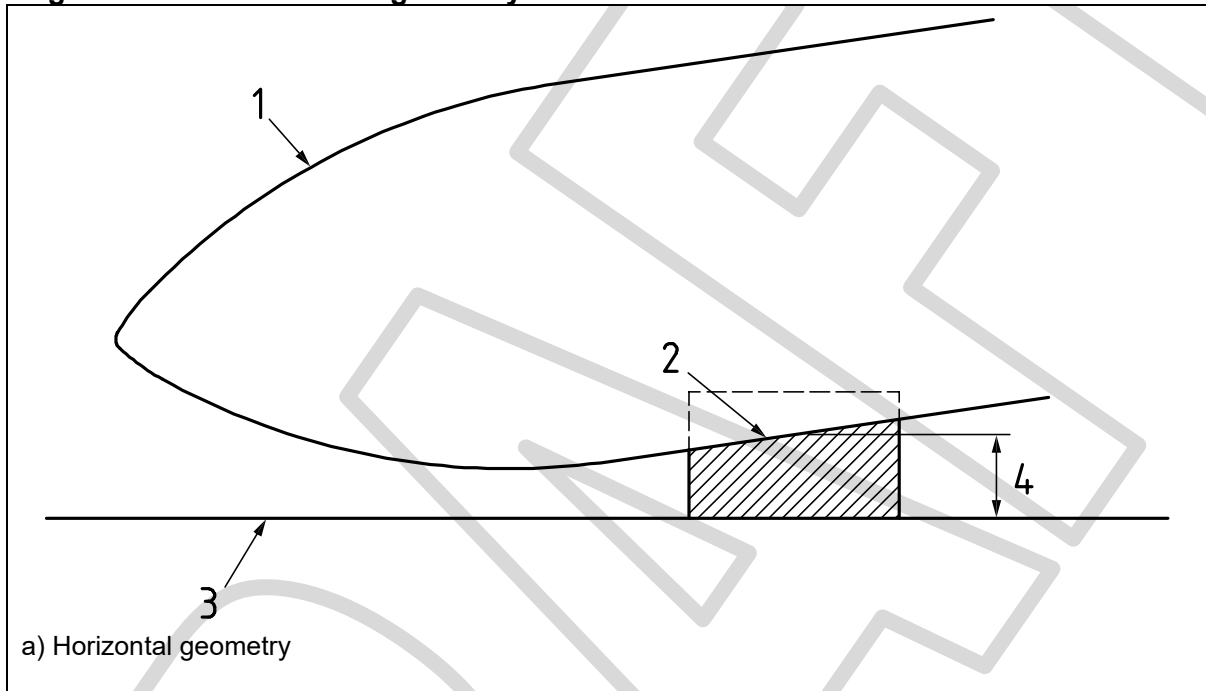
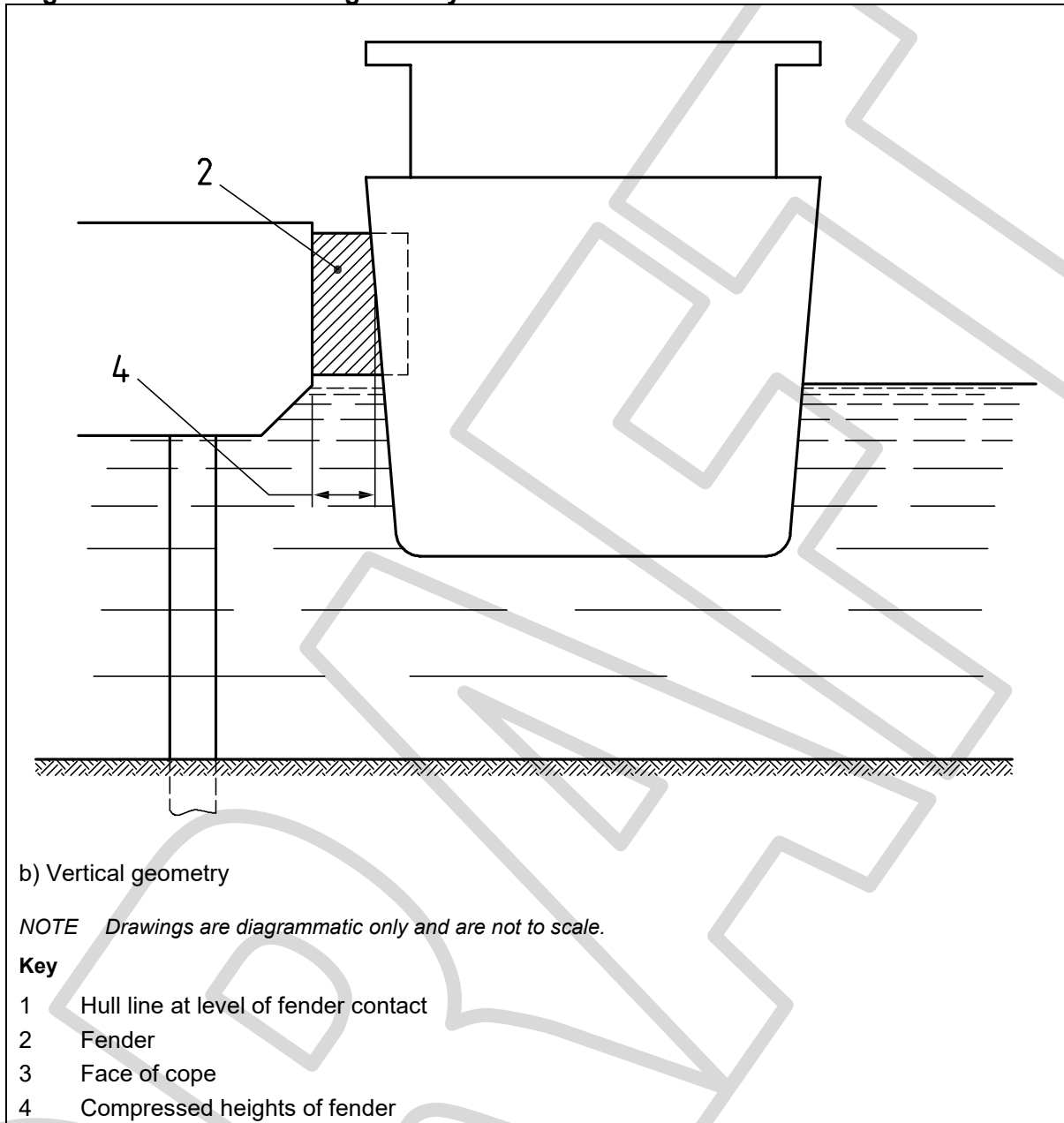


Figure 8 – Hull and fender geometry at contact



4.7 Moored reactions

Whilst a vessel is moored against a berth, the fenders are subject to the following loads or combinations of loads from the moored vessel, and should be designed to accommodate them:

- loads due to wind and currents on the vessel pushing the vessel onto the berth;
- hydrodynamic loads from passing vessels forcing the vessel onto the berth (especially applicable for berths adjacent to shipping lanes where vessels pass relatively close at speed);
- loads resulting from wave-induced motion response of the vessel;
- mooring loads from mooring lines:
- vessels mooring using constant tension winches, which give large loads on fenders;

- berth-based capstans, which are occasionally used to pull the vessel into the berth;
- vertical and horizontal loads on the face of the fenders caused by the motions of the vessel (surge, heave, roll, pitch, yaw and sway). These all give rise to friction on the fender face, although sway leads to repeated compressions of the fenders as the vessel moves away from and back onto the fender.

NOTE The above loadings can significantly reduce the life of fenders due to the effects of fatigue. When vessels are berthed for long periods and subjected to cyclic loading (from wind / wave/swell) vessels can experience hull damage (This applies to both pneumatic and elastomeric fenders - with or without panels)

The geometry of any berth should be taken into account, as this often leads to uneven loading of fenders.

Supporting structures will also be subject to moored reactions from all types of fenders and these should be accommodated in the design of the supporting structures.

4.8 Moored vessels subject to wave action

COMMENTARY ON 4.8

It is becoming more common for moored vessels to be subject to wave action as a result of:

- *berths being in more exposed locations; or*
- *long term mooring of vessels such as Floating Storage and Regasification Units (FSRU) for LNG terminals, where the vessels are likely to be moored in more extreme conditions.*

Where moored vessels are subject to wave action, dynamic mooring analyses should be carried out to establish the behaviour of the whole mooring system and the effect on the fendering. The analysis should consider:

- possible range of vessels;
- state of loading (e.g. in ballast or fully loaded);
- mooring lines and their pretensioning; and
- range of wave conditions.

NOTE 1 The behaviour of the mooring system depends on the natural frequency of the moored vessel, which also depends on all the listed factors. It might not be obvious which case is critical, for example, the critical case might not be the largest vessel.

The design of the fendering should take into account the cyclic loading that they are subject to and the effect of this cyclic loading on fender behaviour.

The behaviour of fenders under these conditions are likely to be different and it is recommended that the manufacturer is consulted. It is recommended that as a minimum the deflection of such fenders should be limited so that they do not buckle during such cyclic loading.

NOTE 2 Published data on fenders is typically based on testing where there is a minimum of 1 h between compressions, whereas under cyclic loading the fender might be compressed every 10 to 20 s.

In particular, buckling fenders might fail during cyclic loading at deflections less than the rated deflections.

Any limits on the mooring of the vessel should be documented in the facility operating manual.

5 Calculation of berthing energies

5.1 Characteristic and design berthing energy

Two levels of berthing energy, characteristic, E_k , and design, E_d , should be established for the design of the fendering system and the supporting berth structure.

The characteristic berthing energy should be calculated in accordance with **5.2** and **5.3**.

The characteristic berthing energy should be multiplied by the berthing energy factor, γ_E , to give the design berthing energy, using the equation:

$$E_d = \gamma_E E_k$$

The berthing energy factor should be established based on a risk assessment, taking into account the likelihood of the characteristic berthing energy being exceeded and the consequences of the fendering system being overloaded (e.g. the time required to replace the damaged fender and consequences for downtime of the berth; potential for damage to vessels). The risk assessment process should identify strategies to eliminate, reduce and mitigate structural and operational risks.

NOTE 1 When using a risk-based approach, typical values of the berthing energy factor are 1.5 for low-risk, low consequence situations and 2.0 for high-risk, high consequence situations.

NOTE 2 In the absence of data being available for a statistical approach, the following values for the berthing energy factor may be used:

- for a continuous quay handling conventional cargo vessels: 1.5;
- for a ferry berth: 2.0;
- for an LPG or LNG berth: 2.0; and
- for an island berth: 2.0.

NOTE 3 A means of significant risk reduction is the installation of equipment on board the ship or on the berth to monitor the vessel's berthing angle as well as the berthing velocities, both normal to the berth and rotational, to ensure that they are maintained within permissible operating limits. Where berthing velocity and berthing angle monitoring equipment is installed, the risk is reduced and for a low risk, low consequence situation an energy factor of 1.35 may be used.

5.2 Calculation of characteristic berthing energies for alongside berthing

5.2.1 General

The characteristic berthing energy E_k to be absorbed from a vessel berthing approximately parallel to the berth by the fendering system should be calculated using the following equation:

$$E_k = 0.5 C_M M_D (V_B)^2 C_E C_S C_C$$

where:

- C_M is the hydrodynamic mass coefficient described in 5.2.4
- M_D is the characteristic displacement of the design vessel described in 5.2.3
- V_B is the characteristic berthing velocity described in 5.2.2
- C_E is the eccentricity coefficient described in 5.2.5
- C_S is the softness coefficient described in 5.2.6
- C_C is the berth configuration coefficient described in 5.2.7

5.2.2 Berthing velocities

COMMENTARY ON 5.2.2

The velocity at which a vessel approaches a berth is the most significant of all factors in the calculation of the energy to be absorbed by the fendering system.

The approach to the choice of berthing velocities will depend on the knowledge of the various factors that influence the choice and in particular the location of the berth(s) to be designed.

For berthing velocities at ferry and Ro-Ro berths, see 5.3.

5.2.2.1 General

To establish the berthing velocity the designer should follow one of the following design approaches:

- a) existing ports and terminals with:
 - 1) similar design conditions; and
 - 2) different design conditions;
- b) new ports and terminals.

5.2.2.2 Existing ports and terminals

For existing ports and terminals, the designer should take the following approach:

- a) consult with the port pilots and terminal operators to establish the following:
 - 1) the types and sizes of vessels currently using the port/terminal;
 - 2) the existing fendering systems used in the port and their design parameters;
 - 3) the berthing procedures, and in particular the degree of control of berthing provided by use of tugs and/or thrusters;
 - 4) the types of navigation aids and speed of approach monitoring equipment in use;
 - 5) the prevailing environmental conditions, i.e. wind, waves and currents;
 - 6) the availability of data from environmental monitoring equipment;
 - 7) any environmental operating limits for berthing operations;
 - 8) if available, the recorded berthing velocities with statistical data for similar operations and environmental conditions;
 - 9) records or reports of any damage to the fendering system or supporting structures; and
 - 10) risks of human error or equipment malfunction in consideration of accidental operating conditions.
- b) For the new berth(s) establish the following:
 - 1) the types and sizes of vessels proposed to use the new berth(s);
 - 2) The berthing procedures to be assumed in the design;
 - 3) The types of navigation aids and speed of approach monitoring equipment that will be provided at the berth once constructed;
 - 4) the prevailing environmental conditions, i.e. wind, waves and currents with a comparison to the existing facilities; and
 - 5) the proposed number and frequency of berthing events within the design working life of the fenders and the design working life of the structure.

5.2.2.3 Limiting design conditions for existing ports and terminals

Following further consultation with the existing port's pilots and terminal operators, the designer should choose the new berthing velocities based on the existing berthing velocities only where the following apply:

- a) similar type and size of vessels;
- b) similar locations, i.e. have similar environmental conditions;