BRITISH STANDARD

BS 6349-4:
1994

Maritime structures —

Part 4: Code of practice for design of fendering and mooring systems

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/11, Maritime structures, upon which the following bodies were represented:

Association of Consulting Engineers
British Steel Industry
Concrete Society
Federation of Civil Engineering Contractors
Health and Safety Executive
Institution of Civil Engineers
Institution of Structural Engineers
Oil Companies International Marine Forum
Permanent International Association of Navigation Congresses
TBV Consult (formerly Department of the Environment, Property Services Agency)

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Contents

Foreword

This Part of BS 6349 has been prepared under the direction of the Technical Sector Board for Building and Civil Engineering (B/-) and supersedes BS 6349-4:1985 which is withdrawn.

This edition introduces technical changes but it does not reflect a full review or revision of the standard, which will be undertaken in due course.

Following suggestions from the Maritime and Waterways Board of the Institution of Civil Engineers, the Standards Committee for Civil Engineering Codes of Practice set up an ad hoc panel to make further studies. The panel's report, presented in 1975, concluded that existing British codes were inadequate for the special aspects of maritime structures and that there was a need for such a code. A format was proposed that divided the work into two distinct stages.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

The standard is issued in seven Parts as follows:

— *Part 1: General criteria;*

— *Part 2: Design of quay walls, jetties and dolphins*;

— *Part 3: Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates*;

— *Part4: 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*.

Data from Part 1 that are of particular importance to this Part are reproduced in Annex A.

Information on mooring lines is given in Annex B.

A British Standard does not purport to include all the necessary provisions of a contact. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 42, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Section 1. General

1 Scope

This Part of BS 6349 gives guidance on types of fenders, fendering systems and layouts, mooring devices and ropes, mooring system layouts for commercial vessels, and recommendations as to their suitability for various applications and locations.

The code is intended principally for use in respect of commercial installations.

NOTE 1 Application of this code to naval bases may require additional data from the relevant naval authorities as regards allowable hull contact pressures, especially for submarines, and as regards the distances at which vessels will be off the quay and the configuration and type of mooring arrangements.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 6349, the following definitions apply.

2.1
elastomeric fender units

units formed of rubber that absorb berthing energy by virtue of the work required to deform them elastically by compression, bending or shear or a combination of such effects

2.2
pneumatic fender units

units comprising rubber bags filled with air under pressure that absorb berthing energy by virtue of the work required to compress the air above the normal pressure obtaining in the bag

2.3
gross registered tonnage (grt)

the gross internal volumetric capacity of the vessel as defined by the rules of the registering authority and measured in units of 2.83 m^3 (100 ft^3)

2.4
deadweight tonnage (dwt)

the total mass of cargo, stores, fuels, crew and reserves with which a vessel is laden when submerged to the summer loading line.

NOTE Although this represents the load carrying capacity of the vessel it is not an exact measure of the cargo load

2.5
displacement

the total mass of the vessel and its contents

NOTE This is equal to the volume of water displaced by the vessel multiplied by the density of the water.

3 Symbols

The following symbols are used in this Part of BS 6349. More than one meaning is given to some of the symbols and the specific meaning is given in each case in the text where the symbols are used.

B	Beam of vessel
C	Clearance between hull of vessel and face of cope
C_b	Block coefficient of the vessel's hull
C_C	Berth configuration coefficient
C_E	Eccentricity coefficient
C_M	Hydrodynamic mass coefficient
C_S	Softness coefficient
D	Draught of ship
D	Diameter of fender
E	Effective kinetic energy of berthing vessel
H	Height of compressible part of fender
K	Radius of gyration of ship
L	Length of fender parallel to berthing face
L	Length of vessel's hull between perpendiculars
L_S	Length of the smallest vessel using the berth
L_L	Length of the largest vessel using the berth
M	Mass of vessel
M_D	Displacement of vessel
R	Reactive force of fender
R	Distance of the point of contact from the centre of mass of the vessel
V	Velocity of vessel in direction of approach
V_B	Velocity of vessel normal to the berthing face
α	Angle of approach of vessel
γ	Angle between the line joining the point of contact to the centre of mass of the vessel and the normal to the axis of the vessel
δ	Deflection of fender unit
Δ	Deflection of fender unit
μ	Coefficient of friction

Section 2. Fendering

4 General principles

4.1 Provision of fendering

It has been the practice in some ports not to provide fendering to berths other than simple timber rubbing strips, particularly where they are situated in sheltered locations such as impounded dock basins. The trend to the use of larger vessels and the siting of berths in more exposed locations such as the outer reaches of rivers and in the open sea has lead to the more widespread use of fendering systems.

The decision to fender a berth is a policy matter but wherever possible this policy should only be formulated after due consideration of all the factors involved.

The design should take account of the proposed method of operating the berth with particular reference to the use or non-use of tugs where this can be foreseen. The design should be sufficiently robust to accept without damage relatively small loads in directions or positions not anticipated in the main design analysis.

Berths may be required in a variety of locations ranging from very sheltered to open sea conditions. A range of such categories is given in Table 1.

There are also a number of types of vessel having particular requirements for berthing accommodation that may influence the appropriate type of fendering for them (see Table 2).

The types of berth location given in Table 1 cover the various situations that may occur, and the list of features to be taken into account in the design of the fendering system covers aspects which the designer should consider. In particular the range of water level will require a fendering system that is suitable for all possible water levels which may occur, and with large variations this becomes particularly important. Winds, waves and current will also vary depending on the berth location. Finally with specialized trades, such as bulk coal, ore, oil and petrochemical products, particular requirements are necessary, and the fendering system should be designed accordingly for particular vessel sizes and characteristics.

4.2 Principles of berthing

A large ship about to berth should be brought, by tugs and/or the use of her engines, to a position in front of her berth and stopped dead a short distance off, parallel to her berth. The layout out of her moorings to the berth mooring points will then commence.

The ship will be pushed or warped slowly into the berth, ideally achieving a gentle contact while making a small angle with the berth.

Table 1 — Typical categories of berth location

Type	Features to be taken into account in the design of the fendering system
Impounded basins	Approximately constant water level Usually sheltered from high winds Limited fetch for local wave generation Negligible current Range of ship sizes limited by lock dimensions Usually standard type cargoes related to berth equipment
Tidal basins	Greater range of water levels than impounded basins Limited wave exposure Limited current
Estuarial berths	Maximum tidal range and currents Greater wave exposure than tidal basins Often dedicated berths with single class or type vessels
Coastal berths	Full exposure to wind, wave and currents Usually specialized trades: bulk, coal, ore, oil Single type vessels and handling equipment

Since the ship will most frequently come alongside at a slight angle to the berth, it will initially make contact with only one fender. The ship will then rotate round before striking further fenders.

Tugs, launches and other small craft will tend to approach their berths more directly than for large ships.

Ferries and roll-on/roll-off (Ro-Ro) ships approach their berths in a rather different way which is explained in **4.7.6**.

The above berthing principles may be assumed when designing fendering systems in accordance with this code of practice.

4.3 Overall design

The function of the fendering system is to protect the berth structure against damage from ships approaching, lying alongside or leaving the berth and to limit the reactive forces on the ship's hull to acceptable values.

The range of available fender systems both of proprietary and purpose-made types is considerable and selection should take account of the following factors.

a) Acceptable reactive forces and deflections of both the berth structure and the ship's hull. It is essential that particular attention is paid to deflection limits on berths carrying pipelines, rail mounted cranes and shiploaders.

b) Types and hull forms of vessels.

c) The energy to be absorbed by the fender having regard to the location and approach conditions of the berth and its method of operation.

d) Tidal range and range of freeboards of vessels to be accommodated.

e) Acceptable limits to the distance between berth cope and side of hull after the vessel is moored in relation to the outreach of oil loading arms, crane jibs, shiploader booms and similar equipment.

The design of the fender system has to be integrated with that of the berth structure as not all types of fender are compatible with all types of structure.

Table 2 — Vessel categories

Type	Features to be taken into account in the design of the fendering system
Train and vehicle ferries	Quick turn round End berthing High docking velocities Intensive use of berth (see also notes 1, 2 and 4)
Roll on-roll off (Ro-Ro) vessels	Loading ramps, slewed or end loading (vessel mounted or shore based) End berthing (see also notes 1 and 2)
LNG/LPG carriers	Shallow draught even at full load Low berthing pressure on hull Single type vessels using dedicated berth Need to avoid fire hazards from sparking or friction (see also notes 1 and 3)
Coastal tankers	Very low amidships freeboard Intensive use of berth Need to avoid fire hazard sparking or friction (see also notes 3 and 4)
Container ships	Flared clipper bows with liability to strike shore-side installations (see also note 1)
Bulk carriers	Need to be close to berth to minimize shiploader outreach Possible need to be warped along berth for shiploader to change holds Large change in draught between empty and fully laden conditions (see also note 1)
Passenger liners	Little change of draught between empty and fully laden condition (see also note 1)
Tankers	Need to be close to berth to reduce loading arm length Large change in draught between empty and fully laden conditions Need to avoid fire hazard from sparking or friction (see also note 1)
General cargo vessels	Need to be close to berth to minimize outreach of quayside cranes and/or ship's gear Large change of draught between empty and fully laden conditions Possible long occupancy of berths
Coastal cargo vessels	Short straight run of body (see also note 4)
Miscellaneous tugs, supply boats, barges, lighters and fishing boats	Need very substantial fendering for heavy use Timber fendering usually provided (see also notes 2 and 4)
Yachts	Need for short fendering which is sometimes provided by the yachts themselves

NOTE 1 The vessels are possibly fitted with bulbous bows.
NOTE 2 The vessels are possibly fitted with belting.
NOTE 3 The vessels do not necessarily have manifolds at the amidships position.
NOTE 4 The vessels may often berth without the aid of tugs.

4.4 Materials and workmanship

Fender systems incorporate some or all of the conventional construction materials of steel, iron, concrete and timber together with natural or synthetic rubber, nylon and other man-made fibres. All these materials and the associated workmanship should be in accordance with the relevant British Standards, or other equivalent internationally recognized standards, and with clauses **56, 58, 59, 60, 61, 67,** and **68** of BS 6349-1:1984.

4.5 Vessel size

Dimensions and tonnages, etc. relating to fully laden vessels are given in BS 6349-1.

NOTE For ease of reference, **17.2** of BS 6349-1:1984 has been reproduced as Annex A in this Part.

Where vessels are berthed in a partially laden condition, reference can be made to builder's plans, load-displacement curves or tables to ascertain draught and displacement values.

For berths dedicated to loading operations it is considered imprudent to design for vessels berthing only in ballast or part laden condition. If contemplating such an approach, the designer should first satisfy himself as to the risk of a more heavily laden vessel having to be accommodated, and the possibility of a fully laden vessel having to return to the berth should not be overlooked.

4.6 Berthing velocities

The velocity with which a ship closes with a berth is the most significant of all factors in the calculation of the energy to be absorbed by the fendering system. Particular attention should therefore be given to obtaining the most appropriate value. Suggested values of transverse berthing velocities are given in Table 6 of BS 6349-1:1984, but these values only apply to sheltered conditions. In more difficult conditions velocities may be estimated from Figure 1 on which five curves are given corresponding to the following navigation conditions.

a) Good berthing, sheltered.

b) Difficult berthing, sheltered.

c) Easy berthing, exposed.

d) Good berthing, exposed.

e) Navigation conditions difficult, exposed.

Although based on observations, Figure 1 gives low approach velocities for large ships which can easily be exceeded in adverse conditions. Where there are unfavourable cross currents berthing velocities of up to 0.25 m/s may occur.

Where adequate statistical data on berthing velocities for vessels and conditions similar to those of the berth being designed are available, then the velocity should be derived from these data in preference to the tabulated values.

For ship velocities at Ro-Ro and ferry berths see **4.7.6**.

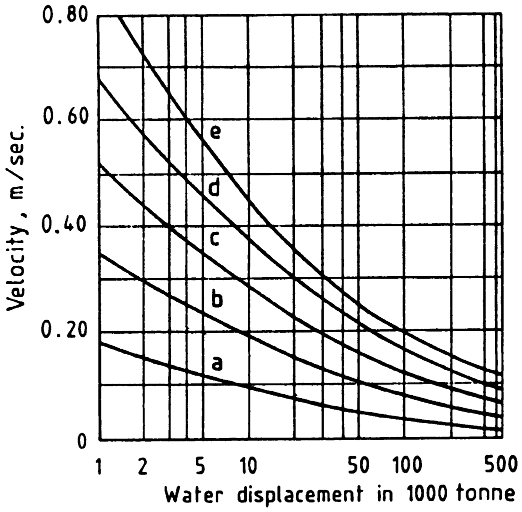


Figure 1 — Design berthing velocity as function of navigation conditions and size of vessel (Brolsma et al, 1977)

4.7 Berthing energies

4.7.1 *General*

Details of the assessment of the total energy of the moving vessel and its associated hydrodynamic mass are given in clause **41** of BS 6349-1:1984.

This value may need to be modified to assess the amount of energy E (in kN·m) to be absorbed by the fender system by addition of factors C_E, C_S and C_C, giving the following equation:

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

where

- C_M is the hydrodynamic mass coefficient;
- M_D is the displacement of the ship (in t);
- V_B is the velocity of the vessel normal to the berth (in m/s);
- C_E is the eccentricity coefficient;
- C_S is the softness coefficient;
- C_C is the berth configuration coefficient.

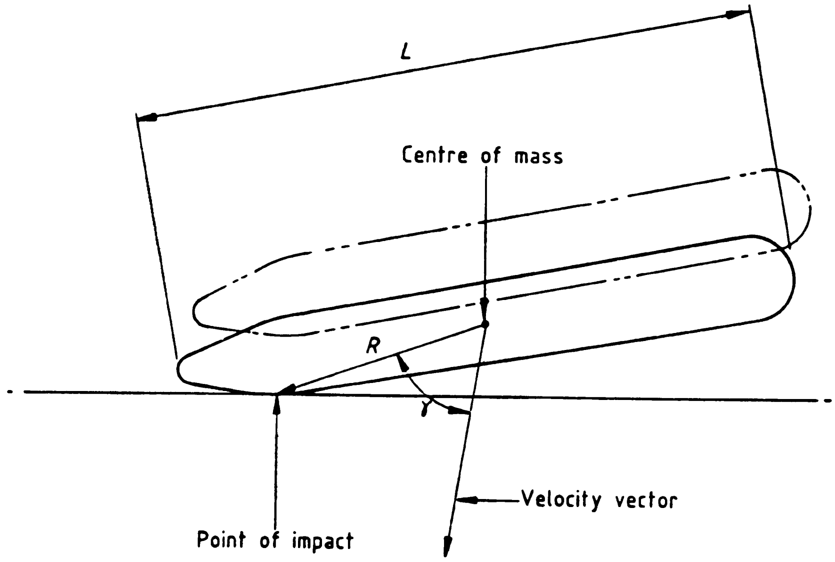


Figure 2 — Geometry of vessel approach to berth

Each fender should be designed to absorb the above berthing energy. For this purpose a "fender" may comprise any one of the following:

a) a single elastomeric or pneumatic unit, dolphin pile, or other energy absorbing unit;

b) a number of energy absorbing units coupled together to form a composite energy absorbing unit;

c) a number of energy absorbing units in sufficiently close proximity that they can be considered to act together if located at the first point of impact of the ship.

4.7.2 ***Hydrodynamic mass coefficient***

The hydrodynamic mass coefficient allows the movement of water around the ship to be taken into account when calculating the total energy of the vessel by increasing the mass of the system. The hydrodynamic mass coefficient C_M may be calculated from the following equation (see bibliography [1]):

$$C_M = 1 + \frac{2D}{B}$$

where

D is the draught of the ship (in m);

B is the beam of the ship (in m).

Use of this formula will generally lead to values of C_M in the range 1.3 to 1.8.

In general, a reduced underkeel clearance will increase this coefficient but the correct value to be used in a particular situation is uncertain. It is recommended that the calculated energy to be absorbed by the fender system be compared with records from a neighbouring berth, if available, or with data such as that given by PIANC (see bibliography [6]).

4.7.3 ***Eccentricity coefficient***

The eccentricity coefficient C_E allows for the reduction in energy transmitted to the fender system when the point of impact is not opposite the centre of mass of the vessel and may be calculated by means of the following equation:

$$C_E = \frac{K^2 + R^2 \cos^2 \gamma}{K^2 + R^2}$$

where

K is the radius of gyration of the ship and may be calculated from the formula:
$K = (0.19C_b + 0.11)\ L$

where

L is the length of the hull between perpendiculars (in m);

C_b is the block coefficient (see Table 3).
C_b = displacement/(length of hull between perpendiculars × beam × draught × density of water).

R is the distance of the point of contact from the centre of mass (in m);

γ is the angle between the line joining the point of contact to the centre of mass and the velocity vector (see Figure 2).

The above expression is often simplified by assuming γ = 90°, resulting in:

$$C_E = \frac{K^2}{K^2 + R^2}$$

Table 3 lists typical ranges of value for the block coefficient for various modern types of ships.

Table 3 — Typical ranges of C_b

Vessel type	Range of C_b
Tanker/bulk	0.72 to 0.85
Container	0.65 to 0.70
Ro-Ro	0.65 to 0.70
Passenger	0.65 to 0.70
Dry cargo/combi	0.60 to 0.75
Ferry	0.50 to 0.65

4.7.4 ***Softness coefficient***

The softness coefficient allows for the portion of the impact energy that is absorbed by the ship's hull. Little research into energy absorption by ship hulls has taken place, but it has been generally accepted that the value of C_S lies between 0.9 and 1.0. For ships which are fitted with continuous rubber fendering C_S may be taken to be 0.9. For all other vessels C_S = 1.0.

4.7.5 ***Berth configuration coefficient***

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 quay wall. The value C_C is between the ship's hull and quay wall. The value of C_C is influenced by the type of quay construction, and its distance from the side of the vessel, the berthing angle, the shape of the ship's hull, and its under keel clearance. A value of 1.0 for C_C should be used for open piled jetty structures, and a value of C_C of between 0.8 and 1.0 is recommended for use with a solid quay wall.

4.7.6 ***Berthing energies in ferry and Ro-Ro berths***

4.7.6.1 *General*

The three modes of berthing for ferries and Ro-Ro ships in common use are as follows:

a) making a transverse approach to berth alongside a quay and using the ship's own ramps for vehicle access;

b) making a transverse approach to a row of breasting dolphins and after coming to rest then moving slowly longitudinally to berth end-on against a shore ramp structure;

c) making a direct longitudinal approach to berth end-on against a shore ramp structure but using side breasting dolphins as a guide.

These three modes of berthing are illustrated in Figure 3 a), Figure 3 b) and Figure 3 c).

The berth layouts for modes b) and c) are similar and therefore both types of approach could occur at the same berth.

Mode a) is most likely to be adopted by the larger Ro-Ro vessels where bow and stern are not specifically designed for berthing forces. Mode c) is most likely to be adopted by ferries where bow or stern are designed for end berthing. It is important that the berthing provision is conformable with the ship's characteristics and the appropriate method of approach.

4.7.6.2 *Mode a)*

The fendering should be designed to absorb energies calculated in accordance with **4.7.1**.

4.7.6.3 *Mode b)*

4.7.6.3.1 *Side fenders*

Berthing energy for the side fenders should be calculated as in mode a).

4.7.6.3.2 *End fenders*

The end fenders should be designed to absorb the total energy E (in kN·m) of the ship. This energy is calculated from the following equation:

$$E = 0.5\ MV^2$$

where

V is the velocity of the vessel in the direction of approach (in m/s);

M is the mass of the vessel (in t).

NOTE 1 In the absence of factual data, V may be taken as 0.15 m/s.

NOTE 2 The values C_M, C_S, C_C and C_E may each be taken as unity for end-on berthing.

4.7.6.4 *Mode (c)*

4.7.6.4.1 *Side fenders*

The energy E (in kN·m) to be absorbed by the side fenders should be calculated from the equation:

$$E = 0.5 M_D C_M\ C_S C_C C_E\ (V \sin a)^2$$

where

M_D is the displacement of the vessel (in t);

C_M is the hydrodynamic mass coefficient;

C_S is the softness coefficient;

C_C is the berth configuration coefficient;

C_E is the eccentricity coefficient, calculated in accordance with mode a);

V is the velocity of the vessel in the direction of approach (in m/s);

a is the angle of approach [see Figure 3c)].

A minimum value of 15° is recommended for a except in cases where the berth geometry restricts the vessel to a less angled approach.

Due to the high power of most ferries and rapid turn-round times, operating speeds are generally higher than for other vessels. It is therefore recommended that the velocity V should be taken as follows [see Figure 3 c)]:

outer end dolphin 2.0 m/s to 3.0 m/s;

inner end dolphin 0.5 m/s to 1.0 m/s.

4.7.6.4.2 *End fenders*

The end fenders should be designed to absorb the total energy E (in kN·m) of the ship. This energy is calculated from the following equation:

$$E = 0.5M(V \cos a)^2$$

where

M is the mass of the vessel (in t);

V is the velocity of the vessel in the direction of approach (in m/s);

a is the angle of approach.

NOTE 1 In the case of ferries V should be taken in the range 0.5 m/s to 1.0 m/s.

NOTE 2 The values C_M, C_S, C_C and C_E may each be taken as unity for end-on berthing.

4.8 Berthing reactions and load distribution

4.8.1 ***General***

Berthing reactions are a function of the berthing energy and the deformation characteristics of the fender system. Typical reaction/deformation curves for fender types are given in clause **5**. Berthing loads should be distributed in such a manner that:

a) contact pressures on the ship's hull are kept within acceptable limits;

b) direct contact between hull and berth structure is prevented;

c) the capacity of the fender is not exceeded.

4.8.2 ***Hull pressures***

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

For LNG/LPG tankers and very large crude carriers (VLCC's), acceptable contact pressures will generally be between 15 t/m^2 and 20 t/m^2.

4.8.3 ***Fender reaction due to angular berthing***

Unless the point of impact is on the straight run of the hull and the vessel is parallel to the berth at impact the fender unit will receive an angular loading. The hull geometry over the impact area should therefore be considered in both horizontal and vertical planes (see Figure 4 and Figure 5) to establish:

a) the angle of application of load to individual fenders;

b) deflection of individual energy absorbing units within the fender and hence the aggregate amount of energy absorbed by the complete fender;

c) clearance between hull and berth structure.

Most manufacturers of proprietary elastomeric units and pneumatic fenders supply correction factors to the performance data of their units for use under angular berthing conditions. For flexible elastic dolphins, gravity fenders, etc., the effects of angular berthings should be analysed from first principles.

Where circumstances dictate that angled approaches will be the general practice at a particular berth, consideration may be given to angling the individual fender elements relative to the berth in order to create a closer approximation to parallel berthing conditions and hence more efficient performance of the fender (see Figure 6).

4.8.4 ***Fender frames***

Where a fender frame is used to reduce the contact pressure, or to couple a series of units into a single fender, the fender frame should be one of the following:

a) a proprietary type as produced by the fender manufacturer and demonstrated by him as being adequate to carry the applied loads;

b) a purpose designed steel frame with stresses and constructional details in accordance with BS 449-2 or BS 5950-1;

c) a purpose designed timber frame with stresses in accordance with BS 5268-2 treating berthing impacts as short term loadings.

Steel frames should be faced with suitable materials to minimize abrasive contact with the hull of the vessel. Facing materials may be of timber or polymers. In cases of particularly high wear the use of steel plate facing may be considered. Fixings should be such that worn or damaged facing panels can be easily and rapidly replaced. The heads of fixing bolts, set crews, etc. should be recessed into the wearing face to avoid direct contact with the hull plating, with an allowance for wear of the facing panels.

4.8.5 *Shear capacity of fenders*

Vessels moving longitudinally or vertically induce friction forces at the contact surface between fender and hull. These forces will induce shear deformations in the fender and these should be kept within acceptable limits. (Shear deflections may be limited by chains connecting appropriate parts of the fender assembly.) In the absence of information from a fender manufacturer, shear forces can be calculated using the relevant coefficient of friction, μ, multiplied by the normal force at the fender face. Typical values of μ are given in Table 4.

Table 4 — Coefficients of friction of fender facing materials in dry conditions

Material	Coefficient of friction μ
Polyethylene	0.2
Nylon	0.2
Rubber	0.5
Timber	0.3

NOTE The above coefficients of friction only apply where smooth contact surfaces are present. Hence they will not apply where the ships using the berth have rusty hulls or protuberances on their hulls as is the case, for example, with the rivets and plate ends of older vessels. In the latter cases the designer should consider higher values.

4.9 Factors of safety and design stresses

4.9.1 *General*

Two levels of impact energy, normal and abnormal, should be established for the design of the fender system and the supporting berth structure.

The berthing energy as computed in accordance with **4.7** is based on normal operations and may be exceeded for accidental occurrences such as:

a) engine failure of ship or tug;

b) breaking of mooring or towing lines;

c) sudden changes of wind or current conditions;

d) human error.

To provide a margin of safety against such unquantifiable risks it is recommended that, unless a lower value can be shown to have been satisfactory in similar circumstances, the ultimate energy capacity of each fender should be up to double that calculated for normal impacts (see **4.7.1**).

Because of the non-linear energy/deflection and reaction/deflection characteristics of most fender systems the effects of both normal and abnormal impacts on the fender system and berth structures should be examined.

4.9.2 *Compressible fender on rigid structure*

Where there is a compressible fender on a rigid structure, all the energy has to be absorbed by the fender, the structure being assumed to have zero or negligible energy absorbing capacity.

There is little information available on compressible fenders loaded beyond the maximum energy absorption value. The fender unit should therefore be selected with a maximum value not less than the design abnormal energy level.

This may be achieved either by using a compressible fender of this rating or by using a compressible fender to absorb the normal impact energy, in series with a collapsible steel fender to protect against abnormal loading, which should be easily replaceable.

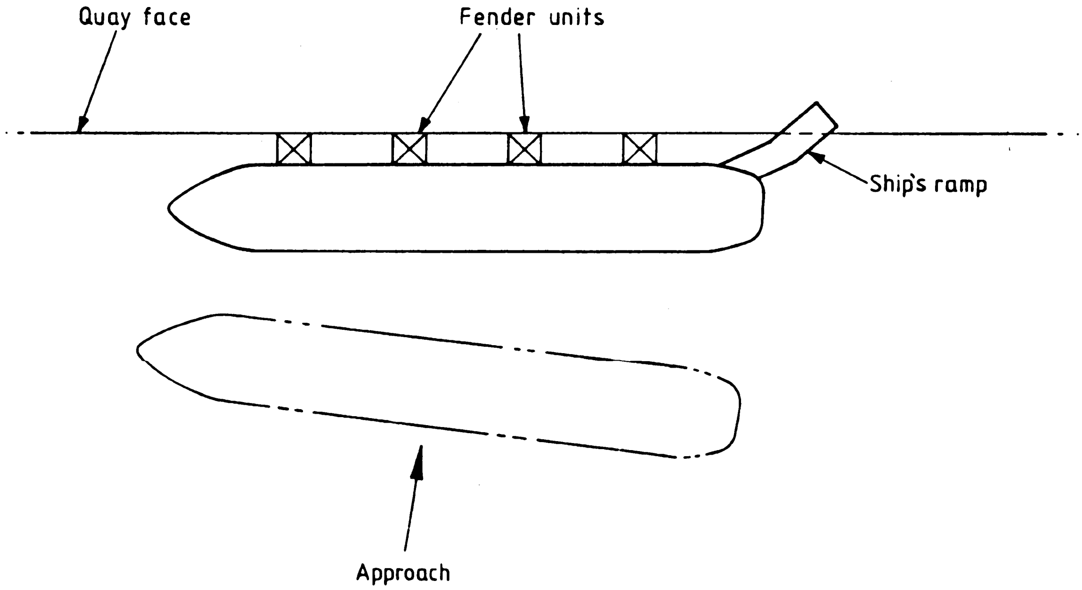
The reactions corresponding to given energy absorption may be obtained directly from the performance curves for a given fender. The normal and abnormal reactions should be taken as the maximum reactions occurring over the ranges zero to normal and zero to abnormal respectively.

The fender manufacturer may state a tolerance on the figures quoted for reactions and energies. If not, the tolerance of ± 10 % should be taken into account in the design of the fendering system.

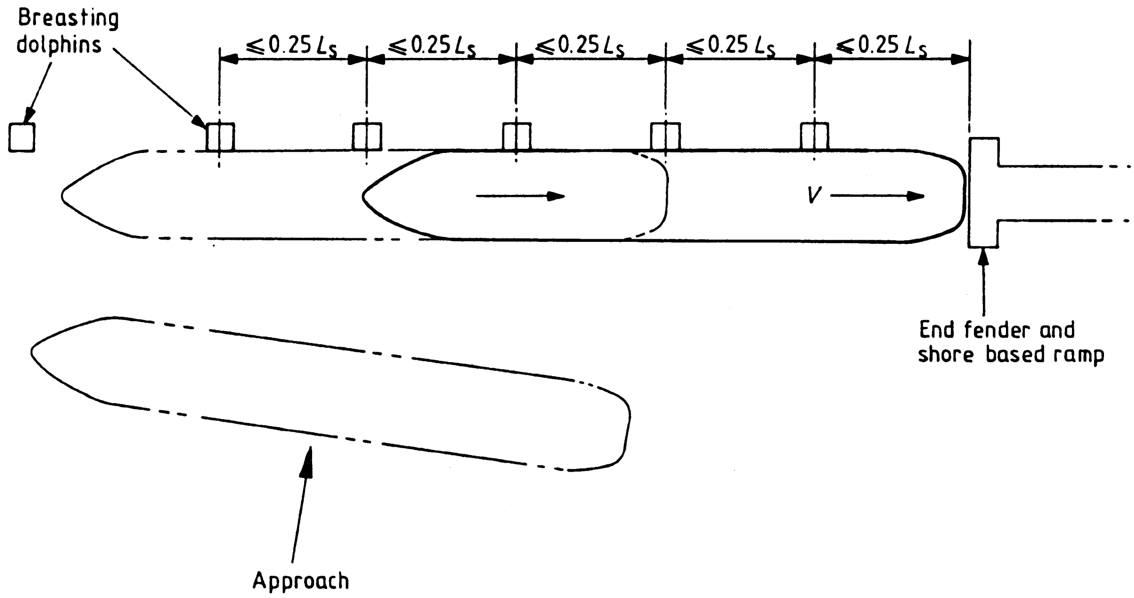
Under the normal reaction, stresses in the steel components of the fender system should not exceed the normal permissible stresses given in BS 449-2 associated with elastic design of the system. Under the abnormal reaction, such stresses in the system should not exceed 0.8 of the yield stresses.

It should be noted that the maximum permitted stress levels at normal and abnormal energies cannot always both be realized.

NOTE For the allowable elastic stresses in the berth structure under the action of the berthing forces and the load factors to be applied to the berthing forces for limit state design of the berth structure, reference should be made to BS 6349-2.

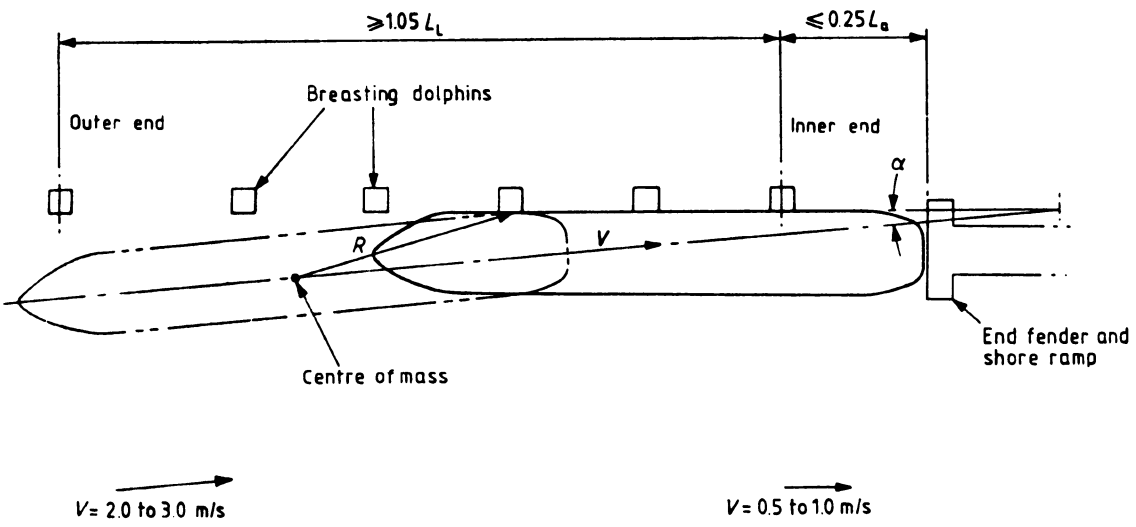


a) Berthing mode



b) Berthing mode

Figure 3 — Ferry and Ro-Ro vessel berthing



c) Berthing mode

Figure 3 — Ferry and Ro-Ro vessel berthing

4.9.3 ***Flexible steel pile dolphins***

In the case of flexible steel pile dolphins all the energy of impact has to be absorbed by lateral deflection of the piles. Energy absorption is a function of the square of the bending stress.

The pile section should be selected to operate at 0.8 yield stress under abnormal energy conditions. For the recommended ratio between abnormal and normal energies of 2.0, this gives the normal energy bending stress as 0.57 yield stress.

4.9.4 ***Flexible steel pile dolphins with compressible fenders***

In certain circumstances requiring large energy absorption, compressible fenders may be mounted on flexible dolphins. The assessment of safety factors becomes complex and should be carried out from first principles, taking into account the value of the compressible fender at the load compatible with the limiting stresses in the steel as discussed in **4.9.2** and **4.9.3**.

4.9.5 ***Flexible pre-cast concrete pile dolphins***

It is recommended that concrete piles for use in flexible dolphins are pre-stressed.

4.9.6 ***Flexible timber pile dolphins***

For small dolphins in locations such as yacht marinas, timber, generally greenheart or pitch pine, may be used instead of steel. Working stresses should be in accordance with BS 5268-2, treating berthing impacts as short term loadings.

4.9.7 ***Berthing beams***

Berthing beams may be provided in the following situations.

a) As a fendering structure for a piled jetty, generally in locations where a large range of vessel sizes is to be accommodated or where it is advantageous not to design the jetty itself for large horizontal forces. Inclined berthing beams are generally used in these cases.

b) To prevent vessels from running aground or causing damage to existing installations as, for example, at difficult approaches to locks.

Berthing beams generally consist of a fendered steel or concrete beam above water level supported by steel cantilever piles. The cantilever piles may be vertical or outward raking; in the latter case the structure is known as an inclined berthing beam. Some berthing beams are partially supported against horizontal forces by elastomeric units braced against piled strong points; the strong points are generally located near the ends of the berthing beam.

The following points are important in the design of all berthing beams.

c) The spacing of the piles should be such that they carry similar dead load working stresses.

d) Unless strong points are being used in the design, more slender or more widely spaced piles should generally be used at the ends of the berthing beam than in the middle. The choice and arrangement of the piles should be such that under an abnormal impact near the end of the beam both the piles near the impacted end and those in the central stiffer section will be loaded to a value as near as possible to the permissible stress.

The permissible stress may be taken as 0.8 of the yield stress. The bending and tension of the berthing beam should be considered when calculating these stresses.

e) Small fenders will generally be required to prevent damage to the berthing face under the initial impact. These fenders need only be designed to absorb 5 % of the abnormal berthing energy.

In addition to the above points, when designing inclined berthing beams the supporting piles should be raked outward so that they are near their working stress under the dead load of the beam. Typical rakes range from 1:5 to 1:12. On vessel impact, when the piles will bend back, the stress in the pile should change from the dead load stress, through neutral stress up to the permissible stress already defined. Buoyancy effects should be considered in the design, low water being the critical condition under dead load and high water the critical condition under live load.

4.10 Mounting and suspension

Mounting and suspension systems for fenders should be of robust and simple design with the use of hinges, anchor chains, turnbuckles and similar devices kept to a minimum. Parts of mounting systems situated permanently below water level or in the splash zone need special attention to ease maintenance and the replacement of damaged units.

Where fenders are mounted on structures with cathodic protection against corrosion, consideration should be given to the mounting system to prevent stray electrical currents having corrosive or other adverse effects on the fender units.

Only one type of metal should be used to avoid electro-chemical corrosion, and no mountings (including stainless steel) should be allowed to touch steel reinforcement in concrete.

Suspension systems for such items as horizontal timber or rubber fenders designed to float up and down on the tide should allow easy travel of the movable elements and minimize mechanical wear and the aggravation of corrosion in the supporting structure. The dimensions of the back-up structure should be checked to ensure that proper contact is made between the fender and the structure at all states of the tide.

Mounting systems should be such that if severe overloading of the fenders occurs transmission of the overload and subsequent damage to the supporting structure is prevented or minimized. In circumstances where severe overloading is expected which may lead to failure of the fender to berth connections, suitable back-up measures should be taken to prevent the fender unit becoming detached from the berth structure.

4.11 Application of fender layout for berths

4.11.1 ***General***

Fender systems may be formed of groups of individual fenders as described in **5.1** to **5.8** or a combination of differing types of fenders. Fender systems may be classified in three general categories, i.e. those for continuous quays, those for island berths and those for lead-in jetties. Other systems will generally be variants of or combinations of these three categories.

4.11.2 ***Continuous quays***

On continuous quays there is generally no precise delineation of individual berths in order to give flexibility of operation and the accommodation of a wide range of vessels. In such cases the fendering system should allow a ship to berth at any position along the length of the quay. It may consist of either:

a) a continuous berthing frame supported on fender piles driven in front of the quay or directly on the face of the quay on elastomeric units (see Figure 7);

b) a series of individual fenders, the spacing of which should comply with the following (see Figure 8):

1) the fenders should prevent the vessels striking the berth structure when berthing on the bow or stern quarters (see Figure 5), and allow sufficient fenders to be mobilized for energy absorption;

2) the fenders should allow vessels to lie alongside with adequate support from the fenders along the straight run of the ship's hull.

For condition 2) it is recommended that the fender spacing does not exceed 0.15 L_S where L_S is the length of the smallest ship.

4.11.3 *Island berths*

Where vessels are berthed about a fixed point such as oil loading arms, the primary fendering can be concentrated at two or more points depending on the range of vessels to be accommodated. These can be in the form of localized strong points within a loading platform or separate berthing dolphins positioned about the loading platform (for typical layouts see Figure 9, Figure 10 and Figure 11). The spacing of primary fenders has to take account of the actual geometry of the vessels to be berthed but should be in the range 0.3 L to 0.4 L where L is the length of the ship to be accommodated. Where the range of vessel sizes is large, then provision of an inner and outer set of primary fenders may be necessary (see Figure 11).

Where there is an operational requirement for small vessels such as tugs, maintenance and stores craft to lie against the loading platform, it will be necessary to provide a secondary fendering system. Design of this system has to take particular account of:

a) prevention of direct impact between vessels and equipment on the loading platform;

b) restriction of lateral deflection of the loading platform to limits acceptable for the equipment.

The primary berthing face should be positioned sufficiently forward of the loading platform to ensure that under maximum deflection of the fenders the vessel does not strike the platform or overload the secondary fenders.

4.11.4 *Lead-in jetties*

4.11.4.1 *General*

Fendering systems for guiding vessels into the entrances of confined areas, such as locks, dry-docks, ship-lift systems and passageways, may comprise either a continuous faced structure or a series of individual dolphins.

4.11.4.2 *Continuous faced systems*

Continuous faced systems may be formed of either:

a) a rigid structure faced with:

1) individual elastomers;

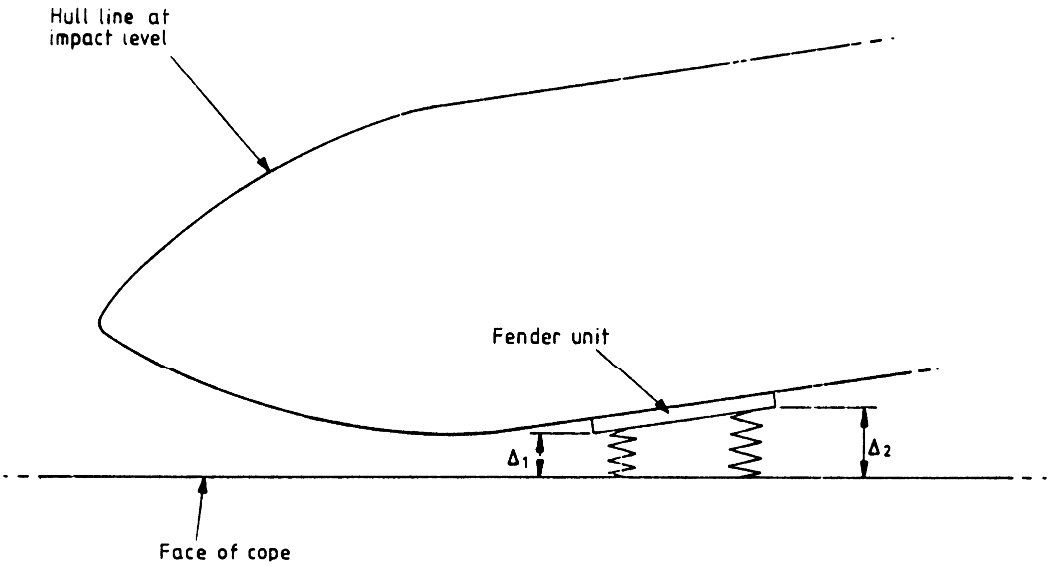
2) fender frame mounted on elastomer and/or fender piles; or

b) a flexible jetty or berthing beam.

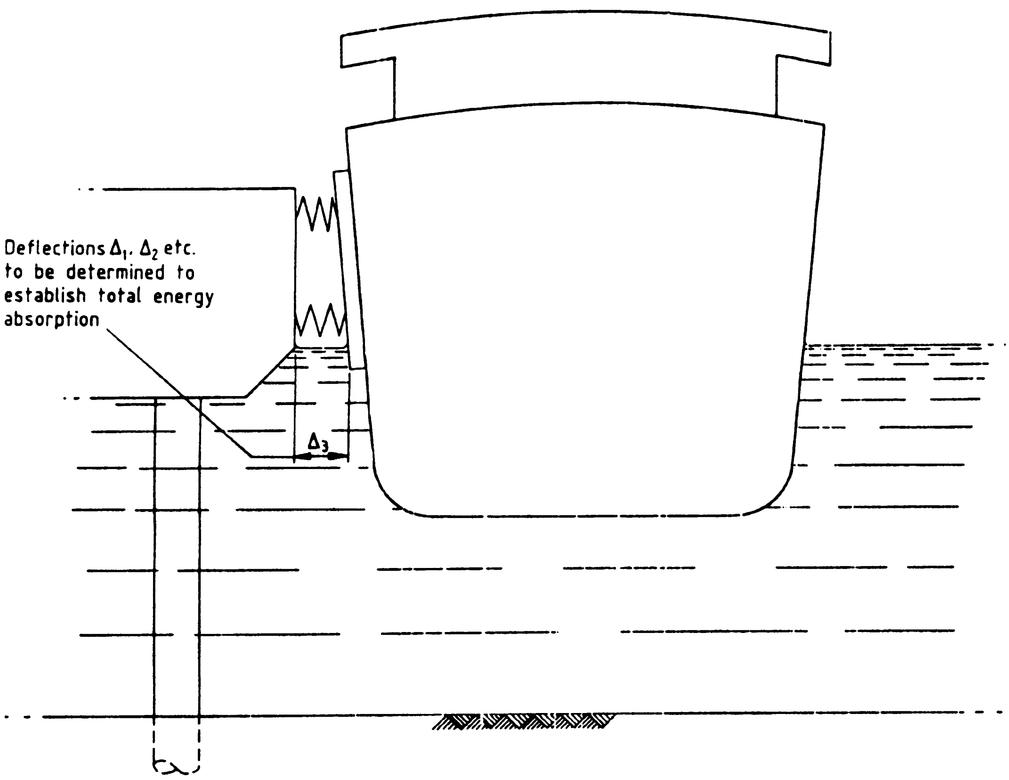
4.11.4.3 *Dolphin system*

Dolphins forming a lead-in system may be of the elastic type, gravity type or the rigid type with energy-absorbing fender units. Spacing should be such as to allow the smallest design vessel to be able to lie alongside with at least two dolphins in contact with the straight run of the hull (see Figure 12).

A maximum spacing of dolphins of 0.25 L_S is recommended where L_S is the length of the smallest design vessel (excluding tugs and small coastal vessels where it is considered that they can proceed safely without the aid of dolphins).



a) Horizontal geometry



b) Vertical geometry

NOTE. Δ_1, Δ_2, Δ_3 are deflections of the fender unit (in m).

Figure 4 — Hull and fender geometry at impact

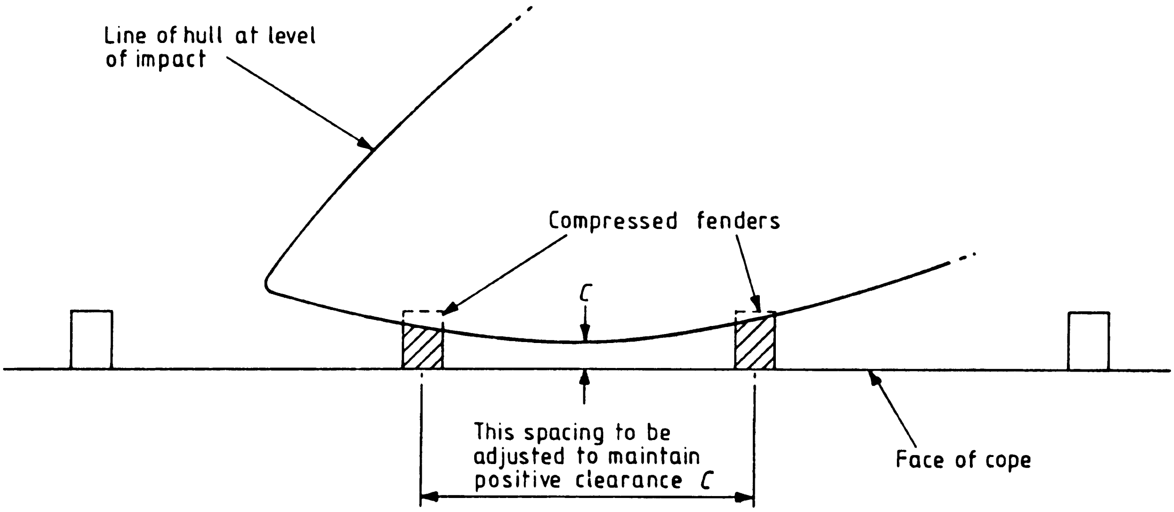


Figure 5 — Plan showing hull and cope geometry at impact

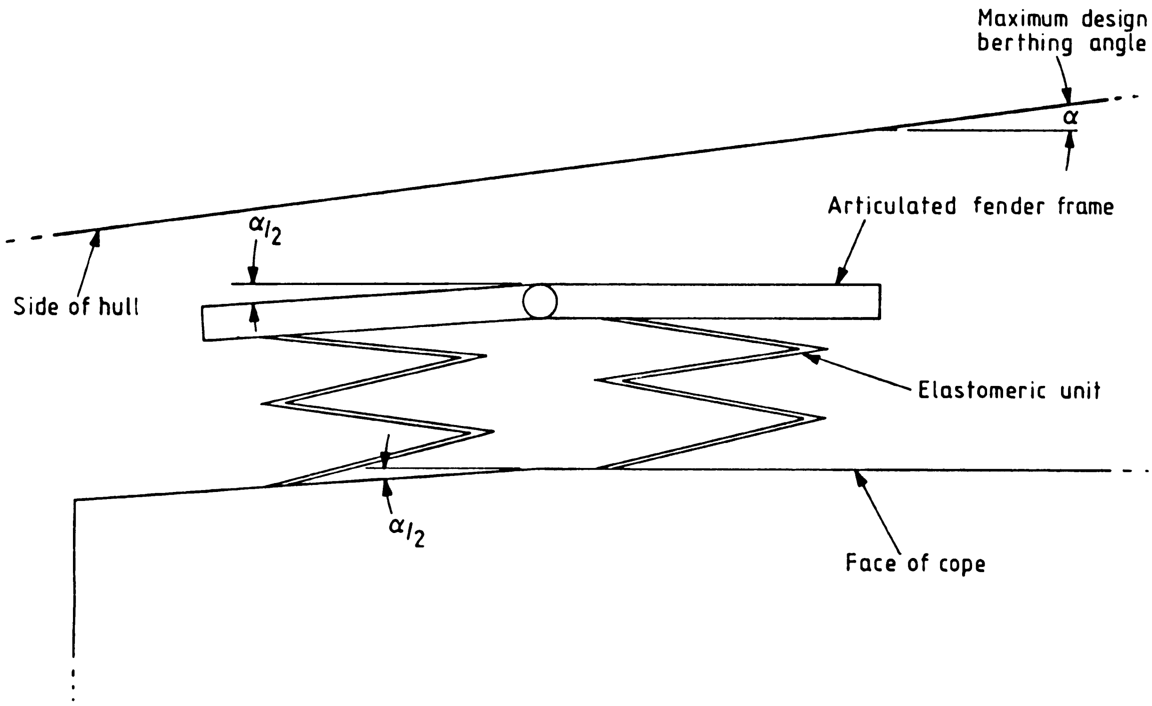
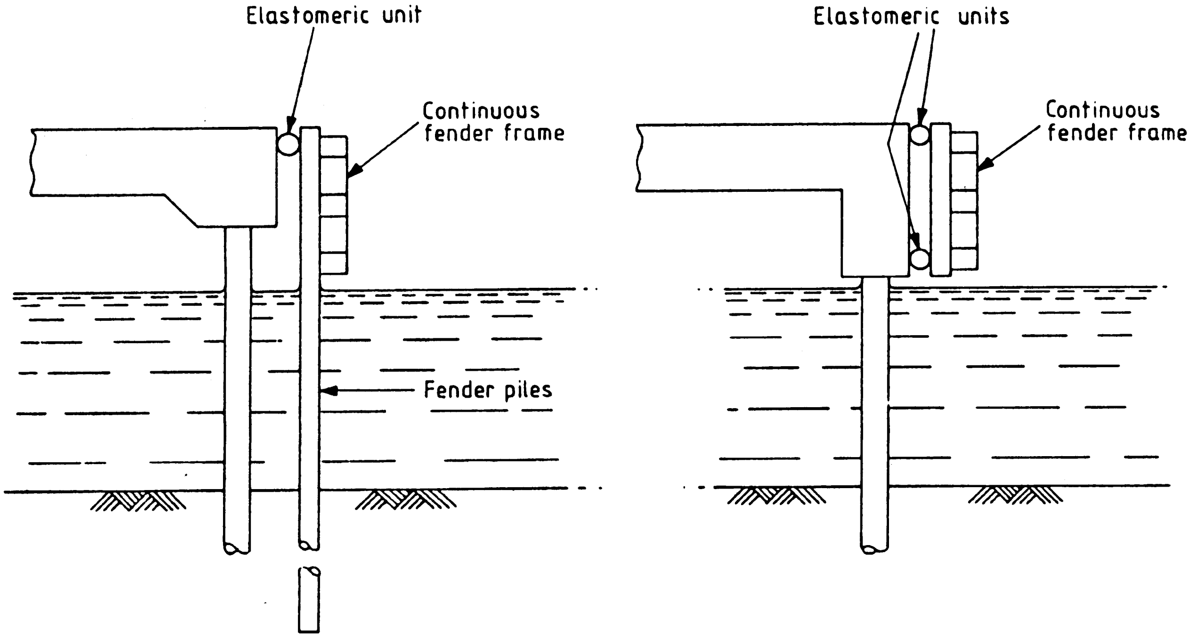


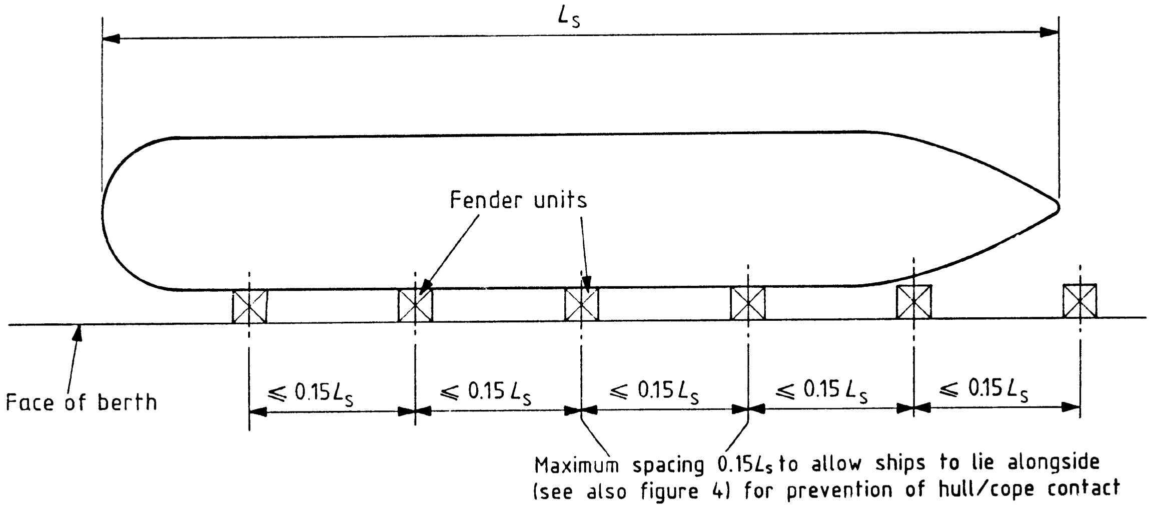
Figure 6 — Plan showing angled fender units



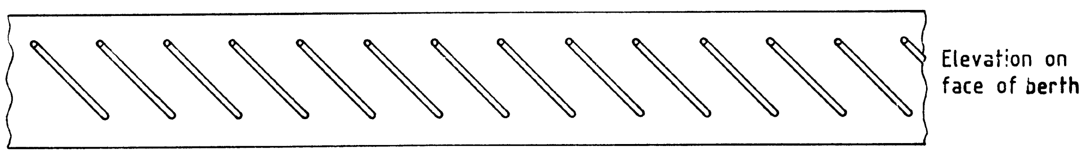
a) Supported on fender piles

b) Supported on the face of the quay

Figure 7 — Continuous fending facing



a) Layout using large fender units



b) Layout using small elastometric units

Figure 8 — Fender layout on a continuous quay

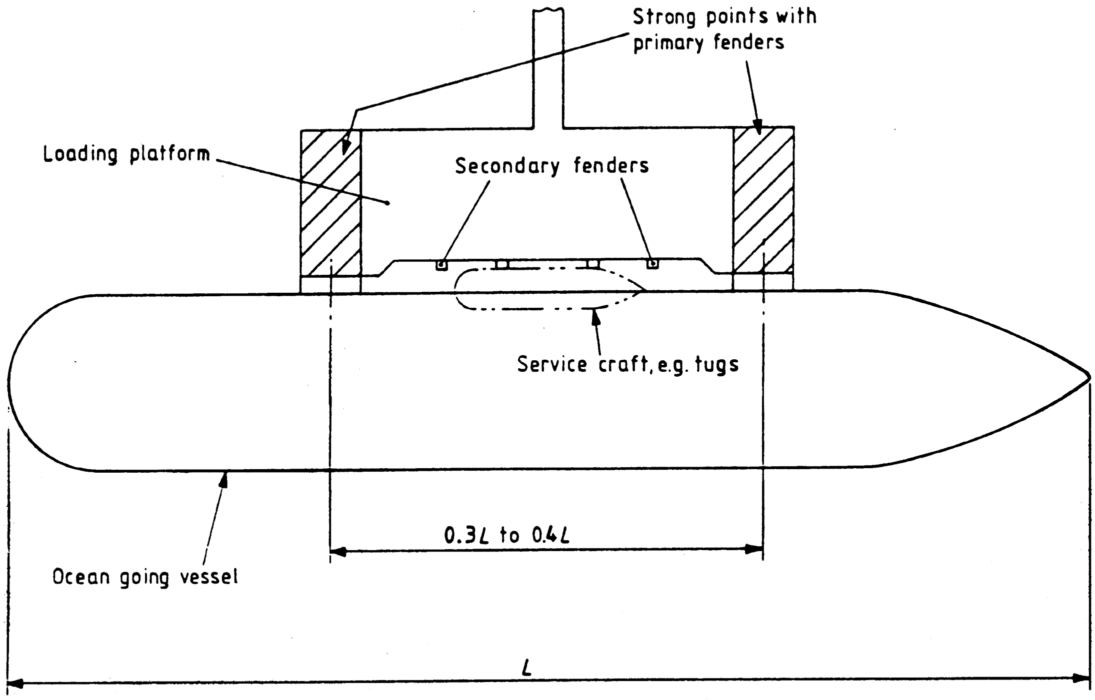


Figure 9 — Plan of single island berth

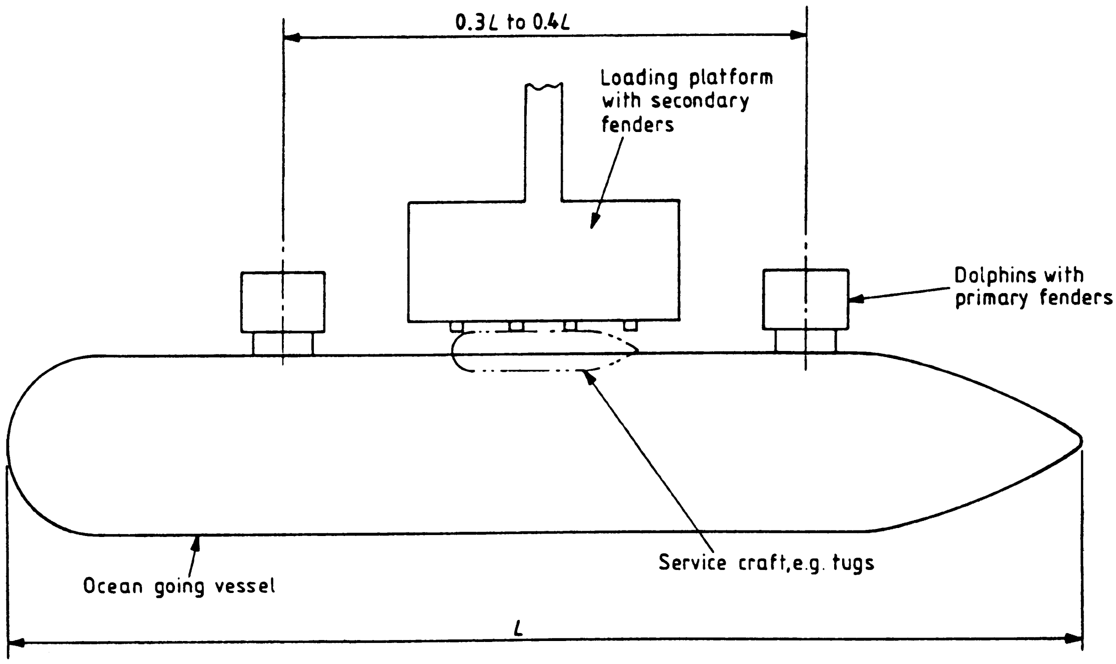


Figure 10 — Plan of three-island berth

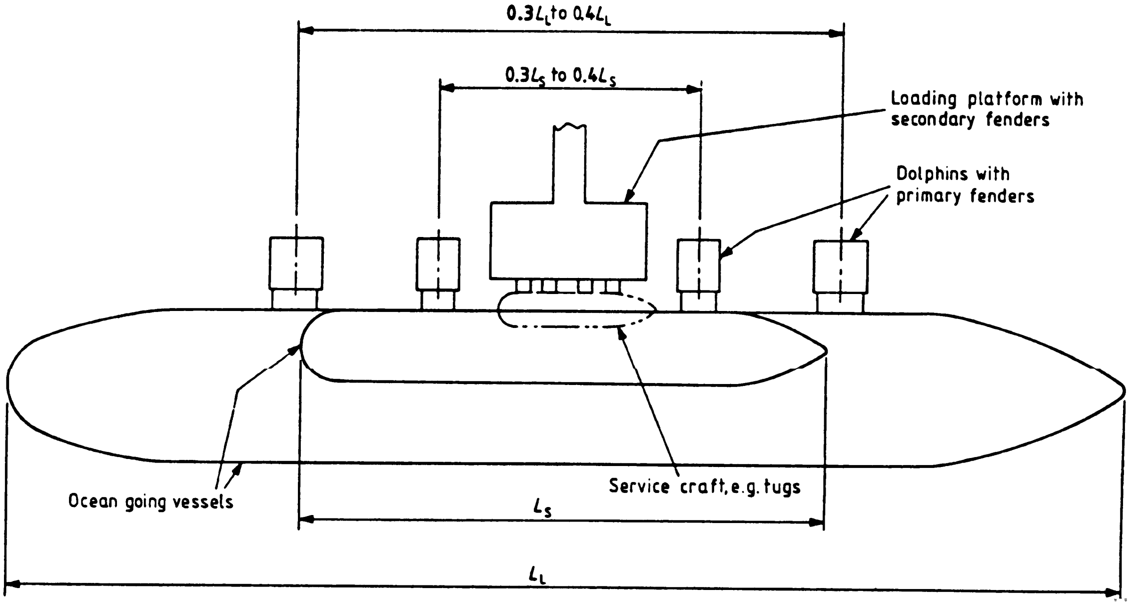


Figure 11 — Plan of five-island berth

5 Types of fender

5.1 Fenders using elastomeric units

5.1.1 *General*

This category of fenders represents the largest group in general use. Elastomeric units are made of natural or synthetic rubber formed into various shapes and absorb the impact energy by means of their deflection. Elastomeric units are generally hollow but solid rubber blocks may be obtained.

Elastomeric units are generally mounted directly on rigid structures such as caissons, solid quays or piled structures having minimal energy absorption capacity of their own.

5.1.2 *Mounting*

Mounting arrangements should comply with **4.10**. If the supporting berth structure is of concrete, it should be fitted with built-in threaded anchor sockets for the fender fixing bolts.

Bolts should preferably be of stainless steel, or galvanized, so that corrosion is minimized to allow easy removal of the fender units for maintenance or replacement. Sherardized or electroplated steel bolts may be used in locations where corrosion is to a lower degree or where it is of lesser importance.

A complete fender may comprise a single elastomeric unit with direct contact with the ship's hull or with a suitably faced berthing frame to reduce hull pressure, or a group of elastomeric units connected to a common berthing frame.

5.1.3 *Types and characteristics*

The general characteristics of the various commercially available elastomeric units are given in Table 5.

The performance curves shown in Table 5 illustrate a 50 % deflection which is the limit of deflection under normal impact conditions recommended by the manufacturers of most elastomeric units. For the limiting deflections under abnormal impact conditions, reference should be made to the manufacturer's published performance curves.

5.2 Pneumatic and foam-filled fenders

5.2.1 *Pneumatic fenders*

Pneumatic fenders comprise a hollow rubber bag filled with air, berthing energy being absorbed by the work required to compress the air. They are generally in the form of cylinders either with domed ends floating in front of the berth structure and compressed diametrically, or with an outer domed end, mounted directly on the berthing face and compressed axially. Contact with the ship can be direct or via a berthing frame mounted over one or more pneumatic fenders.

Pneumatic fenders are pressurized to a pre-set value in their uncompressed condition and some are fitted with pressure relief valves. The fender should be capable of absorbing the abnormal berthing energy (see **4.9.1**) at a compression not exceeding that specified as the maximum by the fender manufacturer and the relief valve (if provided) should be set to operate at a compression slightly above this level.

5.2.2 *Foam-filled fenders*

Foam-filled fenders consist of a resilient closed cell block covered by a reinforced rubber skin, berthing energy being absorbed by the work required to compress the foam cells. They are generally in the form of cylinders with domed ends floating in front of the berth structure.

5.2.3 *Mounting*

Mounting of both floating and fixed types should comply with **4.10**.

Mooring systems for floating fenders, which generally comprise chains or wire ropes with swivels and shackle connections to anchor points in the fixed structures, should:

a) retain the fender close to the berthing face at all states of the tide and in all wind, wave and current conditions when the berth is either empty or occupied;

b) prevent the fender from rolling up over the cope under the berthing action;

c) be suitably protected to minimize damaging abrasion against the berth;

d) minimize damage to the berth structure in the event of the fender being dragged off-station by an incorrect vessel approach or by any other cause.

The contact area of the fender increases considerably with compression, and the mounting on the berth should allow the full contact area between fender and berth to be developed under impact over the full tidal range.

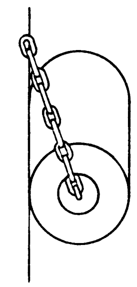
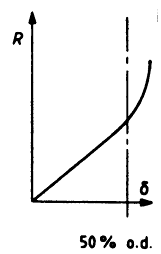
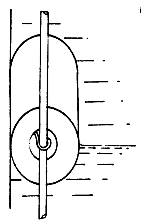
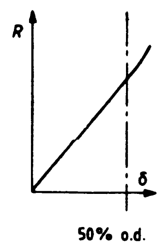
In some cases it may be necessary to extend the beating face above the cope to prevent floating fenders from riding over, provided this is compatible with the accommodation of the mooring system and berth operations.

Mounting systems for fixed pneumatic fenders should comply with the recommendations for fenders using elastomeric units.

5.2.4 *Pneumatic and foam-filled fender characteristics*

The general characteristics of commercially available pneumatic and foam-filled fenders are given in Table 6.

Table 5 — Elastomeric units: types and characteristics

Type	Shape and mounting	Approximate size range mm	Energy range t m/m	Reactive force range t/m	Performance curve	Remarks
Hollow cylindrical	May be horizontal, vertical, catenary or diagonal 	Outside diameter of fender = 100 to 3 000 Generally the inside diameter of the fender is half the outside diameter	0.1 to 110	4 to 210		Generally simply suspended against berthing face. Type of suspension dependent on size of fender; may be chains or rods
Cylindrical floating		Outside diameter of fender = 500 to 2 500	2 to 50	20 to 90		Relative density abort 0.97. Energy absorption about 75 % of hollow cylinder. Suspension by anchored cables

NOTE 1 *R* is the reactive force of the fender.

NOTE 2 If the chain or rod forms a substantial percentage of the bore of the cylindrical fender, the performance curve will be affected.

Table 5 — Elastomeric units: types and characteristics

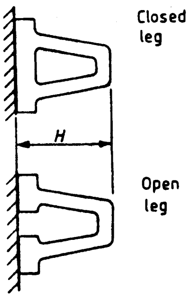
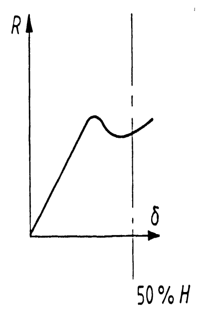
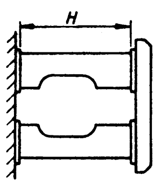
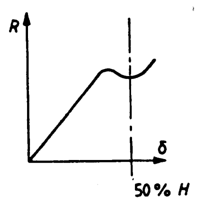
Type	Shape and mounting	Approximate size range mm	Energy range t·m	Reactive force range t	Performance curve	Remarks
V-shaped		H = 150 to 1 300	0.3 to 60	6 to 110		Large variety of rubber grades made with single base plate (closed leg) or double base plate (open leg); also with resin board facing to decrease surge friction. It is also possible to use multiple units with a fender frame.
Buckling column		H = 400 to 2 500	3 to 160	20 to 180		Large variety of rubber grades. It is used with a fender frame. Reaction R at least 30 % less than for V-shaped fenders. Fenders may need to be supported by piles
NOTE R is the reactive force of the fender.						

Table 5 — Elastomeric units: types and characteristics

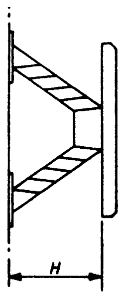
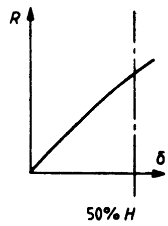
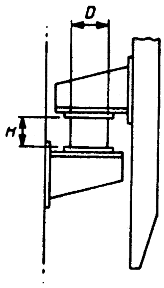
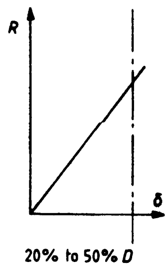
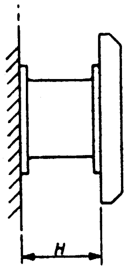
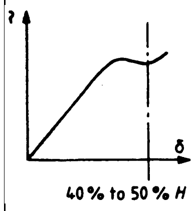
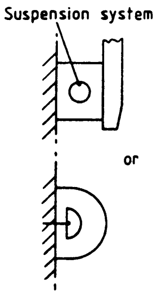
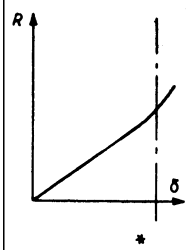
Type	Shape and mounting	Approximate size range mm	Energy range t m	Reactive force range t	Performance curve	Remarks
Shear fender multi-bonded		H = 500 to 1 650	1 to 50	30 to 100		May be mounted horizontally or vertically or grouped with fender frame. Will probably require facing panel to be supported
Shear fenders		D = 400 to 550 H = 190 to 270	1 to 3	10 to 30		Can be mounted in vertical pairs
NOTE D is the diameter of the fender. R is the reactive force of the fender.						

Table 5 — Elastomeric units: types and characteristics

Type	Shape and mounting	Approximate size range	Energy range	Reactive force range	Performance curve	Remarks
Hollow cylindrical: axially loaded		mm H = 300 to 3 500	t·m 0.4 to 700	t 4 to 600		Large variety of rubber grades available
Rectangular square and "D" hollow		mm Cross-sectional dimensions vary from 150 × 125 to 305 × 305	t·m/m 1 to 4	t 30 to 90		* Large variation in performance in relation to deflection limits

NOTE D is the diameter of the fender.
R is the reactive forces of the fender.

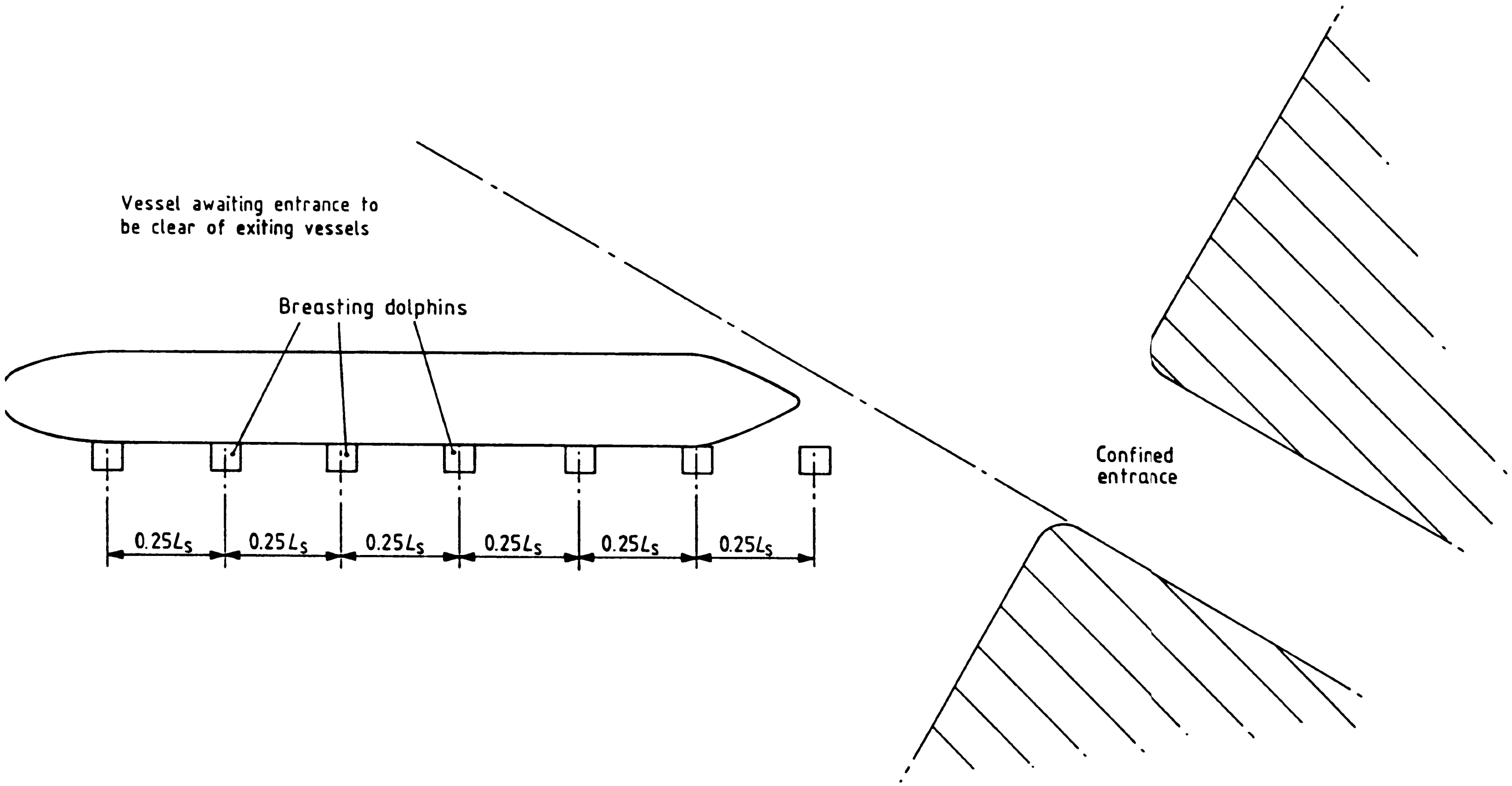
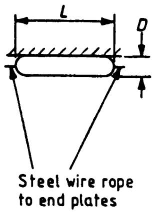
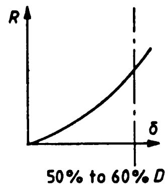
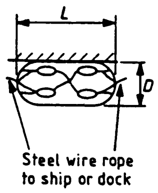
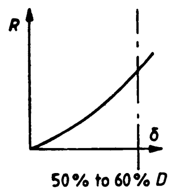


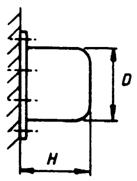
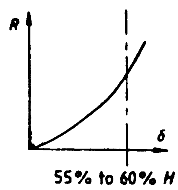
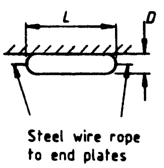
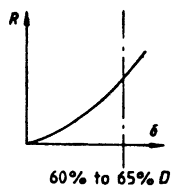
Figure 12 — Lead-in jetty layout

Table 6 — Pneumatic fenders: types and characteristics

Type	Shape and mounting	Approximate size range mm	Energy range t·m	Reactive force range t	Performance curve	Remarks
Low pressure air floating (0.007 N/mm^2)		D = 1 000 to 4 500 L = 3 000 to 30 000	1 to 700	10 to 1 100		
High pressure air floating (0.05N/mm^2) With or without pressure relief valve		D = 300 to 6 000 L = 3 000 to 12 000	0.03 to 850	1 to 800		Usual protection by cable net and tyres

NOTE L is the length of the fender parallel to the berthing face.
D is the diameter of the fender.
R is the reactive force of the fender.

Table 6 — Pneumatic fenders: types and characteristics

Type	Shape and mounting	Approximate size range mm	Energy range t·m	Reactive force range t	Performance curve	Remarks
Pneumatic end loaded		D = 600 to 2 000 H = 450 to 1 500	1 to 50	10 to 150		Initial air pressure 0.1 N mm^2
Foam-filled		D = 900 to 6 000 L = 1 500 to 1 2 000	3 to 1 650	15 to 1 300		

NOTE L is the length of the fender parallel to the berthing face.
D is the diameter of the fender.
R is the reactive force of the fender.

5.3 Flexible dolphins

5.3.1 *General*

Flexible dolphins are formed of vertical or near vertical piles cantilevered from the river or sea-bed which absorb the berthing energy by deflection of the pile heads horizontally under the berthing impact. Dolphins may be formed of piles acting either singly or in groups that are suitable for blows from any direction or of panels of box/sheet piling that are most suitable for primary blows perpendicular to the panel only.

5.3.2 *Geotechnical considerations*

Suitability of flexible dolphins is dependent on soil conditions capable of resisting the horizontal loads exerted by the embedded length of the pile during impact of the vessel and of returning the pile to its original position when the berthing or other applied forces have ceased to act.

5.3.3 *Loadings*

Flexible dolphins should be designed to resist the following forces, and the effects of torsion from:

a) berthing impact;

b) rope pulls where the dolphin is also used for general mooring purposes or for warping vessels into passages, locks and dry-docks;

c) wind, wave and current effects;

NOTE Particular attention should be given to dynamic effects where cantilever dolphins are located in areas with fast flowing currents.

d) the moored vessel being blown against the berth.

5.3.4 *Methods of pile analysis*

The embedment conditions of the piles may be analyzed by an elastic method such as that proposed by Reese and Matlock (see reference [1]) or other recognized method.

5.3.5 *Materials*

In order to obtain maximum energy absorption, piles are usually of weldable quality high tensile steel with a guaranteed minimum yield stress in the range 350 N/mm^2 to 690 N/mm^2. Tubes in which the strength varies through the pile length to suit the varying bending moments are fabricated for this application and may be used either singly or in groups.

The less highly-stressed upper section of the piles should be of normal structural grades of mild or high tensile steel to facilitate the welding on of decks and other fittings.

Deck units and associated items should be of normal grade structural steel, concrete or composite construction.

5.3.6 *Design stresses and deflections*

5.3.6.1 *Pile stresses*

Although pile deflections are primarily limited by consideration of stress and energy factors, deflections should also be limited such that:

a) deflected dolphins do not foul adjacent structures;

b) access bridges or catwalks supported by the dolphins are not dislodged;

c) there is no direct contact between the ship's hull and the walls of the piles.

5.3.6.2 *Decks*

Steel and concrete stresses should be in accordance with BS 449-2 or BS 5950-1 and BS 8110 as appropriate.

5.3.7 *Decks and berthing frames*

Decks if necessary should be capable of transmitting to the piles the primary berthing force, the secondary reaction due to friction and all associated moments including torsional moments induced by the eccentricity of the impact. It is essential that the deck system supports the berthing face at a sufficient distance from the piles to prevent contact between them and the hull as they deflect.

Where contact pressures are acceptable, contact between hull and dolphin may be via vertical rubbing strips bolted to the face of the pile but berthing frames should be provided where necessary to keep contact pressures within acceptable limits.

Flexible dolphins formed of groups of piles should have a deck or series of decks at various levels connected to a common berthing frame. These decks may be of steel or concrete construction and should be capable of fully mobilizing all piles in the group to resist the berthing blow.

In all cases of flexible pile dolphins local crushing effects at the points of application of the impact forces should be investigated and stiffening provided as necessary. This may be in the form of internal steel ring stiffeners or concrete plugs and they should be designed to avoid shattering and subsequent displacement under impact.

The berthing frame may be in one plane or of a "wrap-around" type dependent on the direction or directions from which berthing blows will be received.

Dolphins of panels of sheet/box piles should have an adequate waling system at their heads to distribute berthing loads. Contact between dolphin and hull may be either via vertical rubbing strips or a berthing frame.

5.3.8 ***Flexible dolphins with elastomeric or pneumatic fenders***

Where particularly large berthing energies are required to be absorbed, the capacity of flexible dolphins can be enhanced by the addition of a pneumatic fender or elastomer to the front face of the dolphin. If floating pneumatic fenders are used, the berthing frame of a multi-pile dolphin or the panel width of a box/sheet pile dolphin should be sufficient to support the pneumatic units in their compressed condition. The mounting system should comply with **5.2.3**.

5.4 Fender piles

5.4.1 ***General***

Fender piles are piles installed in front of a berth to protect it from impact but do not form part of the system supporting the berth deck. Fender piles may be individual units or interconnected by means of walings or frames. They may be of two types as follows.

a) Piles in front of and entirely separate from the berth structure, in which case they should be designed as flexible cantilevers in accordance with **5.3**. Due consideration should be given to providing sufficient clearance for the pile heads to deflect under impact without fouling the main berth structure.

b) Piles as in a) with the pile heads propped off the main berth structure with an elastomeric unit.

5.4.2 ***Elastomeric units for fender piles***

Elastomeric units of the cylindrical type under diametrical or axial compression or types deforming under horizontal shear are those most generally used for supporting the heads of fender piles. Local pressure between pile head and rubber should not exceed the manufacturer's recommended value and where necessary spreader plates may be attached to the pile head.

5.5 Gravity fenders

5.5.1 ***General***

Fenders of this class have usually been designed to meet the requirements of a particular situation such as a high tidal range and their application is now limited by the ready availability of cheaper factory-manufactured fender systems. They are subject to a number of disadvantages as discussed in **5.9.4**.

5.5.2 ***Operation***

Gravity fenders operate on the principle of converting the kinetic energy of berthing into potential energy by raising the centre of gravity of a suspended mass beneath the deck. Mounting is usually achieved by means of a system of cables or chains in a pendulum arrangement, or by hinges or by locating sliding bearings.

5.5.3 ***Typical designs***

One type of suspended gravity fender consists of a weighted heavy box mounted behind steel frames faced with timber and hinged in such a manner that ship impact causes the suspended mass to rotate inwards and upwards, thus gaining potential energy. Suspended concrete blocks and pendulum bells are other variations of the same principle.

5.6 Timber fenders

5.6.1 ***General***

Timber is a traditional material for fendering but the amount of energy that timber can absorb by compression is small. Hence the use of timber is now mainly confined to facing frames, rubbing strips and floating fenders. Timber fenders can take several forms:

a) floating fenders (also known as “camels”);

b) brushwood fenders;

c) hanging fenders;

d) rubbing strips;

e) fender piles.

5.6.2 ***Floating fenders***

Floating fenders can be floating bulks or cylindrical bundles of timbers, such as bamboo, bound by steel wire rope. They are usually suspended and bear against vertical timbers acting as rubbing strips. Floating fenders also serve to separate vessels during ship to ship transfer, and to keep ships off lock walls during raising or lowering of water levels.

5.6.3 ***Brushwood fenders***

Traditionally used in wooded country for small ships, brushwood fenders perform a similar function to floating bundles of bamboo, but after a short initial period buoyancy is usually lost. They are composed of bundles of brushwood (typically oak) bound by wire around inner brushwood cores which carry the suspension cables. Typical sizes are between 2 m to 3 m in diameter and 4 m to 5 m in length.

5.6.4 *Hanging fenders*

Hanging fenders are a frame of vertical and horizontal timber members suspended from the cope level and extending to water level. They are generally suspended from hand held wires and used between the berth face and the vessel during berthing operations where no other fender system exists. They are of a very rudimentary type and should not be considered as part of a permanent system.

5.6.5 *Rubbing strips*

Rubbing strips are described in **60.3.4** of BS 6349-1:1984.

5.6.6 *Fender piles*

The principles governing the design of fender piles in timber are described in **5.4**.

5.6.7 *Materials*

Guidance on such factors as the use of timber in maritime structures, resistance to environmental hazards, functional suitability and fastenings is given in clause **60** of BS 6349-1:1984.

5.7 Mechanical fenders

5.7.1 *General*

The following types of fender fall into the category of mechanical fenders:

a) gravity fenders (see **5.5**);

b) spring fenders (see **5.7.2**);

c) hydraulic fenders (see **5.7.3**);

d) non-recoiling fenders (see **5.7.4**).

5.7.2 *Spring fenders*

Steel springs have been used in fendering systems, usually to provide the top support for fender piles acting as propped cantilevers. The use of synthetic rubber units with their longer maintenance-free life has largely made springs obsolete. Protection against corrosion has to be taken into account when designing spring fenders.

5.7.3 *Hydraulic fenders*

Hydraulic fenders absorb berthing energy by converting it to potential energy in contained water. In principle a berthing frame compresses a series of rubber water bags which raises the water pressure in a header tank or reservoir remote from the fender. This form is particularly useful for sensitive berths, e.g. ferries, because rebound of the vessel off the berth can be eliminated.

5.7.4 *Non-recoiling fenders*

This type of fender is a form of hydraulic fender with a battery of horizontally mounted hydraulic jacks that exert a force against the ship's hull through a fender face, counteracted by the mooring lines. Hence following the berthing impact, the motions of surge, sway and yaw are restrained by friction of the fender faces.

5.8 Miscellaneous types

5.8.1 *Catamaran*

A catamaran is a floating unit either of timber or steel, sometimes with energy absorbing fenders, used to keep the vessel off the berth face. It is commonly used by naval dockyards. It may also be used when vessels berth alongside each other.

5.8.2 *Buoyant fender moored to the sea bed*

As the counterpart of the gravity fender, this unit floating in front of the berthing face is forced backwards and downwards in a berthing approach and exerts its reaction in attempting to recover its position. Like a number of other unconventional types it suffers from difficulties of access and maintenance.

5.8.3 *Collapsible steel fenders*

This type of fender consists of a corrugated steel tube that absorbs energy by plastic deformation. Collapsible steel fenders are not therefore suitable for use as primary fendering, but may be used between elastomeric units and the jetty structure to give additional protection in the event of accidental overloading of the main fendering.

5.8.4 *Rotating fenders*

There are two basic types of rotating fender. The first consists essentially of a pneumatic tyre mounted in a steel wheel rim usually rotating on a vertical axis. The second is a hollow rubber cylinder or ring mounted on a vertical shaft. Both types absorb kinetic energy by deformation of the wheel or cylinder.

Rotating fenders are used on corners and knuckles of quays and jetties, and on dry dock and lock entrances, where no significant vertical ship movement takes place.

5.9 Advantages and disadvantages of fender types

5.9.1 *Fenders using elastomeric units*

5.9.1.1 *Hollow cylindrical (diametrically loaded) fenders*

a) *Advantages:*

1) economical;

2) easy to install or replace individual units;

3) may be mounted to give cover over a large vertical range.

b) *Disadvantages:*

1) susceptible to damage by surging motion of vessel;

2) long length necessary to spread reactive force;

3) larger than other elastomeric units to absorb same energy.

5.9.1.2 *Cylindrical floating (diametrically loaded) fenders*

a) *Advantages:*

1) economical;

2) one unit covers full tide range.

b) *Disadvantages:*

1) susceptible to damage by surging motion of vessel;

2) no resistance to vessel surge;

3) can roll up face of berth unless restrained.

5.9.1.3 *V-shaped fenders*

a) *Advantages:*

1) easy to install or replace individual units;

2) low reaction and high energy absorption with constant reaction over part of deflection range.

b) *Disadvantage:*

1) only cover a small tidal range unless upper and lower rows of fenders provided.

5.9.1.4 *Buckling column fenders*

a) *Advantages:*

1) easy to install or replace individual units;

2) low reaction and high energy absorption with constant reaction over part of the deflection range.

b) *Disadvantages:*

1) has to be used with fender frame;

2) may require horizontal chains to resist longitudinal friction force.

5.9.1.5 *Shear multi-bond fenders*

a) *Advantage:*

1) large energy capacity.

b) *Disadvantages:*

1) complex assembly with large number of bolts susceptible to corrosion;

2) installation more difficult than most fenders using elastomeric units;

3) requires fender frame;

4) may require anchor chains to resist longitudinal and vertical friction forces.

5.9.1.6 *Shear single units*

a) *Advantages:*

1) low reaction force as shear modulus approximately 0.3 times elastic modulus;

2) absorbs rotational effects.

b) *Disadvantages:*

1) low energy absorption;

2) may require anchor chains to resist longitudinal friction force;

3) susceptible to torsion failure when used singly;

4) should have stops to prevent movement beyond an angle of 45°.

5.9.1.7 *Axially loaded hollow cylinders*

a) *Advantages:*

1) easy to install and replace:

2) simple in design;

3) large energy capacity;

4) several units may be coupled to common fender frame to give additional energy capacity.

b) *Disadvantages:*

1) require a fender frame even for single units;

2) may require chains to help carry both weight and longitudinal friction force.

5.9.1.8 *Rectangular or square section solid strips and D-hollow fenders*

a) *Advantage:*

1) simple design, easy to install and replace.

b) *Disadvantages:*

1) generally low energy capacity;

2) long length necessary to spread reactive force.

5.9.2 *Flexible dolphins*

a) *Advantages:*

1) can be purpose-designed for large energy capacity;

2) can be used at deep draught berths where gravity structures may be of prohibitive weight or cost;

3) with multiple decks can carry fender frames to cover large tidal range.

b) *Disadvantages:*

1) can only be used where geotechnical conditions are suitable;

2) difficult or sometimes impossible to repair if heavy overload results in:

i) failure of passive support in ground;

ii) plastic hinge formation in piles resulting in reduced load-carrying capacity.

NOTE Either i) or ii) will result in piles taking up a permanently inclined postion.

3) replacement of damaged piles in front of berth usually necessitates temporary restrictions on berth usage;

4) requires high grade steels and high quality welding.

5.9.3 ***Fender piles***

a) *Advantage:*

1) if closely spaced they provide good protection for berths in large tidal ranges, especially where small vessels are to be accommodated.

b) *Disadvantages:*

1) require suitable geotechnical conditions;

2) replacement of damaged piles in front of berth usually necessitates temporary restrictions on berth usage.

5.9.4 ***Gravity fenders***

a) *Advantages:*

1) can be purpose designed for large energy capacity;

2) can be constructed without use of imported items such as elastomeric units or pneumatic fenders.

b) *Disadvantages:*

1) bearings, hinges of moving section require regular inspection and maintenance;

2) possible disadvantages of large mass elements oscillating and heavy loading on deck;

3) only used in the past to a limited extent and hence limited data available on in-service performance;

4) may require additional vertical piling;

5) generally considered obsolete in UK practice.

5.9.5 ***Floating pneumatic fenders***

a) *Advantages:*

1) large energy capacity;

2) low reactive force;

3) can adapt to curved hull surfaces and angled berthing;

4) full tidal range can be covered with single unit;

5) simple to install and remove; units can be moved from berth to berth as need arises.

b) *Disadvantages:*

1) large diameter keeps vessel further from the cope than other types which leads to:

i) greater first costs for container cranes, shiploaders and similar equipment;

ii) heavier bogie loads for container cranes, shiploaders and similar equipment;

iii) increased operation cycle times for container cranes, shiploaders and similar equipment;

2) require large beating area that may have to extend above general level of berth deck;

3) can roll up face of berth if not suitably restrained;

4) require secondary protection against tearing and puncturing by protrusions from ship's hull.

5.9.6 ***Foam filled floating fenders***

a) *Advantages:*

1) large energy capacity;

2) low reactive force;

3) can adapt to curved hull surfaces and angled berthing;

4) full tidal range can be covered with a single unit;

5) simple to install and remove; units can be moved from berth to berth as the need arises;

6) will not sink immediately or collapse, if punctured.

b) *Disadvantages:*

1) large diameter keeps vessels further from the cope than most other types (see **5.9.5**);

2) require large bearing area that may have to extend above general level of berth deck;

3) can roll up face if not suitably restrained.

5.9.7 ***Fixed pneumatic fenders***

a) *Advantages:*

1) large energy capacity;

2) low reactive force;

3) little loss of efficiency with angled berthing and adapts to curved hull surface;

4) easy to install and replace;

5) several fenders may be coupled to common fender frame to give larger capacity unit.

b) *Disadvantages:*

1) require a protective cap to reduce friction with ship's hull;

2) can be torn or punctured by protrusions from ship's hull.

5.9.8 ***Timber fenders***

a) *Advantage:*

1) easily-worked material for use as facing material to fender frames and as rubbing strips.

b) *Disadvantages:*

1) as primary fender member (e.g. as fender pile) only suitable for small installations, such as yacht marinas and coaster berths;

2) most suitable timbers have to be imported as they are generally hardwoods grown in a limited number of tropical countries only, and some are subject to attack by marine borers;

3) spare timbers for repair purposes require special storage precautions if to be kept in prime condition.

5.9.9 ***Mechanical fenders***

a) *Advantage:*

1) fenders of roller type offer low resistance to forward motion of vessels entering locks; they are particularly useful in protecting corners of quay structures.

b) *Disadvantages:*

1) may require installation in locations where inspection and maintenance are difficult;

2) require mechanical maintenance.

5.10 Areas of applicability of fender types

From the advantages and disadvantages listed in **5.9**, it can be seen that the majority of types of fender may be used for all of the berth categories in Table 1 and all the vessel categories in Table 2. It is for the designer to choose the most suitable for the particular application.

6 Special considerations in the provision of fendering

6.1 Vessels with bulbous bows

Vessels with hulls fitted with bulbous bows pose a greater collision hazard to most berth structures than vessels with a conventional forefoot design. Where such vessels are to be berthed, the underwater geometry of the bow section has to be considered in addition to that at the level of contact with the fender system (see **4.8**). The fender spacing, fender compression and relationship of substructure to the cope face have also to be considered (see Figure 13) to establish a maximum berthing angle a which is acceptable without impact between the bulb and the berth structure.

It is generally impracticable to provide a fender system to safeguard the berth structure against accidental head-on or steeply-angled impacts. Therefore the designer should establish a maximum safe value of the berthing angle that can be economically achieved having regard to both fender and substructure layout.

6.2 Belting

Ferries, tugs, launches and other small craft are often fitted with belting that consists of one or more timber, rubber or curved steel rubbing strips around the vessel. The design of the fendering system should if appropriate take account of this belting.

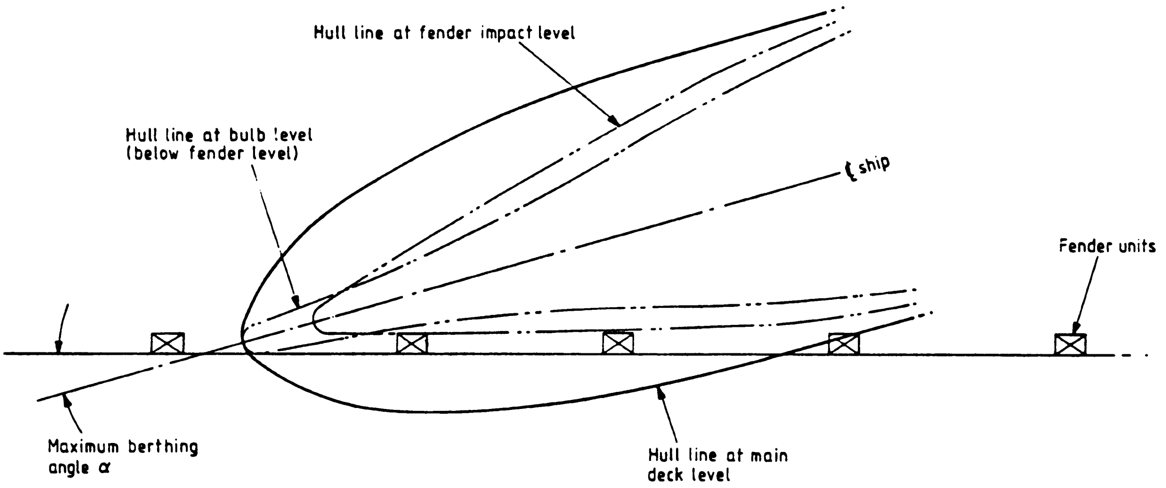


Figure 13 — Plan showing geometry of vessel with bulbous bow

Section 3. Mooring

7 Principles of good mooring

Until the advent of bulk transport of goods and raw materials by sea, the basic requirements of a mooring system were to prevent the vessel from drifting away from a berth or from colliding with adjacent moored vessels. The system had also to allow for assisting in heaving the ship up to the berth and in leaving the berth.

Present situations often require the ship to be accurately held in place in relation to berth-mounted ship loading or discharging equipment which itself may be very limited in movement, e.g. container cranes and articulated booms.

The principle to be followed, regardless of the size of the vessel, is to restrain movement to within acceptable limits by means of an adequate number of mooring lines, which can be readily handled by the operating personnel, compatible with the conditions of wind, tide, weather and other effects likely to be experienced during the relevant period of vessel stay at the berth.

The berth designer should provide facilities to permit all vessels for which the berth was designed to remain safely moored alongside and mooring points should give a satisfactory spread of moorings and be disposed as nearly as possible symmetrical to the mid-point of the berth. It should be noted that vessels such as LNG/LPG tankers and coastal tankers do not necessarily have their manifolds amidships and will not therefore always lie centrally on the berth. The height of mooring points should be such that vertical angles of mooring lines will be as small as practicable and preferably not greater than 25°.

The optimum pattern of mooring lines for normal alongside berthing is likely to consist of a basic web of breast, head and stern lines extending from or near the extremities of the vessel, together with spring lines from approximately the quarter points of the vessel.

The physical nature and layout of the berth or terminal will affect the manner in which the mooring objectives are achieved and the relative position of shore-mounted mooring equipment may result in a pattern of lines that gives an inferior restraint capability. In such circumstances the berth designer should inform the operator of the berth what assistance may be necessary to achieve adequate restraint consistent with the forces acting on the moored ship and the demand of the discharge or loading operations.

8 Mooring patterns

8.1 General

The normal mooring pattern consists of ropes issuing at the extremities of the ship that make horizontal angles of about 45°, – 90° and – 45° to its axis, plus spring lines at about 10° to its axis, together with breast lines as appropriate (see Figure 14).

In some cases of island, "T" head and similar type berths, mooring points to receive ropes from the ends of the vessels are placed well behind the berthing line. In these cases in order to maximize transverse restraint the ropes are more usually disposed as near as possible at right angles to the ship axis and are kept as near as possible to the same length. Similarly, a sufficient number of spring lines are utilized to provide all the necessary longitudinal restraint.

In the case of continuous quays, in order to ensure that the maximum useful load restraint is placed on the ship with the minimum number of mooring lines, it is necessary to plan the vessel's mooring arrangement so that each rope is as near to the optimum line of action for its intended purpose as is possible. Any proposed mooring layout is dependent on the relative position, spacing and strength of bollards on the quay which nevertheless should be compatible with and suitable for the size and type of vessel using the berth. Generally bollards on a quay should be provided at 30 m centres.

To ensure even distribution of the restraining forces on the vessel it is preferable that the pattern of mooring lines should be approximately symmetrical about midpoint of the vessel and as far apart as possible, subject to any wire (particularly back springs) not "scrubbing" against the ship side or the cope edge.

A high accommodation structure at either stern or bow will increase the wind load locally, but in practice the margin of restraint normally provided for a ship takes care of such eccentric loading. For island tanker berths, the transverse and longitudinal forces applied to the vessel are best absorbed by breast and spring lines respectively, provided these are set out within the approximate limits given in Figure 15. Optimum lengths of mooring lines are usually within the range 35 m to 50 m for the largest vessel.

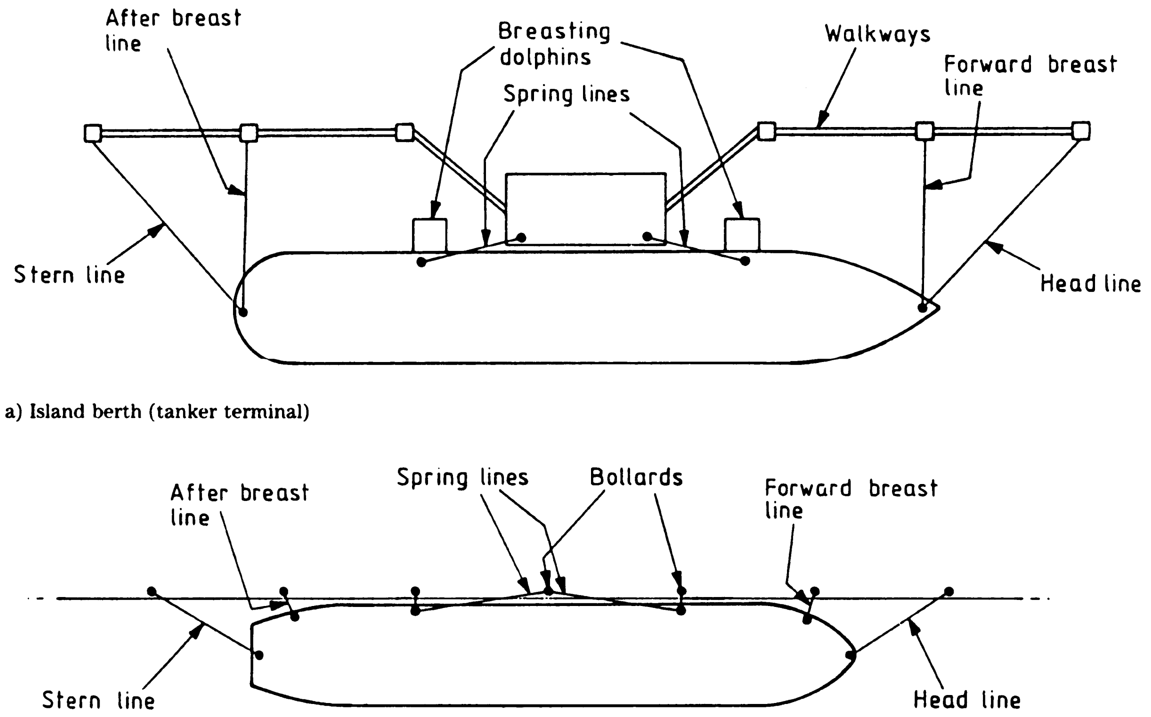
8.2 Breast lines

The restraint required to secure the ship is best obtained using breast lines. These should be aligned perpendicular to the longitudinal centre line of the ship in order to apply the maximum restraint to prevent the vessel being moved broadside from the quay.

8.3 Spring lines

Spring lines should be aligned parallel to the longitudinal centre line of the ship in order to apply the maximum restraint to prevent the vessel surging along the quay.

The spring lines are sometimes referred to as back spring lines due to the apparent contradiction in their direction towards midships, an alignment used to keep these moorings within the length of the vessel and avoiding unnecessary crossing over and chafing of mooring lines at adjacent berths.



a) Island berth (tanker terminal)

b) Continuous quay

Figure 14 — Typical mooring patterns

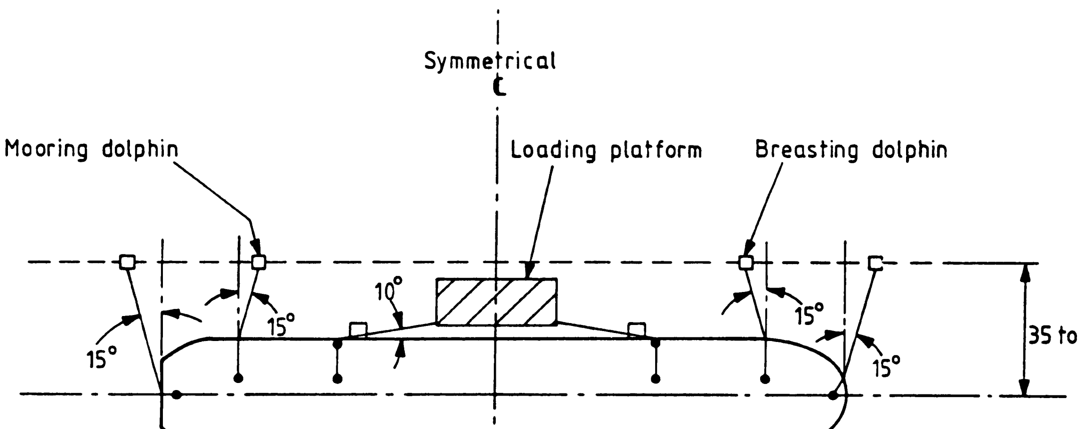


Figure 15 — Optimum angles of mooring lines for island tanker berth

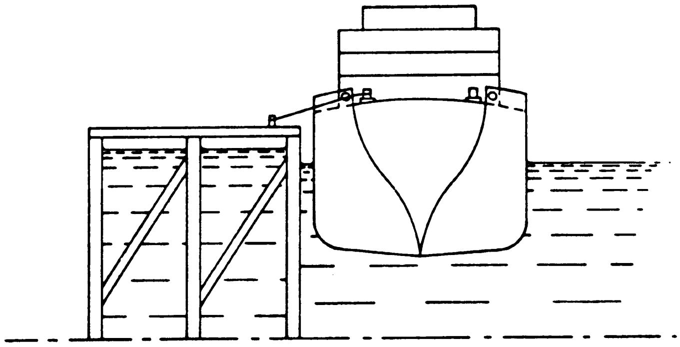
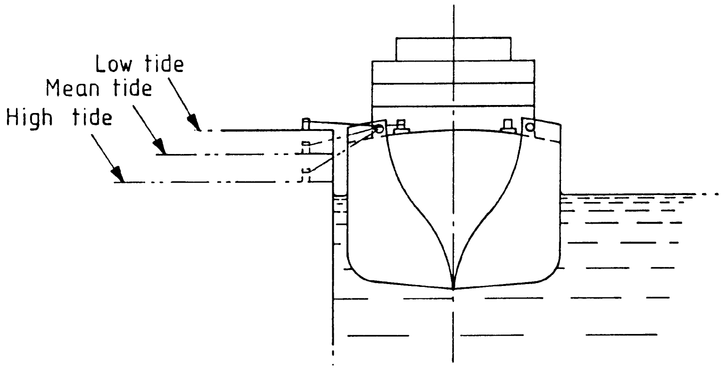
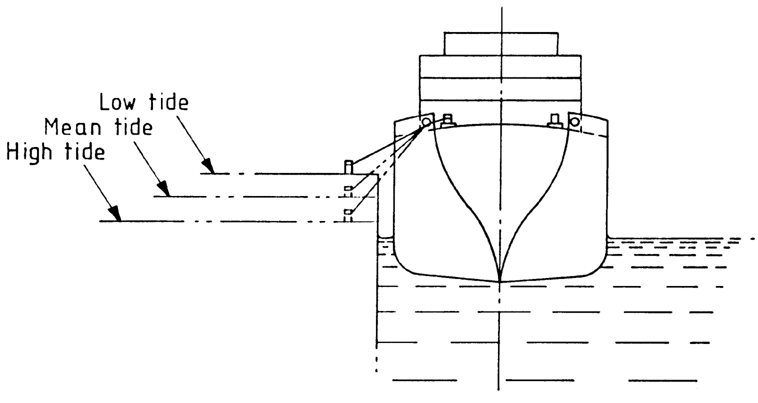


Figure 16 — Vessel under influence of stand- off force



a) Load draught



b) Light draught

Figure 17 — Effect of tidal rise and fall and change in draught or trim

8.4 Head and stern lines

Head and stern lines, depending upon their angle relative to the ship's axis, are in effect either more or less part breast lines and part spring lines.

The use of the head and stern lines is likely to arise where the ship is moored to widely spaced dolphins necessitating corresponding widely spaced mooring connections ashore or for example, where a large vessel has to make use of a quay intended for smaller ships and therefore has to distribute the mooring lines to avoid overloading the bollards on the quay. Conversely a small ship mooring at, for example, a VLCC berth is likely to find the bollards on the quay so far apart as to result in some of the mooring lines being in effect head and stern lines.

Head and stern lines may on occasion be required to assist in the berthing/unberthing manoeuvre or be used in particular situations e.g. where a ship is being moved along a quay without use of main engines or in storm conditions where high winds are blowing parallel to the ship.

9 Forces acting on the moored ship

9.1 General

The principal horizontal forces acting on a moored vessel are generally caused by wind and current. However the mooring system has to be capable of withstanding any combination of forces resulting from the following as may be applicable, while limiting the ship's movement to avoid interference with cargo/passenger operations:

a) wind;

b) current;

c) off-quay hydrodynamic force and hydrodynamic interference from passing ships;

d) ocean or long swell waves;

e) waves caused by passing ships in narrow channels;

f) tidal rise and fall, and change in draught or trim due to cargo operations;

g) ice.

Normally, if the mooring system is designed to accommodate the maximum wind and current forces, the reserve strength will be sufficient to resist other forces that may arise. However, if appreciable surge, waves, ice or other abnormal conditions exist at the terminal, considerable loads may be developed in the vessels' moorings. These forces are difficult to analyse and model testing or field measurement should be used.

9.2 Wind and currents

For the evaluation of wind and current forces acting on a moored vessel, see clause **42** of BS 6349-1:1984.

9.3 Off-quay hydrodynamic force and hydrodynamic interference from passing ships

In circumstances where strong ebb or flood currents are present in the vicinity of the berth or terminal, its alignment to the tidal stream relative to the moored vessel may give rise to hydrodynamic forces.

If the berth is an open or piled structure in such tidal flow conditions, the mass of structure slows the water flow under the berth and initiates a build up of pressure head relative to the open water at the jetty face.

Although the phenomena have long been recognized, very little is so far documented on the magnitude of off-berth or stand-off forces.

The stand-off force is absorbed only by those mooring lines having an adequate transverse component of resistance of movement of the vessel away from the berth (see Figure 16).

9.4 Waves

9.4.1 *Ocean or long swell waves*

For the effects of ocean or long period swell waves on a moored ship, see clause **31** of BS 6349-1:1984.

9.4.2 *Waves caused by passing ships in narrow channels*

For the effects induced by vessels passing in narrow channels, see clause **17** of BS 6349-1:1984.

In situations where the wave is of considerable magnitude, the surge caused can lead to very high shock loadings in the mooring system resulting in failure of ropes or ship-mounted mooring equipment.

9.5 Tidal rise and fall and change in draught or trim due to cargo operations

The changing relationship of vessel deck edge to berth cope due to the a) loading or unloading of the vessel or b) the changing water level under tidal conditions, can induce forces or change the magnitude of loading on the moorings and on the vessel (see Figure 17).

Mooring lines in tension have a maximum restraining effect when horizontal and are reduced in their restraining effect as the angle from the horizontal is increased.

9.6 Ice

The effects of ice on the mooring of a vessel need rarely be considered. When the vessel is moored in icing conditions in a tidal river, there is the possibility of ice becoming trapped between the ship and the quay. This can create a longitudinal force on the vessel due to the piling-up effect of the ice flowing with the tidal current.

10 Loads on mooring points

10.1 Vessels up to 20 000 t displacement

For general cargo vessels and bulk carriers up to 20 000 t displacement, mooring points should be provided with a load capacity as given in Table 7of BS 6349-1:1984. For specialized vessels with high superstructure, e.g. ferries and gas carriers, mooring point loads should be calculated using the methods described in **10.2.2**, **10.2.3** or **10.2.4**.

10.2 Vessels over 20 000 t displacement

10.2.1 *General*

For vessels larger than 20 000 t displacement, calculations should be carried out to determine the probable maximum loadings on each mooring point. The calculations should take into account the expected range of ship sizes.

10.2.2 *Method 1*

The wind and current forces on the ship should be calculated using the method given in clause **42** of BS 6349-1:1984.

The loads on each individual mooring point are then calculated by treating the mooring lines as an elastic system either using hand calculation or a computer.

For calculation by hand, the system should be simplified by assuming that the longitudinal forces are resisted by the spring lines and the transverse forces at the bow and stern by the bow and stern breasting lines respectively. The mooring ropes should be assumed to have the same characteristics, and account should be taken of the lengths and angles of the mooring lines.

10.2.3 *Method 2*

An alternative method of calculating the loads on each individual mooring point is to assume that if the berth has six mooring points then one-third of the total transverse force on the vessel is taken by any one mooring point and the mooring point should be designed for this force at normal working stresses. The longitudinal forces are again assumed to be resisted entirely by the spring line mooring points.

If the berth has only four mooring points, then one-half of the total transverse force on the vessel is taken by any one mooring point.

10.2.4 *Method 3*

If the berth is to be designed for a particular vessel using specified mooring ropes and mooring pattern, the mooring points may be designed at normal working stresses for a force equal to the maximum breaking load of the ropes. Typical rope characteristics are given in Annex B.

10.2.5 *Method 4*

If there is insufficient data to carry out any of the methods described above in **10.2.2**, **10.2.3** and **10.2.4**, Table 7 gives normally acceptable mooring point loads for general cargo vessels and bulk carriers.

Table 7 — Mooring point loads for general cargo vessels and bulk carriers

Ship displacement t	Mooring point load t
20 000 up to and including 50 000	80
Above 50 000 up to and including 100 000	100
Above 100 000 up to and including 200 000	150
Above 200 000	200

For locations of exceptional wind, current or other adverse effects, these mooring point loads should be increased by 25 %.

10.2.6 *Design of mooring point structure*

The mooring point loads derived from methods 1 to 4 are horizontal forces. Account should be taken of the vertical component resulting from the mooring lines not being horizontal in the design of the mooring point structure and the bollard or hook fixings.

The design of the mooring point structure should also take into account the level at which the horizontal force is applied to the structure. The design should also be such that if overloaded the mooring equipment or its anchorage to the structure will fail before the overall structure is damaged.

NOTE See BS 6349-2.

11 On-shore mooring equipment

11.1 General

The range of on-shore mooring equipment considered by this code comprises bollards, quick-release hooks, mooring rings and capstans. Fairleads and cleats may generally be regarded as ship-mounted items and are not therefore included.

11.2 Materials

On-shore mooring equipment is made from structural steel plates, cast and forged steel and cast iron. All these materials and the associated workmanship should be in accordance with the relevant British Standard or other equivalent internationally recognized standard and clause **59** of BS 6349-1:1984.

11.3 Mounting and fixing

Mounting systems should be of robust and simple design to minimize maintenance and allow easy replacement of damaged items. Bolt heads, nuts, etc. should wherever possible be recessed to prevent snagging of lines.

Where quick-release hooks can strike deck surfaces in their released condition, suitable non-structural wearing plates should be provided over the full horizontal arc of travel of the hook assembly (see Figure 18).

Where mooring lines bear locally on cope nosings (e.g. lines to small vessels at low tide), suitable anti-wear strips should be provided to protect both the lines and the berth structure.

11.4 Bollards

Bollards for general purposes are normally manufactured from:

a) cast iron, grade 180 complying with BS 1452:1990; or

b) spheroidal graphite cast iron quality 420/12 complying with BS 2789:1985; or

c) cast steel complying with BS 3100:1991.

Spheroidal graphite cast iron or cast steel increases load capacity over that of normal cast iron for any given design subject to a corresponding strength increase being made in the anchorage bolt system.

Many bollard designs are commercially available but they may be broadly classified into three categories, as follows:

d) pillar type;

e) tee-head type;

f) twin-head type sloping lobes. These types are illustrated in Table 8 together with characteristics and applications.

11.5 Quick release mooring hooks

Hooks should be designed to provide an easy and rapid means of releasing mooring lines from berth to ship under both normal and emergency conditions. The release mechanisms may be actuated locally by manual operation or by electromechanical operation from a remote console. Hooks are therefore of particular application to:

a) oil, gas, and chemical berths where quick release of lines for routine departure of vessels may be required;

b) mooring at island dolphins where personnel access is by launch only.

General characteristics of commercially available hooks are given in Figure 18.

The installation of remote operation equipment is only recommended in situations where a high degree of maintenance can be guaranteed. In all cases local manual override facilities should be provided.

11.6 Mooring rings

Mooring rings should be provided in berth faces at all places where small craft (e.g. customs and pilot launches) require to berth. Rings should be provided to give a mooring facility accessible directly from small craft at all states of the tides and should generally be positioned adjacent to access ladders.

Rings should be recessed into the berth face or otherwise protected with rubbing strips, etc. to prevent them damaging craft. Recesses should be drained if rings are mounted in horizontal surfaces. Mooring rings should be made of solid bar at least 25 mm diameter and secured to the berthing structure with bolts of at least 24 mm diameter.

General characteristics of mooring rings are shown in Figure 19.

11.7 Capstans

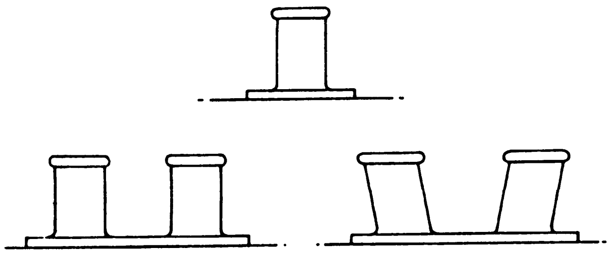
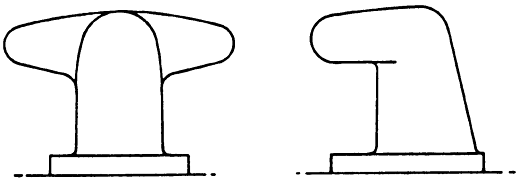
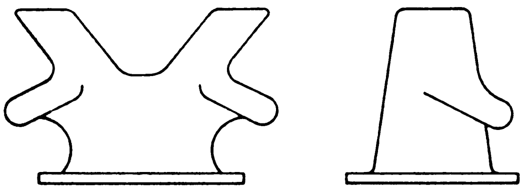
Where mooring lines are too heavy to be attached manually to bollards or mooring hooks or where there is insufficient space for a large enough mooring gang to operate (e.g. on an island mooring dolphin) then electrically driven capstans should be provided to assist bringing lines ashore.

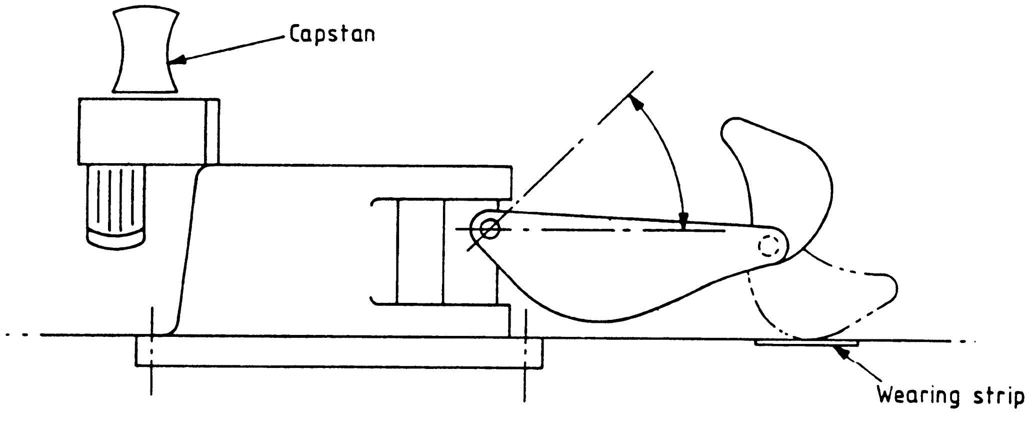
11.8 Safety precautions

Electric motors for capstans, motor starters, associated cabling and switchgear together with all electrical equipment for the remote operation of mooring hooks should have protection characteristics appropriate to the hazard rating of the area in which they are situated.

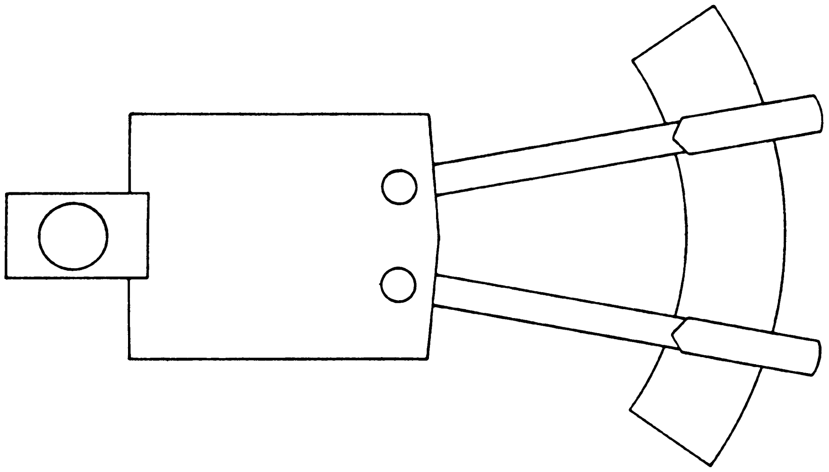
Mooring hooks equipped for remote release should be fitted with adequate safety guards around all moving parts to protect personnel during operating conditions.

Table 8 — Mooring bollards

Type		Normal maximum working load t	Applications
Single and double pillar		200 total	General mooring applications where rope angle is not steep Single pillar type should be used with lines from one ship only Suitable for warping ships along berths, etc.
Tee-head		150	All general mooring applications including steep rope angles Any one bollard should preferably be allocated to lines from one ship only
Sloping lobe		200 total	All general mooring applications including steep rope angles Lines from two ships may be attached without interference



a) Elevation



b) Plan

Characteristics

No. of hooks per unit = 1, 2, 3, 4, 5 or 6

Maximum load per hook: 200 t

Maximum elevation: 45°

Application

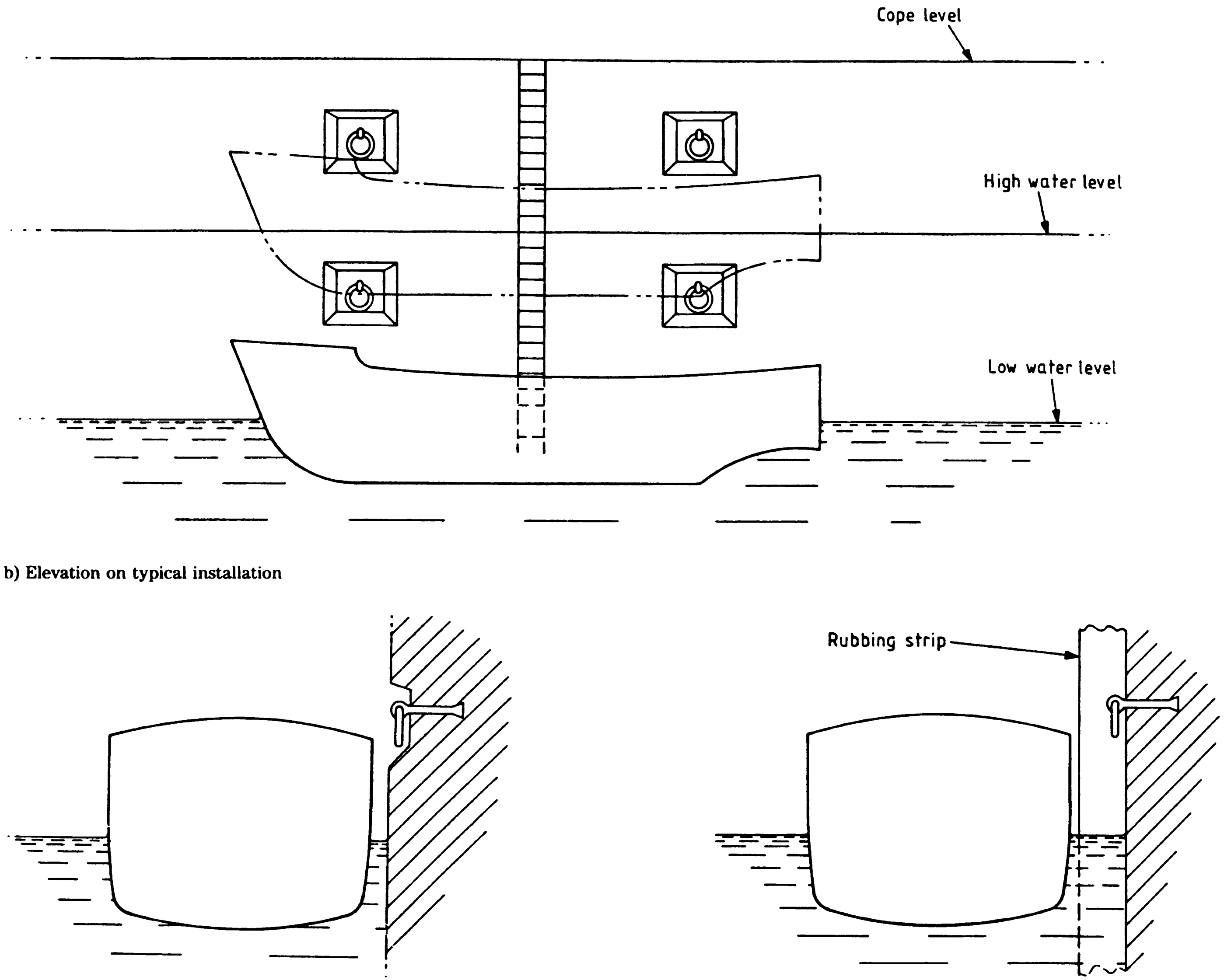
(a) oil, gas and chemical berths requiring rapid routine release capability.

(b) dolphins for all types of berths.

NOTE 1. An electrical supply will be required for the capstan.

NOTE 2. Where small ships are moored to quick release hooks provision should be made to ensure that the ship's lines which may have a steep angle of inclination can fall clear of the hook when it is released.

Figure 18 — Quick release mooring hooks



b) Elevation on typical installation

a) Recessed mounting

c) Non-recessed mounting

Figure 19 — Mooring rings

Annex A Gross registered tonnage, deadweight tonnage and displacement

While navel vessels are customarily described by displacement tonnage, the size of other vessels is frequently quoted in terms of gross registered tonnage (grt) and deadweight tonnage (dwt). The latter values are significant for registration and in assessing the carrying capacity of the vessel. However, for computing berthing energies and other hydrodynamic calculations, the displacement of the vessel is required.

For the purposes of preliminary planning the following relationships may be used to obtain displacement from gross registered tonnage or deadweight tonnage. These values are approximations and should not be used for detailed design unless confirmed by the actual vessel characteristics.

Vessel type	Approximate loaded displacement
Fishing boats	
(small):	grt × (2.5 to 2.0)
(large):	grt × (2.0 to 1.5)
General cargo:	grt × 2, 0 *or* dwt × (1.6 to 1.4)
Passenger liners:	grt × 1.1
Container ships:	dwt × 1.4
Bulk carriers:	dwt × (1.3 to 1.2)

Where two values are quoted in the above relationships, the first approximates to the smaller vessels of a given type.

Annex B Selection of mooring lines on vessels

The selection of diameter, length and number of main mooring lines, whether wire or synthetic, depends upon the size and type of vessel. Table 9 and Table 10 give the normal sizes of synthetic and galvanized steel wire ropes carried by vessels, and the breaking loads of these ropes.

Mooring arrangements should consist of all synthetic or all wire ropes as the use of mixed systems with ropes of different characteristics may lead to accidents.

Annex C Reference and bibliography

C.1 Reference

[1] REESE, L.C. and MATLOCK, H. Non-dimensional solutions for laterally-loaded piles with soil modulus assumed proportional to depth. *Proceedings of the 8th Texas Conference on soil mechanics and foundation engineering*. Austin, Texas, 1956, pp. 1-41.

C.2 Bibliography

1. VASCO COSTA, F. *The berthing ship, the effect of impact on the design of fenders and other structures*. Dock and Harbour Authority, May, June and July, 1964.

2. *Recommendations of the Committee for Waterfront Structures*. 4th English edition (6th German), EAU 1980. Wilhelm Ernst and Sohn, Berlin, Munich, Dusseldorf.

3. TOMLINSON, M.J. *Pile design and construction practice*. 2nd Edition 1981. Viewport Publications, London.

4. Oil Companies International Marine Forum. *Guidelines and recommendations for the safe mooring of large ships at piers and sea islands*, 1978. Witherby and Co. Ltd., London.

5. Oil Companies International Marine Forum. *Prediction of wind and current loads on VLCC's*, 1977. Witherby and Co. Ltd., London.

6. Report of the International Commission for Improving the Design of Fender Systems. Supplement to Bulletin No. 45 (1984) PIANC.

Table 9 — Sizes of synthetic mooring ropes normally carried by vessels, and the breaking load of these ropes

Type	Gross registered tonnage (grt)	Rope diameter mm	Breaking load of eight-stranded plaited polypropylene kN
Dry cargo ships	Up to 2 000	40 to 48	190.2 to 266.7
	Over 2 000 up to and including 4 000	48 to 56	266.7 to 353.0
	Over 4 000 up to and including 8 000	52 to 60	308.9 to 404.0
	Over 8 000 up to and including 15 000	56 to 64	353.0 to 457.0
	Over 15 000	64 to 72	457.0 to 573.7
Ferries	Up to 2 000	40 to 48	190.2 to 266.7
Liners	Over 2 000 up to and including 6 000	48 to 60	266.7 to 404.0
	Over 6 000 up to and including 10 000	56 to 64	353.0 to 457.0
	Over 10 000	64 to 72	457.0 to 573.7
	Deadweight tonnage (dwt)		
Tankers	15 000 up to and including 20 000	56 to 60	353.0 to 404.0
Bulk carriers	Over 20 000 up to and including 40 000	60 to 64	404.0 to 457.0
	Over 40 000 up to and including 70 000	64 to 72	457.0 to 573.7
	Over 70 000 up to and including 120 000	72 to 80	573.7 to 706.1

Table 10 — Sizes of galvanized steel wire ropes normally carried by vessels, and the breaking load of these ropes

Type	Gross registered tonnage	6 × 24 (15/9/Fibre) Fibre main core		6 × 36 (14/7 and 7/7/1) Fibre main core		6 × 36 (14/7 and 7/7/1) Steel core		6 × 37 (18/12/6/1) Fibre main core	
		Nominal diameter	Minimum breaking load at 145 grade	Nominal diameter	Minimum breaking load at 180 grade	Nominal diameter	Minimum breaking load at 180 grade	Nominal diameter	Minimum breaking load at 145 grade
		mm	kN	mm	kN	mm	kN	mm	kN
Dry cargo ships	Up to 2 000	22 to 26	193.2 to 269.7	18 to 22	188.3 to 281.4	×	×	22 to 26	202.9 to 283.4
	Above 2 000 up to and including 4 000	26 to 30	269.7 to 358.9	22 to 26	281.4 to 393.2	22 to 24	304.0 to 361.9	26 to 32	283.4 to 429.7
	Above 4 000 up to and including 8 000	28 to 32	311.8 to 407.9	24 to 28	335.3 to 456.9	22 to 26	304.0 to 424.6	28 to 32	328.5 to 429.7
	Above 8 000 up to and including 15 000	×	×	26 to 28	393.2 to 456.9	24 to 28	361.9 to 493.3	×	×
	Above 15 000	×	×	28 to 32	456.9 to 596.2	28 to 32	493.2 to 644.2	×	×
Ferries	Up to 2 000	22 to 26	193.2 to 269.7	18 to 22	188.2 to 281.4	×	×	22 to 36	202.9 to 283.4
Liners	Above 2 000 up to and including 6 000	26 to 32	269.7 to 407.9	22 to 28	281.4 to 456.9	22 to 26	304.0 to 424.6	26 to 32	283.4 to 429.7
	Above 6 000 up to and including 10 000	×	×	26 to 28	393.2 to 456.9	24 to 28	361.9 to 493.3	×	×
	Over 10 000	×	×	28 to 32	456.9 to 596.2	28 to 32	493.3 to 644.3	×	×
	Deadweight tonnage								
Tankers	15 000 up to and including 20 000	×	×	26 to28	393.2 to 456.9	24 to 26	361.8 to 424.6	32	429.6
Bulk carriers	Above 20 000 up to and including 40 000	×	×	28	456.9	26 to 28	424.6 to 493.2	×	×
	Above 40 000 up to and including 70 000	×	×	28 to 32	456.9 to 596.2	28 to 32	493.2 to 644.3	×	×
	Above 70 000 up to and including 120 000	×	×	32 to 35	596.2 to 712.9	32 to 36	644.3 to 815.9	×	×

NOTE × denotes not available for these vessel sizes

List of references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 449, *Specification for the use of structural steel in building.*
BS 449-2, *Metric units.*
BS 1452, *Specification for flake graphite cast iron.*
BS 2789, *Specification for spheroidal graphite or nodular graphite cast iron.*
BS 3100, *Specification for steel castings for general engineering purposes.*
BS 5268, *Structural use of timber.*
BS 5268-2, *Code of practice for permissible stress design, materials and workmanship.*
BS 5950, *Structural use of steelwork in building.*
BS 5950-1, *Code of practice for design in simple and continuous construction: hot rolled sections.*
BS 6349, *Maritime structures.*
BS 6349-1, *General criteria.*
BS 6349-2, *Design of quay walls, jetties and dolphins.*
BS 8110, *Structural use of concrete.*
CP 3, *Code of basic data for the design of buildings.*
CP 3-V, *Loading.*
CP 3-2, *Wind loads.*

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