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Guidelines for the Design of Fenders Systems: 2002

MarCom
Report of WG 33
2002

INTERNATIONAL NAVIGATION ASSOCIATION

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GUIDELINES FOR THE DESIGN OF FENDER SYSTEMS: 2002

Report of Working Group 33
of the
MARITIME NAVIGATION COMMISSION

INTERNATIONAL NAVIGATION
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DE NAVIGATION

2002

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This report has been produced by an international Working Group convened by the Maritime Navigation Commission (MarCom). Members of the Working Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendation on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state of the art on this particular subject. PIANC disclaims all responsibility in case this report should be presented as an official standard.

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GUIDELINES FOR THE DESIGN OF FENDER SYSTEMS: 2002

PIANC WORKING GROUP MarCom
WG 33 FENDERING GUIDELINES

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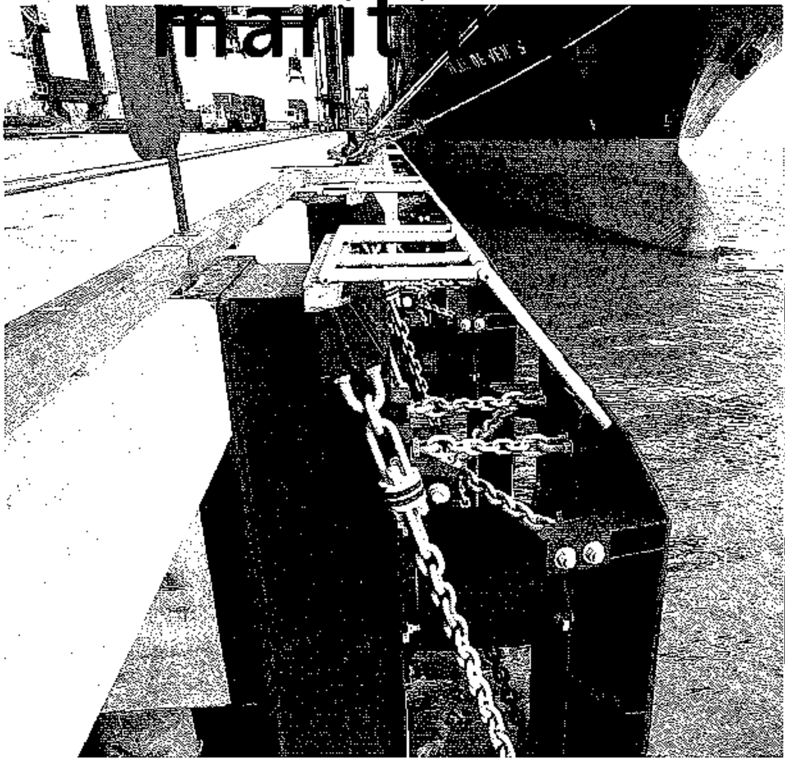

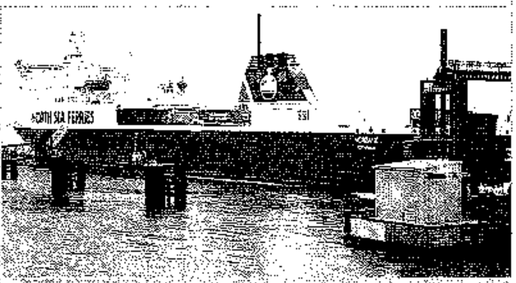

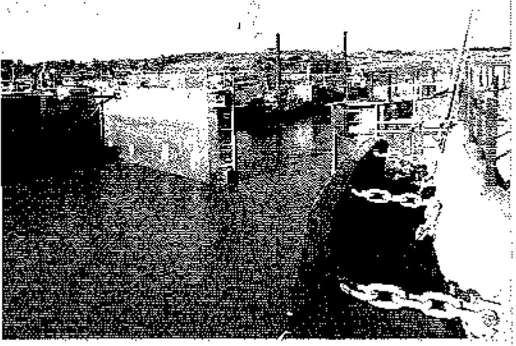

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FOREWORD

The 1984 Report has been part of the design office since it was published and as the practice in technical organisations, International Navigation Association (PIANC) MARCOM decided it was time to update this well used document. Accordingly, Working Group 33 was formed.

These guidelines are written for a wide audience including governments, port authorities, private consulting practices, planning agencies, universities and suppliers. Its purpose is to allow designers and suppliers to have a common ground to plan and design.

It contains new approaches to fender design with appendices to help and inform.

This document 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 guidelines are intended principally for use in respect of commercial installations by experienced engineers.

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.

Sincere thanks is due to all the members of the Working Group No 33 for providing their experience and help in developing the report, writing the sections and reviewing and polishing the report.

Meetings of the Working Group

Although there were national correspondence groups set up, it was decided that plenary meetings were still required and valuable. In all, nine meetings were held in London, Rotterdam, Brussels, Bilbao and Rome.

1. INTRODUCTION

1.1 TERMS OF REFERENCE

The Terms of Reference for the working group agreed by the MarCom were as follows:

- collection and assessment of comparable design documents and methods used in member countries;
- collection and assessment of current fender options with performance and test details;
- slim down the text from the 1984 PIANC report;
- scrutinising the following:-
  - ⇒ Formulae for Cm;
  - ⇒ Inventory of fender systems;
  - ⇒ Parameters and coefficients used in design of fender systems;
  - ⇒ Hull pressure;
  - ⇒ Approach velocities, accuracy of manufacturers catalogue data and use of velocity correction factors;
  - ⇒ Ro/Ro, container and ferry berths;
  - ⇒ Guidelines for future fender design.
- Seek comments from industry involved in fendering systems, e.g. users, manufacturers and designer.

1.2 METHOD OF UNDERTAKING THE TASK

The method of approach selected for this updating of the 1984 Guidelines for Fendering was to use correspondence groups based in the working group member's countries as a means for getting the current design and construction practice used for providing fendering.

In addition, meetings were held with fender suppliers to gather their present methods of supply and testing of materials and any changes foreseen in the future.

The report was split into sections which enabled every country to participate and a lead country appointed to co-ordinate each section of the final report.

1.3 SUMMARY

The intention of this report has been to update and reduce the information given in the previous report of the International Commission for Improving the Design of Fender Systems, 1984, with new testing protocols and appendices containing basic useful information for the designing engineer.

1.4 ACKNOWLEDGEMENTS

Due regard is given to the manufacturers of fender materials and all members of the national correspondence groups who we thank for their unstinting help.

1.5 DEFINITIONS

For the purposes of this document, the following definitions apply.

1.5.1 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.

1.5.2 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 obtained in the bag.

1.5.3 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 $2.83\ m^3$.

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

1.5.5 displacement (tonnes)

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

1.5.6 vessel size

Large vessels mentioned in this document are in the following categories:

Oil Tankers, combination carriers and Ore carriers
- in excess of 200,000 DWT

Liquid gas carriers
- transport capacity in excess of 125,000 m^3

Container carriers
- overall length in excess of 250 m

Ferries and Ro/Ro
- overall length in excess of 90 m or 4500

1.5.7 lowest astronomical tide (LAT)

lowest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.

1.5.8 highest astronomical tide (HAT)

highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.

1.6 SYMBOLS

The following are some of the symbols used in this document. If there is more than one meaning, it is given, in each case, in the text where those symbols are used.

B	Beam of vessel
C	Positive clearance between hull of vessel and face of cope
Cab	Abnormal Impact factor
Cb	Block coefficient of the vessel's hull
Cc	Berth configuration factors
Ce	Eccentricity coefficient
Cm	Virtual dynamic mass coefficient
Cs	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
Lpp	Length of vessel's hull between perpendiculars
Ls	Length of the smallest vessel using the berth
LL	Length of the largest vessel using the berth
$\underline{M}$	Mass of vessel 95% confidence level
M	Mass of vessel
M_D	Displacement of vessel (Specific to confidence level)
R	Reaction force of fender
R	Distance of the point of contact from the centre of mass of the vessel
α	Angle of approach of vessel
γ	Angle between the line joining the point of contact to the centre of mass of the vessel (R) and the vessel speed vector (V)
δ	Deflection of fender unit
Δ	Deflection of fender unit
μ	Coefficient of friction

2. PRINCIPLES OF FENDERING

2.1 WHY USE FENDERING

It was once stated, some years ago, "there is a simple reason to use fenders: it is just too expensive not to do so". Although it may be a rather pragmatic and one-sided view, there certainly is a germ of truth in the statement. In addition to the financial aspect, safety is probably an even more important reason to install fenders.

Nowadays it is common practice to apply fender assemblies comprising energy-absorbing rubber elements in ports which have to accommodate large vessels. However, port authorities have an approach which is both commercial and practical; therefore, if conditions allow (relatively small vessels, mild environmental conditions), ports may opt for the installation of low-cost fenders and/or apply locally available material. Wooden fenders, rubber tyres or the like are therefore still regularly encountered all over the world, even in major ports.

The increased necessity and the economic reasons to use fendering come from various sources:

a) the use of fenders contributes to minimization of the life-cycle construction and operations costs;

b) changes in the vessels:

- vessels are becoming more and more expensive in building and operation. This implies that the use of material for building a vessel is being economized, without sacrificing their seaworthiness, but the risks of damage to vessels in port has increased;

- the costs of demurrage of a vessel in case of repair or in case of idle time when a vessel is not capable to berth, has increased tremendously;

- windage area of vessels has increased substantially (container and cruise vessels);

- larger vessels carrying larger cargoes of hazardous goods.

c) the deeper waters required for the modern vessels result in less protected berths, thus an increase of the energy generated by a berthed vessel as a result of waves, wind and currents. The use of a carefully designed modern fender system may allow a berth facility to be located in surroundings without the protection of expensive breakwaters;

d) fenders, generally in combination with a compatible mooring line arrangement, may be used to reduce the movements of vessels in consideration of the unloading operations;

e) an important factor favouring the use of fendering is safety: this relates only to the safety of the people working in the port or in the surroundings thereof, but also to the prevention of damage to the port infrastructure and the vessel and, last but not least, to protection of the environment. Damage to vessels, and especially to vessels carrying hazardous cargoes, as a result of an undesired hard encounter between vessel and quay or jetty may result in a calamity especially when it is not protected by fenders.

Fenders may also be used to keep the vessel at a certain distance from the jetty or quay what may be of importance in case of raker piles under a jetty or a shallow area in front of a quay.

2.2 FENDERING PRINCIPLES

Fendering is basically the interface between a vessel and the berth facility. This medium serves to absorb a certain portion of the kinetic energy of a vessel without damage to the vessel and the waterfront structure. In the case of rubber fenders, which are generally relatively soft, the majority of the energy is absorbed through elastic deflection of the fender. But, possibly also the deflection of the berth facility and/or the vessel's hull will contribute to the absorption of the kinetic energy. On the other hand, when a vessel berths against a single vertical pile the majority of the energy will be absorbed by the deflection of the relatively flexible pile (see Section 6.6).

The deflection multiplied by the reaction force which is generated and a certain efficiency factor equals the kinetic energy.

For a rubber fender this relation can be expressed mathematically as follows, whereas it is assumed that only the rubber fender will absorb the kinetic energy (hence neglecting e.g. the energy absorption through deformation of the berth structure and the vessel's hull):

$$E_f = f * R_m * d_m$$

where:

E_f = the vessel's kinetic energy which is to be absorbed by the fender (in kNm)

f = factor representing the energy absorbing efficiency of the fender system (between 0 and 1)

R_m = maximum fender reaction force (in kN)

d_m = maximum fender deflection (in m)

The factor f is depending entirely on the fender characteristics, viz. the relation between deflection and reaction force (see figure 2.1 & 2.2).

The R/E_f -ratio (Fender Factor) provides knowledge of a fender system, whereas the R and Ef values shall be taken at the design (or rated) deflection of the fender. A low R/E_f -ratio indicates that low reaction forces are generated to absorb the required energy which is often considered favourable. In some cases, however, it is not required that fenders absorb energy and then a high R/E_f is advantageous, e.g. for surface-protecting fenders. (See Table 3.2)

The energy that is absorbed by the fender system during compression is partially returned to the vessel (the vessel is pushed back) and partially dissipated in the form of heat within the material (hysteresis). See also figures below:

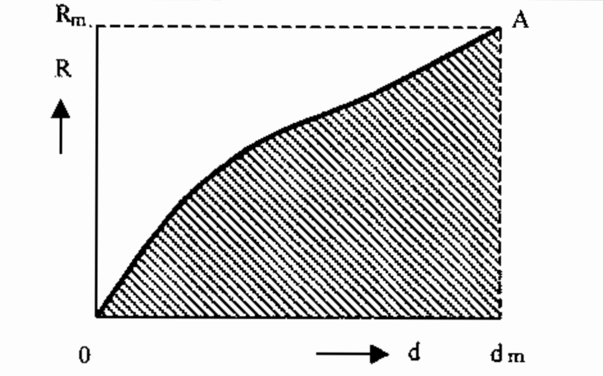


Figure 2.1 energy absorption

Figure 2.1: the shaded area represents the energy absorption; factor f is equal to the shaded area divided by the rectangular area **O-Rm-A-dm**

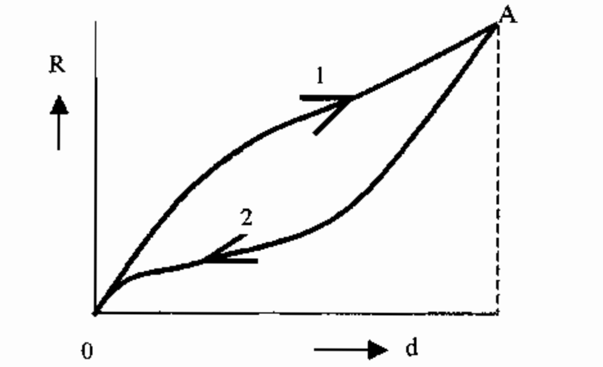


Figure 2.2 compresson

Figure 2.2: Curve 1 represents the compression of the fender, Curve 2 the decompression of the fender, whereas the area between those two curves is the energy dissipated (warmth generated) as a result of hysteresisis.

The selection of a fender or fender system should be tuned to the following stages of usage:

a) during the berthing process (initial contact between vessel and berth facility);
The berthing process consists of a vessel approaching the berth facility, generally under an angle with a certain approach velocity defined as the velocity perpendicular to the face of the facility. The impact of the vessel in motion on the facility must be absorbed in such way that no damage occurs to vessel or facility.

b) while the vessel is moored;
With respect to the situation around the berthed vessel along the berth facility, a distinction can be made between the operational regime and the safety regime.
The operational regime is the regime in which it is still possible to load and unload the vessel, the safety regime is the regime in which it is still possible to allow the vessel alongside the berth without endangering the vessel, the berth or the fendering.

In both regimes the fender should be able to absorb the energy generated by the vessel. The energy is partially transformed by the fender through elastic deformation into heat and into a reaction force. This reaction force acts in two directions, leading to a concentrated load on the berth facility and to a load on the vessel's hull. This reaction force is especially of importance when:

- the berth facility is sensitive to horizontal forces (structure on piles);
- the vessel is moored and moves due to waves.

2.3 FENDER DESIGN BASIS

The design of a fender system deserves as much attention as the design of any other element of the structure of which it is a part. The selection of fender system and type and the selection of the system and type of structure should be interactive.

The fender should be designed in such way that:

- the berthing of the vessel to the berth facility takes place without damage;
- the vessel and the berth (including the fenders) do not get damaged when the vessel is moored;
- the periods of operation and safety are extended as much as possible.

The design process of a fender system could follow these steps:

- determination of the functional programme of requirements;
- determination of operational aspects;
- assessment of the site conditions;
- assessment of the design criteria;
- calculation of the energy to be absorbed by fender (during berthing or when moored);
- select a suitable fender system and type based on the energy and above criteria;
- determine the reaction force and related friction force;
- check impact of the forces on the structure and on the vessel and the implications of the selected fender for the face of the structure; aspects to be considered are e.g.: The berthing model, geometry for bulbous bow and fender spacing are shown on the Vessel Approach Figure 2.3.1, and Island Berths Figures 2.3.2 & 2.3.3.

The above process may have to be repeated several times to select the most optimal fender for the specific situation. There are numerous fender brands and each of those brands offers various types of fenders and most often several standard dimensions for each fender type. It is the task of the design engineer to select the fender of which the specified characteristics meet (or come closest to) the design requirements.

A flow chart for the design of a fender system or the selection of a fender is shown in Figure 2.3.

Note that the design criteria for Abnormal Berthing should be addressed before selecting the fender layout.

2.4

It is strongly recommended that an appropriate testing regime is established to ensure that the final fendering system meets the design criteria.

Appendix A & B set out guidelines on such testing procedures.

Of course, the manufacturer of the fender should arrange for a qualified testing regime so that all parties can be sure of the material characterstics and the fender's performance (as indicated in the manufacturers' brochures).

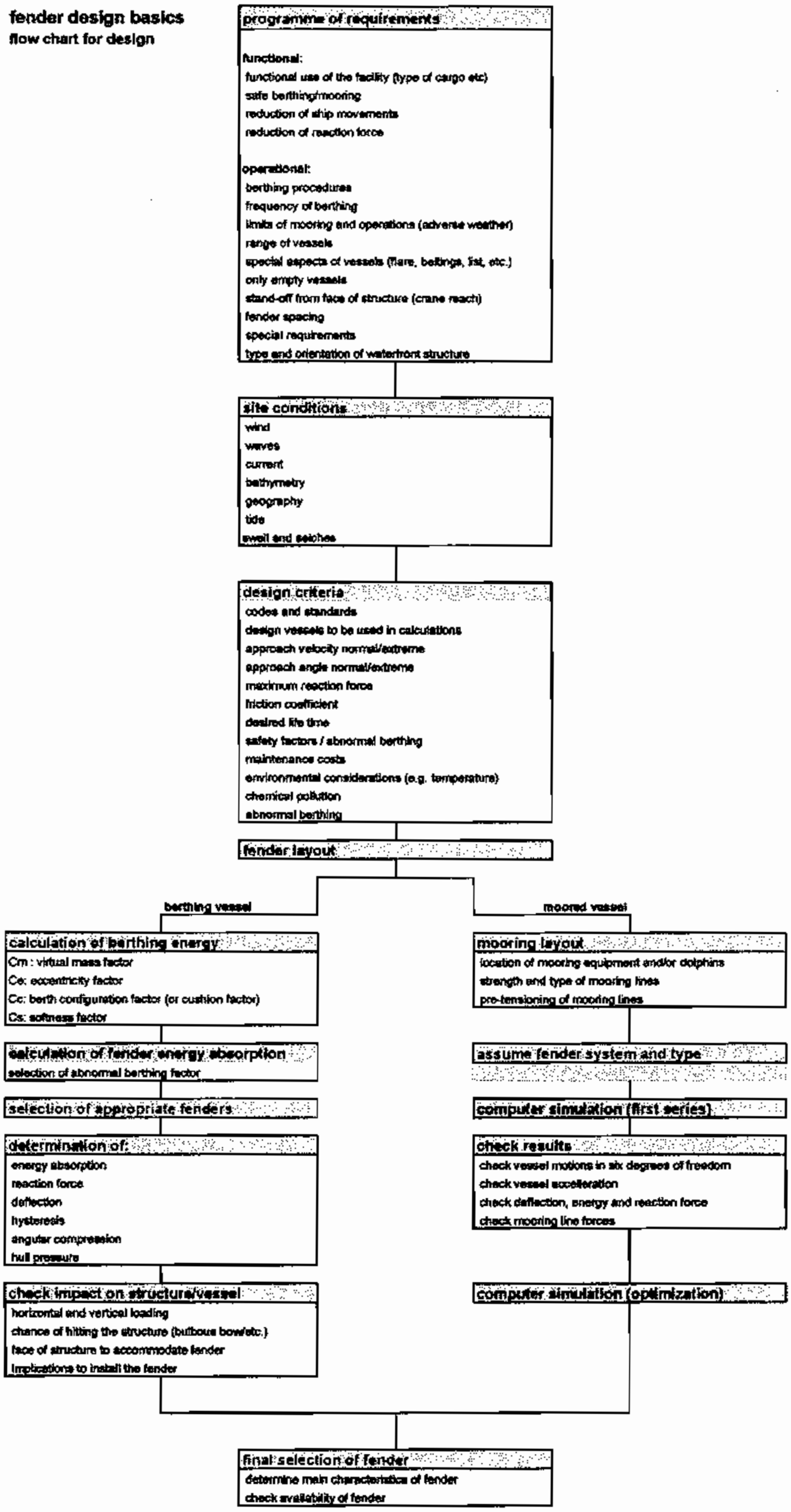


Figure 2.3 Flow Chart for fender design

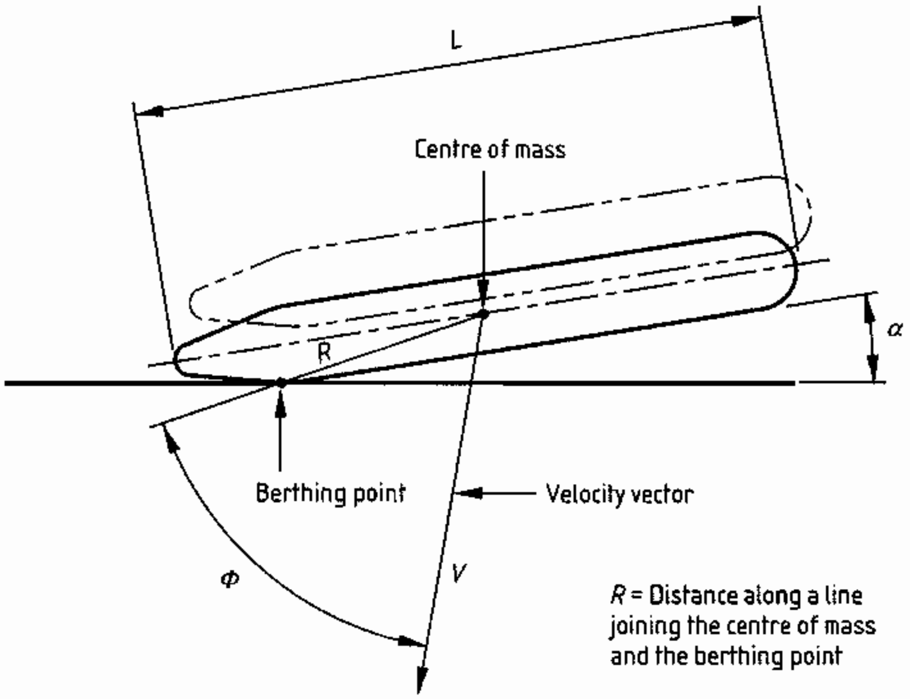


Figure 2.3.1 BERTHING MODEL

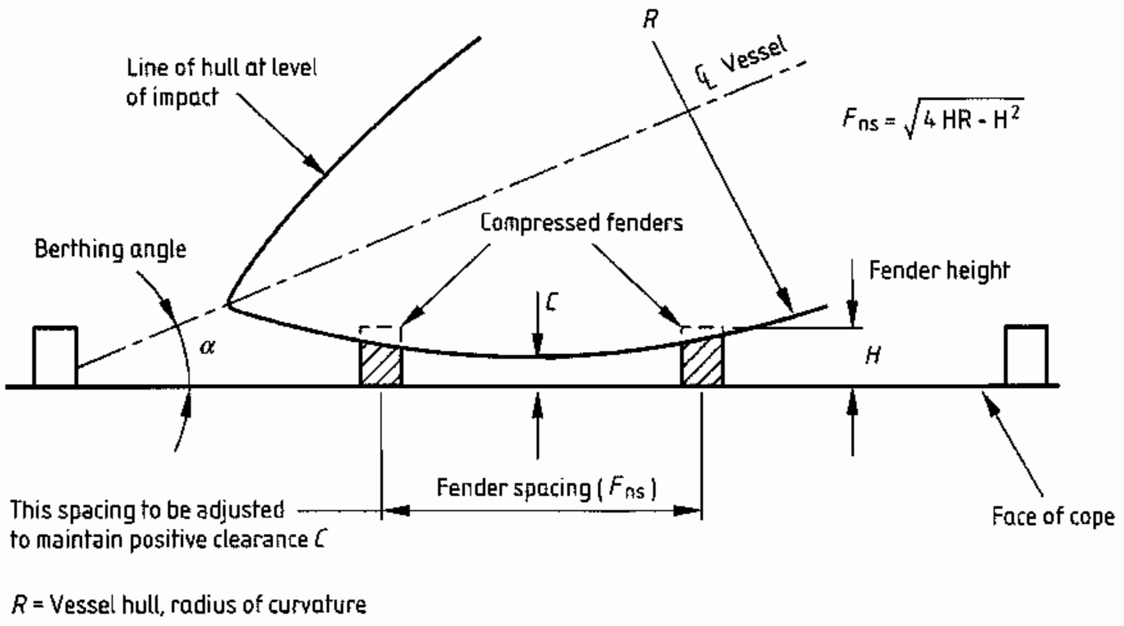


Figure 2.3.2 FENDER SPACING

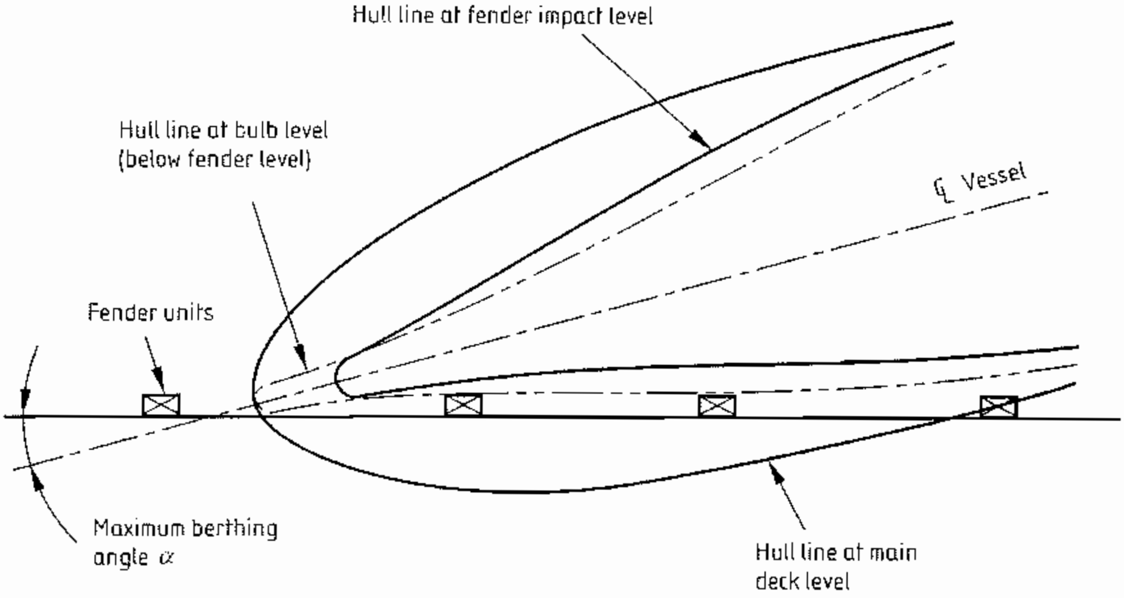


Figure 2.3.3 GEOMETRY OF VESSEL WITH BULBOUS BOW

3. FENDER SYSTEMS AVAILABLE

3.1 INTRODUCTION

The present chapter describes the more ordinary types of fender systems commonly used and the principles and characteristics of the major categories of fender systems in common use.

3.2 DESCRIPTION OF VARIOUS FENDER SYSTEMS

3.2.1 General

Marine fenders provide the necessary interface between berthing ships and berth structures. Therefore the principal function of fenders is to transform ships' berthing energies into reactions which both the ships and berth structures can safely sustain. A properly designed fender system must therefore be able to gently stop a moving or berthing ship without damaging the ship, the berth structure or the fender. Once ships are safely moored, the fenders should be able to protect the ships and the berth structures from the motions caused by wind, waves, current, tidal changes and loading or unloading of cargo. The design of fenders shall also take into account the importance of the consequences, suffered by the ship and the berthing structure in case of excessive ship berthing energy.

Fender systems can be categorised according to the mode by which they absorb or dissipate the kinetic energy of the berthing ship. Table 3.1 shows the various major categories of fender systems in common use. As can be seen from the table, most fender systems are based primarily on the principle of the conversion of kinetic energy of the ship into potential energy of the fender. Only a collapsible unit which dissipates the kinetic energy through the plastic deformation of steel or concrete between the fender unit and berth structure, do not utilise this principle. Steel corrugated units are always used in conjunction with another type of fender unit for which it serves as the energy absorbing equivalent of an electric fuse.

Other systems may exist which have either very limited application or have not been widely accepted. Also many existing fender systems are variations or combinations of several of the systems listed. A single or easy solution to all fender problems does not exist. Each combination of vessel, type of berth structure and berthing conditions has different requirements. Factors having impact on the choice of fender are: size of ships, navigation methods, location, tidal differences, water depths, etc. A ship berthing along an exposed berth structure will obviously have other demands on the fender system than if it was to berth along a sheltered berth structure.

Table 3.1 lists the range of standard sizes, energy absorption capacities, reaction forces, rated maximum deflections etc. for the various types of ordinary fender systems in use. All are of the category that converts energy by elastic deformation. Fender manufacturers are constantly carrying out research and developing variations and improvements to these systems, so the fender system designer is advised to consult manufacturers regarding the availability of new fender units. Also, the various fender manufacturers may have different names for fender units of similar appearance and performance characteristics and Table 3.2 does not necessarily include all names for each basic type of fender unit.

Most of the characteristics listed in Table 3.1 are based on data published by fender unit manufacturers and actual fender performance may vary by as much as ten percent. Also, the characteristics are based on perpendicular impacts, and fender performance may vary considerably when subjected to angular impacts, which is the most common case.

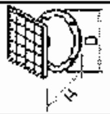
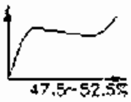
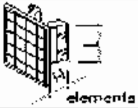
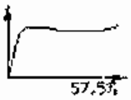
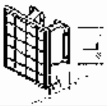
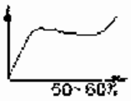
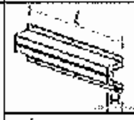
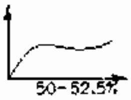
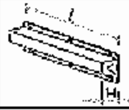
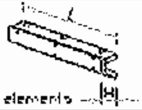
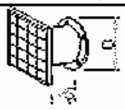
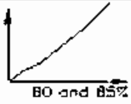
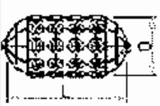
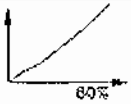
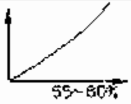
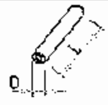
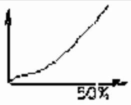
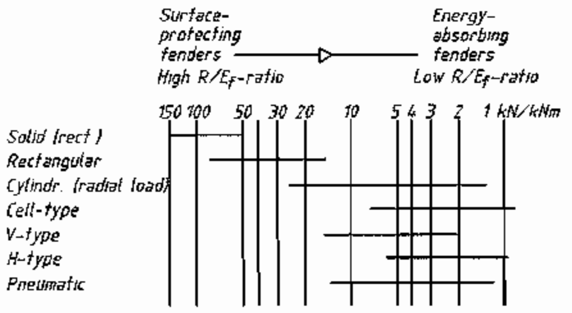
	Type	Fender shape	Sizes in mm	Reaction kN	Energy kNm	Performance curve
Backling type fender	Circular shape of the bucking fender with panel contact		D/H 500/300 ↓ 3200/2000	60 ↓ 4660	9 ↓ 4840	
			D/H 650/400 ↓ 3350/3000	56 ↓ 5688	10 ↓ 6570	
	Longitudial shape of the bucking fender with panel contact		H/L 300/600 ↓ 1800/2000	66 ↓ 1708	9 ↓ 1260	
			H/L 400/500 ↓ 2500/4000	140 ↓ 6900	22 ↓ 7000	
	Bucking fender with direct contact		H/L 250/1000 ↓ 1000/2000	150 ↓ 2290	15 ↓ 940	
			H/L 200/1000 ↓ 1300/3500	150 ↓ 3400	10 ↓ 1500	
			H/L 300/600 ↓ 1000/2000	45 ↓ 646	6 ↓ 297	
Pneumatic	Airblock		D/H 600/450 ↓ 3200/3200	138 ↓ 6210	15 ↓ 4990	
	Pneumatic		D/L 500/1000 ↓ 4500/12000	50 ↓ 10570	4 ↓ 9080	
	Foam filled		D/L 1000/1500 ↓ 3500/8000	200 ↓ 4050	41 ↓ 3000	
Side loaded	Cylindrical		D/L 150/1000 ↓ 2800/5800	80 ↓ 6600	3 ↓ 5000	

Table 3.1 Different types of energy absorbing elastic deformation rubber units.

Table 3.2 indicates that fenders are either mainly transmitting energy or mainly absorbing energy. As can be seen, for example, the different sizes of cylindrical fenders have, under side loading, a fender factors R/Ef varying from about 25 kN/kNm to about 1.3 kN/kNm.



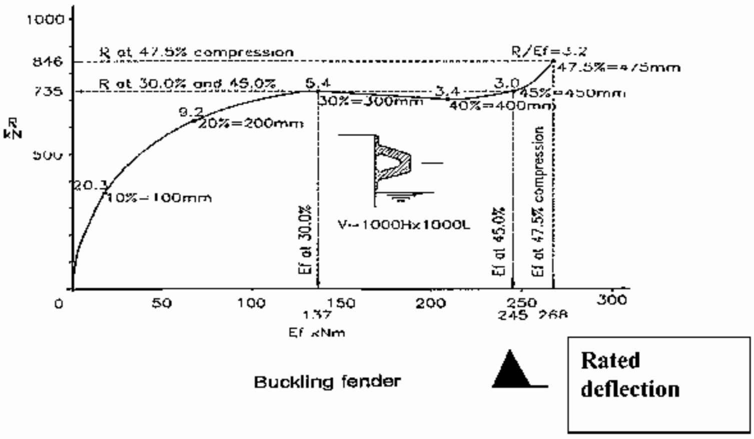
The Fender Factor=R/Ef=Reaction in kN to be transferred to the quay per kNm energy absorbed by the fenders.

Table 3.2 Fender Factors for different types of rubber fenders

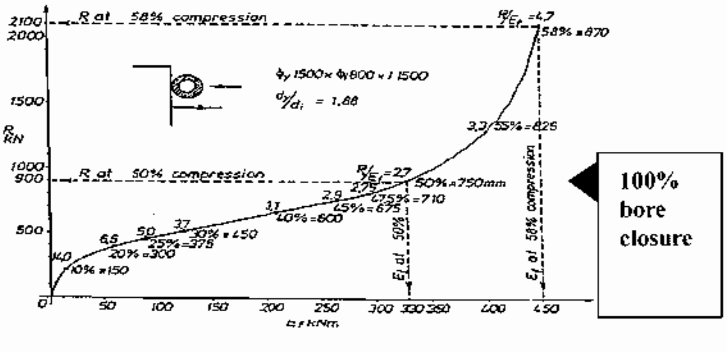
Figure 3.1 illustrates what happens when a ship is berthing. A fender with a 1500 mm Outside Diameter (OD), 800 mm Inside Diameter (ID) and 1500 mm length will absorb an impact energy of 330 kNm at about 50 % deflection. The resulting force to be resisted by the berth structure will be 900 kN with a fender factor R/Ef 900/330=2.7 kN/kNm. What is interesting about these large fenders, which are designed for bigger ships, is that they have a high fender factor with low compression (at 10% compression R/Ef = 14.0 -kN/kNm). Where smaller ships are concerned, they will have little energy-absorbing effect but function more as surface-protecting fenders. The curve shows that the fender factor decreases with increasing compression, as far as 50% when it is 2.7 kN/kNm. Beyond this the factor increases with increasing compression

It must be realised that rubber fenders absorb energy even beyond 'rated deflection' (defined by the manufacturers), but the forces to be resisted by the berth structures will then increase excessively. This is due to the fact that beyond 'rated deflection' most rubber fenders begin to transmit more reaction rather than absorb more energy, usually.

As fenders or quays can only withstand a fixed reaction before failure, fender structures can be provided with devices or overload collapsible unit to prevent overload or damaging of the berth structure. The collapsible units can be constructed either in concrete or steel, and installed between the fender and the berth structure. To prevent failure or damage to the fender, the collapsible unit can be designed to collapse for a reaction force equal to the fender reaction at bout 55 to 60% compression of the fender



Buckling fender



Side loadec cylindrical fender

Figure 3.1 The effects achieved at various degrees of compression of a side loaded fender

4. DETAILED FENDER DESIGN

4.1 DESIGN BASIS

Before starting the design of a fender system it is advisable to make a careful evaluation of the requirements which the fender system has to fulfil.

The following points shall be taken into account in the fender selection procedure:

- a moored vessel may give larger forces than a berthing vessel;
- a small vessel may give rise to a greater berthing energy than a larger vessel;
- a larger fender may give a larger reaction force than a smaller fender when absorbing the same berthing energy;
- a relatively large fender may act as a solid wall on a small vessel (bouncing off phenomenon).
- corrosion: a specific issue to be addressed during the design of fender assemblies is corrosion. The influence of corrosion on the steel components of fenders is elaborated and discussed in 4.1.5.

4.1.1 Functional requirements

Depending on the situation where fenders are applied some or all of the following functional requirements may have to be considered:

- the functional use of the facility (type of cargo to be handled etc.);
- to allow for safe berthing of a vessel;
- to allow for a safe mooring of a vessel;
- the protection of the vessel;
- the protection of the berth structure;
- the reduction of the vessel's movements under influence of wind, waves and currents;
- the reduction of the vessel's movements under influence of the loading or unloading operations;
- the reduction of the reaction force as a result of the berthing and mooring of a vessel.

4.1.2 Operational aspects

The following operational aspects may have to be considered:

- the berthing procedures;
- the frequency of berthing;
- the limits of mooring (under adverse weather conditions);
- the limits of operation (maximum vessel's motions under adverse weather or sea conditions);
- the range of vessels that may make use of the facility (size and type);
- special aspects of the design vessel (flare, beltings etc);
- there may be only empty vessels berthing;
- the maximum stand-off from berth face;
- any special requirement as a result of the type of structure or method of construction (pre-fabrication etc);
- eccentric loading of a fender system.

4.1.3 Site conditions

The site conditions are of importance for the selection of the fender system and the fender. With sufficient site data, the design of a fender system and the berth structure can be optimized and costs can be saved in the end. Reduction of the costs of site investigations may decrease the investment costs, but could also result in higher maintenance costs and/or more damage as a result of non-optimal design. Collection of sufficient site data is therefore recommended, and it is the task of the designer to advise on the extent of the data collection programme.

The data required about the site may concern:

- wind;
- waves (long waves, swell, seiches, random waves);
- currents;
- water depth/bathymetry;
- tides;
- temperature;
- ice conditions.

4.1.4 Design criteria

Following the assessment of the functional and operational requirements and based on the site conditions, the design criteria that will be used in the calculation of berthing and mooring energies and the selection of the fender system can be determined.

Design criteria:

- the codes and standards to be used;
- the design vessel(s) to be used in the calculations;
- the approach velocity under normal conditions and checking for abnormal conditions;
- the berthing angle under normal conditions and checking for abnormal conditions;
- the maximum reaction force (horizontal and vertical);
- the vessel's allowable hull pressure;
- the friction coefficient;
- the desired life time;
- the minimum or maximum fender spacing;
- the safety factors to be used;
- whole life considerations (see Section 5);
- maintenance periods.

4.1.5 Corrosion

All metals suffer more from corrosion in a maritime environment than on shore. This is mainly due to:

a) The formation of galvanic cells within the metals of the structures acting as anodes and cathodes and the solution of salts in seawater acting as the electrolyte. Corrosion can be severe in the splash zone due to the presence of abundant oxygen. Differing metals form galvanic cells due to their differing electro-chemical potentials. This effect can occur between welds and the parent metal.

b) Microbial action inducing galvanic cells. A phenomenon of accelerated corrosion due to Sulphate Reducing Bacteria (SRB) or similar, which can cause exceptionally high rates of corrosion, has been identified in a large number of ports in the UK and many other countries. This form of attack usually occurs close to Lowest Astronomic Tide (LAT) level and is sometimes referred to as Accelerated Low Water Corrosion (ALWC) but in some cases it has occurred down to sea bed level.

At present, there is no method by which its occurrence or the resulting rate of corrosion can be predicted. It is usually uneconomic to adopt a corrosion allowance as this can be up to an order of a magnitude larger than for normal corrosion.

For fender installations consideration should be given to facilitate the replacement of affected elements should this type of corrosion occur or, in the case of fender piles the installation of cathodic protection which is thought to be beneficial or physical protection in the form of concrete or other non-organic protective coatings.

c) The steady erosion of the corrosion products, such as rust in the case of structural steels by wave or vessel abrasive action or by floating fenders against their supporting structure or by cyclic deflections especially if the structure is designed to absorb energy by deflection. The accelerated corrosion referred to in (b) above may be further enhanced by abrasive action.

d) The inadequacy of planned methods of prevention and/or maintenance by owners.

Consideration should be given to the influence of corrosion on the design of fenders and their accessories. Unprotected steel will begin to reduce in thickness immediately after it is installed. The onset of corrosion may be delayed by an appropriate paint system, suitably maintained. The design should be based on steel thicknesses at the time of first maintenance or, if no maintenance is planned, at the expiry of the design life.

Corrosion rates will vary according to local conditions and the position of the fender in the inter tidal zone and may be significantly higher in hotter climates. The effect of corrosion on fender integrity and safety factors will also depend upon whether the steel is exposed on both faces, or just one face. In the case of chains and bolts, loss of diameter affects sectional area with very rapid loss of strength once corrosion begins - often making periodic replacement more economic rather than using excessively large sizes to maintain minimum safety factors throughout the full fender system design life.

4.1.6 Steel panels and fender frames

Steel panels and fender frames are critical to the correct performance of the fender system. They may be subject to a combination of uniformly distributed loads, line loads or point loads according to the types of vessels which use the fenders.

Limit state design codes should be used to determine the construction of the steel panels and frames. Input loads from the ship hull, the elastomeric fender unit and chain connections should all be considered.

Design calculations should consider bending, shear and local buckling in the steel panels and fender frames. Local buckling should be checked as inadequately supported webs in the panel grillage may be prone to collapse under line load or point load conditions.

Recommended minimum thicknesses for steel in fender panels are:

Plates exposed on two surfaces:	12 mm
Plates exposed on one surface:	9 - 10 mm
Internal members (not exposed):	8 mm

4.1.7 Chains

Chains are often used to control the dynamic geometry and enhance the performance of fender systems. The following types of chains are used:

- Weight chains are used to support the steel frame and prevent drooping of the elastomeric fender units. They must also resist vertical frictional forces where there are large tidal variations, changes in vessel draught during loading and discharge or where sea swell may cause the ship to heave on the berth.
- Shear chains are used to limit the lateral movement of the steel frames, particularly where vessels are regularly warped along the berth.
- Tension chains are used to prevent excessive tensile loads on the elastomeric fender units in cantilever designs and to ensure the most efficient use of the elastomer elements. Smaller tension chains sometimes supplement weight chains to prevent fender droop.
- Keep chains are used to enable a fender to be recovered easily after damage has been incurred and are addition al to the normal support system.

Chains may suffer higher rates of wear and corrosion than other fender components. This can rapidly reduce load capacity of the chain, so consideration should be given to periodic inspection and replacement during the operating life of the system.

If chains become overloaded, it is desirable that an easily replaceable component should fail first. Care should be taken to ensure fender integrity is not compromised due to the failure of an overload failure element.

4.2 BERTHING ENERGY - THE DETERMINISTIC APPROACH

Introduction

The deterministic method is the oldest and so far most commonly used method for fender design. The method is outlined in detail in the following sections. The designer should carefully consider whether this method is indeed suitable for the specific situation. Especially in cases where external forces may have an impact on the berthing energies, more sophisticated methods may be required.

The following section concerns a vessel in the process of berthing. Energies generated by a vessel in moored condition are covered in section 4.5 (Computer simulation).

4.2.1 Energy equation for a vessel in the process of berthing

The kinetic energy of a moving vessel may be calculated as:

$$E = {}^{1}/_{2} * M * v^{2}$$

where:

E = kinetic energy of the vessel itself (in kNm)
M = mass of the vessel (= water displacement) (in tonnes)
v = speed of the approaching vessel perpendicular to the berth (in m/s)

The design energy that has to be absorbed by the fender can be calculated as:

$$Ed = \frac{1}{2}\ \underline{M} * v^{2} * Ce * Cm * Cs * Cc$$

where:

Ed = design energy (under normal conditions) to be absorbed by fender system (in kNm)
$\underline{M}$ = mass of design vessel (displacement in tonnes), at chosen confidence level. Usually 95 % confidence level (Refer to Appendix C for values)
V = approach velocity of the vessel perpendicular to the berth (in m/s)(use 50 % confidence level)
Ce = eccentricity factor
Cm = virtual mass factor
Cs = softness factor
Cc = berth configuration factor or cushion factor

Based on the manufacturer's performance curve for a selected fender, a fender reaction force can be defined for the calculated kinetic energy of the vessel. This force is a characteristic load, which should be used as specified in the code used for design of the quay structure. Berthing mode may affect the choice of vessel approach speed and the safety factor for abnormal conditions.

Abnormal impact conditions can be accounted for as discussed in 4.2.8.

4.2.2 Mass of the design vessel (M)

Generally the size of cargo carrying vessels is expressed in Dead Weight Tonnage (DWT).

The size of passenger vessels, cruise vessels or car ferries is generally expressed in Gross Registered Tonnage (GRT).

DWT is the cargo carrying capacity of a vessel including bunkers (fuel, water, etc.).

GRT is the internal capacity of a vessel measured in 100 ft^3 (100 ft^3 = 2.83 m^3).

For the energy calculation the displacement of a vessel is required. The displacement tonnage (M) of a vessel is the total mass of the vessel and can be calculated from the volume of water displaced multiplied by the water density. In most case the vessel's fully loaded displacement is used in the fender design.

For guidance on displacement tonnage factors for various vessel types, see Appendix C, if more accurate data is not available.

4.2.3 Approach velocity (v)

The approach velocity v is the most influential variable in the calculation of the berthing energy. The approach velocity is defined as the vessel speed at initial berthing contact, measured perpendicular to the berth.

The actual approach velocity is influenced by a large number of factors such as:

- prevailing physical boundary conditions: the influence of waves, wind and current should be considered;
- ease of navigation: is the approach to the berth easy or difficult?
- method of berthing: are berthing aids used, is berthing always parallel, when is the forward motion of the vessel stopped, etc;
- type of vessel: is the vessel equipped with powerful engines, quick reacting engines, bow thrusters, etc;
- use of tugs: are tug boats used, how many and of sufficient capacity?
- frequency of berthing: at berths with a high berthing frequency, generally higher berthing velocities are experienced;
- size of vessel: the approach velocity of larger vessels is generally less than the approach velocity of smaller vessels; range of vessels expected at the berth must be considered;
- berth appearance: ship masters will berth more careful when approaching a desolate berth instead of a new, modern berth;
- type of cargo: a vessel with hazardous cargo will generally berth under better controlled circumstances, the use of berthing aids for example;
- windage area of the vessel: a vessel with a large windage area is considerably more susceptible to wind;
- human factor: a most important factor, this may concern the level of experience, etc.

Designers must consider that the design values for the approach velocity should be close to the expected actual berthing speeds. It is the task of the designer to obtain data on the local conditions and seek out vessel operators, port engineers, ship owners, etc. in order to gain insight into the applicable conditions and to decide on the most likely and/or appropriate approach velocity.

The British Standard on Fenders (BS 6349 Part 4) has adopted the design approach velocity as recommended by Brolsma et al. in 1977 (see Figure 4.2.1). In line with Baker (1953) Brolsma distinguishes five navigation conditions but does not elaborate on those conditions except that all vessels berthed with tug assistance. However, to date no more pertinent or accurate data has been found.

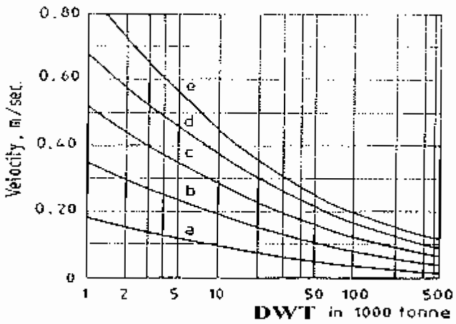


Figure 4.2.1. Design berthing velocity (mean value) as function of navigation conditions and size of vessel (Brolsma et al. 1977)

a. Good berthing conditions, sheltered

b. Difficult berthing conditions, sheltered

c. Easy berthing conditions, exposed

d.* Good berthing conditions, exposed

e.* Navigation conditions difficult, exposed

* These figures should be used with caution as they are considered to be too high.

Mean value is taken to be equivalent to the 50% confidence level.

Although based on observations, the values given in Figure 4.2.1 show low approach values for large vessels which can easily be exceeded in adverse conditions.

For the majority of cases it is considered sufficiently accurate to distinguish the above conditions. It is assumed that the environmental conditions are closely related to the degree of exposure of the berth (exposed, partly exposed or sheltered). In absence of more accurate figures, the following practical values may be adopted for the approach velocity v (in m/s):

Table 4.2.1 Suggested Approach Velocity(Mean Values) m/s
(Taken from the Spanish ROM Standard. 0.2-90)

Vessel displacement in tonnes	**Favourable Condition**	**Moderate Conditions**	**Unfavourable Conditions**
Under 10,000	0.2 - 0.16	0.45-0.30	0.6-0.40
10,000 - 50,000	0.12 - 0.8	0.3-0.15	0.45-0.22
50,000 - 100,000	0.08	0.15	0.20
over 100,000	0.08	0.15	0.20

Mean value is taken to be equivalent to the 50% confidence level. The figures given above are indicative, with tug assistance. The full graphs are set out in the ROM standard

In case the berthing manoeuvre takes place without tug boat assistance, the above figures will be increased considerably.

For vessel to vessel approaches and the related closing velocities, reference is made in Section 6.5.

Special attention is to be paid to berths used by smaller vessel, e.g. a tug boat jetty, as these smaller vessels tend to berth at relatively high speeds.

In recent decades more and more berths, especially tanker/chemical berths, have been equipped with berth approach detection systems. Information from these systems, if available, may be used to establish design approach velocities for specific facilities.

4.2.4 Eccentricity factor (Ce)

For the eccentricity factor two different scenarios have to be distinguished:-

- a berth with continuous fendering;

- a berth with breasting dolphins (or island berth).

An important role in the determination of this factor is the berthing angle.

The berthing angle is also of importance for the determination of the reduction in energy absorption capacity of fenders, as a result of angular compression resulting in non-uniform deflections.

Berthing angle

Measurements in Japan have shown that for vessels larger than 50,000 DWT the berthing angles are generally less than 5 degrees with only occassionally an angle of 6 degrees. It is therefore suggested that 6 degrees be used as a maximum approach angle for these vessels.

For smaller vessels, and especially for vessels which berth without tug boat assistance, the berthing angle may be larger, say 10 - 15 degrees (e.g. feeders/coasters 8 - 10 degrees and barges 15 degrees).

See Figure 2.3.1, Berthing Model

Eccentricity factor Ce

The eccentricity factor can be calculated with the following formula:

$$C_e = \frac{K^2 + K^2 * \cos^2 \varphi}{K^2 + R^2}$$

or simplified, assuming ϕ is 90 degrees:

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

K = radius of gyration of the vessel (depending on block coefficient, see below) (in m)
R = distance of point of contact to the centre of the mass (measured parallel to the wharf) (in m)
ϕ = angle between velocity vector and the line between the point of contact and the centre of mass

Figure 4.2.2 Ce Factor shows the relationship.

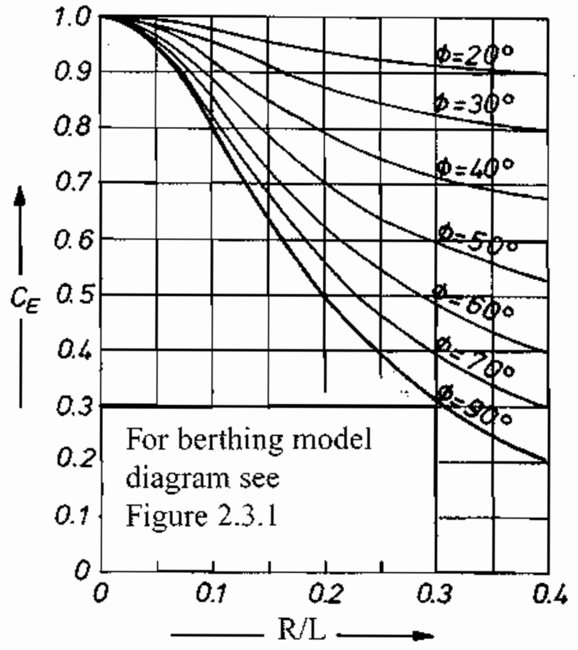


Figure 4.2.2 Ce Factor.
As a function of ϕ and R/L

$$K = (0.19\, C_b + 0.11) * L \quad \text{and} \quad C_b = \frac{M}{L*B*D*\rho}$$

where:
Cb = block coefficient (usually between 0.5 - 0.9, see below);
M = mass of the vessel (displacement in tonnes);
L = length of vessel (in m);
B = breadth of vessel (in m);
D = draft of vessel (in m);
ρ = density of water (about 1.025 ton/m^3 for sea water)

Lacking other data, the following may be adopted for the block coefficient:

For large tankers, K can be taken as approximately 0.25 L.

In the case where there is no accurate data or, in case only a quick assessment is made, the following figures may be used:

for a continuous berth:
quarter point berthing, the berthing point of the vessel is some 25% of the vessels length from the bow:
Ce = 0.5

for a berthing dolphin:
The berthing point of the vessel is some 35% of the vessels length from the bow:
Ce = 0.7

For Ro/Ro vessels the Ce factor is taken as 1.0 for the end fenders.

4.2.5 Virtual mass factor (Cm)

For the virtual mass factor (also referred to as 'added mass factor' or 'hydrodynamic mass factor') several formulae are in use (Stelson, Malvis, Ueda, B.F. Saurin, Rupert, Grim, Vasco Costa, Giraudet) and much research work has been done.

Cm is generally defined as:

$$C_m = \frac{M + M_v}{M}$$

M = mass of the vessel (displacement in tonnes)
M_v = virtual mass (in tonnes)

Some of the formulae used to obtain input for the calculation of Cm are given below.

Shigeru Ueda

$$M_v = \rho L D^2 * \frac{\pi}{2}$$

where:
ρ = density of water (about 1.025 ton/m^3 for sea water);
L = length of vessel (in m);
D = draft of vessel as used for calculation of mass of design vessel (in m).

Table 4.2.2

For container vessels	0.6 - 0.8
for general cargo vessels and bulk carriers:	0.72 - 0.85
for tankers:	0.85
for ferries:	0.55 - 0-65
for Ro/Ro-vessels	0.7 - 0.8

The formula of Shigeru Ueda originates from 1981 and is based on model experiments and field observations.

The formula can be transformed into:

$$C_m = 1 + \frac{\pi * D}{2\, C_b * B}$$

where:

C_b = block coefficient (see sub section 4.2.4);
B = breadth of the vessel (in m).

Vasco Costa

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

This formula was published in 1964 and is also used by the British Standards Institute. It is valid under the following circumstances:

1) the keel clearance shall be more than 0.1 * D; and
2) the vessel's velocity shall be more than 0.08 m/s.

Conclusion

For the purpose of comparison, the above formulae have been used to calculate the values of Cm for several vessels. From Table 4.2.3 Cm Factor, it can be seen that the values range between 1.45 and 2.4, whereas the average values range between 1.51 and 1.99.

Cm values are influenced by both the vessel characteristics and also the amount of water under the vessel (keel clearance). Furthermore, it is clear that the outcome of the formulae differs and shows differences between each other. Each formula has restrictions and must be used with care. The earlier PIANC report (supplement to bulletin 45, 1984) compared the results of research and formulae. Unless the designer has good reasons to apply other values, it is recommended :

for very large keel clearances ie (0.5 * D):
then use Cm = 1.5
for small keel clearances ie (0.1 * D):
then use Cm = 1.8
for keel clearances in between 0.1*D and 0.5*D:
use linear interpolation

The above Cm values are valid for transverse approaches. A Cm value of 1.1 is recommended for longitudinal approaches.

4.2.6 Softness factor (Cs)

This factor is determined by the ratio between the elasticity of the fender system and that of the vessel's hull. Part of the kinetic energy of the berthing vessel will be absorbed by elastic deformation of the vessel's hull. Cs expresses the kinetic energy portion of the berthing vessel onto the fender.

The following values are often used:

- for soft fenders and for smaller vessels Cs is generally taken as 1.0;
- for hard fenders and larger vessels Cs lies between 0.9 and 1.0 (e.g. for VLCC Cs = 0.9).

The British Standard Code of Practice for Maritime Structures (BS 6349) suggests in Part 4 on the 'Design of fendering and mooring systems' that a hard fendering system can be considered as one where the deflections of the fenders under impact from ships for which the fenders are designed, are less than 0.15 m.

In most cases the contribution of the vessel's hull to the energy absorption is only limited. It can therefore be concluded that there appears little merit in maintaining the distinction between soft and hard fenders. This results in a general value of Cs = 1.0.

Tabel 4.2.3 Cm Factor

Cm values for different vessels and selected formulae.The vessel dimensions are actual and approximate to the 50% confidence limit shown in Appendix C.
Cb values produced by Akakura from the Lloyds data for the 50% confidence limit are given below as a comparison

			vessel 1 container	vessel 2 container	vessel 3 tanker	vessel 4 tanker	vessel 5 cargo	vessel 6 cruise	vessel 7 cruise	vessel 8 ore carrier	vessel 9 car ferry	vessel 10 cargo
dimensions	**DWT***		**33,000**	**50,000**	**100,000**	**200,000**	**50,000**	**131,000**	**102,000**	**70,000**	**13,000**	**10,000**
length	L		260	290	270	325	232	310	272	244	195	144
breadth	B		32.2	32.3	39	47.2	30	38.6	35.4	37.8	24	19.4
draft	D		12.0	11.0	14.6	19.0	12.7	8.6	8.2	13.3	6.7	8.2
displacement	MD		51,000	68,200	119,700	233,300	68,200	64,400	63,600	84,300	13,000	13,800
Actual Cb			0.50	0.65	0.79	0.78	0.75	0.61	0.79	0.67	0.40	0.59
Akakura Cb			0.66	0.66	0.79	0.79	0.75	0.57	0.57	0.84	0.49	0.75
							Cm					
Shigeru Ueda			2.18	1.83	1.77	1.81	1.88	1.57	1.46	1.82	2.08	2.13
Vasco Costa			1.75	1.68	1.75	1.81	1.85	1.45	1.46	1.70	1.56	1.85
average			1.96	1.76	1.76	1.81	1.87	1.51	1.46	1.76	1.82	1.99

*** for cruise vessels use GRT**

4.2.7 Berth configuration factor (Cc)

The berth configuration factor (also referred to as 'cushion factor') indicates the difference between an open structure (e.g. a jetty on piles) and a closed structure (quay wall).

In case a vessel is nearing a closed structure and the gap between the vessel's hull and the vertical quay wall is closing, the water between the vessel and the quay wall will be squeezed away. In case it is difficult for the water to be squeezed away then the water will act as a cushion and a certain amount of the berthing energy will dissipate, hence reducing the energy to be absorbed by the fender(s). The extent of this cushion effect depends on several factors:

- quay structural support;
- keel clearance;
- velocity and angle at approach;
- thickness of the fender;
- vessel's hull shape.

Basically, if there is an easy way out for the water between vessel and quay wall, then the cushion effect will hardly occur, e.g. in case of a large keel clearance, an angular approach, etc. The same is valid if the approach velocity is so low that the water will not be trapped between vessel and quay.

Experience has indicated that for a solid quay wall about one quarter of the energy of a berthing vessel is absorbed by the water cushion, and therefore the following values appear to be justified:

- for open berths and corners of quay walls Cc is generally taken as 1.0;
- for (solid) quay walls under parallel approach is Cc generally taken as 0.9.

N.B. Parallel approaches only occur under highly controlled conditions. It is important to bear in mind that for an approach angle in excess of 5 degrees, the cushion disappears.

4.2.8 Factors for Abnormal Impacts

4.2.8.1 Introduction

Fenders and fendering systems not only have to cater for normal impacts due to the design vessel under maximum design conditions, but also have to be capable of catering for a reasonable abnormal impact due to mishandling or accident, which will occur from time to time.

4.2.8.2 Normal Impact

A normal impact is that which is calculated for a particular berth as set out elsewhere in this report. The energy calculated for a normal impact will have taken into account the displacement of vessels using the berth including the effect of added mass of water, the approach velocity taking into account the type of vessels, frequency of use, the familiarity of the operator with the berth, the type of berth and its exposure to wind and current.

4.2.8.3 Abnormal Impact

An abnormal impact occurs when the normal calculated energy to be absorbed at impact is exceeded. The reasons for abnormal impacts can be mishandling, malfunction or exceptionally adverse wind or current or a combination of them.

4.2.8.4 Design for Abnormal Impact

The factor for Abnormal Impact should be applied to the berthing energy as calculated for a normal impact to arrive at the abnormal berthing energy. This factor should enable reasonable abnormal impacts to be absorbed by the fendering system without damage. It would not be practicable to design for an exceptionally large abnormal impact and it must be accepted that such an impact would result in damage.

The selection of the abnormal impact factor should take into account the following:

(a) The effect that a fender failure would have on berth operations
Berths whose configuration results in dependence on a single fender system or group such that the berth would be inoperative if damage was incurred, should be attributed a higher factor than berths with multiple fenders, or fendering systems, which can continue to operate if one or more sustained damage.

(b) Frequency of berthing
Berths which have a high frequency of berthing will statistically have a higher probability of abnormal impact and should be attributed a higher factor.

(c) Berths with very low approach velocities
For use whilst the vessel is berthing. Berths which are designed for very low approach velocities e.g. below 0.1 m/sec requiring a high degree of skill and judgement on behalf of the mariners are more likely to incur abnormal impact than berths designed with higher approach velocities requiring less skill. Berths designed for very low

approach velocities should therefore be attributed a higher factor for abnormal impact (refer to Table No in 4.2.5) unless design velocities are in the 95% confidence level. This latter can only be achieved with suitable measuring and feed back systems.

The factor for abnormal impact when derived should not be less than 1.1 nor more than 2.0 unless exceptional circumstances prevail. If it is possible to achieve a large confidence value in the approach velocity then the factor for abnormal impact can be 1.0.

(d) Vulnerability of the structure supporting the fender or fender system
If an abnormal impact results in damage to the structure supporting the fender or fender system, the cost and time involved in repairs are likely to be disproportionally large. The type and vulnerability of the supporting structure is an important consideration in determining the factor for abnormal impact. The fender reactions due to abnormal impact should be used for the design of the supporting structure with no reduction in safety factor or load factor in carrying out the design of the structure.

It is considered advisable to check the supporting structure against failure for loads substantially greater, (of 2-3 times greater), than the reactions due to abnormal impact depending on the likely consequences of damage to the structure.

The principle of progressive failure may be employed to ensure that the less expensive and more easily vulnerable items fail first.

(e) Range of vessels using the berth
Where berths are used by a wide range of vessels and the largest vessels, for which the abnormal impact has been derived, only use the berth occasionally, the factor for abnormal impact may be reduced. Conversely, if the smallest vessels only use the berth occasionally and the majority are the larger vessels, a higher factor for abnormal impact may be appropriate.

In any event, care should be taken not to increase the factor for abnormal berthing to such an extent that the fender capacity and consequently the fender reaction becomes detrimental to small vessels using the berth.

(f) Hazardous cargoes
Where berths are to be used by vessels with hazardous cargoes, the manner of berthing should be controlled and advantageous environmental conditions chosen such that normal impacts are not exceeded.

4.2.8.5 Guidance on selection of Factor for Abnormal Impact

The designers' judgement should be paramount in determining the appropriate factor.

The following table gives general guidance on the selection of the factor for abnormal impact to be applied to the design energy.

Table No 4.2.5

Type of Berth Impact	Vessel	Factor for Abnormal Impact Applied to Berthing Energy (Cab)
Tanker and Bulk Cargo	Largest Smallest	1.25 1.75
Container	Largest Smallest	1.5 2.0
General Cargo		1.75
Ro-Ro and Ferries		2.0 or higher
Tugs, Work Boats, etc.		2.0

Where the berth is to be designed for a range of vessels, the largest and smallest vessels and their appropriate berthing energies should be considered.

It is recommended that the factors derived from the above table are then modified in accordance with 4.2.8.4 above.

The factor of abnormal impact when derived should not be less than 1.1 nor more than 2.0 unless exceptional circumstances prevail.

If abnormal impacts resulting in damage occur frequently, the design criteria may have been set too low and a reappraisal of both the normal and abnormal criteria should be carried out.

4.2.8.6 Steel panels and fender frames

When using limit state codes, appropriate load factors should be applied to the input loads for the design of steel panels and fender frames with consideration given to both the normal and abnormal impact cases. Generally, higher load factors should apply in the normal impact case and lower load factors should apply in the abnormal impact case. Both conditions should be checked to determine the worst case, which will not necessarily occur during the abnormal impact case.

4.2.8.7 Chains

When chains are employed, the chain sizes are determined by multiplying the calculated chain loads by a factor. For normal impacts the factor should be between 3 and 5. For abnormal impacts, when chain loads may be higher, the factor should be at least 2. The highest factored load (from the normal or abnormal impact case) should be less than or equal to the Minimum Breaking Load (MBL) of the selected chain.

4.3 FENDERS AS PART OF MOORING SYSTEM

(1) General procedure of fendering system design considering vessel motions

Vessel motion shall be considered against winds and waves, swells, and long period waves entering from the ocean. Especially, in the design of mooring systems of offshore deep water terminals, forces due to vessel motions are also important items to be considered as well as vessel berthing forces. As for permanent mooring facilities such as vessels used for restaurants, hotels, museums, and floating terminals, the mooring systems including fendering systems shall be designed taking into account the motions of vessels or floating bodies due to winds and waves. To evaluate or improve the working ratio of mooring facilities constructed at the sites, adverse environmental conditions such as winds and waves, the motions of moored vessels have to take into account load-deflection characteristics of mooring ropes and fenders. To estimate mooring forces due to vessel motions, computer simulations or hydraulic model tests are commonly used. The method of computer simulation is described in the Chapter 4.5.

(2) Items to be considered in restraining vessel motions

(a) General

The type and the size of mooring systems consisting of fenders and mooring ropes should be decided taking into account the following items:

- deflection and reaction of fenders
- tension of mooring ropes
- strength of vessel's hulls
- shear force of fenders
- vessel motions
- tidal current and suction by passing vessels

(b) Fender deflection and reaction

The maximum fender deflection due to wave and wind forces during the mooring process must not exceed the allowable value of deflection as well as the maximum deflection during berthing. Maximum reaction is one of the largest design forces for mooring facilities. For flexible dolphins, maximum fender reaction is usually the dominant design force. The maximum reaction force needs to be limited, taking into account the strength of a vessel's hull.

The load-deflection characteristics of mooring systems shall be considered to reduce sub-harmonic motions which are due to the asymmetry of load-deflection characteristics of the fenders and mooring ropes.

(c) Tension of mooring ropes

The maximum tension of mooring ropes due to wave and wind forces shall be smaller than the allowable value of tension of mooring ropes. The safety factors of tension for synthetic ropes and wire ropes shall be properly decided. To reduce sub-harmonic motions in swaying and long period oscillations in surging, the type and the size of mooring ropes should be properly selected taking into account the external forces.

(d) Strength of vessel hull

To prevent excessive concentration of the vessel mooring forces as well as berthing forces on the fendering systems and the vessel, protection panels should be provided as required to reduce the load on the unit area (face pressure).

(e) Shear force on fender

In general, vessel motions are likely to generate shear forces between the hull of the vessel and the fender face, due to swaying.

A resin pad (e.g. polyethylene) in front of the protector panel is recommended to reduce shearing forces acting on the fenders.

Sometimes the shear forces are favourable or desirable, as they can limit the motion of the vessel. The facing should be chosen to suit the situation.

Further information can be found in BS 6349, Part 4, 1994.

(f) Allowable vessel motions

For the effective operation of cargo handling, vessel motions should be smaller than the allowable values. Allowable vessel motion varies by vessel type, cargo handling equipment and component of motions. Research has been carried out and the allowable vessel motion whilst cargo handling are presented in the PIANC Working Group 24 report (1995) which gives the values of motion criteria for safe working conditions by compiling the research. The vessel motion forms part of the output of the integrated computer programmes, described in Chapter 4.5, and should be checked against the allowable motions given in Working Group Report 24.

4.4 HULL PRESSURE

While absorbing the berthing energy of a vessel the fender will give a reaction force to both the vessel and waterfront structure. Under normal berthing conditions no plastic deformation of the ship's hull should take place. Unfortunately, vessels are mainly designed to sail, not to berth. Reaction forces of a fender system appears to be of little concern to naval architects. Vessels are becoming larger and larger, side plate thickness is becoming smaller and smaller and the distance between web frames is increasing. The permissible hull pressures given by shipowners are decreasing.

Table 4.4.1. Hull Pressure Guide

Type of vessel	Hull Pressure kN/m^2
Container vessels 1st and 2nd generation	<400
3rd generation (Panamax)	<300
4th generation	<250
5th and 6th generation (Superpost Panamax)	<200
General cargo vessels	
=/< 20.000 DWT	400-700
> 20.000 DWT 40	<400
Oil tankers	
=/< 60.000 DWT	<300
> 60.000 DWT	<350
VLCC	150-200
Gas carriers (LNG /LPG)	<200
Bulk carriers	<200
SWATH	}
RO-RO vessels	} these vessels are usually belted
Passenger Vessels	}

It should be noted that ships with belting produce a line load on the fenders and can be considerably higher than the hull pressure quoted below.

4.4.1 Hull structure

The ships hull structure is generally comprised of three components:

1. Side plating, thickness 15-20 mm;
2. Longitudinal stiffeners, mostly spaced at approximately 0.86 m - 0.90 m;
3. Transverse frames.

The dimensions of all three components may vary with type and age of ship and shipbuilder.

New tendencies are:

1. the use of steel with higher strength;
2. increasing of distance between transverse frames, e.g. 6.28 m for 5th and 6th generation container vessels and 3.14 m for earlier generation vessels);
3. berthing energies are increasing and allowable hull pressures decreasing.

Data about vessels is hard to get. When data of the vessels are not available figures of table 4.4.1 can be used as a general guide.

Note: Where hull pressures may be critical, naval architect or vessel owners should be consulted for specific requirements.

These figures include the factors of safety normally used by Classification Societies.

However, if the side plating, longitudinal stiffeners and side traverses data is given, the permissible hull pressure can be calculated.

For large vessels as a rule of thumb the permissible pressure on hull impact is at least equal to the maximum hydrostatic pressure (vessel fully laden / at maximum draft) which can act on the vessels hull.

Warning:
Special attention should be paid to the positions of the horizontal chains on a fender panel. When chains are installed below the fender, the rotation of the fender panel, due to the vessel's flare, can be restricted. Line loads may occur which exceed the permissible hull pressure.

4.5 COMPUTER SIMULATION

4.5.1 INTRODUCTION

New terminals are increasingly constructed at sites with adverse environmental conditions. Often these terminals are without or only with little protection against wind, waves and currents. These sites are designated to be used not only by small, manoeuvrable vessels, but also by large and relatively less-equipped vessels. Heavy demands are therefore put on the fendering system, both during the berthing manoeuvre as well as when the vessel is moored alongside.

In order to design an optimal mooring lay-out and make the best fender choice, it is necessary to determine in advance the interaction between vessel and fenders. For difficult site conditions computer simulations provide a good means to evaluate the complex physical processes and to determine the external forces acting on fenders. They also provide the possibility to examine a large number of design alternatives in a short period of time.

4.5.2 Development of computer programs

(1) Traditional computer programs

The dimensions and the layout of a fender system are determined by the following two distinct processes:

a) The berthing manoeuvre where the energy to be absorbed by the fender is mostly determined by the vessel's speed at the first contact between vessel and fender. This speed is a function of the vessel's size and the environmental conditions.

b) The vessel moored alongside the berth where the maximum forces on the fender are determined by the vessel motions, generally resulting from wave action.

For each process a separate computer program is used: a 'vessel manoeuvring' program for the berthing process and a 'moored vessel' program for the vessel tied alongside the berth. This works well in design situations where the site is reasonably protected. However, when considering present day projects, more sophisticated computer programs are required to correctly simulate the physics of berthing and mooring at unprotected terminal sites, along ocean coasts with high sea and swell waves, or in large estuaries with large tidal and current variations combined with waves.

Traditionally, the berthing process of the vessel is simulated using a 'vessel manoeuvring' program. These programs generally simulate the horizontal movement behavior (2D) of sailing vessel assisted by tugs if required. These programs lack a number of features, which are necessary for the severe environmental conditions at modern project sites. Under these conditions the impact velocity is largely dependent on the vessel motion in waves during the berthing manoeuvre, not only on the mean drift force, but also on the first order and second order time-varying wave response.

Furthermore the programs mostly use constant coefficients for the hydrodynamic reactions of the vessel, where under these circumstances only coefficients depending on the frequency of motion can reproduce the correct motion and damping behavior. Also they mostly lack sufficient sophisticated mooring line and especially fender interaction which typically act on a much different (far shorter) time scale.

The process of the vessel tied alongside is simulated with a 'moored vessel' program. These programs simulate the behavior of the vessel at berth, under varying conditions of wind, waves and current. Traditional moored vessel simulation programs assume that the motions are relatively small, thereby keeping the relative direction of external forces (waves, wind, current, fenders) constant and/or at a fixed impact point. However at exposed sites the moorings are often designed to be flexible and the vessel is subject to relatively large motions where the normal assumption of 'small motions' is no longer valid. Furthermore the vessel is actually both active as well as moored, when considering current velocities over 5 knots, or using propeller and tugs.

Considering the above, the solution is obvious: an integrated computer model for both berthing and moored vessels to be used in modern day terminal design, encompassing the features of both the traditional models and expanding to cope with increasing demands.

(2) Integrated programs

To correctly address the problems for fendering design at difficult site conditions it is necessary to use more advanced simulation models. These integrated simulation models, to be used both for berthing manoeuvres as well as moored vessel response, are now being completed and introduced on the consultancy market. They will especially address the following aspects:

Six degrees of freedom response to first order wave forces
High velocities and accelerations during the initial contact with the fenders during berthing and therefore high impact forces are the result of the vessel response to waves. This is of course especially so for less protected berths. Therefore, a correct simulation of the vessel berthing manoeuvre should include the vessel's first order wave response in six degrees of freedom and not only mean wave drift forces as is commonly the case in manoeuvring models.

Space-varying wave forces
The model must compute and apply all wave forces in real-time within the simulation and not as time-series computed in advances as is usually done in moored vessel simulations. Phases and amplitudes of each wave component change according to position and orientation of the vessel. This method allows for large motions, for the berthing manoeuvre, and flexible moorings at exposed sites or at buoys (SPM's)

Multiple wave field
It must be possible to model multiple irregular waves (typically sea and swell), including bound and free traveling long waves.

Time-dependent hydrodynamic reaction forces
During berthing the physical process changes from a typically long time-scale (manoeuvring) to a typically short time-scale (impact) and back again. This means that the vessel's hydrodynamic response characteristics cannot be assumed constant during this process, as is commonly the case with manoeuvring models which use the added mass coefficient for zero speed. A correct simulation demands frequency-dependent hydrodynamic reaction forces. This introduces, for instance, also a correct hydrodynamic damping of the vessel motion when it hits the fender (contrary to using constant coefficients in which case the only damping introduced is that of the fender).

Time-dependent other environmental conditions
Incorporating time-dependent wind (gusts), current flow (including dynamic effects) and water-level fluctuations (tide) is important for various locations, both for berthing (especially wind) as well as for moored vessels.

Detailed mooring and fender interaction
The point of contact with the fender should be determined correctly in the three-dimensional space. The fender characteristics (in-line and sheer-component) are to be modeled non-linear, with hysteresis effects and with pile deflection characteristics when applicable. Also mooring lines, mooring buoy facilities, anchors and other mooring equipment should be modeled non-linearly.

Sophisticated manoeuvring characteristics of the vessel
This should include correct vessel, propeller and rudder behavior during close-quarter manoeuvring.

Berthing aids
Assisting tugs should be modeled at least with their correct resistance and lift/drag characteristics. Also reduced towing or pushing effectiveness in waves and wave shielding on the vessel's lee side should be modeled, as well as the use of lines and winches during berthing procedure.

Output
Simulation results should be available both in the form of time-signals of vessel motions (incl. velocities and accelerations), mooring line forces, fender forces and vessels track, as well as visually animated both in the horizontal and vertical plane in order to allow for a better understanding of difficulties or problems encountered with a specific design.

(3) Stochastic simulation

Sometimes design conditions include a large number of design parameters with large variations per parameter, for instance vessel type, size, loading condition, approach speed, approach manoeuvre, mooring equipment, wave, wind, current strength and directions, water level, etc. In that case and also in cases where a deterministic approach might lead to an unnecessarily conservative design, it is preferable to follow a probabilistic approach.

For the berthing manoeuvre simulation this means that based on a number of pre-determined general approach strategies, the program must be able to generate a large array of human-pilot like berthing manoeuvres and simulate them under a large array of environmental conditions. Investigations aimed at generating a generally applicable method are presently being considered at universities, but are still in the early development stage.

For the moored vessel simulation the situation is somewhat more simple. Here only a large number of simulations has to be executed, without the necessity to emulate human control. Again statistical analysis of the results will lead to a probabilistic design force determination.

4.5.3 Computer program specifications

The computer simulation programs to be used for the design of fendering systems should model a number of essential effects described in 4.5.2.

(1) Berthing simulation

Berthing simulation program must include effects of:

* vessel maneuvering characteristics depending on hull form, rudder, propulsion and thrusters

* environmental effects such as water depth, wind, waves and current (location and time dependent)

* assistance of tugboats

* non-linear fender modeling and three-dimensional determination of the vessel's hull point of contact with the fender

* actual characteristics of rudder and propeller with detailed modeling of the interaction between rudder, propeller and hull. This allows for realistic vessel maneuvering in all modes of operation (maneuvering ahead, astern, sideways, accelerating, stopping, being or pushed).

* use of controllable pitch propellers and multiple propellers

*detailed tug modeling with towing and pushing possibility; control of towing-line length, towing position and towing angle; tug effectiveness must be realistically restricted depending on the speed and relative direction of the tow, of the tugs own speed and of the waves at the tug location; when required for probabilistic design: use of a computer pilot-emulator who steers the vessel in a human-like fashion and controls engine, rudder and assisting tugs, based on a human of pre-determined basic strategies.

(2) Moored vessel simulation

a) General idea of simulation
Moored vessel programs must be dynamic, six degree of freedom time-domain simulation models and should include effects of:

- irregular waves from multiple directions
- simultaneous application of multiple wave systems, viz. short waves, swell, bound and free traveling long waves and seiches
- first order wave forces and wave drift forces
- wind, including gusts
- time-dependent current flow (including dynamic effect) and water-level fluctuations (tide)
- water motions induced by passing vessels (surface, flow, waves and wash)
- hydrostatic and hydrodynamic (added mass, damping) reaction forces
- non-linear models of mooring lines, fenders, buoy mooring facilities, anchors and other mooring equipment
- forces dependent on the actual vessel's location, orientation and velocity (commonly moored vessel models assume the motions of the vessel to be small and keep the relative direction of external forces constant)
- fender forces applied at the correct point-of-contact in the three-dimensional space
- possibility for the application of special fender constructions and winch layouts
- output in the form of time-signals of vessel motions, mooring line forces and fender forces.

b) Ordinary simulation method
A moored vessel has six components of motion, i.e. surge, sway, heave, roll, pitch and yaw. Some components such as sway and roll interact each other. Therefore, the equation of motions of moored vessel becomes a second order differential equation with six degrees of freedom.

There are two simulation methods for time domain analysis of the equation of motions as follows.

The equation of motions of **T-1** is shown as follow:

$$\sum_{i=1}^{6}(M_{ii}+m_{ij}(\infty))\ddot{X}_i(t)+\sum_{i=1}^{6}\left(\int_{-\infty}^{t}L_{ij}(t-\tau)\dot{X}_i(\tau)d\tau+D_i(t)\right)\sum_{i=1}^{6} \quad (4.5.1.1)$$

where, M_{ii}; Vessel's mass, $m_{ij}(\infty)$; Constant added mass, $Xi(t)$; Vessel displacement at time t, $Lij(t)$; Retardation function, $Di(t)$; Damping force due to mooring lines and viscosity at time t, Cij; Restoring force coefficient, Gij ; Mooring force coefficient, and $Fj(t)$; External forces at time t. And i and j show the mode of vessel motions (1-6).

The retardation function and the constant added mass are calculated as follows:

$$L_{ij}(t)=\frac{2}{\pi}\int_{0}^{\infty}B_{ij}(\sigma)\cos\sigma t\,d\sigma \qquad (4.5.1.2)$$

$$m_{ij}(\infty)=A_{ij}(\sigma)+\frac{1}{\sigma}\int_{0}^{\infty}L_{ij}(t)\sin\sigma t\,dt \qquad (4.5.1.3)$$

where, $Aij(\sigma)$; Added mass at σ, $Bij(\sigma)$; Damping coefficient at σ and σ, angular frequency.

The equation of motions of **T-2** is shown as follow:

$$\sum_{i=1}^{6}(M_{ii}+A_{ij}(\sigma_0))\ddot{X}_i(t)+\sum_{i=1}^{6}(B_{ij}(\sigma_0)\dot{X}_i(t)+D_i(t))+\sum_{i=1}^{6}(C_{ij}+G_{ij})X_i(t)=F_j(t)$$

(4.5.1.4)

In **T-1** method, radiation forces do not depend on one frequency because of the retardation function. On the other hand, radiation forces in **T-2** method are set to be constant at one period, σ_0 . Radiation forces are usually represented the value at the significant wave period or at the natural period of vessel motions. When the spectrum of external forces is wide band, it is better to use the equation of **T-1**.

c) Specified simulation method considering actual fender performance (Hybrid Simulation)
In the simulation, the fender effect is regarded as compressive reaction force on one direction. But in the actual usage in mooring, not only the compression but also shearing and bending forces due to the moored vessel motions act on the fenders. So, the fender performance will be changed variously by many factors such as viscous-elastic characteristics of rubber itself and chemical reasons. In order to improve the fender performance description in the simulation, a specified simulation method considering

the actual fender performance (hybrid simulation) is developed. Hybrid simulation can be also considered the speed factor, temperature factor, including compression characteristics and shearing characteristics of fender in the feed back procedure. It is composed of a computer and tri-axial exciters (sway, roll, heave). In the simulation, the external forces are calculated and stored in memory beforehand. During the simulation, the computer integrates the equations of motions using the real time fender forces from the tri-axial exciters giving simultaneously the vessel motions to each exciter.

4.5.4 External forces on moored vessel

(1)Wave forces
Wave forces acting on the vessel's hull are the hydrodynamic forces due to incident waves to the moored vessel. They are usually calculated by using a potential theory which is in the frequency domain analysis. Wave forces due to irregular waves are also calculated by superposition of component wave forces by taking phase differences into account. The frequency spectra of Bretschneider-Mitsuyasu, JONSWAP or any other type can be used to simulate irregular waves.

Generally, it is necessary to distinguish between short period waves (storm and swell waves, with period less than 20s) and long period waves, also known as long waves, with periods typically between 30s and 5 min. and amplitudes smaller than normal waves.

(2)Wind forces
The drag coefficients by wind are determined, according to the results of the wind tunnel test. The frequency spectra of wind by Davenport, Hino or any other type are used in the simulation as a fluctuating wind speed.

(3)Current forces
Current forces are caused by pressure drag. Normally for vessels moored in a harbour basin the current velocity is negligible, while for berth in rivers or estuaries the current velocity may be considerable and cause problems.

(4)Added mass and damping
In the simulation of vessel motions, the effect on added mass and damping forces shall be considered. Radiation forces are hydrodynamic forces, due to the compulsory vessel motion of unit amplitude for each component. For convenience in the computer simulation, these are divided into a component proportional to the vessel's acceleration (added inertia forces) and a component proportional to the vessel's velocity (damping forces).

The added mass and damping coefficients considerably depend on the frequency. And, for a free vessel, heave, pitch and surge are coupled together and, separately, roll, sway and yaw. But for a vessel near solid quay, all six degrees of freedom of movement are coupled together by the asymmetric flows around the vessel. It should be considered that the radiation forces are influenced by not only the quay but also the under keel clearance of the vessel.

4.6. FENDER SELECTION

When the energy to be absorbed by the fender has been calculated in line with the preceding, the most appropriate fender system can be selected. Each fender manufacturer provides in his brochures the performance data of the various fender types he produces. The actual performance of the fenders not only depends on the type of fender, the size and the elastomer material grade, but also on several external conditions. The performance of fenders is (in most cases) influenced by angular compression, by the temperature, by the compression speed, etc.

The standard fender performance as presented in the brochures is the result of fender tests under certain ambient and compression conditions. The deviation from the standard fender performance, as a result of the different conditions to be experienced on site, is to be taken into account when the final selection of fender.

Furthermore, the manufacturer's brochures often indicate that the actual fender performance may deviate (e.g. some 10%) from the figures quoted for both energy absorption capacity and reaction force.

It is common practice to adopt the performance figures at rated deflection as the reference, hence those figures should be higher than the calculated figures (taking into account the possible influences as described above).

The fender performance is usually valid only if the fender has been preconditioned by compression to the rated values, at least three times before use. If not, the first maximum compressions produced by a vessel, may well give higher than expected reactions

Appendix D presents two case studies showing the effects of temperature, berthing/compression speed, etc.

Besides the energy and the above aspects, various other criteria do play a significant role as already indicated in Figure 2.3.

E.g. possible limitations with respect to the area to which the fender can be mounted, limitations with respect to the maximum reaction force, the required stand-off distance, etc. Furthermore, it may be even the case that the moored vessel conditions are more critical than the conditions during the berthing procedure.

5. WHOLE LIFE CONSIDERATIONS

5.1 INTRODUCTION

By its very nature any fender system will sustain impact from vessels, and thus the general philosophy of fender design is to ensure that the whole system can cater for these impacts by, in the first instance, being robust but also being easily repairable. What is sought in fender design is a cushion for the vessel which remains in place for the maximum time possible.

It can be expected that rubber fender units that comply with the Specification given in Appendix E of these guidelines, can achieve a working life in excess of 20 years. Fender panels should be designed to give a service life of 20 years assuming adequate and planned maintenance, but in practice this often is not achieved due to vessel damage.

5.2 FACING

Facing usually comprises one of the following:

a) Timber

b) Resin (Polyethylene)

c) Steel

Each requires particular consideration in detailing to ensure longevity of the facing and consequently of the supporting structure.

Facing of whichever material requires appropriate fixing and through bolts should be used whenever possible.

Vessels with belting can be particularly damaging to facings. An extra wear allowance may be appropriate if vessels with belting are berthed frequently or if the belting on the vessels is poorly maintained.

The use of the three facing materials is indicated below.

5.2.1 Timber

Timber is a useful facing material but care should be taken to ensure that material is obtained only from sustained renewable forests.

The choice of timber facing will be limited by supply but in general "wild" grained timbers such as elm are preferable. Greenheart and similar hardwoods are useful for backing timbers but not for facing.

Wherever possible, backing timbers should be provided for all facing timbers and, except in very cold environments, should be chosen to be resistant to marine borers.

Timber Research and Development Association (TRADA) publications (published in the UK) provide useful information on the likely resistance of timber, species by species, to attack by marine borers.

5.2.2 Resin (Polyethylene)

This material provides a particularly low friction surface for facing of fender panels and is most widely used as a facing for modern fender systems, especially Ultra High Molecular Weight (UHMW) polyethylene.

5.2.3 Steel

Where frequent berthing takes place, such as ferry ports, the most appropriate fender face has been found to be steel. High friction forces can occur between the vessel's hull and the fender face, which can be beneficial when vessels are berthed at lively locations. Consideration, however, should be given to the effects of bimetalic corrosion when using steel facing for any fender system.

Caution in design must be taken, concerning the possibility of sparks arising from steel to steel contact when designing crude oil, chemical products and gas terminals.

5.3 FENDER SUPPORT SYSTEMS

The three systems of fender support, those of pile and frame, chain suspension and unit support, need to take into account the requirement for a fender system to remain operative even though damage may have been sustained by an exceptional impact. It is preferable to have units which are easily removed before the next berthing takes place. A berth can usually remain in service despite a reduction in the fender provision, provided that the loss of a unit or its supporting structure does not foul the berth. For this reason, whenever possible, fenders should have "keep chains" to enable the damaged fender to be recovered including an additional keep chain where vertical chains are used to support the fender panel.

Chains are to provide support of fender panels or against lateral loading of the fender system. These should be galvanised and the chain system should have an overload failure element which will fail first. Anchor plate fixings should be substantially stronger than the overload failure element within the chain system to avoid damage to the parent structure. This will enable new chains to be used, with confidence, after an exceptional impact has parted the chain system.

The framing to any facing material should be designed to enable any repairs to be undertaken easily. For instance, consideration should be given to the type of joints for the backing members. It should be remembered that when a fender panel is in need of repair it is usually because the vessel causing the damage has approached the berth at such an angle as to impact behind the normal berthing line.

5.4. WORKMANSHIP AND DETAILING

The longevity of any fender system is dependent upon the amount of use, inspection and maintenance of the system. In order for the berth to remain in use, it is more practicable to have fender units which can be replaced. Nevertheless, the damaged unit should be repairable. Good workmanship and detailing will assist repair and maintenance and some examples are given below:

a) All bolts greased with waterproof grease prior to assembly. Any coach bolts in timber similarly treated.

b) Provision of specific overload failure elements in the system.

c) Seam welding to all plating.

d) Care in application of any coating system.

5.5 INSPECTION AND MAINTENANCE

Inspection regimes will vary from installation to installation depending upon the frequency of call of vessels and the exposure of the berths.

It is suggested that for ports which are normally busy, inspection of the fender system should be organised into two sections; that provided by the operator's mooring crew, and that provided by the maintaining organisation.

Pre-berthing and post berthing visual inspections by the mooring crew provides some protection against accumulative vessel impact damage. Such inspections must be recorded.

Visual inspection by the maintaining organisation is best done on a low tide cycle and inspection will be dependent upon occupancy of the berth, the aim should be for monthly inspection. If the tidal range is large and mobile suspended access is not available, boat access will be required.

The prime cause of rapid deterioration of a fender system is the neglect of the fender face in whatever type of material. This is particularly true of fendering in ports which receive belted vessels. Damage to the belting or to the fender face breaks the accommodation between the two and thus the damaged face of one causes damage to the other.

Timber facing must be maintained so that adequate clearance is always provided from the timber face to embedded bolt heads. This is of particular importance at berths where petroleum products or hazardous cargoes are handled.

Steel wearing plates can be tolerant to deformation but renewal of wearing plates should be considered if persistent damage is sustained.

5.6 FUTURE CONSIDERATIONS

In deciding upon the fender system to be provided at a berth, consideration should be given to the likely advances in vessel design. In recent years, advances in naval architecture have produced very different shaped hulls from the classic ship shape.

In Ro-Ro vessel design threshold heights have increased dramatically. This can cause the vessel's belting to overtop the fendering systems provided. Damage has thus occurred due to the vessels belting "sitting" on the fender units. Provision of tapered tops to the fenders can prevent this occurrence.

The provision of capital spares should be considered as manufacturers are not necessarily able to produce a replacement fender unit up to 20 years after the provision of those installed at inception. Berthing structures can thus be safeguarded by the rapid replacement of adequate fendering.

6. SPECIAL CASES

6.1 CONTAINER SHIPS AND BARGES

6.1.1 Introduction

This section addresses the fendering requirements for vessels which are dedicated to the transportation of containerised cargo. Containerisation of cargo is generally based on 20 foot equivalent unit (TEU) or forty foot equivalent unit (FEU) formats. Containers are manufactured in a range of types which include dry box, refrigerated freight and liquids in tanks.

Container vessels range in size from small feeder vessels which may carry 70 TEU, or less, up to vessels which at present carry in excess of 6,000 TEU. Large container vessels may soon exceed 8,000 or even 12,000 TEU. Historically container vessels have been restricted to Panamax size, with a beam less than 32.2 metres. The large vessels now constructed are Post Panamax with beams in excess of 32.2 metres.

Many small vessels have self loading and unloading capability or Ro/Ro capacity. Larger vessels are restricted to berths in terminals where cranage has sufficient outreach. Dedicated refrigerated cargo vessels, "Reefers", often have container capacity and may be geared for self loading and unloading. Many vessels are capable of carrying a mix of refrigerated and non-refrigerated containers. Containers are stored in the holds of vessels and on hatch covers at deck level. Some classes of vessels are hatchless and many use cellular guides. Combination vessels are capable of transporting a mix of containers and bulk or break bulk cargoes. Typically these vessels are fitted with vessel's gear and are not totally dependent on quayside cargo handling equipment to load and offload containers. The particular problem associated with these vessels is the need to keep fender panels below the quay level to permit landing of the quarter ramps which are fitted to some vessels.

Container barges are configured to transport a range of containerised cargoes. The vessels are used either for transhipment from the vessel to shore or for shipment on rivers or canals. Therefore these barges come in a broad range of sizes, lengths and freeboards. Not all barges can be assumed to be fitted with belting fenders. Generally barges are unlikely to be fitted with their own cargo handling equipment. However, there are local variations where transhipment barges do have cranage.

6.1.2 Particular Aspects to be Considered

Fendering for container vessels has to consider the following specific issues:

Increased efficiency in cargo handling has significantly reduced the time a vessel spends alongside a berth. Reduced turn around times translate into a higher frequency of berthing.

Berths at major terminals will be expected to operate year round in a range of weather conditions.

Large container vessels rely upon shore cargo handling equipment therefore the crane outreach is of critical importance. In general, the horizontal distance from wharf face to fender face should be kept to a practicable minimum, in order to reduce the required crane outreach. There must be sufficient clearance to reduce the chance of the flare of the vessel hitting a crane leg at the edge of the quay, for example.

Container vessel hulls, like most other vessels, are not designed to take high external loads from fenders. Consideration must always be given to the spreading of fendering system loads evenly along the side of the vessel. Certain classes of vessels are constructed with large amounts of high tensile steel. In the more structurally sensitive areas of these vessels damage will generally command a premium cost to repair.

Container berths and their fendering systems will generally be required to cater for a wide range in vessel sizes and configurations, including barges. The types of port will generally dictate the type of service and therefore the vessels which will berth.

Rolling motion of a vessel, especially during self unloading, can be reduced by selecting a high friction fender.

The prevention of catching or hanging up and consequential damage of vessel sides and structures with the lower or higher edges of the fendering system must be considered. The topside flare, both fore and aft, of all modern seagoing container vessels is considerable, but as each vessel or class of vessel is unique, guidance can not be given on the expected flare.

6.1.3 Design of Fenders for Container Vessels

Fender Spacing and Layout:

Fendering systems should be designed to spread the berth loads evenly along as much of the vessel side as is possible. Many vessels have considerable amounts of topside flare forward and aft, below main deck level. In the bow the amount of curvature in the main deck, in plan view, will also vary. As a result the parallel or flat areas of the side of a vessel may be reduced by as much as one third, or more, of its overall length.

Tidal range and the shape of the vessel will dictate the vertical dimension of the fendering. The lower edge of the fendering will need to be positioned so as to prevent the possibility of the fendering catching on low freeboard vessels at low states of the tide. The upper edge of the fendering will need to be configured so as to prevent or accommodate contact being made with vessels with considerable amounts of flare.

Certain lengths of wharf edge may be required, additionally to permit use of quarter or vessel side ramps. It may be necessary to make provision to enable certain sections of fendering to be removed or substituted for different types of vessels or means of cargo handling at container quays, even though the declared traffic is initially containers.

6.2 RO/RO VESSELS INCLUDING FERRIES

6.2.1 Introduction

This section considers all roll on/roll off vessels carrying freight, either unaccompanied, that is on road, rail or vessels' trailers or cassettes without tractor units or drivers, or accompanied, this is with individual tractor units and road trailers with drivers and trade cars. The criteria for freight vessels and passenger ferries have considerable overlap with the distinction that passenger ferries may have more frequent berthings and faster turnarounds. Passenger ferries will generally have a greater number of openings such as windows and doors as well as protuberances such as lifeboats for which due consideration must be given.

Ro/Ro vessels can be divided into two main categories as follows:

(a) Vessels with bow and/or stern ramps which require a shore ramp structure at the bow or stern.

(b) Vessels with side or quarter ramps which can be landed on the quay. Side and quarter ramps are particularly appropriate where the tidal range is small and a fixed conventional quay is suitable for landing ramps. Many vessels however, have the capability to cope with a range of levels, for example, by having long quarter ramps or side ramps which can operate off different decks within the vessel. Where the tidal range is large, it may be necessary to provide a floating pontoon to land the vessel's ramp.

6.2.2 Particular Aspects to be Considered

The fendering for Ro/Ro vessels when compared with other vessels has to take into account the following factors:

a) Ro/Ro vessels usually require a short turn around time in port – consequently the vessels are more likely to berth at higher approach speeds. The tight schedules that Ro/Ro vessels usually operate often result in them having to berth in unfavourable weather conditions. Additionally, berths are likely to be subject to more berthings per year and delays due to damage to the fendering system are less acceptable when compared to other cargo berths. It is particularly important that fendering systems for Ro/Ro berths are designed to be robust and easily maintained.

b) Ro/Ro vessels are usually fitted with a belting strip, or multiple belting strips, which projects from the hull. This belting is usually located at the level of the main trailer deck and is typically 250mm high and 300mm wide. This results in the vessels applying a line load to the fenders.

To overcome this, the fendering usually is provided with a suitably stiff facing panel. Such facing panels may result in double contact between the vessel and the fender with the second contact either at the top or bottom of the panel depending on the level of contact. This needs to be checked and if it is considered unacceptable then one of the following may be required:

- a long lever arm pivot fender for example using a fender pile to ensure that the fender face does not tilt excessively.
- parallel movement fender system for example based on torsion bar.

It is important to ensure that the facing panel extends sufficiently far vertically so that the belting cannot ride over the top or get caught underneath the panel whilst the vessel is on the berth. The panel should be designed to cater for a tidal range from LAT to HAT plus an allowance for weather variations and for operational variations in vessel draught and trim during loading/unloading.

In order to satisfy this requirement, the fender panels often have to extend above the quay level. The effect that this may have on the mooring lines should be checked to ensure that the vessel can be moored safely. This can cause problems where vessels with side or quarter ramps are to be accommodated and where the berth is also used for other cargo vessels. In these cases, it may be not acceptable to extend the fender panel above the quay in which case the top of the fender panel should be sloped to prevent the belting sitting on the fender panel. This results in significant downward vertical forces on the fender which should be allowed for in the design.

(c) Ro/Ro vessels often have a large windage area relative to their displacement. This combined with the requirement to operate in all weather conditions increases the likelihood of a heavy berthing.

It should be noted however, that Ro/Ro vessels are usually very manoeuvrable with bow or stern thrusters and / or other similar equipment fitted.

6.2.3 Ship Berthing Manoeuvres

6.2.3.1 Transverse Ship Approach to the Berth

Berthing alongside transverse to the berth may be considered in the following cases:

a) For vessels with side and quarter ramps.

b) For vessels with bow and/or stern ramps, when the Ro/Ro vessels make a transverse approach to the berth. The vessels then move along the quay often under mooring winch control, using the side fenders for guidance until they are the appropriate distance from the shore ramp structure.

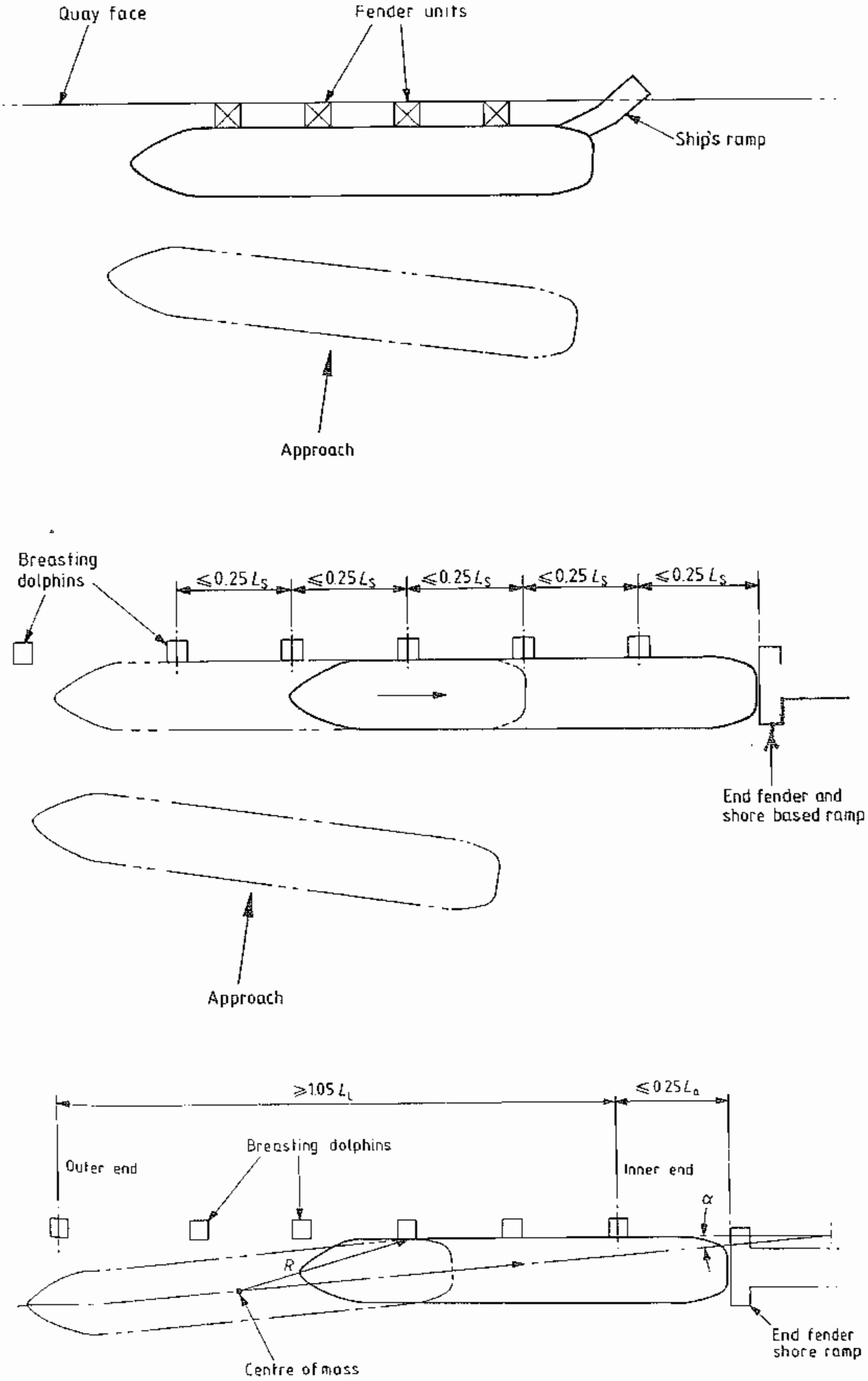


Figure 6.2.1 Ferry and Ro/Ro Vessel Berthing

For new dedicated Ro/Ro facilities the berth will usually have independent breasting fenders with no continuous quay. However, where the berth caters for both Ro/Ro and conventional cargo or uses an existing berth, there may be a continuous quay.

6.2.3.2 Head on Vessel Approach to the Berth

Berthing head on is normally only practised by regularly scheduled Ro/Ro ferries on shorter routes. For this berthing manoeuvre, side breasting dolphins are provided as a guide to the vessel but the vessel berths directly against the shore ramp structure or a separated end fender.

In principle, this method of berthing is not preferred as any berthing accident may damage the shore structure at the most critical and complex part of the Ro/Ro shore faci-lities.

One version of nesting fenders is where fenders guide the vessel into and hold the vessel in the correct transverse location. This system is generally only used on short scheduled Ro/Ro ferry routes with dedicated vessels. The fendering would be designed to suit a particular vessel and if an alternative vessel is used, it may be necessary to modify the vessel so as to present the same profile to the fendering. Large transoms may have to be allowed for in the design of any side fendering.

6.2.4 Design of Fendering

6.2.4.1 Side Fenders

Side fenders should be designed in accordance with Section 4, taking into account the higher berthing speeds and frequency of use.

The fender spacing should be assessed taking into account the vessel characteristics and berthing procedure but should not normally be greater than 0.25L, where L is the length of the smallest vessel using the berth. Where a continuous quay is provided, the spacing will usually be closer than this with similar requirements for checking bow radius, flare and quay overhang as for other vessels.

Berthing mode and spacing is indicated on Figure 6.2.1.

Attention is drawn to the effect of the belting on the height of the fender panel (see Section 6.2.2), and if the panel has to extend above the quay level, the effect on mooring lines and side and quarter ramps will need to be checked.

The lead in fender should usually be designed for a mid-point berthing. At some berths this fender may also need to allow for vessels to be turned.

In ice conditions, ferries often have to berth by sliding along the berth and leaning against the fender panel. This is done to push ice blocks off the berth, which may cause extra transverse loads to fenders.

The method of departing from the berth should also be considered. Ro/Ro vessels often leave the berth by moving along the berth on the main engines while using a bow thruster to move the bow out and then depart. This may require the fender adjacent to the shore ramp to be designed for extra forces from the vessel during turning.

For modern vessels (last generation Ro/Ro), it is necessary to consider the flare angle during the fender selection process. The hull geometry, over the impact area should be considered in both horizontal and vertical planes.

When determining the eccentricity factor (Ce), account should be taken that the values of the block coefficient may be lower for Ro/Ro vessels (Cb = 0.7 - 0.8) than for normal cargo vessels. It should be noted that the centre of gravity of Ro/Ro vessels does not lie in the centre of the vessel length, but is further towards the stern.

6.2.4.2 End Fenders

In some instances, end fenders are provided not only where vessels berth end on but also where vessels berth transversely, usually to prevent the vessel accidentally striking the shore ramp. When this should be provided is a matter of judgement on how far the vessel has to moor from the shore end ramp (this depends on the length of the vessel's ramp), the wind, wave and current conditions at the berth, the manoeuvrability of the vessels and any manoeuvring restrictions at the berth.

Operational expertise of the vessels should be considered.

Some older Ro/Ro vessels have blunt ended ramps without finger flaps. The ramp is landed into a recess in the shore ramp. In these circumstances, end fendering has to be provided to ensure that excessive forces are not applied to the shore ramp from the blunt end of the vessel's ramp.

End fenders can be installed in one of three positions as follows:

1. At the vessels end of the shore ramp.
   In this case the vessel strikes the fender directly and the force is usually transmitted to the abutment via the shore ramp. The large reaction force needs to be taken into account in the design and maintenance of the hinge bearings.

2. At the shore end of the shore ramp.
   A fender is installed between the shore ramp and its abutment. The vessel strikes the shore ramp which transmits the impact into the fender. The considerable horizontal movement of the shore ramp needs to be taken into account in the design and construction of the ramp supporting system and as a result this arrangement tends to be more suitable for buoyant or semi-buoyant shore ramps rather than lift systems. It can however be used for the latter.

This system tends to be used where it is important that the vessel is berthed very close to the shore ramp, for example where the vessel is used to help support the weight of the ramp.

3. Independently of the shore ramp, for example on an independent fender beam. This will usually be more expensive than the other options as an independent structure will be required.

The independent end fender located in position 3 is preferred and in any case is recommended where end berthing is to be the normal method. Where vessels berth transversely and the fendering is only provided in case of accidents locations, 1 and 2 may be acceptable.

Vessels with bow ramps (generally ferries) present particular problems. The end fendering has to be designed to ensure that the vessel strikes the fender whilst providing sufficient clearance between any bulbous bow and the shore ramp structure. Special consideration needs to be given to any facing as the bow stem produces a large concentrated load.

End fenders should be designed in accordance with Section 4. Where the energy equation is used the full displacement of the vessel should be used and consideration given to the appropriate virtual mass to be allowed.

6.3 HIGH SPEED CRAFT – CATAMARANS, SWATHS AND MONOHULLS

As defined in the IMO International Code of Safety for High Speed Craft (HSC Code) Resolution MSC.36(63).

Special attention should be given for the design of berths for High Speed Craft (HSC). These vessels are usually constructed of aluminium and as a consequence are more susceptible to impact damage than a steel vessel. It is important that the fendering contacts the vessel at the correct location and not in concentrated points. Particular consideration should be given to parallel motion fenders, e.g. torsion bar, as fast ships are less likely to be tolerant of double contacts. Pneumatic fendering may be appropriate in some instances. Berths are often specialised, designed for specific vessels especially for fast freight vessels.

6.3.1 Virtual Mass Factor, Cm, for Catamaran Craft

Multi-hulled vessels tend to have a greater beam to length ratio than conventional vessels – therefore consideration should be given to the virtual mass, which may be significantly more than for a similar mono-hulled vessel. Advice should be sought from the ship builder to establish Cm and model tests may be required.

Where it is not possible to carry out model tests, a reasonable approximation has been observed using published formulae, as shown in 4.2.5 subject to the following modifications to input data:

$$M_V = L^* D^* B$$

L = Average submerged length
D = Average draught calculated by dividing the submerged elevational area by the average submerged length
B = Maximum width of a single hull below water
M_V = Mass of a single hull

By adopting such modifications, the effect of twin hulls is taken into account by using the full displacement in the energy equation.

It is advisable to calculate values of Cm using all of the published formulae before selecting a value.

6.3.2 Setting Out of Fender Line

The beltings on certain HSC ferries curve on plan and elevation. It is important to ensure that fender faces engage with the parallel parts of the belting. Consideration may need to be given to angling the fender faces to suit the shape of the vessel.

Certain fast ferries operate with fixed stern connections to purpose made linkspans such that they do not rely upon the fenders for support whilst at the berth. With such systems it is important to establish a fixed setting out line for the fender face so that the vessel can use the fenders to align itself with the linkspan before finally reversing and engaging with the attachment mechanism.

The positions of the fixed setting out line should be sufficiently close to the vessel's final berthed position to permit easy engaging with the linkspan. Sufficient distance must be allowed to ensure that the vessel is clear of the fender line whilst it is attached to the linkspan, say 100mm.

6.3.3 Fender Panel Height

Due to the relatively light displacement, HSC ferries are very susceptible to variations in draught during loading and unloading and are more lively when at the berth. The designer should obtain a full appreciation of factors which affect the vessel draught, when determining the fender face panel height. Important considerations are:

- light freeboard
- laden freeboard
- heel during loading
- variations in freeboard along the length of the vessel during berthing and loading
- roll and heave due to environmental conditions and passing vessels.

Where major maintenance operations are to be performed, such as removing water jets or repairing hull membranes, the abnormal draught conditions, where one part of the vessel is ballasted clear of the water, may need to be catered for.

6.3.4 Vessel Approach Angle

Many modern fast ferries incorporate sophisticated power systems which permit a high degree of control and manoeuvrability. High windage areas and low displacement increases the possibility of manoeuvring difficulties at low speeds in gusty conditions. Consideration should be given when designing and detailing the fenders, to accommodate initial vessel contact at relatively steep angles.

6.3.5 Vessel Belting

First point of contact on HSC must be the belting. The beltings on HSC ferries are usually fabricated from aluminium plate or extrusions.

Such beltings, which may be multiple, may have some of the following characteristics:

- low allowable contact pressure
- susceptibility to point load damage during angled berthing
- susceptibility to abrasion damage from steel faced fenders, bolts on timber or polyethene facings
- susceptibility to galvanic corrosion with prolonged contact with dissimilar metals.

6.3.6 Fender Contact Face

Due to the nature of hulls of High Speed Craft, to avoid damage to the vessel's belting, the fender designer should incorporate the following features into the fender design:

- Width of fender face panel to suit berthing reaction load without over stressing belting
- Ensure that face panel edges incorporate an adequate lead in and that the face panel can rotate on plan to accommodate angled berthing without resulting in damage due to point loads
- Ensure that the face panel facing surface is of suitable material and that fixing bolts are well recessed
- Where floating pneumatic fenders are used against the hulls of aluminium ferries, chain net fittings should not be used. If used, the chains should be fully sleeved to avoid steel to aluminium contact.

6.3.7 Underwater Attachments and Hull Construction

Many HSC ferries have underwater attachments which protrude beyond the hull line. These include:

- ride control fins
- fixed bilge keel fins
- hydrofoils
- bulbous keels
- water jets.

It is important to understand fully the configuration of such projections and of the underwater hull profile to ensure that the fender and the fender support structure do not conflict with them, whilst the vessel is at rest or during berthing when the fender panel may be deflected.

6.3.8 Vessel Superstructure

The superstructure on HSC is usually of light weight aluminium construction, or similar. It is important to ensure that the fenders do not contact such superstructure particularly during berthing at low water, when the deflected fender face panel may be angled out at the top.

6.4 LARGE VESSEL

6.4.1 INTRODUCTION

'Large Vessel' is defined in 1.5.6.

6.4.2 Layout of dolphins for berthing a large vessel

For the fixed berthing facilities for large vessel, the cargo handling platform is to be central, with a pair of breasting dolphins and inner & outer mooring dolphins arranged on each side.

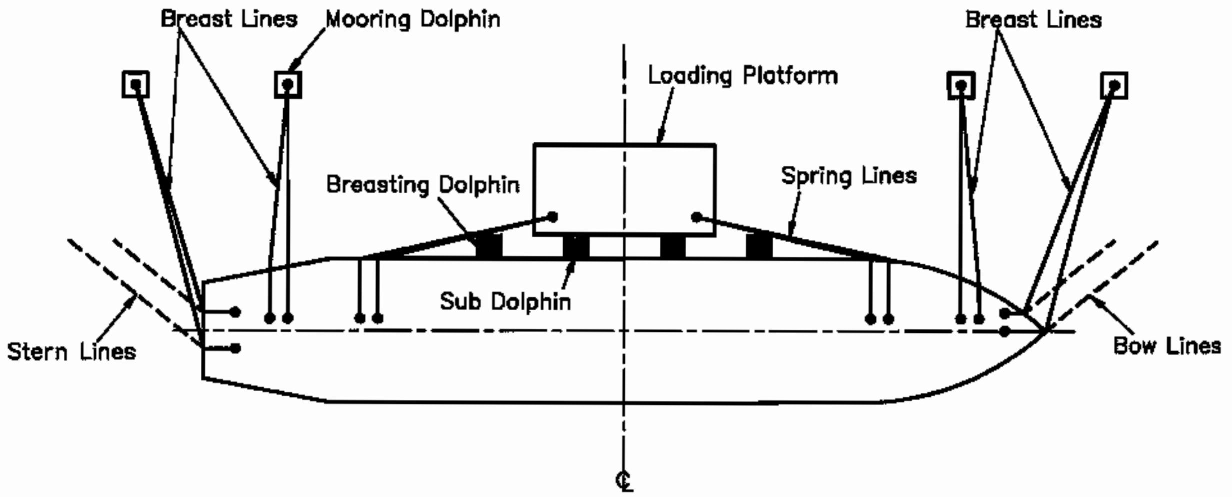


Figure 6.4.1 Layout of dolphins for berthing large vessels

In case the vessel length is smaller than the nominated berth, sub-dolphins should be positioned if necessary. Figure 6.4.1 shows the general layout for each dolphin. Bow and stern lines will effect the vessel motion when alongside the berth.

As the tension in the mooring lines effect the compression of the various fenders, this will have a marked effect on the fendering system, as a whole.

6.4.3 Fender system for the large vessel

Fender systems should be determined considering not only the absorption of the external load by the vessels berthing and mooring, but also the hull pressure of the vessel and the reaction load to the structure to ensure protection of them both.

It is general for piled dolphins with vertical piles that the energy absorption by deformation of fender and dolphin is taken into consideration. On the other hand, for the dolphin with coupled, battered piles, only the fender is to absorb the energy, because the reaction load to deform the dolphin is so high that it might damage the vessel's hull and possibly the dolphin structure.

Fenders should be selected taking into consideration the characteristics under angular compression as the large vessel usually berth with angle. It should be also considered that all fenders in the face line should not work under such an angular approaching condition.

Hull Pressures are indicated in 4.4.

6.4.4 Dimensions of large vessel

As dimensions of large vessels are required for the calculation of berthing energy and these are not always available, refer to Appendix C for vessel's dimensions.

The displacement of the vessel, which is the important factor for the calculation of berthing energy, is calculated by the equation also shown in Appendix C, and it can be applied for 95% of the likely vessels.

6.5 VESSEL TO VESSEL

Introduction

Design considerations for fenders for vessel to vessel operations are somewhat different from those for vessel to dock berthings. The primary design considerations are:

- Standoff Distance
- Energy Absorption
- Fender Type and Style
- Vessel Operational Considerations.

Fender reaction pressure against the vessel hull is also a potential design consideration; however, most modern vessel to vessel fenders have been designed to have reaction pressures substantially lower than allowable vessel hull pressures.

6.5.1 Standoff Distance

Standoff distance for vessel to vessel operations is often the overriding consideration in the selection of the fender size or type. The standoff distance must be large enough to keep the vessel hulls or superstructures from hitting together as the vessels roll, with an adequate margin of safety.

The vessel's hull shape, superstructure height and shape, and roll angle (which is a function of sea conditions, vessel dynamics, vessel forward speed, and orientation relative to the prevailing wind and sea conditions) must be considered in selecting an appropriate standoff distance. Product transfer equipment (i.e. hoses, manifolds, booms, etc) may also be a standoff consideration. Experienced mooring masters have developed their own "Rules of Thumb" for vessel to vessel standoff requirements, and should be consulted where possible. Manufacturers of specialised vessel to vessel fenders may also be a useful source of data, since their catalogues often contain recommended fender sizes for different vessel sizes.

Approximate fender standoff in good weather as a function of vessel size is given in the table shown below. For two vessels of different displacement tonnage's, "A" tons and "B" tons, respectively, calculate the vessel size "C" to be used in the table from:

$$C = \frac{2AB}{A+B}$$

Equation 1.

These fender standoff distances are general and other parameters may need to be evaluated prior to making a final decision on the size, particularly in rough weather or under special operational circumstance.

Table 6.5.1 Fender Stand Off Distance

VESSEL SIZE **DISPLACEMENT Tonnes**	**FENDERS STAND OFF DISTANCE**
500	0.9-1.0 m
1000	0.9-1.4 m
3000	1.2-1.7 m
6000	1.2-2.0 m
10,000	1.5-2.2 m
25,000	1.5-2.2 m
50,000	1.8-2.5 m
100,000	2.4-3.3 m
200,000	2.4-3.7 m
330,000	3.3-4.0 m
470,000	4.0-4.5 m
790,000	4.2-4.5 m

Note that the table uses displacement tonnage, not DWT, GRT, etc.

Appropriate conversion factors can be found in Appendix C.

6.5.2 Energy Absorption

The energy absorption to be absorbed by the fender system is the second most important design consideration for vessel to vessel fenders. The generally accepted design practice is to require that each fender in the system have sufficient energy absorbing capacity to absorb the largest anticipated impact load. Each fender must be capable of absorbing the full impact load since vessels almost always contact only one fender on initial impact.

A number of parameters go into establishing the design berthing energy. The most significant parameters are the two vessels' displacement and the berthing velocity.

The berthing energy that must be absorbed by a fender is calculated from the basic kinetic energy equation. This is given in Section 4.2.1.

For Vessel-to-Vessel applications the M term becomes:

$$M = \frac{M1 * M2}{M1 + M2}$$

Equation 2.

Where: M1 = M1 + Mv1 for Vessel No. 1
M2 = M2 + Mv2 for Vessel No. 2

Where : M1, M2 = Vessel displacement tonnage for Vessels 1 and 2, respectively.

And Mv1, Mv2 = Virtual mass for Vessels 1 and 2, respectively.

The vessel mass M, which is used in the energy calculation, is the same as the vessel's displacement tonnage.

Virtual mass is the term used to account for the entrained volume of water moving with the vessel. It may be estimated in a number of ways (see Section 4.2.5).

Using formula (2) above, the virtual mass must be calculated for each vessel separately.

The relative velocity of impact, "v" or the "closing" velocity, is the velocity normal to the berthing plane at the moment of vessel contact with the fender. It is influenced by the wind and sea conditions, skill of the pilot(s), the size and loading of the vessels, and the type of propulsion. An additional consideration for vessel-to-vessel applications is whether both vessels are under way or one is stationary.

Because the berthing energy is proportional to the square of the velocity, "v" is the single most important factor in calculating the berthing energy. Design closing approach velocities for vessel to vessel transfers are generally higher than those assumed for vessel to dock berthings.

Typical design vessel closing velocities for vessel to vessel transfers under good weather conditions are shown below.

Table 6.5.2 Closing Velocities

Vessel Size (Displacement tonnes)	Closing Velocities (m/s)
500-8,000	0.3-0.5
10,000-45,000	0.25-0.4
50,000-85,000	0.2-0.3
100,000-200,000	0.2-0.25
330,000 and up	0.15-0.25

Caution should be exercised when using these values, particularly when the operation is expected to be conducted under other than good weather conditions.

6.5.3 Fender Type and Style

Many vessel to vessel operations use large foam-filled or pneumatic fenders. The fenders used in vessel to vessel transfer operations offshore are divided into two categories.

Primary fenders which are positioned along the parallel body of the vessel to afford the maximum possible protection while alongside, and secondary fenders which may be used to protect bow and stern plating from inadvertent contact during berthing and unberthing.

The table is included to provide a quick reference guide to fender selection and is intended to be used simply to provide only an indication of suitability under the conditions specified. It is understood that different approach velocities would give very different berthing energy.

The table 6.5.3 below gives approximate numbers and sizes for typical fenders. Foam filled fenders may differ slightly in size and it is strongly recommended that individual fender manufacturers or vessel to vessel agencies be consulted prior to using numbers and sizes for a particular operation.

6.5.4 Vessel Operational Considerations

Vessel operational considerations are highly dependent upon the specifics of the type of operation. Ship and port owners should be consulted before deciding upon final details of the fender system.

Often, permissible sea state conditions will be specified for allowing an operation to commence or stop.

For lightering or other similar cargo transfer operations, one vessel is initially fully laden and the other light. The berthing energy for a given approach velocity would therefore be less than two fully laden vessels. Some allowance for this can be made by adjusting both the displacement tonnage and the added mass of the light vessel.

Because a light vessel may present significantly more surface area for the wind to contact, the approach manoeuvre may be difficult. Also, the effect of waves may be greater on the light vessel. Both of these factors may contribute to higher approach velocities than normally anticipated.

Table 6.5.3 Quick Reference Guide For Fender Selection

Displacement	**Relative Berthing Velocity**	**Energy**	**Suggested Quantity Pneumatic Fender**	**Typical Fender**
Tonnes	m/s	kNm		Metres
1000	0.3	24	3 or more	1.0 x 2.0
3000	0.3	74	"	1.5 x 3.0
6000	0.3	140	"	2.5 x 5.5
10,000	0.25	170	"	2.5 x 5.5
30,000	0.25	400	4 or more	3.3 x 6.5
50,000	0.20	480	"	3.3 x 6.5
100,000	0.15	540	"	3.3 x 6.5
150,000	0.15	710	5 or more	3.3 x 6.5
200,000	0.15	930	"	3.3 x 6.5
330,000	0.15	1550	4 or more	4.5 x 9.0
500,000	0.15	2310	"	4.5 x 9.0

After the two vessels are located alongside one another, operational considerations will dictate whether the actual transfer operation can occur while the vessels are underway (and therefore can maintain some steerage), or whether the vessels must stay in one position. For a moored vessel with a second vessel alongside, the vessels obviously cannot be underway. These considerations may affect the seakeeping of the two vessels, and therefore, the upper limit of sea conditions under which the operations can continue.

Rigging for mooring the two vessels together should be considered by the designer, or cargo transfer areas. Also it must be compatible with quick depart manoeuvers under emergency conditions together with operating personnel. Spring lines and breast lines may be utilized, as may bow and stern lines. The location of the rigging must not interfere with the hoses.

6.6 FLEXIBLE DOLPHINS AND BERTHING BEAMS

6.6.1 General

Flexible dolphins are 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 a single pile or of a group of piles acting together.

Berthing beams are formed of a row of flexible piles covered by one or more horizontal girders which are equipped with panels of rubbing material e.g. wood, polyethylene, rubber, etc. Both structures can be equipped with rubber fenders in order to enhance the energy absorption capacity.

6.6.2 Application

Flexible dolphins are commonly used at jetties where unloading takes place at dedicated places, e.g. for liquid bulk, gas, oil, etc.

In front of the loading platforms often berthing beams are used, especially when small ships have to be also accommodated and/or large berthing angles are likely to occur. Berthing beams are also often used as guiding structures for locks and bridgepiers.

Considerations for using flexible dolphins or berthing beams instead of fenders mounted on the jetties are:

- separation of functions: avoiding fenderloads on operational structures, such as loading platforms in order to reduce movements and vibrations;
- safety aspects: in the case of overload due to calamities etc. the operations structures can be kept intact.

6.6.3 General technical aspects

In order to provide a safety margin in case of accidental extreme berthing, it is recommended to increase the distance between the face of the fender panel (fenderline) and the structure, e.g. a distance of twice the maximum elastic deformation of the pile enables a possible (plastic) energy absorption of over 3 times the "elastic" design-energy (provided that the pile has enough yielding capacity).

The clearance between fender face and pile has to be enough to prevent the pile from being touched by the berthing ship. In addition to the maximum deflection, the heel and any belting of the ship has to be taken into account.

The energy capacity of a flexible pile is proportional to the square of the steel stress and linear to the applied wall thickness.

Hence the use of high tensile steel and a large wall thickness is effective for high energy absorption.

When selecting the design level of the seabed bottom, the effect of scour around the pile has to be taken into account

6.6.4 Loading and load factors.

Flexible dolphins should be designed to resist the following forces:

a. berthing impact

b. hawser forces where the dolphins is also used for mooring purposes

c. wind, wave and current effects on the ship.

The following load factors for the limit state design method are advised :

Load factor: depending on the pile capacity to resist overloads by plastic yielding.

- no yielding possible: $\gamma = 1.25$
- yielding possible until a displacement of at least two times the maximum elastic displacement: $\gamma = 1.0$.

Soil parameters: the factors as indicated in geotechnical specifications should be used. Material factor on steel: normally a factor of 1.0 can be adopted.

In the case of not predominantly static loading, the decrease in the fatigue strength with reference to the static strength has to be observed (especially in welds).

When the Working Stress Design is used, the allowable stress in the design standard of each country should be used.

6.6.5 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 returning the pile to its original position when berthing or other applied forces have ceased to act.

For the pile analysis, four methods are mentioned:

a. The methods based on the earth pressure theory under ultimate equilibrium condition of the soil, e.g. BLUM's method (EAU, ref.1), Brinch Hansen's method;

b. An elastic approach (subgrade reaction), as proposed by Matlock and Reese (OTC 1204 & 2312, 1970 & 1975 respectively) and conform the API standards using p-y curves;

c. The PHRI method in which the soil is regarded as non-linear, as proposed by The Port and Harbour Research Institute (See references).

d. The best method to describe the soil - pile interaction is a three dimensional finite element model that takes plastic deformation into account. However this approach is elaborate and requires specific soil data.

When adopting the design values for soil parameters, toe level, etc. it is important to keep in mind that both stiff and soft behaviour of the subsoil and minimum and maximum toe level should be considered. Stiff soil and high toe level with impact on a low level are important as they effect the dimensions of the cross-section of the pile.

6.6.6 Materials

If dolphins requiring a high energy absorption capacity are required, it is practical and economical to construct them of higher-strength, weldable fine-grained structural steels. Steel qualities with yield stresses within the range of 355 to 690 N/mm^2 are used (ref. 6).

Piles are mostly of circular shape and built up of sections with variable wall thicknesses, see Figure 6.6.1.The upper sections should be of easy weldable steel to facilitate welding on site of the upper section, deck or other fittings. It is recommended to select wall thicknesses large enough to enable some plastic deformation before local buckling of the pile shell occurs. Another way to reduce the local buckling problem is to fill the pile up to a height of 6-10 m above the bottom level with a mixture of sand and gravel or concrete.

Special attention should be given to the horizontal welds in cases of severe corrosion attack combined with fatigue effects. In these cases a lower strength steel quality is advised.

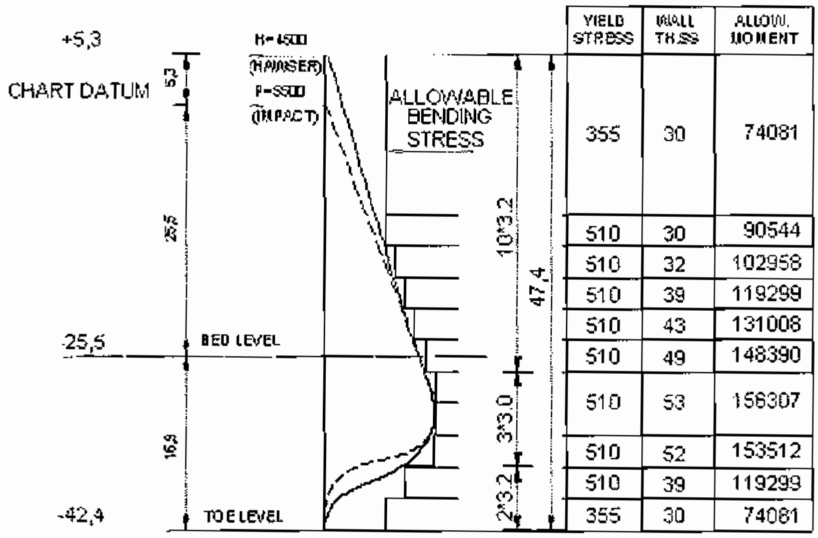
6.6.7 Equipment and details of breasting dolphins

The contact area between ship and breasting dolphin is mostly formed by a panel of hard wood or a steel panel with ultra high molecular weight polyethylene (UHMW) pads.

The size of the panel should be based on the allowable hull pressure as described in section 4.4.

For a better distribution of the contact pressure on the vessels hull, the panel may be designed to be able to rotate. In Figure 6.6.2 an example is given.

Often breasting dolphins are also equipped with bollards, ladders, lighting and a small platform on top of the pile, see Figure 6.6.3.



YIELD STRESS	WALL THSS	ALLOW. MOMENT
355	30	74081
510	30	90544
510	32	102958
510	39	119299
510	43	131008
510	49	148390
510	53	156307
510	52	153512
510	39	119299
355	30	74081

Figure 6.6.1 Bending moments allowable moments and pile makeup

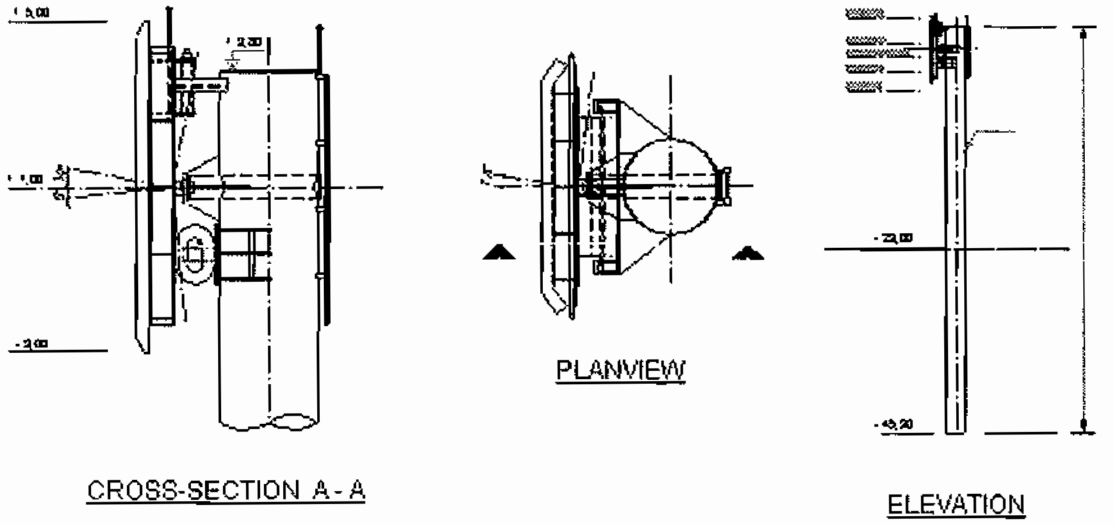


Figure 6.6.2 Example of flexible dolphin

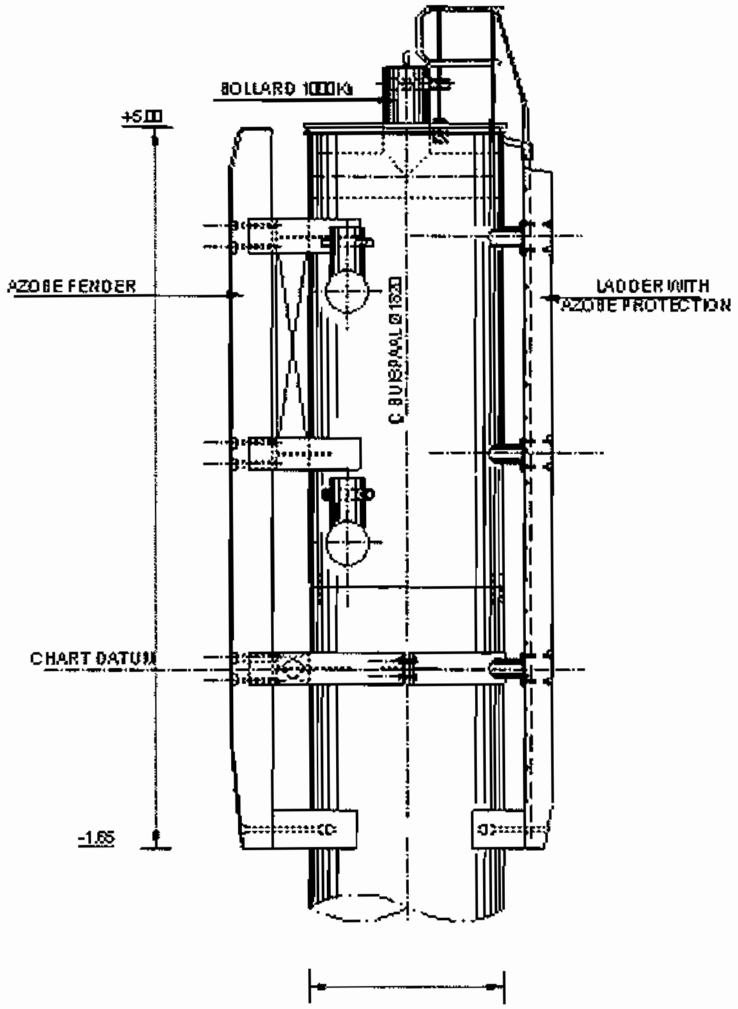


Figure 6.6.3 Head of dolphin

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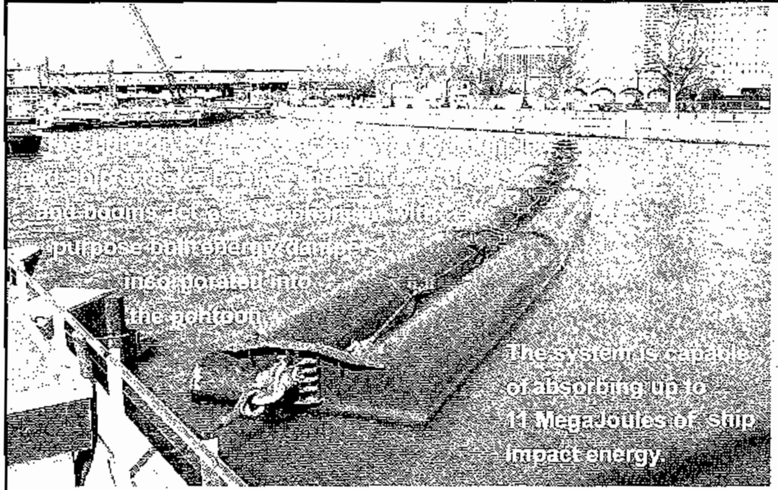
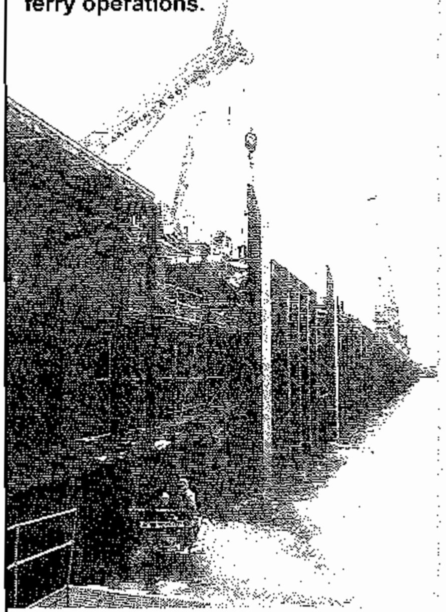


[illegible] and booms act as a [illegible] with purpose-built energy dampers incorporated into the pontoon.

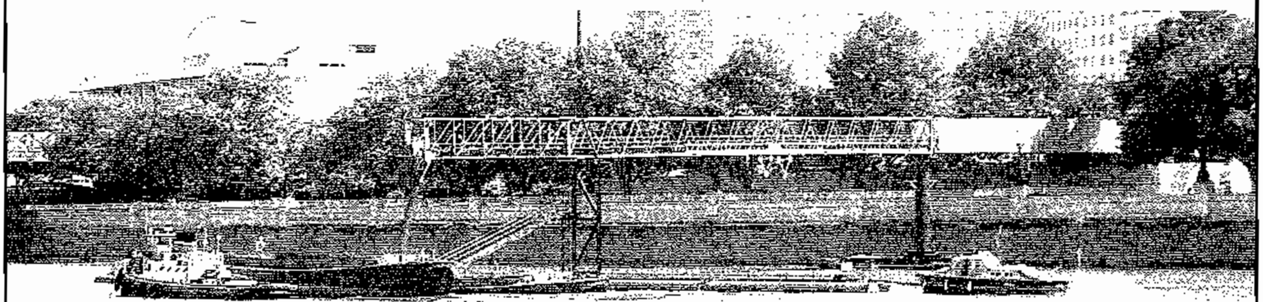
The system is capable of absorbing up to 11 MegaJoules of ship impact energy.

Increasing vessel size required a replacement of the Heysham's timber fendering. We used fender panels backed by cones and large spacer units. The replacement was constructed during normal ferry operations.



Unusual Fendering Problems call for innovative solutions...

At Newhaven cross-channel ferries turn in a tight basin by rotating around a stern fender. Heavy ship beltings with angular corners destroyed conventional fending units. Our solution was a resilient wall of steel.



A prohibition on the use of piles for Jubilee Gardens temporary jetty required a novel solution. We designed a narrow berthing pontoon 80m long which acted as a "buoyancy fender". The pontoon was secured by radial arms to sunken barges.

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APPENDIX A

PROCEDURE TO DETERMINE AND REPORT THE PERFORMANCE OF MARINE FENDERS

1. INTRODUCTION

1.1 A marine fender is an energy-absorbing device that is typically secured against the face of a marine facility for the purpose of attenuating the forces inherent in arresting the motion of berthing vessels safety. Most modern fenders fall into three general classifications based on the material employed to absorb energy:

a) Solid rubber fenders where the material absorbs the energy

b) Pneumatic (air-filled rubber) fenders where air absorbs the energy

c) Foam filled fenders where the foam core absorbs the energy.

1.2 This document establishes the recommended procedures for testing, reporting and verifying the performance of marine fenders. The primary focus in this document is on "solid-type" rubber fenders, used in berthside application for commercial and naval vessels. Appendix B deals with pneumatic fenders. The testing protocol does not address other fender types and materials of construction nor small fendering " bumpers" used in pleasure craft marinas, mounted to hulls of work vessels, military vessels or those used in similar applications. Its primary purpose is to ensure that engineering data reported in manufacturers' catalogues is based upon common testing methods throughout the industry.

1.3 "Solid-type" rubber fenders are available in a variety of basic types with several variations of each type, and multiple sizes and rubber compounds for each variation. Depending on the particular design, "solid-type" rubber fenders may also include integral components of steel, composites, plastics or other materials. Geometrical and component variations of "solid type" rubber fenders should be performance tested and reported according to this protocol. All variations of rubber compounds need not be tested and this is left to the manufacturer's discretion to test an adequate portfolio of compounds to enable a particular compound performance to be predicted.

1.4 This protocol consists of three parts:-

a) Definition of Rated Performance Data (RPD), which defines minimum requirements for manufacturers' published catalogues data;

b) Definition of test apparatus and basic performance-test procedures;

c) Supporting protocols and other tests:
   i. Velocity Factor (VF) determination
   ii. Temperature Factor (TF) determination
   iii. Contact angle effect determination
   iv. Durability testing
   v. Temperature stabilization
   vi. Verification/quality assurance testing
   vii. Rubber property testing.

2. FENDER PERFORMANCE AND REPORTING

2.1 GENERAL

2.1.1 All testing shall define fender performance under linearly-decreasing or sinusoidal-decreasing deflection velocities to simulate actual, vessel-berthing conditions.

Rated Performance Data (RPD), manufacturers' published performance curves and/or tables, shall be based on:

a) Initial deflection (berthing) velocity of 0.15 m/s and decreasing to no more than 0.005m/s at test end;

b) Testing of fully broken-in fenders;

c) Testing of fenders stabilized at 23C±5C;

d) Testing of fenders at zero degree angle of approach;

e) Deflection (berthing) frequency of not less than one hour.

2.1.2 Catalogues shall also include nominal performance tolerances as well as data and methodology to adjust performance curves and/or tables for application parameters different from RPD conditions. Adjustment factors shall be provided for the following variables:

a) Other initial velocities: 0.001, 0.05, 0.10, 0.20, 0.25 and 0.30 m/s deflection (approaching) velocity, decreasing to no more than 0.005 m/s at test end;

b) Other temperatures: +50° C, +40° C, +30° C, +10° C, 0° C, -10° C, -20° C, -30° C;

c) Other contact angles: 3, 5, 8, 10, 15 and 20 degrees.

In addition, RPD shall contain a cautionary statement that published data do not necessarily apply to constant-load and cyclic-loading conditions. In such cases, designers are to contact fender manufacturer for design assistance.

2.1.3 Adjustment factors for velocity and temperature shall be provided for every catalogue rubber compound or other energy-absorbing material offered by each manufacturer.

2.2 FENDER TESTING

This document establishes procedures to be able to standardize the performance characteristics of fenders being tested using two methods:

- The traditional and widely used Constant Velocity (CV) Method, and
- Decreasing Velocity (DV) Method.

Performance testing to establish design data may use either of two methods:

2.2.1 Method CV – Constant-slow-velocity deflection of full size fenders with performance adjusted by velocity factors developed from scale model tests. This method is the preferred method of a majority of manufacturers.

Test to establish initial performance data by full-size fender under the constant-slow 0.0003-0.0013 m/s (2-8 cm / min) velocity. Establish VF obtaining scale-model test and calculate the RPD of full-size fender.

Establish adjustment factors from scale model test for initial berthing velocities other than 0.15 m/s.

Velocity Factor shall be the ratio of performance-test results of scale models under the following conditions:

a. a constant slow strain rate similar to the strain rate of full-size fender at its test speed.

b. decreasing-speed deflection with initial strain rate similar to that of the full-size fender RPD and other deflection conditions.

2.2.2 Method DV – Linearly or sinusoidally-decreasing-velocity deflection of full-size fenders.

Test parameters shall be as defined for published RPD. RPD tests shall start at 0.15 m/s. Tests to establish adjustment factors for initial berthing velocities other than 0.15 m/s shall start at those other initial velocities.

3. TEST APPARATUS

3.1 The test apparatus shall be equipped with a calibrated load measuring device such as load cell(s) or pressure transducer and linear transducer(s) for measuring displacement capable of providing continuous monitoring of fender performance.

The test apparatus shall be capable of recording and storing load-cell and transducer data at intervals of 0.01H-0.05H, where H is a fender's nominal height, and storing manually-entered inputs. The following information shall include, as a minimum:

a. Serial number and description of test item

b. Date, time at start and time at end of test

c. Location of test facility and test apparatus ID

d. Stabilization temperature of test specimen

e. Test ambient temperature

f. Graphic plot(s) and tabular printout(s) of:
   i. Deflection velocity vs. deflection (optional) (If not plotted, deflection velocity and its characteristics shall be separately noted)
   Applicable to Method DV only:
   ii Reaction vs. deflection
   iii Energy vs. deflection.

3.2 For fender tests, all equipment used to measure and record force and deflection shall be calibrated, and certified accurate to within ±1 (one) percent in accordance with ISO or equivalent JIS or ASTM requirements. Calibration shall be performed within one year of the use of the equipment, or less, if the normal calibration interval is shorter than one year. Calibration of Test Apparatus shall be checked annually by a qualified third-party organization, using instrumentation, which is traceable to a certified, national standard.

3.3 The test apparatus shall deflect specimens according to the Test Protocol, (Section 4.0) below.

4. TEST PROTOCOL

The performance test shall deflect specimens according to either of the two methods listed below. Clear and unambiguous calculations must be provided for any adjustments made to the test results.

4.1 METHOD CV

a. Break-in specimen by deflecting three or more times to its rated deflection or more, as recommended by the manufacturer.

b. Remove load from specimen and allow it to "recover" for at least one hour.

c. Before conducting performance test, stabilize fender temperature, see Section 5.1. Temperature stabilizing time can include time for preceding steps 4.1.a. and 4.1.b.

d. Deflect specimen once at constant slow 0.0003-0.0013m/s (2-8 cm/min) deflection.

e. Stop test when deflection reaches rated deflection or more, as recommended by the manufacturer.

f. Adjust performance to rating temperature (23°C±5°C), if required, or to desired application temperature by multiplying both energy and reaction results by Temperature Factor, TF (Section 5.3).

g. Adjust performance to desired initial berthing velocity, by adjusting both energy and reaction results by Velocity Factor, VF (Section 5.2).

4.2 METHOD DV

a) Break-in specimen by deflecting three or more times to its rated deflection or more, as recommended by the manufacturer.

b) Remove load from specimen and allow it to "recover" for at least one hour.

c) Before conducting performance test, stabilize fender temperature in accordance with Section 5.1. Temperature stabilizing time can include time for preceding steps 4.2.a. and 4.2.b.

d) Deflect specimen once at a linearly-decreasing or sinusoidally-decreasing variable deflection velocity as defined in the equations below:

$$V = V_o(D-d)/D \qquad \text{[EQ. 4.1]}$$

or 0.005 m/s whichever is greater

or

$$V = V_o\cos(\pi d/2D) \qquad \text{[EQ. 4.2]}$$

or 0.005 m/s whichever is greater

where:

V = Instantaneous deflection velocity of fender
V_o= Initial deflection velocity (actual berthing condition)
d = Instantaneous deflection of fender
D = Rated deflection of fender

e) Stop test when deflection reaches rated deflection or more, as recommended by the manufacturer.

f) Adjust performance to rated temperature (23°C±5°C), if required, or to desired application temperature by multiplying both energy and reaction results by Temperature Factor, TF (Section 5.3).

5. SUPPORTING PROTOCOLS

5.1 TEMPERATURE STABILIZATION

5.1.1 Test temperature for full-size specimens is defined as the same as the stabilization temperature, as long as ambient temperature at the test apparatus is within ±15° C of the stabilization temperature and testing is completed within two hours.

5.1.2 To stabilize rubber temperature, store specimen at a constant temperature ±15° C. Record air temperature of the space where specimen is stored within 3m of specimen surface, either continuously or twice a day, no less than ten hours apart.

5.1.3 Stabilization time shall be not less than $20x^{1.5}$ days or more as recommended by the manufacturer, rounded to the next whole day (x = dimension of greatest rubber thickness, in metres).

5.2 VELOCITY FACTOR, VF

One of the following protocols shall be followed to determine the Velocity Factors, VF, for every combination of fender configuration, initial velocity other than RPD velocity, fender height and energy-absorbing material. Specimens for determining VF may be either full-size fenders or models, as noted below, provided they are not smaller than 0.1m. in height.

5.2.1 Method CV – Testing of scale model maintaining strain rates as described in 2.2.1 a) and 2.2.1 b).

The model should be accurately scaled to the model proposed for sale.

a) Test model sized fenders as per Section 4.2 at n x 0.15 m/s initial velocity at 23° C±5° C (n : model height / actual height).

b) Repeat step a. (above) at other initial velocities (including the constant slow velocity).

c) Derive VF's, from the data in steps 5.2.1a. and 5.2.1.b. (above) per the following method:

i. Energy Velocity Factor and Reaction Velocity Factor by Method CV

VF_{ca} and VF_{ra}, shall be defined by the following equations:-

$$VF_{ca} = E_{vM} / E_{RPD} \qquad \text{[EQ. 5.1]}$$

$$VF_{ra} = E_{vM} / R_{RPD} \qquad \text{[EQ. 5.2]}$$

where:

E_{vM} = Energy absorption at other initial velocities than as 5.2.2.b

E_{RPD} = Energy absorption at the initial velocity than as 5.2.2.a at the model

E_{vM} = Reaction at other initial velocities per section 5.2.2.b

R_{RPD} = Reaction at the RPD initial velocity per section 5.2.2.a at the model

ii. Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a = E_{RPD} \times VF_{ca} \qquad \text{[EQ.5.7]}$$

$$R_a = R_{RPD} \times VF_{ra} \qquad \text{[EQ.5.8]}$$

where:

E_a = Energy absorption at alternative initial velocity

R_a = Reaction at alternative initial velocity

E_{RPD} = Energy at RPD initial velocity

R_{RPD} = Reaction at RPD initial velocity

5.2.2 Method DV - Testing of full size fender at decreasing-rate deflection velocity

a) Test full-size fender models per Section 4.1 at 0.15m/s initial velocity 23°C+5°C.

b) Repeat step a. (above) at other initial velocities.

c) Derive the VFIs from the data in steps 5.2.1.a. and 5.2.1.b.(above) per the following method:

i Energy Velocity Factor and Reaction Velocity Factor by Method A DV

$$VF_{ca} = E_v / E_{RPD} \qquad \text{[EQ. 5.1]}$$

$$VF_{ca} = R_v / R_{RPD} \qquad \text{[EQ. 5.2]}$$

where:

E_v = Energy at other initial velocity per Section 5.2.1.b.

E_{RPD} = Energy at the RPD initial velocity per Section 5.2.1.a

R_v = Reaction at other initial velocity per Section 5.2.1.

R_{RPD} = Reaction at the RPD initial velocity per Section 5.2.1.a

ii Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a = E_{RPD} \times VF_{ca} \qquad \text{[EQ. 5.3]}$$

$$R_a = R_{RPD} \times VF_{ra} \qquad \text{[EQ. 5.4]}$$

where:

E_a = Energy at alternative initial velocity

R_a = Reaction at alternative initial velocity

E_{PRD} = Energy at RPD initial velocity

R_{RPD} = Reaction at RPD initial velocity

5.3 TEMPERATURE FACTOR, TF

The following shall be completed for every rubber compound.

5.3.1 Tests of the rubber compound and fender type at each of the following temperatures:

-30°C, -20°C, -10°C, 0°C, 10°C, 23°C, 30°C, 40°C, 50°C

5.3.2 The preliminary Temperature Factor, TFp, for each rubber at each temperature shall be its shear modulus at that temperature divided by its shear modulus at 23°C.

5.3.3 Confirm the TFp's by conducting standard performance tests, either Method CV or Method DV, Stabilize specimens at the temperature per Section 5.1.2. and 5.1.3. Specimens may be either full-size fenders or models not smaller than 0.1m in height. Test specimens in test apparatus maintained at test temperature for duration of test.

Test specimens shall be stabilized at –20°C, 0°C, and +23°C. Divide the results at –20°C and 0°C by the result at +23°C. If these results corroborate the shear-modulus results within +5%, the TFp's shall be the TF's.

5.3.4 If the performance tests do not corroborate the shear-modulus data, further tests shall be conducted on specimens stabilized in temperature-controlled environments at the following temperatures:

-30°C, -20°C, -10°C, 0°C, +10°C, +23°C, +30°C, +40°C and +50°C. The TF's for each of these temperatures, Tft's, shall then be calculated by the following formula:

$$TF_t = R_t/R_{23} \qquad \text{[EQ. 5.9]}$$

where:

R_t = Reaction at temperature other than 23°C (highest reaction below 35% deflection)

R_{23} = Reaction at 23°C (highest reaction below 35% deflection)

However, in the case of fenders whose reaction does not drop after a peak around 30% deflection in low temperature, TF shall be based upon the ratio of maximum reactions when energy absorption specified by the fender manufacturer is achieved.

6. VERIFICATION/QUALITY ASSURANCE TESTING

6.1 ENERGY/REACTION COMPLIANCE TESTING

Verification/quality assurance testing to determine compliance with either RPD or other, customer-specified energy and reaction requirements (Required Performance) shall be performed in a test apparatus, as described in Section 3.

Samples for verification testing shall be actual fender elements fabricated for the project location.

6.1.1 Test Sample according to Method CV (Section 4.1.) or Method DV (Section 4.2.), adjusting performance to Required Performance as specified in Sections 4.1.f or 4.1.g and 4.2.f.

6.1.2 A fender provides Required Performance (Required Energy and Reaction) within production tolerances, if it meets both the following requirements simultaneously at any point during the test described in Section 6.1.1:

a. Velocity-and-temperature-adjusted energy absorbed in equal to or greater than Required Energy multiplied by the nominal energy tolerance (low end) specified in its catalogue data.

b. Velocity-and-temperature-adjusted reaction is no more than Required Reaction multiplied by the nominal reaction tolerance (high end) specified in its catalogue data.

6.1.3 The fender samples for energy/reaction verification testing shall be selected according to a sample scheme agreed between the customer and fender manufacturer. If a specific sampling scheme has not been noted, a minimum of ten percent of the fender order shall be tested for compliance with energy/reaction requirements.

6.2. BREAK-IN DEFLECTION

Break-in deflection of actual elements should be at least manufacturer' rated deflection. At least one cycle should be performed.

6.2.1 Break-in deflection shall be mandatory for all fenders with catalogue reaction rating of 100 tonnes or more to be installed on monopiles or pile-supported pier structures. Break-in deflection of other fenders shall be as stipulated by the customer.

6.3 OTHER TESTING

Production fenders may be tested for conformance with specified material properties, alternate performance requirements, and/or durability characteristics.

6.3.1 Verification/quality assurance testing of production fenders may be requested by the customer to insure product conformance with specified contact angle performance, durability, and/or material property characteristics.

6.3.2 Other testing requirements, including selection of sampling scheme, shall be as agreed between customer and fender manufacturers.

7. OTHER TESTS

7.1 EFFECT OF CONTACT ANGLE

7.1.1 Manufacturers shall include graphs or tables defining the effect of deflecting fenders at the contact angles listed in Section 2.1.2.c. This data may be generated mathematically or by testing performed on either actual fender elements or on scale models or arrays. It must reflect the effect of angle contact on an entire fender assembly, not just an individual element.

7.1.2 The following is the procedure for defining the effect of each contact-angle/configuration combination. The test shall be made on the two major axes of the fender unit:

a. Using a test apparatus as described in Section 3, execute the steps of the test procedure defined in Section 4.1. or 4.2..

b. Determine the base-case energy rating for 0-degree contact angle of the specimen at the deflection or reaction limit recommended by the manufacturer.

c. Allow the specimen to recover outside the test apparatus for at least one hour or more as recommended by manufacturer.

d. Simulate the desired contact angle and repeat the test cycle only of step 7.1.2.a.

e. Determine the energy rating of the specimen in the contact angle test at the manufacturer's recommended deflection or reaction limit.

f. The contact-angle factor is the energy determined in the step 7.1.2e divided by that determined in step 7.1.2.b.

This factor is applied to energy only. No factor need be applied to reaction, since the maximum reaction is as defined by the zero-degree-contact-angle performance. For combined horizontal and vertical contact angles, multiply the contact-angle factor for the horizontal direction by the contact-angle factor for the vertical direction if the factors for both directions are different.

7.2 DURABILITY

7.2.1 Each combination of fender type and energy-absorbing material shall be tested for durability to insure its suitability to withstand repeated deflections without enough recovery time to return to original performance characteristics.

7.2.2 The test specimen may not be smaller than the smallest fender of the same basic design offered for sale. The specimen L/H ratio may not be less than the lowest ratio of any catalogues model of the same, basic design.

7.2.3 Before the test begins, stabilize the specimen's temperature to +23°C+5°C per Section 5.1, Temperature Stabilization. Do not artificially cool the specimen during the test.

7.2.4 The test shall consist of 3.000 deflections of the specimen to its rated deflection at a maximum period of 150 seconds.

7.2.5 The criterion for successful completion of the durability test is no cracks or defects visible to the naked eye after the 3.000 deflections.

7.3 PHYSICAL PROPERTIES OF RUBBER

The properties recommended in this section are those that help assure acceptable resistance to the effects of aging and environmental attack. The following physical properties of rubber are recommended as standard requirements:

Resistance to heat aging:

Test tensile strength, elongation and hardness per JIS, ASTM or ISO standards. Then place a second set of samples into an oven maintained at 70°C+/-1°C for a period of 96 hours. After removing the samples from the oven, repeat the same tensile strength, elongation and hardness tests. Compare the results before and after heat aging. The following are the minimum requirements for satisfactory aging resistance:

a. Tensile Strength after aging: not less than 80% of original value.

b. Elongation after aging: not less than 80% of original value.

c. Hardness after aging: not more than 8 points Shore A of increase from original value.

Resistance to ozone:

Conduct a standard, ozone-exposure chamber ozone-exposure test per one of the following standards:

_ JIS K 6259 40°C, 20% elongation and 50 pphm ozone level

_ ASTM D 1171, ozone exposure, method A, 38°C

_ ISO 1431-1, procedure A 40°C, 20% elongation and 50 pphm ozone level.

After 72 hour's exposure, there shall be no visible cracking of the test strips.

7.4 DIMENSIONS

Fenders shall meet manufacturer's specified dimensional tolerances.

APPENDIX B

PROCEDURE TO DETERMINE AND REPORT THE PERFORMANCE OF PNEUMATIC FENDERS

1. INTRODUCTION

1.1. A pneumatic type marine fender (here in after referred as pneumatic fender) is an energy-absorbing device that is typically secured against the face of a marine facility and the ship's hulls for the purpose of attenuating the forces inherent in arresting the motion of berthing vessels safety. Pneumatic fenders are designed to absorb the berthing energy primarily by a compressive air contained in the hollow space.

1.2. This document establishes the recommended procedures for testing, reporting and verifying the performance of pneumatic fenders. The testing protocol does not address other fender types and materials of construction. Its primary purpose is to ensure that engineering data reported in manufacturers' catalogues is based upon common testing methods throughout the industry.

For the cases of ship to ship operation and/or spacer purpose between ship and ship or jetty, procedure for verifying effect of deflection (berthing) velocity may not be necessary to be taken place as a fender selection shall be made by taking two main factors into consideration, i.e. an energy absorption of fender and an appropriate stand-off distance, in which the deflection velocity factor is comparatively small in the actual vessel berthing conditions.

1.3. "Pneumatic fenders" are made by synthetic cord reinforced rubber sheet with compressive air inside. There are two kinds of pneumatic fenders, floating types and fixed types. Depending on the particular design, pneumatic fenders may also include integral components of steel, composites, plastics or other materials. All variations of pneumatic fenders should be performance tested and reported according to this protocol.

1.4. The performance of pneumatic fenders whose initial internal pressure shall be set to be a specified air pressure in operational, shall be specified in terms of guaranteed energy absorption (GEA), reaction force at GEA and internal pressure which is equal to the hull pressure at GEA deflection. Basically, the performance of pneumatic fenders is stable relating to temperature variations when the initial internal pressure is set to be the specified pressure.

1.5. This protocol consists of three parts:

a. Definition of Rated Performance Data (RPD), which defines minimum requirements for manufacturers' published, catalog data.

b. Definition of test apparatus and basic performance-test procedure.

c. Supporting protocols:

i.) Temperature stabilization
ii.) Velocity Factor (VF) determination
iii.) Verification testing
iv.) Contact angle effect determination
v.) Durability test
vi.) Puncture resistance test
vii.) Hydraulic pressure test
viii.) Air leakage test
ix.) Compression recovery test
x.) Physical property of rubber
xi.) Dimension

2. FENDER PERFORMANCE AND REPORTING

2.1 GENERAL

2.1.1 All fender performance, except for ship to ship operation and/or spacer purpose, shall be defined under linearly-decreasing or sinusoidally decreasing deflection velocities to simulate actual, vessel-berthing conditions.

Rated Performance Data (RPD), manufacturers' published performance curves and/or tables, shall be based on the following:

a. Testing of fenders stabilized at the specified initial internal pressure and ambient temperature around 23°C.

b. Initial deflection (berthing) velocity of 0.15 m/s and decreasing to no more than 0.005m/s at test end.

c. Testing of fully broken-in fenders.

d. Testing of fenders at zero degree angle of approach.

e. Deflection (berthing) frequency of not less than five minutes.

In case of test to evaluate fender performances for the usages involving standoff distance factor, following tests shall be applied:

a. Testing of fenders stabilized at the specified initial internal pressure and ambient temperature around 23°C.

b. Constant deflection (berthing) velocity as static during test.

c. Testing of fully broken-in fenders.

d. Testing of fenders at zero degree angle of approach.

e. Deflection (berthing) frequency of not less than five minutes.

2.1.2 Catalogues shall also include nominal performance tolerances as well as data and methodology to adjust performance curves and/or tables for application parameters different from RPD conditions. Adjustment factors shall be provided for the following variables:

a. Other initial velocities: 0.001, 0.05, 0.10, 0.20, 0.25 and 0.30 m/s deflection (berthing) velocity, decreasing to no more than 0.005m/s at test end

b. Other contact angles: 3, 5, 8, 10, 15 and 20 degrees

In addition, RPD shall contain a cautionary statement. If necessary, designers are to contact fender manufacturer for design assistance.

2.2 FENDER TESTING

Performance testing to establish design data, RPD, may use the traditional and widely used method Constant Velocity (CV) Method and Decreasing Velocity Method (DV). Performance testing for vessel to vessel operation and/or spacing purposes may use Constant Method (C).

2.2.1 Method CV — Constant-slow-velocity deflection of full-size fenders with performance adjusted by velocity factors developed from scale model tests.

This method is the preferred method of a majority of manufacturers.

Test to establish initial performance data by full-size fender under the constant-slow 0.0003-0.0013 m/s (2-8 cm/min.) velocity. Establish VF obtaining scale-model test and calculate the RPD of full-size fender.

Establish adjustment factors from scale model test for initial berthing velocities other than 0.15 m/s.

Velocity Factor shall be the ratio of performance-test results of scale models under the following conditions:

a. a constant slow strain rate similar to the strain rate of full-size fender at its test speed.

b. decreasing-speed deflection with initial strain rate similar to that of the full-size fender RPD and other deflection conditions.

2.2.2 Method DV — Linearly or sinusoidally decreasing velocity deflection of full-size fenders.

Test parameters shall be as defined for published RPD. RPD tests shall start at 0.15 m/s. Tests to establish adjustment factors for initial berthing velocities other than 0.15 m/s shall start at those other initial velocities.

2.2.3 Method C — Constant-velocity deflection without performance adjustment by velocity factor.

3. TEST APPARATUS

3.1 The test apparatus for performance testing shall be equipped with load cell(s) and linear transducer(s) capable of providing continuous monitoring of fender performance.

The test apparatus shall be capable of recording and storing load-cell and transducer data at intervals of 0.01H-0.05H, where H is a fender's nominal height, and storing manually-entered inputs. The following information shall include, as a minimum:

a. Serial number and description of test item

b. Date, time at start and time at end of test

c. Location of test facility and test apparatus ID

d. Stabilization of initial internal pressure of test specimen

e. Test ambient temperature

f. Graphic plot(s) and tabular printout(s) of:

  i. Deflection velocity vs. Deflection (optional) (If not plotted, deflection velocity and its characteristics shall be separately noted). Applicable to Method DV only.
  ii. Reaction vs. Deflection
  iii. Energy vs. Deflection

3.2 For fender tests, all equipment used to measure and record force and deflection shall be calibrated, and certified accurate to within ± 1 (one) percent, in accordance with ISO or equivalent JIS or ASTM requirements.

Calibration shall be performed within one year of the use of the equipment.

Calibration of Test Apparatus shall be performed by a third-party organization, using instrumentation, which is traceable to a certified, national standard.

3.2 The test apparatus shall deflect specimens according to the Test Protocol, Section 4.

4. TEST PROTOCOL

The performance test to establish design data, RPD, shall deflect specimens according to method CV or DV, and performance testing for ship to ship operation and/or spacer purpose shall deflect specimens according to method C. Clear and unambiguous calculations must be provided for any adjustments made to the test results.

4.1 METHOD CV

a. Break-in specimen by deflecting one or more times to its rated deflection, or more, as recommended by the manufacturer.

b. Remove load from specimen and allow it to "recover" for at least five minutes.

c. Before conducting performance test, stabilize the specified initial internal pressure of fender.

d. Deflect specimen once at constant slow 0.0003-0.0013 m/s (2-8 cm/min) deflection.

e. Stop test when deflection reaches rated deflection, or more, as recommended by the manufacturer.

f. Adjust performance to desired initial berthing velocity, by adjusting both energy and reaction results by Velocity Factor, VF (Section 5.2)

4.2 METHOD DV

a. Break-in specimen by deflecting one or more times to its rated deflection, or more, as recommended by the manufacturer.

b. Remove load from specimen and allow it to "recover" for at least five minutes.

c. Before conducting performance test, stabilize the specified initial internal pressure of fender.

d. Deflect specimen once at a linearly-decreasing or sinusoidally-decreasing variable deflection velocity as defined in the equations below:

$$V = V_0(D-d)/D \qquad \text{[EQ.4.1]}$$

or 0.005 m/s whichever is greater

or

$$V = V_0\cos(\pi d/2D) \qquad \text{[EQ.4.2]}$$

or 0.005 m/s whichever is greater

where:

V = Instantaneous deflection velocity of fender
V_0 = Initial deflection velocity of actual berthing condition
d = Instantaneous deflection of fender
D = Rated deflection of fender

e. Stop test when deflection reaches rated deflection, or more, as recommended by the manufacturer.

4.3 METHOD C

a. Break-in specimen by deflecting one or more times to its rated deflection or more, as recommended by the manufacturer.

b. Remove load from specimen and allow it to "recover" for at least five minutes.

c. Before conducting performance test, stabilize the specified initial internal pressure of fender.

d. Deflect specimen once at constant deflection velocity (2-8 cm/min).

e. Stop test when deflection reaches rated deflection or more, as recommended by the manufacturer.

5. SUPPORTING PROTOCOLS

5.1 TEMPERATURE STABILIZATION

The performance of pneumatic fenders is stable relating to temperature variations when the initial internal pressure is set to the specified pressure as the performance is generated from the compressive elasticity of inside air pressure. The body of a pneumatic fender is covered by the synthetic cord reinforced rubber layer and these influences of the temperature to the performance are normally negligible.

5.2 VELOCITY FACTOR, VF

One of the following protocols shall be followed to determine Velocity Factors, VF, for every combination of fender configuration, initial velocity other than RPD velocity, fender height and energy-absorbing material. Specimens for determining VF may be either full-size fenders or models, as noted below, provided they are not smaller than 0.1 m in height.

5.2.1 Method CV— Testing of scale model maintaining strain rates as described in 2.2.1 a) and 2.2.1 b).

The model should be accurately scaled with same rubber compound offered for sale.

a. Test model-size fenders per Section 4.2 at n x 0.15 m/s initial velocity and the specified initial internal pressure of fender.
(n : model height / actual height)

b. Repeat Step 5.2.1 a. at other initial velocities. (including the constant slow velocity)

c. Derive the VF's from the data in Steps 5.2.1 a. and 5.2.1 b. per the following method:

   i. Energy Velocity Factor and Reaction Velocity Factor by Method CV,

VF_{ea} and VF_{ra} shall be defined by the following equations:

$$VF_{ea} = E_{v\text{-}M}/E_{RPD\text{-}M}$$ [EQ. 5.5]

$$VF_{ra} = R_{v\text{-}M}/R_{RPD\text{-}M}$$ [EQ. 5.6]

where:

$E_{v\text{-}M}$ = Energy at other initial velocity per Section 5.2.1b. at the model
$E_{RPD\text{-}M}$ = Energy at the RPD initial velocity per Section 5.2.1 a. at the model
$R_{v\text{-}M}$ = Reaction at other initial velocity per Section 5.2.1 b. at the model
$R_{RPD\text{-}M}$ = Reaction at the RPD initial velocity per Section 5.2.1 a at the model

   ii. Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a= E_{RPD\text{-}} \times VF_{ea}$$ [EQ. 5.7]

$$R_a= R_{RPD\text{-}} \times VF_{ra}$$ [EQ. 5.8]

where:

E_a = Energy at alternative initial velocity
R_a = Reaction at alternative initial velocity
E_{RPD} = Energy at RPD initial velocity
R_{RPD} = Reaction at RPD initial velocity

5.2.2 Method DV— Testing of full size fender at decreasing-rate deflection velocity

a. Test full-size fenders per Section 4.1 at 0.15 m/s initial velocity and the specified initial internal pressure of fender.

b. Repeat step 5.2.2 a. at other initial velocities.

c. Derive the VFÌs from the data in steps 5.2.2 a. and 5.2.2 b. per the following method:

   i. Energy Velocity Factor and Reaction Velocity Factor by Method A, VF_{ea} and VF_{ra} shall be defined by the following equations:

$$VF_{ea} = E_v/E_{RPD}$$ [EQ. 5.1]

$$VF_{ra} = R_v/R_{RPD}$$ [EQ. 5.2]

where:

E_v = Energy at other initial velocity per Section 5.2.2 b.
E_{RPD} = Energy at the RPD initial velocity per Section 5.2.2 a.
R_v = Reaction at other initial velocity per Section 5.2.2 b.
R_{RPD} = Reaction at the RPD initial velocity per Section 5.2.2 a.

   ii. Corrected energy and reaction performance is then calculated by the following formulas:

$$E_a= E_{RPD} \times VF_{ea}$$ [EQ. 5.3]

$$R_a= R_{RPD} \times VF_{ra}$$ [EQ. 5.4]

where:

E_a = Energy at alternative initial velocity
R_a = Reaction at alternative initial velocity
E_{RPD} = Energy at RPD initial velocity
R_{RPD} = Reaction at RPD initial velocity

6. VERIFICATION/QUALITY ASSURANCE TESTING

6.1 ENERGY/REACTION COMPLIANCE TESTING

Verification testing to determine compliance with either RPD or other, customer-specified energy and reaction requirements (Required Performance) shall be performed in a test apparatus, as described in Section 3. Samples for verification testing shall be actual fender or the miniature size fender at bigger than 1/5 (one fifth) scale size of the actual height (or diameter).

Test Sample according to Method CV (Section 4.1) or Method DV (Section 4.2), adjusting performance to Required Performance as specified in Sections 4.2.f.

6.2 BREAK-IN DEFLECTION

Break-in deflection of actual fender, which is mandatory for all solid type fenders, is not required for pneumatic fender, as difference of the first-break-in reaction force and the second-broken-in reaction force is negligible.

6.3 OTHER TESTING

Production fenders may be tested for conformance with specified material properties, alternate performance requirements, and/or durability characteristics.

6.3.1 Verification/quality assurance testing of production fenders may be requested by the customer to insure product conformance with specified contact angle performance, durability, and/or material property characteristics.

6.3.2 Other testing requirements, including selection of sampling scheme, shall be as agreed between customer and fender manufacturers.

7. OTHER TESTS

7.1 EFFECT OF CONTACT ANGLE

7.1.1 Manufacturers shall include graphs or tables defining the effect of deflecting fenders at the contact angles listed in Section 2.1.2.b. This data may be generated mathematically or by testing performed on either actual fender elements or on scale models or arrays. It must reflect the effect of angle contact on an entire fender assembly, not just an individual element.

7.1.2 The following is the procedure for defining the effect of each contact angle/configuration combination. The test shall be made on the two major axes of the fender unit:

a. Using a test apparatus as described in Section 3, execute the steps of the test procedure defined in Section 4.1, 4.2, or 4.3.

b. Determine the base-case energy rating for 0-degree contact angle of the specimen at the deflection or reaction limit recommended by the manufacturer.

c. Allow the specimen to recover outside the test apparatus for at least five minutes.

d. Simulate the desired contact angle and repeat the test cycle only of step 7.1.2 a.

e. Determine the energy rating of the specimen in the contact angle test at the manufacturer's recommended deflection or reaction limit.

f. The contact-angle factor is the energy determined in the step 7.1.2.e, divided by that determined in step 7.1.2.b.

This factor is applied to energy only. No factor need be applied to reaction, since the maximum reaction is as defined by the zero-degree-contact-angle performance.

For combined horizontal and vertical contact angles, multiply the contact-angle factor for the horizontal direction by the contact-angle factor for the vertical direction if the factors for both directions are different.

7.2 DURABILITY

7.2.1 Each combination of fender type and energy-absorbing material shall be tested for durability to insure its suitability to withstand repeated deflections without enough recovery time to return to original performance characteristics.

7.2.2 The test specimen may not be smaller than 0.2 m height (or diameter) of the same basic design offered for sale. The specimen L/H ratio may not be less than the lowest ratio of any catalog model of the same, basic design.

7.2.3 Before the test begins, stabilize the specialized initial internal pressure of fender and ambient temperature around 23°C per Section 5.1. Do not artificially cool the specimen during the test.

7.2.4 The test shall consist of 3.000 deflections of the specimen to its rated deflection at a maximum period of 150 seconds.

7.2.5 The criterion for successful completion of the durability test is no cracks or defects visible to the naked eye after the 3.000 deflections.

7.3 PUNCTURE RESISTANCE TEST

7.3.1 Puncture resistance test shall be performed to confirm that the products have puncture resistance strength.

7.3.2 The test shall be conducted in accordance with the standard "ISO 12236 Geotextiles and geotextile-related products - Static puncture test (CBR test)".

7.3.3 The specimen of puncture test shall be made as same as materials, construction and production method except number of ply of reinforcement cord layer which shall be the smallest number, i.e. normally two plies for the smallest size fender.

7.3.4 The force applied to brake through the specimen based on the specification shall be bigger than 15kN (3.4 kips).

7.4 HYDRAULIC PRESSURE TEST

7.4.1 Hydraulic pressure test shall be performed to confirm the endurable pressure of pneumatic fenders.

7.4.2 The internal pressure of the test shall be set as a pressure at the specified energy absorption in non-compression situation.

7.4.3 The test shall be conducted for ten minutes and there shall be no leakage of water and no harmful defects during the test.

7.5 AIR LEAKAGE TEST

7.5.1 Air leakage test shall be performed for all pneumatic fenders.

The air leakage test shall be conducted with the initial internal pressure for more than thirty minutes and the test results shall confirm that there is no air leakage of the initial internal pressure.

7.6 COMPRESSION RECOVERY TEST

7.6.1 The fenders are compressed and released repeatedly at very short period of time during ship mooring. Therefore compression recovery test shall be performed to confirm that the fenders have sufficient compression recoverability.

7.6.2 After compression of the fender to guaranteed energy absorption deflection, the fender shall be fold at the deflected condition for one minute, then release the load instantaneously. The fender diameter (or height) shall be recovered more than 97% of the original diameter within five minutes after the load to the fender released.

7.6.3 The test may be performed on miniature size fender, if the fender is too large to be mounted on the testing machine. The reduction scale shall be bigger than 1/30 (one thirtieth).

7.7 PHYSICAL PROPERTY OF RUBBER

Pneumatic fender shall satisfy requirements of physical property of rubber, which ensure durability of the products for long term.

Resistance to heat aging:

Test tensile strength, elongation and hardness per JIS, ASTM or ISO standards. Then place a second set of samples into an oven maintained at 70°C +/-1°C for a period of 96 hours. After removing the samples from the oven, repeat the same tensile strength, elongation and hardness tests. Compare the results before and after heat aging. The following are the minimum requirements for satisfactory aging resistance:

a. Tensile Strength after aging: Not less than 80% of original value.

b. Elongation after aging: Not less than 80% of original value.

c. Hardness after aging: Not more than 8 points Shore A of increase from original value.

Resistance to ozone:

Conduct a standard, ozone-exposure chamber ozone-exposure test per one of the following standards;

- JIS K 6259 40C, 20% elongation and 50 pphm ozone level
- ASTM D 1171, ozone exposure, method A , 38C
- ISO 1431-1, procedure A 40C , 20% elongation and 50 pphm ozone level

After 72 hour's exposure, there shall be no visible cracking of the test strips.

7.8 DIMENSION

Fenders shall meet manufacturer's specified dimensional tolerance.

APPENDIX C

VESSEL DIMENSIONS

1. CONCEPT

In designing port facilities, including fenders, the dimensions of the Design Vessel (DV) are one of the most important conditions. The DV is the largest vessel among those that are expected to use the facility. If the DV has been specified previously, the dimensions of this specified vessel are used. If not, the dimensions are calculated by the ship type and DWT (Dead Weight Tonnage) / GRT (Gross Registered Tonnage) of the DV.

For this purpose, the relations of ship dimensions and DWT / GRT are analysed.

2. ANALYSIS PROCEDURE

2.1 PROCESSED DATA

The processed data is mainly from Lloyd's Register of Shipping (June 1995) to determine the dimensions of the DV. This database of vessel dimensions is one of the most reliable in the world. Lloyd's Register of Shipping, however, does not provide the projected wind areas of ships. Therefore, Ports & Harbour Research Institute (P.H.R.I) and Port and Harbour Bureau of M.O.T. had collected the projected wind areas of ships using the results of questionnaires sent to Japanese shipyards and Nippon Kaiji Kyokai. It must be noted that the reliability of the analysis of projected wind areas is not as accurate as that of the other ship dimensions, because the number of vessel wind areas data is much smaller than that of the other dimensions.

2.2 VESSEL TYPE

Vessel dimensions vary according to the type. The type of DV should be determined as accurately as possible. For this Appendix, the DV is divided into 8 types, based on the classification of Lloyd's Register of Shipping:

General Cargo, Bulk Carrier Vessel, Container Vessel, Oil Tanker, Ro/Ro Vessel, Passenger Liner and Ferry and Gas Carrier.

3. VESSEL DIMENSIONS WITH A GIVEN CONFIDENCE LIMIT

When designing port facilities, the confidence limit should be determined considering the function, the usage, the environmental condition, the Design Vessel, etc. for the particular facilities, using engineering experience

Table C-1 shows ship dimensions for 50% and 75% confidence levels. The dimensions of the DV can be determined using this table. For comparison of displacements, including 95%, for use with the initial design, Table C-2 is provided.

The choice of DWT or GRT depends upon the type of vessel. A vessel carrying heavy cargo is adequately expressed by DWT, while a vessel carrying light cargo is adequately expressed by GRT. Because DWT is the measure signifying weight, while GRT is the measure signifying volume. The relation between vessel type and explanatory variable is defined as:

DWT: General Cargo Ship, Bulk Carrier, Container Ship, Oil tanker and Ro/Ro Ship

GRT: Passenger Ship, Ferry and Gas Carrier

The relations between Dead Weight Tonnage and Gross Registered Tonnage of each ship type can be taken as follows:

General Cargo	GRT = 0.712 DWT
Bulk Carrier	GRT = 0.538 DWT
Container	GRT = 0.880 DWT
Oil Tanker	GRT = 0.553 DWT
Ro/Ro	GRT = 1.217 DWT
Passenger Liner	GRT = 7.657 DWT
Ferry	GRT = 4.490 DWT
Gas Carrier	GRT = 1.185 DWT

For other confidence levels it is suggested that the technical note of the Port and Harbour Research Institute, Ministry of Transport, Japan. No 911 September 1998, "Ship Dimensions of Design Ship under Given Confidence Limits " be used.

All analysis in Appendix C has been carried out byYasuhiro Akakura (Systems Laboratory, Planning, and Design Standard Division, Port and Harbour Research Institute, Ministry of Transport, Japan).

Please note that the 95% confidence limits in that document should be used with extreme care. It is considered that up to the 50% to 75% limits are accurate and more appropriate to use than the dimensions given for the 95% confidence limit for initial design purposes (see Table C-1).

However, for deciding the mass of a vessel without actual dimensions or figures, Table C-2 has been given, as an aid. It should further be noted that PIANC Working Group 30 Report, June 1997 "Approach Channels. A guide to design " also contains a table of typical ship dimensions as Appendix B p 72. This is useful as another reference but there is no source quoted. It does give figures for much larger vessels in each vessel type.

Appendix C. Table C-1 **Confidence Limit: 50%**

Type	Dead Weight Tonnage (t)	Displacement (t)	Length Overall (m)	Length P. P. (m)	Breadth (m)	Depth (m)	Maximum Draft (m)	Wind Lateral Area (m^2)		Wind Front Area (m^2)	
								Full Load Condition	Ballast Condition	Full Load Condition	Ballast Condition
General cargo Ship	1,000	1,580	63	58	10.3	5.2	3.6	227	292	59	88
	2,000	3,040	78	72	12.4	6.4	4.5	348	463	94	134
	3,000	4,460	88	82	13.9	7.2	5.1	447	605	123	172
	5,000	7,210	104	96	16.0	8.4	6.1	612	849	173	236
	7,000	9,900	115	107	17.6	9.3	6.8	754	1,060	216	290
	10,000	13,900	128	120	19.5	10.3	7.6	940	1,340	274	361
	15,000	20,300	146	136	21.8	11.7	8.7	1,210	1,760	359	463
	20,000	26,600	159	149	23.6	12.7	9.6	1,440	2,130	435	552
	30,000	39,000	181	170	26.4	14.4	10.9	1,850	2,780	569	709
	40,000	51,100	197	186	28.6	15.7	12.0	2,210	3,370	690	846
Bulk Carrier*	5,000	6,740	106	98	15.0	8.4	6.1	615	850	205	231
	7,000	9,270	116	108	16.6	9.3	6.7	710	1,010	232	271
	10,000	13,000	129	120	18.5	10.4	7.5	830	1,230	264	320
	15,000	19,100	145	135	21.0	11.7	8.4	980	1,520	307	387
	20,000	25,000	157	148	23.0	12.8	9.2	1,110	1,770	341	443
	30,000	36,700	176	167	26.1	14.4	10.3	1,320	2,190	397	536
	50,000	59,600	204	194	32.3	16.8	12.0	1,640	2,870	479	682
	70,000	81,900	224	215	32.3	18.6	13.3	1,890	3,440	542	798
	100,000	115,000	248	239	37.9	20.7	14.8	2,200	4,150	619	940
	150,000	168,000	279	270	43.0	23.3	16.7	2,610	5,140	719	1,140
	200,000	221,000	303	294	47.0	25.4	18.2	2,950	5,990	800	1,310
	250,000	273,000	322	314	50.4	27.2	19.4	3,240	6,740	868	1,450
Container Ship**	7,000	10,200	116	108	19.6	9.3	6.9	1,320	1,360	300	396
	10,000	14,300	134	125	21.6	10.7	7.7	1,690	1,700	373	477
	15,000	21,100	157	147	24.1	12.6	8.7	2,250	2,190	478	591
	20,000	27,800	176	165	26.1	14.1	9.5	2,750	2,620	569	687
	25,000	34,300	192	180	27.7	15.4	10.2	3,220	3,010	652	770
	30,000	40,800	206	194	29.1	16.5	10.7	3,660	3,370	729	850
	40,000	53,700	231	218	32.3	18.5	11.7	4,480	4,040	870	990
	50,000	66,500	252	238	32.3	20.2	12.5	5,230	4,640	990	1,110
	60,000	79,100	271	256	35.2	21.7	13.2	5,950	5,200	1,110	1,220
Oil Tanker	1,000	1,450	59	54	9.7	4.3	3.8	170	266	78	80
	2,000	2,810	73	68	12.1	5.4	4.7	251	401	108	117
	3,000	4,140	83	77	13.7	6.3	5.3	315	509	131	146
	5,000	6,740	97	91	16.0	7.5	6.1	419	689	167	194
	7,000	9,300	108	102	17.8	8.4	6.7	505	841	196	233
	10,000	13,100	121	114	19.9	9.5	7.5	617	1,040	232	284
	15,000	19,200	138	130	22.5	11.0	8.4	770	1,320	281	355
	20,000	25,300	151	143	24.6	12.2	9.1	910	1,560	322	416
	30,000	37,300	171	163	27.9	14.0	10.3	1,140	1,990	390	520

Appendix C. Table C-1

Confidence Limit: 50%

Type	Dead Weight Tonnage (t)	Displacement (t)	Length Overall (m)	Length P. P. (m)	Breadth (m)	Depth (m)	Maximum Draft (m)	Wind Lateral Area (m^2)		Wind Front Area (m^2)	
								Full Load Condition	Ballast Condition	Full Load Condition	Ballast Condition
	50,000	60,800	201	192	32.3	16.8	11.9	1,510	2,690	497	689
	70,000	83,900	224	214	36.3	18.9	13.2	1,830	3,280	583	829
	100,000	118,000	250	240	40.6	21.4	14.6	2,230	4,050	690	1,010
	150,000	174,000	284	273	46.0	24.7	16.4	2,800	5,150	840	1,260
	200,000	229,000	311	300	50.3	27.3	17.9	3,290	6,110	960	1,480
	300,000	337,000	354	342	57.0	31.5	20.1	4,120	7,770	1,160	1,850
Ro/Ro Ship	1,000	1,970	66	60	13.2	5.2	3.2	700	810	216	217
	2,000	3,730	85	78	15.6	7.0	4.1	970	1,110	292	301
	3,000	5,430	99	90	17.2	8.4	4.8	1,170	1,340	348	364
	5,000	8,710	119	109	19.5	10.5	5.8	1,480	1,690	435	464
	7,000	11,900	135	123	21.2	12.1	6.6	1,730	1,970	503	544
	10,000	16,500	153	141	23.1	14.2	7.5	2,040	2,320	587	643
	15,000	24,000	178	163	25.6	16.9	8.7	2,460	2,790	701	779
	20,000	31,300	198	182	27.4	19.2	9.7	2,810	3,180	794	890
	30,000	45,600	229	211	30.3	23.0	11.3	3,400	3,820	950	1,080
Passenger Ship	1,000	850	60	54	11.4	4.1	1.9	426	452	167	175
	2,000	1,580	76	68	13.6	5.3	2.5	683	717	225	234
	3,000	2,270	87	78	15.1	6.2	3.0	900	940	267	277
	5,000	3,580	104	92	17.1	7.5	3.6	1,270	1,320	332	344
	7,000	4,830	117	103	18.6	8.6	4.1	1,600	1,650	383	396
	10,000	6,640	133	116	20.4	9.8	4.8	2,040	2,090	446	459
	15,000	9,530	153	132	22.5	11.5	5.6	2,690	2,740	530	545
	20,000	12,300	169	146	24.2	12.8	7.6	3,270	3,320	599	614
	30,000	17,700	194	166	26.8	14.9	7.6	4,310	4,350	712	728
	50,000	27,900	231	197	30.5	18.2	7.6	6,090	6,120	880	900
	70,000	37,600	260	220	33.1	20.7	7.6	7,660	7,660	1,020	1,040
Ferry	1,000	810	59	54	12.7	4.6	2.7	387	404	141	145
	2,000	1,600	76	69	15.1	5.8	3.3	617	646	196	203
	3,000	2,390	88	80	16.7	6.5	3.7	811	851	237	247
	5,000	3,940	106	97	19.0	7.6	4.3	1,150	1,200	302	316
	7,000	5,480	119	110	20.6	8.5	4.8	1,440	1,510	354	372
	10,000	7,770	135	125	22.6	9.5	5.3	1,830	1,930	419	442
	15,000	11,600	157	145	25.0	10.7	6.0	2,400	2,540	508	537
	20,000	15,300	174	162	26.8	11.7	6.5	2,920	3,090	582	618
	30,000	22,800	201	188	29.7	13.3	7.4	3,830	4,070	705	752
	40,000	30,300	223	209	31.9	14.5	8.0	4,660	4,940	810	860
Gas Carrier	1,000	2,210	68	63	11.1	5.3	4.3	350	436	121	139
	2,000	4,080	84	78	13.7	6.8	5.2	535	662	177	203
	3,000	5,830	95	89	15.4	7.8	5.8	686	846	222	254
	5,000	9,100	112	104	17.9	9.4	6.7	940	1,150	295	335
	7,000	12,300	124	116	19.8	10.6	7.4	1,150	1,410	355	403
	10,000	16,900	138	130	22.0	12.0	8.2	1,430	1,750	432	490
	15,000	24,100	157	147	24.8	13.9	9.3	1,840	2,240	541	612
	20,000	31,100	171	161	27.1	15.4	10.0	2,190	2,660	634	716
	30,000	44,400	194	183	30.5	17.8	11.7	2,810	3,400	794	894
	50,000	69,700	227	216	35.5	21.3	11.7	3,850	4,630	1,050	1,180
	70,000	94,000	252	240	39.3	24.0	11.7	4,730	5,670	1,270	1,420
	100,000	128,000	282	268	43.7	27.3	11.7	5,880	7,030	1,550	1,730

*) Full Load Condition of Wind Lateral / Front Areas of log carrier don't include the areas of logs on deck.
**) Full Load Condition of Wind Lateral / Front Areas of Container Ships include the areas of containers on deck

Appendix C. Table C-1 **Confidence Limit: 75%**

Type	Dead Weight Tonnage (t)	Displa-cement (t)	Length Overall (m)	Length P. P. (m)	Breadth (m)	Depth (m)	Maximum Draft (m)	Wind Lateral Area (m²)		Wind Front Area (m²)	
								Full Load Condition	Ballast Condition	Full Load Condition	Ballast Condition
General Cargo Ship	1,000	1,690	67	62	10.8	5.8	3.9	278	342	63	93
	2,000	3,250	83	77	13.1	7.2	4.9	426	541	101	142
	3,000	4,750	95	88	14.7	8.1	5.6	547	708	132	182
	5,000	7,690	111	104	16.9	9.4	6.6	750	993	185	249
	7,000	10,600	123	115	18.6	10.4	7.4	922	1,240	232	307
	10,000	14,800	137	129	20.5	11.6	8.3	1,150	1,570	294	382
	15,000	21,600	156	147	23.0	13.1	9.5	1,480	2,060	385	490
	20,000	28,400	170	161	24.9	14.3	10.4	1,760	2,490	466	585
	30,000	41,600	193	183	27.8	16.2	11.9	2,260	3,250	611	750
	40,000	54,500	211	200	30.2	17.6	13.0	2,700	3,940	740	895
Bulk Carrier*	5,000	6,920	109	101	15.5	8.6	6.2	689	910	221	245
	7,000	9,520	120	111	17.2	9.5	6.9	795	1,090	250	287
	10,000	13,300	132	124	19.2	10.6	7.7	930	1,320	286	340
	15,000	19,600	149	140	21.8	11.9	8.6	1,100	1,630	332	411
	20,000	25,700	161	152	23.8	13.0	9.4	1,240	1,900	369	470
	30,000	37,700	181	172	27.0	14.7	10.6	1,480	2,360	428	569
	50,000	61,100	209	200	32.3	17.1	12.4	1,830	3,090	518	723
	70,000	84,000	231	221	32.3	18.9	13.7	2,110	3,690	586	846
	100,000	118,000	255	246	39.2	21.1	15.2	2,460	4,460	669	1,000
	150,000	173,000	287	278	44.5	23.8	17.1	2,920	5,520	777	1,210
	200,000	227,000	311	303	48.7	25.9	18.6	3,300	6,430	864	1,380
	250,000	280,000	332	324	52.2	27.7	19.9	3,630	7,240	938	1,540
Container Ship**	7,000	10,700	123	115	20.3	9.8	7.2	1,460	1,590	330	444
	10,000	15,100	141	132	22.4	11.3	8.0	1,880	1,990	410	535
	15,000	22,200	166	156	25.0	13.3	9.0	2,490	2,560	524	663
	20,000	29,200	186	175	27.1	14.9	9.9	3,050	3,070	625	771
	25,000	36,100	203	191	28.8	16.3	10.6	3,570	3,520	716	870
	30,000	43,000	218	205	30.2	17.5	11.1	4,060	3,950	800	950
	40,000	56,500	244	231	32.3	19.6	12.2	4,970	4,730	950	1,110
	50,000	69,900	266	252	32.3	21.4	13.0	5,810	5,430	1,090	1,250
	60,000	83,200	286	271	36.5	23.0	13.8	6,610	6,090	1,220	1,370
Oil Tanker	1,000	1,580	61	58	10.2	4.5	4.0	190	280	86	85
	2,000	3,070	76	72	12.6	5.7	4.9	280	422	119	125
	3,000	4,520	87	82	14.3	6.6	5.5	351	536	144	156
	5,000	7,360	102	97	16.8	7.9	6.4	467	726	184	207
	7,000	10,200	114	108	18.6	8.9	7.1	564	885	216	249
	10,000	14,300	127	121	20.8	10.0	7.9	688	1,090	255	303
	15,000	21,000	144	138	23.6	11.6	8.9	860	1,390	309	378
	20,000	27,700	158	151	25.8	12.8	9.6	1,010	1,650	355	443
	30,000	40,800	180	173	29.2	14.8	10.9	1,270	2,090	430	554
	50,000	66,400	211	204	32.3	17.6	12.6	1,690	2,830	548	734
	70,000	91,600	235	227	38.0	19.9	13.9	2,040	3,460	642	884
	100,000	129,000	263	254	42.5	22.5	15.4	2,490	4,270	761	1,080
	150,000	190,000	298	290	48.1	25.9	17.4	3,120	5,430	920	1,340
	200,000	250,000	327	318	52.6	28.7	18.9	3,670	6,430	1,060	1,570
	300,000	368,000	371	363	59.7	33.1	21.2	4,600	8,180	1,280	1,970

Appendix C. Table C-1

Confidence Limit: 75%

Type	Dead Weight Tonnage (t)	Displacement (t)	Length Overall (m)	Length P. P. (m)	Breadth (m)	Depth (m)	Maximum Draft (m)	Wind Lateral Area (m^2)		Wind Front Area (m^2)	
								Full Load Condition	Ballast Condition	Full Load Condition	Ballast Condition
Ro/Ro Ship	1,000	2,190	73	66	14.0	6.2	3.5	880	970	232	232
	2,000	4,150	94	86	16.6	8.4	4.5	1,210	1,320	314	323
	3,000	6,030	109	99	18.3	10.0	5.3	1,460	1,590	374	391
	5,000	9,670	131	120	20.7	12.5	6.4	1,850	2,010	467	497
	7,000	13,200	148	136	22.5	14.5	7.2	2,170	2,350	541	583
	10,000	18,300	169	155	24.6	17.0	8.2	2,560	2,760	632	690
	15,000	26,700	196	180	27.2	20.3	9.6	3,090	3,320	754	836
	20,000	34,800	218	201	29.1	23.1	10.7	3,530	3,780	854	960
	30,000	50,600	252	233	32.2	27.6	12.4	4,260	4,550	1,020	1,160
Passenger Ship	1,000	1,030	64	60	12.1	4.9	2.6	464	486	187	197
	2,000	1,910	81	75	14.4	6.3	3.4	744	770	251	263
	3,000	2,740	93	86	16.0	7.4	4.0	980	1,010	298	311
	5,000	4,320	112	102	18.2	9.0	4.8	1,390	1,420	371	386
	7,000	5,830	125	114	19.8	10.2	5.5	1,740	1,780	428	444
	10,000	8,010	142	128	21.6	11.7	6.4	2,220	2,250	498	516
	15,000	11,500	163	146	23.9	13.7	7.5	2,930	2,950	592	611
	20,000	14,900	180	160	25.7	15.3	8.0	3,560	3,570	669	690
	30,000	21,300	207	183	28.4	17.8	8.0	4,690	4,680	795	818
	50,000	33,600	248	217	32.3	21.7	8.0	6,640	6,580	990	1,010
	70,000	45,300	278	243	35.2	24.6	8.0	8,350	8,230	1,140	1,170
Ferry	1,000	1,230	67	61	14.3	5.5	3.4	411	428	154	158
	2,000	2,430	86	78	17.0	6.8	4.2	656	685	214	221
	3,000	3,620	99	91	18.8	7.7	4.8	862	903	259	269
	5,000	5,970	119	110	21.4	9.0	5.5	1,220	1,280	330	344
	7,000	8,310	134	124	23.2	10.0	6.1	1,530	1,600	387	405
	10,000	11,800	153	142	25.4	11.1	6.8	1,940	2,040	458	482
	15,000	17,500	177	164	28.1	12.6	7.6	2,550	2,690	555	586
	20,000	23,300	196	183	30.2	13.8	8.3	3,100	3,270	636	673
	30,000	34,600	227	212	33.4	15.6	9.4	4,070	4,310	771	819
	40,000	45,900	252	236	35.9	17.1	10.2	4,950	5,240	880	940
Gas Carrier	1,000	2,480	71	66	11.7	5.7	4.6	390	465	133	150
	2,000	4,560	88	82	14.3	7.2	5.7	597	707	195	219
	3,000	6,530	100	93	16.1	8.4	6.4	765	903	244	273
	5,000	10,200	117	109	18.8	10.0	7.4	1,050	1,230	323	361
	7,000	13,800	129	121	20.8	11.3	8.1	1,290	1,510	389	434
	10,000	18,900	144	136	23.1	12.9	9.0	1,600	1,870	474	527
	15,000	27,000	164	154	26.0	14.9	10.1	2,050	2,390	593	658
	20,000	34,800	179	169	28.4	16.5	11.0	2,450	2,840	696	770
	30,000	49,700	203	192	32.0	19.0	12.3	3,140	3,630	870	961
	50,000	78,000	237	226	37.2	22.8	12.3	4,290	4,940	1,150	1,270
	70,000	105,000	263	251	41.2	25.7	12.3	5,270	6,050	1,390	1,530
	100,000	144,000	294	281	45.8	29.2	12.3	6,560	7,510	1,690	1,860

*) Full Load Condition of Wind Lateral / Front Areas of log carrier don't include the areas of logs on deck.

**) Full Load Condition of Wind Lateral / Front Areas of Container Ships include the areas of containers on deck

Appendix C. Table C-2 VESSEL DISPLACEMENTS. Confidence Limits: 50%, 75%, 95%

Type	Dead Weight Tonnage (t)	Displacement (t)			Type	Dead Weight Tonnage (t)	Displacement (t)		
		50%	75%	95%			50%	75%	95%
General Cargo Ship	1,000	1,850	1,690	1,850	Ro/Ro	1,000	1970	2,170	2,540
	2,000	3,040	3,250	3,560		2,000	3,730	4,150	4,820
	3,000	4,460	4,750	5,210		3,000	5,430	6,030	7,010
	5,000	7,210	7,690	8,440		5,000	8,710	9,670	11,200
	7,000	9,900	10,600	11,600		7,000	11,900	13,200	15,300
	10,000	13,900	14,800	16,200		10,000	16,500	18,300	21,300
	15,000	20,300	21,600	23,700		15,000	24,000	2,700	31,000
	20,000	26,600	28,400	31,000		20,000	31,300	34,800	41,400
	30,000	39,000	41,600	45,600		30,000	45,600	50,600	58,800
	40,000	51,100	54,500	59,800	Passenger	1,000	850	1,030	1,350
Bulk Carrier	5,000	6,740	6,920	7,190		2,000	1,580	1,910	2,500
	7,000	9,270	9,520	9,880		3,000	2,270	2,740	3,590
	10,000	13,000	13,300	13,800		5,000	3,580	4,320	5,650
	15,000	19,100	19,600	20,300		7,000	4,830	5,830	7,630
	20,000	25,000	25,700	26,700		10,000	6,640	8,010	10,500
	30,000	36,700	37,700	39,100		15,000	9,530	11,500	15,000
	50,000	59,600	61,100	63,500		20,000	12,300	14,900	19,400
	70,000	81,900	84,000	87,200		30,000	17,700	21,300	27,900
	100,000	115,000	118,000	122,000		50,000	27,900	33,600	44,000
	150,000	168,000	173,000	179,000		70,000	37,600	45,300	59,300
	200,000	221,000	227,000	236,000	Ferry	1,000	810	1,230	2,240
	250,000	273,000	280,000	291,000		2,000	1,600	2,430	4,430
Container Ship	7,000	10,200	10,700	11,500		3,000	2,390	3,620	6,590
	10,000	14,300	15,100	16,200		5,000	3,940	5,970	10,900
	15,000	21,100	22,200	23,900		7,000	5,480	8,310	15,100
	20,000	27,800	29,200	31,400		10,000	7,770	11,800	21,500
	25,000	34,300	36,100	38,800		15,000	11,600	17,500	31,900
	30,000	40,800	43,000	46,200		20,000	15,300	23,300	42,300
	40,000	53,700	56,500	60,800		30,000	22,800	34,600	63,000
	50,000	66,500	69,900	75,200		40,000	30,300	45,900	83,500
	60,000	79,100	83,200	89,400					
Oil Tanker	1,000	1,450	1,580	1,800	Gas Carrier	1,000	2,210	2,480	2,910
	2,000	2,810	3,070	3,480		2,000	4,080	4,560	5,370
	3,000	4,140	4,520	5,130		3,000	5,830	6,530	7,680
	5,000	6,740	7,360	8,360		5,000	9,100	10,200	12,000
	7,000	9,300	10,200	11,500		7,000	12,300	13,800	16,200
	10,000	13,100	14,300	16,200		10,000	16,900	18,900	22,200
	15,000	19,200	21,000	23,900		15,000	24,100	27,000	31,700
	20,000	25,300	27,700	31,400		20,000	31,100	34,800	40,900
	30,000	37,300	40,800	46,300		30,000	44,400	49,700	58,500
	50,000	60,800	66,400	75,500		50,000	69,700	78,000	91,800
	70,000	83,900	91,600	104,000		70,000	94,000	105,000	124,000
	100,000	118,000	129,000	146,000		100,000	128,000	144,000	169,000
	150,000	174,000	190,000	216,000					
	200,000	229,000	250,000	284,000					
	300,000	337,000	368,000	418,000					

APPENDIX D

SELECTION OF FENDER SIZE - CASE STUDIES

Two case studies are given showing the effect of temperature and strain rate.

Case study-1 is for a 30,000 DWT vessel using the temperature factor (TF) and the velocity factor (VF).

Case study-2, where the berth for a 30,000 DWT vessel is shared with a 3,000 DWT vessel, with the effect of TF and VF shown.

Each case study uses the condition that the environmental temperature ranges between 10°C to 40°C.

1. CASE STUDY-1

a) Design criteria:-

- Vessel size: max. 30,000 DWT;
- Kind of vessel: General cargo;
- Approach berthing velocity: 0.10 m/s (Vmin). See also Table 4.2.1;
- The 50% confidence level is adopted for the design berthing velocity;
- Designated maximum reaction limit: less than 980 kN;
- The environmental temperature range of the quay where the fender is to be installed is assumed as follows:

  Environmental temperatures
  Highest 40° C (T_{max})
  Lowest 10° C (T_{min})

- Factor for abnormal impact: 1.75. See Table 4.2.5.

b) Calculating berthing energy

i) Water displacement of the vessel (M_D)
Appendix C. Table C-3, dead weight tonnages and equivalent displacement tonnages are shown.

Displacement tonnage of a General Cargo vessel (30,000 DWT) ie Mass of vessel (95% confidence value) **M** is 45,600 tonnes

For other confidence levels, not shown in Table C-1, use the references given in the Appendix C.

ii) Virtual mass factor (C_m)

Virtual mass factor (C_m) is calculated by the following formula, which in this case is that of Shigeru Ueda.
See Section 4.2.5.

$$C_m = 1 + (\pi/2\ Cb) \times (d/B)$$

where Cb is the Block coefficient

$$[M / (LBD\rho)] = 0.77$$

M: Vessel Mass, 50% confidence value
d: Draft (m) = 10.9 m
B: Moulded breadth (m) = 26.4 m
L: Length of the ship (m) = 170 m
ρ: Specific weight of seawater (1030 N/m³)

$$Cm = 1 + (\pi/2 \times 0.77) * (10.9/26.4) = 1.84$$

iii) Eccentricity factor (Ce)

Assuming quarter point berthing, Eccentricity factor (Ce) is 0.5.

iv) Berthing configuration factor (Cc) and Softness factor (Cs)

According to the design standard, both factors are to be 1.0.
Cc = 1.0
Cs = 1.0

v) Calculating berthing energy (Ev)

Berthing energy is calculated by the following kinetic equation.

$$Ev = \tfrac{1}{2}\ \underline{M}v \cdot V^2 \cdot Cm \cdot Ce \cdot Cc \cdot Cs \cdot Cab$$

(Abnormal Load Factor)

$$= (45600/2) \cdot 0.10^2 \cdot 1.84 \cdot 0.5 \cdot 1.0 \cdot 1.0 \cdot 1.75$$

$$= 367.1 \text{ kNm}$$

c) Manufacturing tolerance

Considering the manufacturing tolerance of a fender, it is usual that the tolerance of -10% for energy absorption and +10% for the maximum reaction force on the performance figures in the catalogue is allowed.

Manufacturing tolerance
Energy absorption; -10%
Max. reaction force; +10%

d) Temperature factor (TF)

The deviation of performance by the environmental temperature is corrected by the temperature factor (TF). Taking the performance value at 23C as the standard values in the catalog (TF=1), the temperature factors can be shown as follows at the highest and the lowest temperature ($TF_{(Tmax)}$, $TF_{(Tmin)}$).

Environmental temperature 40°C, TF(Tmax) ; 0.945[1]
10°C, TF(Tmin) ; 1.055[2]

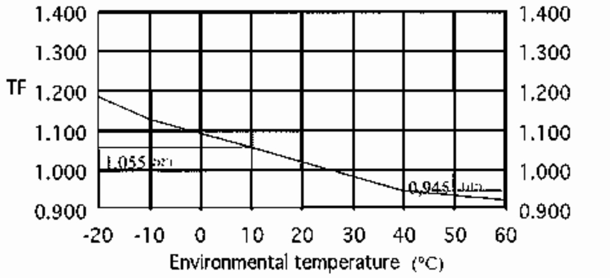


Figure 1 Temperature Factor (TF) Case Study I

Strain rate is defined in the following formula:

Strain rate (V_s) = Compression speed (Vc) / Fender height (H) x 100 [EQ.1]

The 1 m high fender is taken as instance, the strain rate for design berthing velocity of 0.10 m/s is calculated as follows:

Strain rate (V_s) = (0.10 m/s / 1m)x100 = 10%/s

The deviation of performance by compression speed is shown by the velocity factors

(VF_E: for energy absorption, VF_R: for reaction force). As to the 1 m high fender, taking the performance obtained by the compression test at a compression speed of 0.15m/s as the standard (VF_E=1.0, VF_R=1.0).

In case, the fender is 2 m high and berthing velocity is 0.10 m/s, the strain rate is 5.0%/s. Therefore, the catalog value should be converted to the performance of 15%/s by using the velocity factor of this strain rate.

The velocity factors at the actual strain rate are given from Figure 2.

Here, the velocity factors should be studied for the slowest berthing velocity ($VF_{E(Vmin)}$, $VF_{R(Vmin)}$).

Then, velocity factors at 10%/s are defined referring to Figure 2

$VF_{E(Vmin)}$; 0,990[3]
$VF_{R(Vmin)}$; 0,988[4]

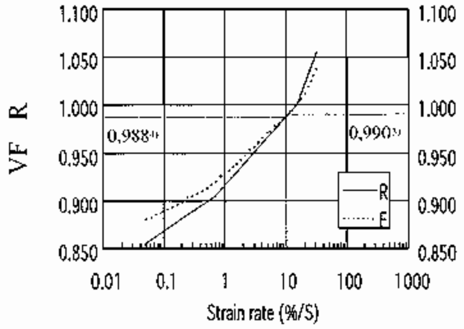


Figure D.2 Velocity factor Case Study I

e) Required performance

i) At 40C
30,000 DWT (40°C)

The following energy absorption capacity (E) is required for the fender.

$$E = E_v / (VF_{E(Vmin)} \times TF_{(Tmax)} \times 0.9)$$
$$= 367.1/(0.990 \times 0.945 \times 0.9) = 436.0 \text{ kNm}$$

The reaction force of the fender should be less than the following figure.

$$R = R_v / (VF_{R(Vmin)} \times TF_{(Tmax)} \times 1.1)$$
$$= 980.0 / (0.988 \times 0.945 \times 1.1) = 954.2 \text{ kN}$$

ii) At 10°C
30,000 DWT (10C)

Required energy absorption of the fender :

$$E = E_v / (VF_{E(Vmin)} \times TF_{(Tmin)} \times 0.9)$$
$$= 367.1/(0.990 \times 1.055 \times 0.9) = 390.5 \text{ kNm}$$

Maximum reaction force of the fender :

$$R = R_v / (VF_{R(Vmin)} \times TF_{(Tmin)} \times 1.1)$$
$$= 980.0 / (0.988 \times 1.055 \times 1.1) = 854.7 \text{ kN}$$

Table 1 Required performance

	30,000 DWT	
	40°C	10°C
Minimum required energy absorption	436.0 kNm	390.5 kNm
Maximum reaction force	942.8 kN	854.7 kN

It means that the standard performance (compression speed : 0.15 m/s, environmental temperature; 23°C) in the catalogue should satisfy the following performance for fender size selection:

Minimum energy absorption	436.0 kNm
Maximum reaction force	854.7 kN

If the performance of the 1 m high fender satisfies these figures, this fender is confirmed as a suitable fender.

If not, the fender of different size must be selected and the same procedure should be carried out until the required figures are satisfied.

2.CASE STUDY-2

In this case, where the berth for 30,000 DWT vessel is shared for 3,000 DWT vessel, is studied, the effect of VF and TF is shown clearly.

a) Design criteria

- Vessel size : min. 3,000 DWT
- Kind of vessel : General cargo
- Berthing velocity .20 m/s (V_{max})
  50% confidence value is adopted for the design berthing velocity.
- Designated maximum reaction limit: less than 980 kN
- The environmental temperature range of the quay where the fender is installed is assumed as follows:

Environmental temperature	
Highest	40 C(T_{max})
Lowest	10 C(T_{min})

- Abnormal Impact factor: (Cab) 1.75 refer to Table 4.2.5

b) Calculating berthing energy

i) Water displacement of the vessel (M_D)
In this case, as DWT is 3000.
Then according to table App.C-2 , the displacement tonnage becomes as follows:

Displacement tonnage of the vessel(M_D)	5,210 t
Mass of the vessel (M)	5,210 t

A 95% confidence value is adopted for the above.

ii) Virtual mass factor (C_m)
Virtual mass factor (C_m) is calculated by the following formula:

$$C_m = 1 + ((\pi/2x0.74\ ) \times (\ 5.1/13.9) = 1.78$$

where

C_b : Block coefficient [M / (LBdρ)] = 4,460/(82x13.9x5.1x1030)= 0.74
M : Mass of vessel (50% confidence value)
d : Draft (m) = 5.1 m
B : Moulded breadth (m) = 13.9 m
L : Length of the ship (m) = 82 m
ρ : Specific weight of sea water (1030 N/m³)

50% confidence value is adopted for each M, d, B, L .

iii) Eccentricity factor (C_e)
Assuming quarter point berthing, Eccentricity factor (C_e) is 0.5.

iv) Berthing configuration factor (C_c) and Softness factor C_s)
According to the design standard, the both factors are to be 1.0.
$C_c = 1.0$
$C_s = 1.0$

v) Abnormal Impact factor (Cab)
According to Table 4.2.5, this factor for a General cargo vessel is 1.75.

vi) Calculating berthing energy (E_v)
Berthing energy is calculated by the following kinetic equation.

$$E_v = (\ 5210/2\ ) \times 0{,}20^2 \times 1.78 \times 0.5 \times 1.0 \times 1.0 \times 1.75$$
$$= 162.3 \text{ kNm}$$

c) Manufacturing tolerance

Considering the manufacturing tolerance of a fender, it is usual that the tolerance of -10% for energy absorption and that of +10% for maximum reaction force applied to the performance figures in the catalogue.

Manufacturing tolerance	Energy absorption ;	- 10%
	Max. reaction force ;	+10%

d) Temperature factor (TF)

The deviation of performance by the environmental temperature is corrected by the temperature factor (TF). Taking the performance value at 23°C as the standard values in the catalog(TF=1), the temperature factors can be shown as follows at the highest and the lowest temperature ($TF_{(Tmax)}$, $TF_{(Tmin)}$):

Environmental temperature	40°C, $TF_{(Tmax)}$; 0.945[1)]
	10°C, $TF_{(Tmin)}$; 1.055[2)]

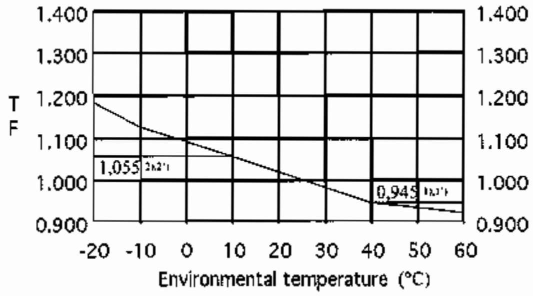


Figure D. 3 Temperature factor (TF) Case study 2

e) Velocity factor (VF)

The deviation of performance by compression speed is shown by the velocity factors (VF_E: for energy absorption , VF_R: for reaction force).

Taking the performance obtained by the compression test at a compression speed of 0.15 m/s as the standard, (VF_E=1.0,VF_R=1.0). The velocity factors at the actual strain rate are given from Figure 4. Here, the velocity factors should be studied for the slowest berthing velocity ($VF_{E(Vmax)}$,$VF_{R(Vmax)}$). The 1 m high fender is taken as instance, the strain rate for berthing velocity of 0.20 m/s is calculated as follows:

Strain rate (V_s) = (0.20 m/s / 1m)x100 = 20%/s

Then, velocity factors at 30%/s are defined referring Figure 4.

$VF_{E(Vmax)}$; 1.010[3]
$VF_{R(Vmax)}$; 1.020[4]

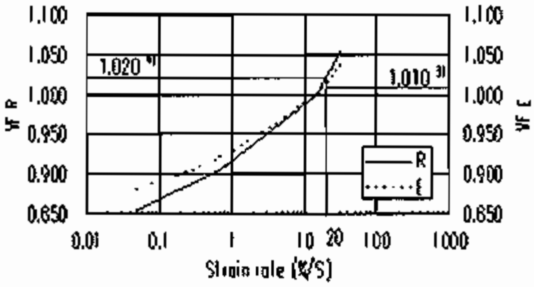


Figure D. 4 Velocity factor Case study-2

f) Required performance

i) At 40°C
3,000 DWT (40°C)
Required energy absorption for the fender.

$$E = E_v / (VF_{E(Vmax)} \times TF_{(Tmax)} \times 0.9)$$
$$= 162.3 / (1.010 \times 0.945 \times 0.9) = 188.9 \text{ kNm}$$

Maximum reaction force for fender:

$$R = R_v / (VF_{R(Vmax)} \times TF_{(Tmax)} \times 1.1)$$
$$= 980.0 / (1.020 \times 0.945 \times 1.1) = 924.3 \text{ kN}$$

ii) At 10°C
3,000 DWT (10C)
Required energy absorption of the fender :

$$E = E_v / (VF_{E(Vmax)} \times TF_{(Tmin)} \times 0.9)$$
$$= 162.3 / (1.010 \times 1.055\ 0.9) = 169.2 \text{ kNm}$$

Maximum reaction force of the fender :

$$R = R_v / (VF_{R(Vmax)} \times TF_{(Tmin)} \times 1.1)$$
$$= 980.0 / (1.020 \times 1.055\ 1.1) = 827.9 \text{ kN}$$

Table 2 Required performance

	30,000 DWT	
	40°C	10°C
Minimum required Energy absorption	436.0 kNm	390.5kN-m
Maximum Reaction force	954.2 kN	854.7 kN
	3,000 DWT	
	40°C	10°C
Minimum required Energy absorption	188.9 kN-m	169.2 kN-m
Maximum Reaction force	924.3 kN	827.9 kN

It means that the standard performance (compression speed : 0.15m/s, environmental temperature : 23°C) in the catalogue should satisfy the following performance for fender size selection.

Minimum energy absorption	436.0 kNm
Maximum reaction force	827.9 kN

Here, the required energy absorption for 3,000 DWT vessel is 188.9 kN-m.

So, it should be confirmed that the maximum reaction force during the energy absorbing process is in the range of constant reaction force range on the performance curve.

APPENDIX E

GUIDELINES FOR SPECIFICATION WRITING

INTRODUCTION

This is a guideline for engineers to provide a plain "Design Criteria" for specifications to fender manufacturers.

This is important in order to acquire economical fenders complying with the required performance.

The design criteria should consist, ideally, of the following parts. They should contain the critical information required by a fender manufacturer.

1. Vessel & Berthing considerations
2. Manufacturing & Quality requirements for fenders
3. Draft Specification. Notes for design criteria
4. Geometrical Information

Part 3. of this Appendix is a guideline draft specification notes of design criteria, provided for engineers as a reference.

1. VESSEL & BERTHING CONSIDERATIONS

This section would cover domain the fender designer needs to know about the berth and it's usage. It particularly needs to avoid ambiguities that would permit different designers coming up with a wide range of berthing energies. The customer pays for energy absorption and the penalty is the reaction on the structure/ship. Many fender types lose performance under certain loading conditions, so these conditions need setting out very clearly.

1) Energy - ship specifications together with dimensions (95% confidence level), berthing speeds (50% confidence of mean value), safety factors, to determine abnormal energy (according to Section 4, Figure 4.2.1, and Table 4.2.5).

2) Types of vessels using the berth with comments on special features such as berthing angles, bow flare angles, beltings, other protrusions or special shapes, permissible hull pressures or belting loads etc.

3) Environmental conditions - exposure of the berth to wind, waves, currents, tides etc. Likely effects of temperature - i.e. ice flows or tropical climates, range of temperatures etc.

4) Geometry - Tidal levels, highest and lowest levels including astronomical levels Fender's available fixing area (Top and bottom, width)

5) Frequency of use of the berth by different classes of ship, draft and freeboard for largest and smallest ship, whether the berth is for loading or discharge or both, whether tugs are sometimes or always used.

6) The maximum and minimum allowable fender projection considering reach of crane, loading arm, etc or flare angle which may hit the quay if the projection is not enough.

7) Type of quay structure(s) the fender would be fitted to - i.e. new or existing concrete quay, or steel platform, etc

8) The maximum reaction limit on quay structure

2. MANUFACTURING & QUALITY REQUIREMENTS

This section is equally important since, no matter how good the theoretical fender arrangement may be, it will not last long if poorly designed or made from low grade materials. This section provides minimum requirements of quality in fender system.

1) Manufactures should be able to demonstrate a satisfactory supply record over a number of years for the type of fender being offered and the application for which it is intended.

2) Manufactures should have published literature on the product where RPD is clearly specified.

3) Manufactures should have an authorized or approved quality system.

4) Fenders offered should have a satisfactory "type approval" certificate in accordance with the new PIANC guidelines. Time should be allowed for companies to prepare for this - it may take some 1-2 years.

5) Customers should make provision to witness quality control testing of both the fender and physical property tests for the materials - either themselves or using third parties.

6) Manufactures should declare the tolerances of their product - typically −10% from min. energy and +10% for max. reaction. They should also declare how the fender performs under other conditions such as angular compression and overload (maximum deflection limits).

7) Steel panel, if any, shall be structured with suitable stiffening members. It shall be appropriately designed to resist the reaction forces imposed by fender and its supporting chains (if any), and keep in equilibrium with the vessel berthing force.

8) Protective treatments of the frontal panel shall be suitable for the environment. They should also be repairable to allow for transport damage or later damage in service.

9) Pads are provided on face of frontal panel to reduce friction of vessel contact. Pads shall be made of a synthetic resin.

10) Material and grade of bolts, anchors need to be specified.

11) If necessary, fender support chains shall be provided. Chains should be designed with appropriate factors of safety. Any corrosion allowance used should be stated.

3. DRAFT SPECIFICATIONS NOTES FOR DESIGN CRITERIA

3.1 FENDER PERFORMANCE

3.1.1 The fender shall be able to absorb the required berthing energy (namely largest energy stipulated) under the combinations of direct and angular compression in the table below.

a. Vessel Size, type (if no actual figures are available, then according to PIANC Appendix C)

b. Berthing velocity of 50% confidence of mean value for vessel (according to Section 4, Figure 4.2.1 and Table 4.2.5)

c. Berthing angle (refer Section 4, Figure 4.2.2)

d. Maximum reaction force at lowest temperature (x +10% tolerance, upper limit)

e. Min. Energy absorption at highest temperature (x - 10% tolerance, lower limit)

f. Environmental temperature, highest and lowest (See Section 4, 4.1.3, Appendix A, 5.3)

g. Safety factor (Section 4. Table 4.2.5)

3.1.2 The selected fender should perform satisfactory under the given environmental conditions of temperature, berthing velocity and berthing angle which all influence the performance.

3.1.3 Fender systems shall be supplied by a reputable manufacturer able to demonstrate a satisfactory supply record over a number of years for the type of fender being offered and a record of successful applications.

3.2 RUBBER FENDER UNITS

3.2.1 Rubber fender units shall be compression moulded from natural or synthetic or both rubber compounds in compliance with Appendix A of "Procedure to Determine and Report the Performance of Marine Fenders, Section 7.3".

3.2.2 The rubber shall be fully vulcanized and homogeneous with no foreign particles, and free from voids, cracks and cuts. Steel plates shall be fully embedded and fully adhered to the rubber during the vulcanization process to avoid separation between the rubber and steel.

3.2.3 Rubber fender shall be tested in accordance with the requirements of Appendix A of "Procedure to Determine and Report the Performance of Marine Fenders".

3.3 STEEL FENDER PANELS

3.3.1 Steel panel shall be structured with suitable stiffening members. It shall be appropriately designed to resist the reaction forces imposed by fender and its supporting chains (if any), and keep in equilibrium with the vessel berthing force. Steel panels shall be fabricated structural mild steel conforming to the latest World Standards of British Standard, ASTM and JIS.

3.3.2 The steel panel shall be sized to exert a hull pressure not more than ## kN/m2 (refer to Section 4, 4.4). It shall be located to accommodate all possible contact elevations of the various vessels, intending to use the facility, under the given geometry of tidal levels and quay structure.

3.3.3 Protective treatment of steel panel shall be coal tar epoxy which is widely used in practice.

3.3.4 Low Friction Pads
Low friction pads materials shall be of synthetic resin. Ultra High Molecular Weight Polyethylene (UHMW-PE) is widely used in practice (PIANC 5.2.2)

3.3.5 Bolts fixings
Material of bolt fixings should be stated.

3.3.6 Chains

If necessary, fender restraint chains shall be provided (Section 4, 4.1.7). Chains should be designed with a stated safety factor (Section 4, 4.2.8.7). The chain materials shall be in accordance with British Standards, ASTM and JIS. The chains shall be galvanized to an approved national standard.

3.4 QUALITY CONTROL

3.4.1 Manufacturer qualifications:

Fender manufacturers shall supply:
"Quality certificate of ISO 9002 or equivalent"
"Supply history of the offered fenders"
"Product literature" at the time of bidding.

3.4.2 Fender performance curves

Testing report with fender performance curves shall be supplied for each different fender type/size at the time of delivery in accordance with Appendix A.

3.4.3 Physical properties of rubber certificate at the time of delivery in accordance with Appendix A.

3.4.4 A mill certificate for steel panel, chains, bolts should be supplied at the time of delivery in accordance with applied standards.

4. GEOMETRICAL INFORMATION

4.1

- Tidal range
- Extreme water levels ie HAT, LAT and surge, if present.
- Top quay level
- Cope thickness
- Seabed level at berth face
- Freeboard of smallest vessel
- Permitted fender reaction

REFERENCES

1. EAU 1996, Empfehlungen des Arbeitsausschusses fur Ufereinfassungen (Recommendations of the Committee for Waterfront Structures Harbours and Waterways EAU 1996, 7th English version)

2. BS 6349: Part 4: 1994, Maritime structures, Code of practice for design of fendering and mooring systems

3. Port Engineering - volume 1 - Per Bruun

4. KUBO K. (1962):"A New Method for Estimation of Lateral Resistance of Piles", Report of Port and Harbour Research Institute, Vol. 2, No. 3, 37 p 9 (in Japanese)

5. Technical Standards for Port and Harbour Facilities in Japan (1991): The overseas Coastal Development Institute of Japan, pp. 156-161

6. UEDA S, K. TAKAHASHI, S. ISOZAKI, H. SHIMAOKA, S. KIUCHI and H. SIRATANI (1993), "Design Method of Single Pile Dolphin Made of High Tensile Steel", Proc. Of Pacific Congress on Marine Science and Technology (PACOM '93) 1993.6, pp 446-475

7. ROM 0.2 – 90, Actions in the Design of Maritime and Harbor Works, April 1990

8. PIANC WG 24 (1995): Criteria for Movements of Moored Vessels in Harbours - A Practical Guide, supplement to Bulletin No.88, 35p.

9. UEDA S. and SHIRAISHI S. (1992), On the Design of Fenders Based on the Vessel Oscillations Moored in Quay Walls, Technical Note of Port and Harbour Research Institute, 55p (in Japanese)

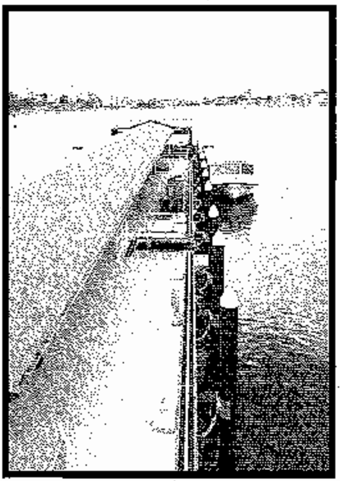
10. PIANC, Report on the International Commission for Improving the Design of Fender System, Supplement to Bulletin No. 45 (1984).

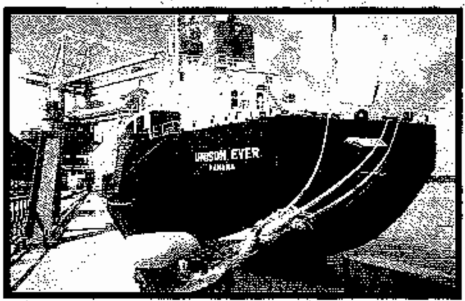
11. THORESEN C.A, Port Design, Guidelines and Recommendation, Tapir Publishers, Trondheim, Norway, 1988.

12. OCIMF, Vessel to vessel transfer guide (Petroleum) 1997

13. OCIMF, Vessel to vessel transfer guide (Liquefied gases) 1995

14. SHIGERU UEDA, RYO UMENMURA, SATORU SHIRAISHI, SHUJI YAMAMOTO, YASUHIRO AKAKURA and SEGI YAMASE, Statistical Design of Fenders, Proceedings of the International Offshore and Polar Engineering Conference, June 2001, pp. 583-588





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